JOVANY URIBE OCAMPO

Integração das metodologias TRIZ e Design Thinking no início do processo de desenvolvimento do produto no setor de equipamentos de saúde pessoal

São Paulo

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JOVANY URIBE OCAMPO

TRIZ and Design Thinking methodologies integration at the beginning of the product development process in the personal health equipment sector

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Banca examinadora

Prof. Dr.: Paulo Carlos Kaminski

Instituição: EP - USP

Julgamento: Aprovado

Prof. Dr.: Eduardo de Senzi Zancul
Instituição: EP - USP

Julgamento: Aprovado

Profa. Dra.: Marcia Elisa Soares Echeveste

Instituição: UFRGS - Externo

Julgamento: Aprovado

Prof. Dr.: Marco Aurélio de Carvalho
Instituição: UTFPr - Externo

Julgamento: Aprovado

Prof. Dr.: Carlos Alberto Costa

Instituição: UCS - Externo

Julgamento: Aprovado

I dedicate this thesis to my family for their love and support during the course of this arduous work.

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The engineer, and more generally the designer, is concerned with how things ought to be – how they ought to be in order to attain goals, and to function.

Herbert Simon

RESUMO

Uribe-Ocampo, J**. Integração das metodologias TRIZ e Design Thinking no início do processo de desenvolvimento do produto no setor de equipamentos de saúde pessoal**. 2022. 254 p. Tese (Doutorado em Engenharia Mecânica) Escola Politécnica da Universidade de São Paulo, são Paulo 2020.

Diferentes autores identificam e abordam as dificuldades encontradas nas fases iniciais do Processo de Desenvolvimento de Produto (PDP), denominado na literatura de *Fuzzy Front End (FFE).* Igualmente acadêmicos indicam como o FFE tem um impacto decisivo sobre o futuro produto, sendo mais acentuado o impacto no contexto de alto grau de inovação ou *High Degree of Innovation* (HDI). Simultaneamente, a fase de FFE é a etapa mais crítica do PDP devido à dificuldade em compreender e articular as oportunidades detectadas. Entretanto, a literatura sobre FFE no contexto do HDI tem carência de propostas funcionais e práticas. Por outro lado, é encontrado um esforço na academia pela incorporação das boas práticas da engenharia no setor de Equipamentos para Saúde Pessoal (ESP), pela confluência de fatores econômicos e sociais neste setor. Os produtos do setor de ESP são altamente regulamentados devido aos riscos inerentes para os usuários. Ademais, o desenvolvimento é considerado complexo e dinâmico, tanto na perspectiva do usuário, quanto na de tecnologia. Assim, o objetivo da presente investigação foi sintetizar, através de pesquisas bibliográficas, a concepção de um modelo de FFE para o setor de ESP da grande área mecânica-eletrônica específico para desenvolver produtos com um alto grau de inovação e concretizado por meio da integração das metodologias TRIZ, que tem ênfase na evolução tecnológica, além do *Design Thinking* (DT), que tem uma abordagem centrada no usuário. Na sequência, validou-se o modelo proposto com quatro aplicações práticas em empresas do setor do ESP. A validação permitiu determinar como este modelo no contexto de HDI, suporta o esclarecimento do problema e a procura de soluções inovadoras, tanto do ponto de vista do usuário como da tecnologia. Os resultados obtidos foram: um modelo de FFE, específico para as empresas industriais da grande área mecânico-eletrônica do setor de ESP, balanceado entre o procedural – descritivo, e o performativo – prescritivo, por meio da inserção de metodologias e, por fim, as técnicas que orientam e apoiam o processo e suas atividades críticas. Desta forma, observou-se que a aplicação prática do modelo permitiu apoiar o desenvolvimento de produtos em sua fase inicial com alto grau de inovação do ponto de vista do usuário e também do ponto de vista tecnológico.

Palavras chave: Alto grau de Inovação, Desenvolvimento de produto. Fuzzy Front End. Design Thinking. TRIZ. Dispositivo Médico.

ABSTRACT

Uribe-Ocampo, J. **TRIZ and Design Thinking methodologies integration at the beginning of the product development process in the personal health equipment sector**. 2022. 254 p. Tese (Doutorado em Engenharia Mecânica) Escola Politécnica da Universidade de São Paulo, são Paulo 2020.

Different authors identify and address the difficulties encountered in the early stages of the Product Development Process (PDP), referred to in the literature as Fuzzy Front End (FFE). Likewise, scholars indicate how the FFE has a decisive impact on the future product, the impact being more pronounced in the context of High Degree of Innovation (HDI). At the same time, the FFE phase is the most critical phase of the PDP due to the difficulty of understanding and articulating the opportunities detected. However, the literature on FFE in the context of HDI lacks functional and practical proposals. On the other hand, an effort is found in academia for the incorporation of good engineering practices in the Personal Health Equipment (PHE) sector, due to the confluence of economic and social factors in this sector. PHE products are highly regulated due to the inherent risks to users. In addition, development is considered complex and dynamic, both from a user and technology perspective. Thus, the objective of this research was to synthesize, through literature research, the conception of an FFE model for the PHE sector of the large mechanical-electronic area specific to develop products with a high degree of innovation and realized through the integration of TRIZ methodologies, which has an emphasis on technological evolution, and Design Thinking (DT), which has a user-centered approach. The proposed model was then validated with four practical applications in companies of the PHE sector. The validation allowed to determine how this model in the context of HDI, supports the clarification of the problem and the search for innovative solutions, both from the user's and the technology's point of view. The results obtained were: an FFE model, specific for industrial companies in the area of large mechanics and electronics of the PHE sector, balanced between the procedural - descriptive, and the performative - prescriptive, through the insertion of methodologies and, finally, of techniques that guide and support the process and its critical activities. Thus, it was observed that the practical application of the model allowed to support the development of products in their initial phase with a high degree of innovation from the user's point of view and also from the technological point of view.

Keywords: Hight Degree Innovation, Product Development. Fuzzy Front End. Design Thinking. TRIZ. Medical Device.

FIGURE LIST

TABLE LIST

LIST OF ABBREVIATIONS AND ACRONYMS

ANVISA	Agência Nacional de Vigilância Sanitária
ARIZ	Algorithm for Inventive Problem Solving
AV/VE	Value Analysis / Value Engineering
CP	Creative Process
DT	Design Thinking
FDA	Food and Drug Administration
FFE	Fuzzy Front End
HDI	High Degree Innovation
ICU	Intensive Care Unit
IFR	Ideal Final Result
ISO	International Organization for Standardization
IV	Inventive Principles
MD	Medical Device
PD	Product Development
PDP	Product Development Process
PHE	Personal Health Equipment
PLM	Product Life-Cycle Management
QFD	Quality Function Deployment
SG	Stage Gate
SM	Separation Methods
SO	System Operator
TE	Trend of Evolution
TRIZ	Theory of Inventive Problem Solving
UCD	User Centered Design

SUMMARY

1. INTRODUCTION

Developing products, which are accepted by the market, provide good economic returns and create barriers to competitors, in essence, this is what a company wants when it engages in new product designs, and especially, when it establishes a process for product development.

The issue to be addressed in this thesis is the synthesis of a product development model for the health care sector - the Personal Health Equipment (PHE). This was accomplished by focusing on the beginning of the Product Development Process (PDP), which is known in the literature as Fuzzy Front End (FFE), but having as its primary characteristic, a high degree of innovation in its products. For the current research, PHE is integrated by Medical Devices (MD), hospital furniture, and assistive products for people with disability, which are designed to improve people's lives under vulnerable conditions. In this chapter, an introduction to the theme under study and the problem surrounding it, will be presented together with its justification, objectives, and research delimitation.

1.1. GENERAL CONTEXT

For their long-term survival, companies need to generate competitive advantages, and one of the ways of generating them is to bring new products into the market. Several authors have dealt with how to conduct new product developments systematically. For their wide dissemination in the literature, the Funnel model by Clark and Wheelwright (1992), and the Stage Gate (SG) by Cooper (1990) , stand out. The latter being the standard model from which the proposals of contemporary authors derive, such as Rozenfeld et al (2006), and Ulrich, Eppinger and Yang (2019) among others.

By studying PDP models from some of the most relevant authors Ocampo; Kaminski (2019) conclude that these methodological proposals, despite having different scopes and structures, share common features, such as the division of the development in phases and activities with decision instances. PDP models are proposed as a business process and not just as an engineering procedure. Integration of different areas of knowledge are essential in the development process. Likewise, senior management plays an important participatory role in the initial stage and in process evaluation. There is a tendency to attach importance to FFE, by considering the company's technology and market strategy for key decision-making projects.

In general, SG-based models introduce a process, which starts with the generation of information during the Phases, and then moves on to the Gates, in which the future of the project is decided. Stages and Gates are defined at the beginning, by generating a convenient process for management, which is repeatable but rigid. It is appropriate for products, which are defined within the incremental innovation paradigm, where technical and market uncertainties are minimal (SALERNO; GOMES, 2018; UNGER; EPPINGER, 2011). Thus, the company undertakes new product designs, based on its current competences, which are linked with the concept of “Exploitation” (BESSANT; ÖBERG; TRIFILOVA, 2014; MARCH, 1991).

In contrast, there exists a radical, disruptive, or discontinuous innovation paradigm, among other names. Under this paradigm, the company needs to develop new skills in order to undertake new product designs, which are identified under the concept of “Exploration” (BESSANT; ÖBERG; TRIFILOVA, 2014; MARCH, 1991). Radical innovation focuses on obtaining products, processes, or services, which exhibit unprecedented performance features, or known features that provide significant improvements in performance or costs, and transform existing markets, or create new ones (LEIFER; O’CONNOR; RICE, 2002).

Nevertheless, there is a spectrum of possibilities between Incremental and Radical innovation (GARCIA; CALANTONE, 2002; O CONNOR et al., 2008; SALERNO; GOMES, 2018). These authors identify Radical Innovation as an exceptional and sporadic event. They also propose an intermediate point between Radical and Incremental Innovation. Garcia & Calantone (2002) indicate Really new innovation, Salerno & Gomes (2018) proposed innovation More Radical, and O Connor et al., (2008) indicate Major innovation. This article focuses on product innovation and will use the term High Degree of Innovation (HDI) to refer to innovation, which is substantially greater than incremental innovation, but it does not meet the definitions or requirements to be considered Radical innovation.

An important point to remark is that HDI as indicated (GARCIA; CALANTONE, 2002; O CONNOR et al., 2008; SALERNO; GOMES, 2018), shares the same issues in the management of Radical Innovation: high uncertainties - mainly market and technology, multiple dimensions, difficulty to understand or articulate the opportunities with the company's current business, difficulty to make economic evaluations, among others.

The authors indicate that the companies have consolidated processes for the realization of projects framed in the context of Incremental Innovation. However, these companies have no adequate practices for the HDI context.

Some of the authors consulted on the theme of FFE indicate that their models are suitable for radical innovation however, when analyzing their articles, they can indeed be framed as being suitable for products having a high degree of innovation instead.

The Development of products with a high degree of innovation implies uncertainties, which in the context of product development, are the lack of information or knowledge. These are generally technical or market uncertainties (SALERNO; GOMES, 2018). Therefore, in the high degree of innovation context, the SG model is not adequate or it could require adjustments and special attention, particularly during early stages (BESSANT; ÖBERG; TRIFILOVA, 2014; CAGAN; VOGEL, 2002; UNGER; EPPINGER, 2011). Due to the rigidity and linearity of the SG process, which implies making important decisions in the early stages of product development where still there is insufficient information, mainly in the context of products with a high degree of innovation (FRISHAMMAR et al., 2016).

In order to reduce uncertainties, ways of acting have been proposed from different areas of knowledge. In Design Theory, Buchanan (1992) indicates how the product design process, with separated stages for analysis and synthesis, is not suitable, and specifically when it comes to social problems, it is not possible to separate the solution from the analysis. On the other hand, product engineering authors, such as (MARKHAM, 2013; TATIKONDA; ROSENTHAL, 2000; UNGER; EPPINGER, 2011), have suggested trial and error and flexibility in the design process, as ways of dealing with uncertainties during the product design. Finally, organizational theory authors mention the most innovative and radical projects as having the greatest uncertainties. Also, they propose ways on how to approach them at the organizational level (O CONNOR et al., 2008; SALERNO; GOMES, 2018).

Cooper (2014) proposes a new SG process, more flexible and adaptive, by incorporating the concept of Spiral into the development process. In addition to including the concept of Spiral within the SG structure, he also suggests the integration of the Agile Development technique into SG. On the other hand, Unger and Eppinger (2011), based on the degree of technical and market uncertainty, propose a reconfiguration of product design, which can be adjusted from a typical SG to a Spiral Structure, with the increase of technical and market uncertainties.

Researchers and company managers have identified that the phase preceding the beginning of a formal project is the most critical of new product development and has an essential influence on its final result (COOPER, 1988; FRISHAMMAR et al., 2016; KHURANA; ROSENTHAL, 1997; KOEN et al., 2001; MARKHAM; LEE, 2013; REID; BRENTANI, 2004; REINERTSEN; SMITH, 1991). The term Fuzzy Front End was introduced by Reinertsen & Smith (1991) and was defined as the period between the generation of an idea for a new product and the company's decision to invest in its development. However, this definition has changed because FFE is an evolving construct. FFE has been labeled under different names, definitions, scopes, and phases in the literature: Fuzzy Front End, Innovation Front End, New Product Front End, or Pre-Development (COSTA; TOLEDO, 2016). In a broader sense, FFE could be defined as all the activities undertaken before the formal and structured process for developing a new product begins.

FFE became a topic of study over the last three decades, with an increasing relevance, as demonstrated by the growing number of publications that appeared in the last 15 years (BORGIANNI; CASCINI; ROTINI, 2018; COSTA; TOLEDO, 2016; GASSMANN; SCHWEITZER, 2014; JOACHIM; SPIETH, 2020; OLIVEIRA; MENDES; MENDES SERRANO, 2022; PARK; HAN; CHILDS, 2021; TAKEY; CARVALHO, 2016). Thus, research on FFE shows significant advances; from the late 1980s to the early 2000s, the focus was on process, under the context of incremental innovation (COOPER, 1988; KHURANA; ROSENTHAL, 1997; REINERTSEN; SMITH, 1991). According to Oliveira et al., (2022), between 2000 and 2010, the FFE construct was consolidated and its influence was verified. Then, since 2010, research on FFE has matured, focusing on deepening some topics and extending the frontiers of FFE to different forms of innovation, such as services and business models. In this period, papers addressing specific topics increased their relevance, e.g., studies addressing idea generation or creativity in FFE.

Research conducted in the last decade indicates gaps in knowledge about FFE. According to Costa & Toledo (2016) FFE needs to be consolidated as regards real model evaluations, proposals of specific and usable models, and the insertion of techniques to execute activities. Florén, et al. (2017) indicates that although studies on FFE have evolved in recent years, they are incomplete and do not effectively help in their practical application in companies because it is not yet clear which activities should be executed at this stage, how to execute and to control them, and what key results are expected.

More recently, Joachim & Spieth (2020) proposes five trends for future research on FFE, among which the following include: understanding the differences and similarities in FFE caused by different types of innovation, such as incremental, radical, service or eco-innovation; improve knowledge about creativity in FFE: creativity conceptualization, creative environment and methods and tools; and furthering the understanding of the FFE process, activities and decision-making. And Park et al. (2021) indicated that most existing models are of the procedure type models, considering 'what' tasks and activities should be carried out. Just a few models are performative-type models, considering 'how' tasks and activities can be executed. The latter generally centered on one or two tasks. The authors indicated that a model that effectively balances performative - descriptive and procedural -prescriptive styles has not yet been identified. Additionally, research related to tools was focused on evaluating existing tools for FFE activities and only a few on presenting new tools to operationalize FFE considering its particularities

Takey and Carvalho (2016) indicate that the main research topics are organization and project product. In this sense, authors like (FRISHAMMAR et al., 2016; REID; BRENTANI, 2004), identify the Early FFE and the Late FFE. At Early FFE, the searching, understanding, and structuring of the opportunities of interest to the company, constitute of the Early FFE. At Late FFE, based on a specific opportunity and with a still embryonic degree of understanding, the project team is expected to generate solutions in the form of concepts to proceed with the formal product development.

Up to this point, the nature of new product designs has been addressed based on their degree of innovation and through the identification of how FFE is a decisive factor, particularly in products with a high degree of innovation.

1.2. PROBLEM

PHEs have some features, which differentiate them from other products; the main ones are: type of users, regulations, technology, and development. About users, PHEs have multiple and varied users, being the main ones: health professionals (specialists, doctors, or assistants), support staff (cleaning or maintenance), patients and their companions, as well as practitioners or students, people with special needs, researchers, and engineers (SANTOS et al., 2012). On the other hand, PHE is intended to improve people's lives, who are under vulnerable conditions. To this purpose, besides functional and usability, issues of the future product, emotional, and symbolic aspects can be determinant. Likewise, because of PHE users' vulnerability conditions, it can be difficult to determine their needs, expectations, and wishes. Besides, these can be contradictory among different users or other stakeholders.

Regarding regulations, PHE industry is highly regulated due to the risks they can pose to different users. Similarly, regulations are continually and rapidly evolving, and, in non-developed countries, these regulations are gradually being implemented. In general, regulations have as ultimate goals, to seek safety for the different users, and or improve its effectiveness. Most international standards and literature refer to DM, but not all PHE can be classified as DM, and the classification of DM varies from country to country. Consequently, it was important to clearly define PHE.

Concerning technology, the health sector, in general, is considered the third most dynamic in the world in terms of innovation, after the military and the telecommunication industries (BNDES, 2012). PHE is part of this sector, and it is continuously in need of innovations to follow the evolution of technologies related to medical treatments. In this way, PHE presents a high level of innovation and new products usually integrate different technologies, such as mechanics, electronics, software, and materials science.

Finally, regarding development, PHE developments are complex, time consuming, and require the intervention of several areas of knowledge such as design, engineering, medicine, among others. Sometimes, these interactions produce contradictory requirements (HERON; TINDALE OBE, 2015). This interdisciplinary integration adds value, and it is critical to successfully generating new solutions. Nevertheless, good developments are difficult to be accomplished due to factors such as ineffective communication, difference in priorities between areas, and even difference in working styles (CUMMINS et al., 2018).

There is an interest in academia and practitioners of integrating best practices from engineering into the PHE industry. In their research, Ocampo and Kaminski (2019) found seven PDP models for PHE, most of which are regulation-centric, and some of them incorporate particularities from the engineering area.

Thus, the models of (MEDINA; KREMER; WYSK, 2012; PIETZSCH; SHLUZAS; PATÉ-CORNELL, 2009), are more focused on complying with regulatory requirements, but less focused on integrating established engineering practices. On the other hand, Santos (2013) suggests a PDP model for PHE, which integrates medical regulations and some engineering best practices, from idea to product discontinuation.

Two proposed PDP models for PHE focus on integrating human needs and requirements into product design. The model of Robert et al. (2012) focused mainly on the technical part of the design, by integrating ergonomic requirements and paying attention to product modularization and optimization. On the other hand, Moody (2015) proposes an integration of both functional and latent human needs, user-centered product validation, and incorporation of the user into product design, being this the only model consulted, which could be considered user-centered. However, these last two models are not finished. They focus only on a few specific aspects of PHE development, but do not delve into how to deal with it.

The current research begins by reviewing the results of the master's thesis written by the same author. The result ended by originating a PDP, going from strategic planning to product discontinuation. That was accomplished by integrating regulatory aspects, which guide the process of development of the PHE, as well as other established practices from engineering product development. The PDP model was proposed for products framed into the incremental innovation (exploitation) paradigm. Meanwhile, the current research will focus more on products with a higher degree of innovation (exploration). That will be done by focusing on Late FFE.

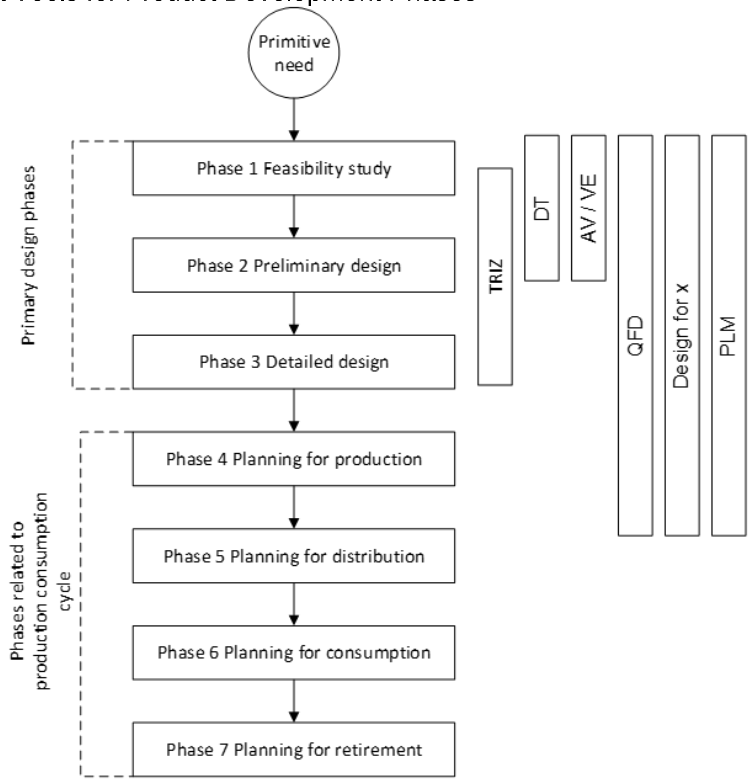
The master's research, from a practical point of view, allowed us to understand the specific context of the necessary activities for the PHE sector, at the beginning of the project. Besides, it allowed us to direct the development of the new product, by integrating user´s requirements, technological, and market strategy of the company, as well as the aspects related to the regulations, which have an important impact in the first phase of the project.

However, in the field study carried out with four companies in the PHE sector, it was found that, in order to develop highly innovative products, companies faced difficulties in treating the development of these products in the same way as other incremental projects. As a consequence, frequent abandonment or intermittence of work, and lack of consensus in the organization on the new product, were observed during the most innovative projects. Which makes it difficult to develop a product based on a problem or opportunity detected. This behavior was found in both mid-sized companies studied in this research project. These findings were corroborated in practice with other companies in the PHE sector in Colombia, Ecuador and Peru[1]. In this way, this master's research provides the initial motivation and justification, by indicating a knowledge gap.

1.3. PDP METHODOLOGY

Different support tools to assist companies in PDP have been conceived, which have been called by various authors like techniques, methods, or methodologies. These support tools assist and present best practices, which hold up the different activities or phases of product development. As seen in Figure 1.1, it indicates how the supporting tools are more intensively applied in the early stages of the PDP.

Figure 1.1 - Support Tools for Product Development Phases



Source: the author based on (ASIMOW, 1962; MAZARAL; DIEGO; ARTACHO, 2004)

[1] The author of the thesis has been working in the PHE sector since 2008, initially as a product development manager, and currently as a technical consultant for the Andean area of DewertOkin Brazil, which operates in the PHE sector.

The incorporation of supporting tools establishes a standardization of project best practices since they contribute in the elaboration and systematization of activities. Therefore, a PDP model, with a high maturity level needs to have supporting tools defined for each phase and activity (ROZENFELD et al., 2006), being more crucial for more innovative designs. FFE authors, such as (ACHICHE et al., 2013; BESSANT; ÖBERG; TRIFILOVA, 2014; COSTA; TOLEDO, 2016), indicate how the insertion of supporting tools generates a positive impact. These insertions are required to have an operational FFE model (COSTA; TOLEDO, 2016).

When looking up the different bibliographic sources, which deal with supporting tools, several terms appear to define them. The main ones are technique, method, and methodology. These terms are more formal, and they have a hierarchy. Other terms used include tools, supporting tools, approach, among others. these terms are more informal, and they are used interchangeably. For this reason, when it comes to the same subject, some authors use different terms throughout the text.

Formal terms will be defined and standardized for the current research, based on definitions from research methodology and the social sciences. Firstly, the technique is a system of assumptions and rules, which allows us to act objectively, to accomplish something, to achieve a goal, or an objective (PANTOJA, 2002). According to Zorrilla, *et al.* (2000) techniques are operating procedures, which can be adapted to different conditions, and specific problems. Secondly, the method comes from the Greek “Methodos,” which means the path or the way of reaching an outcome, and it is the set of procedures and operations, which are performed in order to reach a goal (PANTOJA, 2002). The method represents the way of conducting thoughts or actions to reach an goal (ZORRILLA et al., 2000). And finally, the methodology is made up of terms, “Methodos,” and “Logos,” which means explanation, judgment, treatise, or study of methods, i.e., analysis and refinement of the method in order to build new knowledge, to discover the logic, which articulates them and to propose corrections (PANTOJA, 2002). The methodology represents how to organize the process, to control its results, and to present possible solutions to a problem, which involves decision-making (ZORRILLA et al., 2000).

Therefore, the method is broader than a technique in the sense that it indicates general and non-specific aspects of action, while technique is appropriate for acting objectively in order to achieve a goal. To achieve its goals, a method needs to use a number of techniques. Then, techniques make the method operational (ZORRILLA et al., 2000). Thus, methodology constitutes a higher level of hierarchy than a method does, in that it implies understanding its logic.

Figure 1.1 represents only a few methodologies, methods, and techniques. In practice, they are countless depending on the variations proposed by different authors or even, sometimes the same Supporting Tool may have several names. The current research focuses on the Late FFE, whose essence is to create concepts, based on a previously defined opportunity.

Therefore, methodologies which support Late FFE process are of interest, and the most recognized ones are: Value Analysis / Value Engineering (AV / EV), Design Thinking (DT), Quality Function Development (QFD), and TRIZ. These methodologies have a general approach in order to organize the process by operationally employing various techniques. It should be pointed out that the use of these methodologies, rather than the sum of their operations, requires an understanding of their essence, which will be defined in the current research as methodologies, although some authors use different names.

AV / VE is a methodology based on the functional analysis of product or process, and it aims to improve the function/cost ratio through the analysis of functions, associated components, their costs, and the function perceived value for users (COMMISSION EUROPEAN, 1995; COOK; WISSMANN, 2007); DT is a user-centered methodology, which proposes an iterative process of understanding the problem from the perspective of those involved in it, by creating solutions and validating solutions through prototypes from the early stages (BROWN, 2008); QFD is a methodology to determine users' expectations, or customers' voice, to define these needs as product design objectives, and to maintain that customers´ voice throughout the development process, QFD uses four matrices, being the best known the Quality House, it transforms users' wishes into technical specifications (CHENG; MELO, 2007); and TRIZ is a methodology, which starts with the correct definition of the problem by arriving at an abstraction, which allows understanding and finding a generic definition of the problem, free of technical terminology. After, possible generic solutions are found, which facilitate the generation of solutions to the specific problem (ALTSHULLER, 2007).

When analyzing the VA/VE and QFD methodologies, it is warned that they start from a product, which intends to innovate, by improving its aspects, or by creating a new product from the understanding of the function in AV / VE. In this way, Cheng;

Melo (2007) show how QFD methodology is for product improvement, and it is not indicated for high degree of innovation. On the contrary, DT and TRIZ methodologies starts from the analysis and understanding of the problem, DT methodology starts from the stakeholders (BROWN, 2008), with a user-centered or human-centered approach, whereas TRIZ makes an understanding of the problem based on technology (ALTSHULLER, 2007). Then, solutions are proposed without necessarily having a precedent to improve. In other words, these methodologies can propose solutions by "starting from the scratch."

On the other hand, it was discussed how for the PHE sector, user and technology drivers are determinant. As for the user, a deep understanding is required because the user may not perceive the need, or the device may be at the same time, the solution, and the representation of their disability. Regarding technology, in the context of high degree of innovation, in the PHE sector, it is necessary to consider several technological possibilities, which could imply forgetting current solutions, and with the understanding of users' requirements and limitations of the problem, it may be necessary to provide solutions with new paradigms.

By deepening in the analysis of DT and TRIZ methodologies as to their essence and ways of proceeding (Chapter 7 deals with this theme), one can have at least an initial perception of the possibility of complementing both methodologies. DT and TRIZ methodologies take into account the User and Technology drivers respectively, at a higher and deeper level. The current thesis is not intended to make a study and to compare the main methodologies or even the selection of TRIZ and the DT methodologies. This constitutes one of the limitations of the research, as indicated by Blessing and Chakrabarti (2009) in their text on design research, their initial understanding allows us to determine hypotheses and research questions to be explored and answered in the research process.

Authors like Hentschel and Czinki (2013), Ilevbaren, Probert and Haal (2013) and Moehrle (2005) indicate how complex it is to use TRIZ due to the number of techniques, the lack of identification of a defined process, and the need for long training. On the other hand, DT is criticized for the confusing definition of process, tools, and fundamentals, which are originated in the various proposals by DT authors (JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013; KIMBELL, 2011). In addition, DT is indicated for the generation of innovative products and services, but it is weak in terms of product conceptual proposal generation techniques.

By comparing both methodologies as to their origins, processes, and philosophies, it can be understood that they have very different perspectives, although they share common features, such as systematic approaches to innovation, which allow us to understand the problem situation and the synthesis of the solution. Then, the incorporation of both methodologies in Late FFE, for PHE products. It tends to incorporate functional aspects, and explicit and latent different users' needs, while it allows the integration of technological solutions from different fields of knowledge.

1.4. JUSTIFICATION

This section answers the following questions: What is the importance of the current research for the social, economic, and academic point of view? Why is it required to propose an additional FFE model?

Studies indicate that companies can benefit from both contexts: Incremental and Radical innovation (BRUN, 2016; FERNÁNDEZ; VALLE, 2018; O'REILLY; TUSHMAN, 2008, 2013; ZARAGOZA-SÁEZ et al., 2020). Both types of innovation are important for companies, and they have different roles to play (SALERNO; GOMES, 2018). Thus, for companies operating in dynamic sectors their long-term survival depends on their ability to launch new products that meet or exceed users' expectations. Not only they need to develop incremental-evolutionary products based on their current capabilities, but they also need to undertake new developments with a high degree of innovation by incorporating new capabilities (BESSANT; ÖBERG; TRIFILOVA, 2014; FRISHAMMAR et al., 2016).

Academics suggest that companies have consolidated processes for the implementation of projects framed in the context of Incremental Innovation. However, these companies have no adequate practices for the HDI context (BESSANT; ÖBERG; TRIFILOVA, 2014; GARCIA; CALANTONE, 2002; O CONNOR et al., 2008; SALERNO; GOMES, 2018).

As countries' level of development increases, there is a shift in the focus within the healthcare sector from infectious to chronic degenerative diseases. The latter require more advanced technologies in their treatment (BNDES, 2012). From the economic point of view, this creates opportunities for companies in the PHE sector. On the other hand, society also requires solutions to its problems, which will not always be solved by importing products that are already ready. As pointed out by (BNDES, 2012), the healthcare sector is one of the sectors with the greatest convergence of social and economic aspects.

Also, in the field's study during the master's research with four companies in the PHE sector, it was found that in the mid-sized companies, there exist difficulties in developing products with a high degree of innovation. This feature is common in other sectors, as shown in the bibliographic research. However, in the PHE sector, the specific conditions of a region make it convenient from the social point of view, to conceive solutions to their own problems, and not only to import products. For example, conditions in developed countries generally located outside the tropics and tropical countries are quite distinct: type of disease, climate, culture, economic power, health systems and the like. Even in the medical sector, which belongs to the health field, they talk about "orphan" diseases, which are not of interest to the large pharmaceutical companies because they do not have a big market with purchasing power.

As noted earlier in the research, Ocampo and Kaminski (2019) identified efforts from academia in order to incorporate engineering practices into the PHE sector, by recognizing that this is a sector, which has its own dynamic. On the other hand, FFE authors indicate that there is a need to consolidate proposals for specific and usable models (COSTA; TOLEDO, 2016; FRISHAMMAR et al., 2016).

The proposed FFE models are based on academic studies, or on studies of how companies operate, and consultations with experts. These authors show the benefits that companies could have with the use of FFE models, but there is no practical evaluation of such models' benefits (COSTA; TOLEDO, 2016).

Because of the aforementioned reasons, the proposition of a Late FFE model, for the PHE sector with a high degree of innovation, is justified. It seeks to reduce the gap, which exists in issues of FFE, and product development in the PHE sector. Thus, Late FFE are of academic, economic, and social relevance.

1.5. OBJECTIVES

It has been manifested how the Late FFE is decisive for products with a high degree of innovation. It is an issue, which needs to be consolidated in the academic literature. In addition, as the PHE sector has its own particularities, which make the execution of development projects even more specific. Finally, it has been stated how TRIZ and DT methodologies could be complemented in the Late FFE, for high degree of innovation in PHE sector products, by providing a deep understanding of the User and Technology.

The gaps that drive the present article are: lack of adequate practices for the implementation of projects in HDI, context considering the substantial technical and market uncertainties; the lack of specific, operable and balanced FFE models between what to “make” and “how” to do it; and the need to integrate engineering best practices to the PHE sector.

In this way, the thesis will be guided by the following question: What specificities does FFE have in HDI context, how to insert these specificities in a procedure Late FFE model, and how can TRIZ and DT methodologies be complemented in this context to obtain a procedure and performative model, in specific in the PHE sector?

Thus, the thesis objectives are outlined as follows:

General objective of the thesis:

The current research aims to propose a Late FFE model, directed to products having a high degree of innovation, specific for industrial companies of the PHE sector, by integrating TRIZ and Design Thinking methodologies.

The specific objectives are:

To propose a Late FFE model, focused on products with a high degree of innovation, specific for industrial companies of the PHE sector.

To insert TRIZ and Design Thinking methodologies into the Late FFE model, focused on products with a high degree of innovation, specific for industrial companies of the PHE sector.

1.6. RESEARCH LIMITATIONS

This research uses the results of the author’s master's dissertation, in which he has proposed a PDP model for the PHE sector. Initially it was proposed for products framed in the incremental innovation paradigm. On the other hand, this research also focuses on the Late FFE, and specifically on highly innovative products within the PHE sector.

There exist several methodologies, methods, and techniques, which can support PDP in its different stages, each with its own potentials and limitations. The current research is limited to integrating TRIZ and DT methodologies, specifically on the Late FFE.

For the validation of the proposed model, four applications will be carried out in projects from the PHE sector, by establishing some variables, and by carrying out an assessment of the impact of the methodology on the application. However, one limitation is that statistical validation will not be performed.

The validation of the proposal involves training, monitoring and application of the proposed model of Late FFE. The social environment, which is made up of organizational culture, management support, and external influence, is indicated in the model, and by authors, such as Amabile (1996) as determined in the creative process. One limitation of this research is that social environment cannot be controlled in the application. It is a condition, which exists in the company, and it has influence on the final outcome. Likewise, the motivation of the development team, particularly, intrinsic motivation, is a determinant factor in the final outcome. In training, it is a subject to be treated and stimulated, but it is a variable, which cannot be controlled in the practical applications of the model.

1.7. CHAPTER SUMMARY

Chapter 1 Introduction: it presents a general contextualization of the problem to be investigated, object of study, TRIZ and DT methodologies. It also defines the general and specific research objectives, justification, and limitations.

Chapter 2, Research Methodology: it provides a methodological framework for the research, by describing, in general terms, the methods employed.

Chapter 3, PHE: it performs a description of the three groups of PHE, Hospital Furniture, Medical Devices, and Assistance Product for people with disabilities. Likewise, standards, which have an influence on the development of PHE are reviewed, by determining that there exist standards, which indicate product conditions and requirements for approval and testing. On the other hand, there exist process standards, which impose conditions on PHE development.

Chapter 4, FFE Review: in this chapter, a bibliographical review on FFE is carried out, which allows us to understand its features and main elements, as well as to find some generic models and how the FFE construct has evolved. Also, a gap in academia was identified, which consists of proposing and validating specific models, and integrating these methodologies to support the diffuse stage.

Chapter 5, Review of TRIZ methodology: a review of TRIZ was carried out in order to understand its origins, philosophy, and process. Different authors suggest different ways of applying TRIZ, and the options of techniques can vary greatly, which can lead to confusion. However, the methodological review allowed us to understand the basic principles, which guide the application of TRIZ. Once TRIZ was understood, the manner how it could be integrated with Late FFE was identified.

Chapter 6, Design Thinking Methodology Review: This chapter focuses on decoding DT methodology in order to understand its evolution, theoretical foundations, and procedural guidelines. The theoretical lines, which underlie the DT were identified in order to understand it, and the guidelines, which direct and give meaning to the use of DT, were defined. The understanding of the theoretical foundation and the guidelines made its integration into the Late FFE easy.

Chapter 7, Discussion of TRIZ and DT in Late FFE: once both methodologies are understood, a comparison is made between them. TRIZ focuses on technology and DT on the user. The comparison allowed us to identify differences and similarities, as well as complementary points and possible divergences. Finally, there is a discussion of both methodologies in the Late FFE.

Chapter 8, Late FFE model proposal, by integrating TRIZ and DT methodologies: based on the subsidies of Chapters 4, 5, 6, and 7, a Late FFE model is proposed, by focusing on products in the PHE sector, with a high degree of innovation. Once the model is defined, TRIZ and DT methodologies are integrated within it.

Chapter 9, Pilot project: this chapter describes step by step the process of a pilot project with the application of the late FFE model, which was carried out in a company environment with the participation of the author. The sequence of the process is carried out keeping a parallel with the proposal described in chapter 8.

Chapter 10, Validation: this chapter describes the validation process of the Late FFE model proposed, by indicating the applications within companies in the PHE sector, by describing the process, from the initial assessment of how companies perform Late FFE to the application of the proposed model in product development projects. In addition to this, an analysis of the results is presented.

Chapter 10, Conclusions: in this chapter, the conclusions of this thesis are established, how the final results comply with the proposed objectives, and the limitations determined in the application of the Late FFE model proposed. Likewise, it indicates possible further research, which could be carried out, regarding the results of the current thesis.

2. METHODOLOGY

In the present chapter, the research methodology framework and procedures used are described. Then, the general scheme of the research is indicated and how the chapters are related. Finally, it is presented how the research was carried out, by raising the most relevant points for a better understanding.

2.1. RESEARCH METHODOLOGY FRAMEWORK

The current research is framed within the classifications made by the following authors: (BERNAL TORRES, 2010; DEMO, 2000; GIL, 2002; MARCONI; LAKATOS, 2000; UNIVERSIDADE CATÓLICA DE BRASÍLIA, 2003), as shown in Table 2.1. However, definitions and classifications are specific, depending on both the purpose of the book and the area of knowledge. Table 2.1 also indicates the insertion of the research in the categories shown. The more intense colors indicate the greater relevance of the current research in this classification, being white, not relevant; yellow, relevant average; and green, relevant.

Based on the definitions, this research can be adjusted with the following research categories: applied, regarding nature; empirical, regarding gender; qualitative, regarding the main approach; sectional, regarding temporal aspect; descriptive and explanatory, regarding the objective; bibliographic, regarding the case study, and, to a lesser extent, documentary, regarding the procedures employed.

The classification of research allows us to establish the main aspects, which determine the instruments and the emphasis, both on data collection and analysis. However, research does not have to be completely defined, nor does it have to be excluded. There are no strict limits, indicating which types of research use exclusively which instruments.

Table 2.1 - Research Taxonomy

Criteria	Classification	
Nature	**Basic**: intended to generate new knowledge, although without defined utility.	**Applied**: aimed at generating knowledge for practical application, aimed at specific solutions.
Genre	**Theoretical**: dedicated to re-construct theories, concepts. To improve theoretical and practical foundations.	**Methodological**: serves to inquire scientific methodologies and procedures.
	Empirical: based on facts that happen in everyday life.	**Practical**: linked to praxis, how to use scientific knowledge for intervention purposes.
Main approach	**Qualitative**: considers the dynamic relationship of variables and object of study with the universe.	**Quantitative**: based mainly on mathematical procedures for analysis.
Time considered	**Sectional**: collection of information about the object of study in a unique opportunity.	**Longitudinal:** compares data from the object of study at different times in order to evaluate the transformations.
Objective	**Exploratory**: allows to know or to make the object of study more explicit.	**Descriptive**: illustrates aspects and qualities of the object of study.
	Explanatory: identifies the factors, which contribute to the phenomenon, and explains the reasons behind it.	**Correlational**: measures the variables of the object of study.
Procedures Employed	**Experimental**: analyzes the effect of manipulating variables, in other aspects of the object of study.	**Historical**: analyzes the facts of the past, and tries to find the relationships with the present.
	Documentary: analyzes written information about the object of study.	**Bibliographical**: carried out with material already prepared by other authors.
	Experimental: method based on the observation or manipulation of variables, which affect the object of study.	**Case Study**: analyzes a unit of a universe.
	Participant research: characterized by the interaction of the researcher with the object of study.	**Ex post facto**: research based on the facts of the past; diversification of variables.

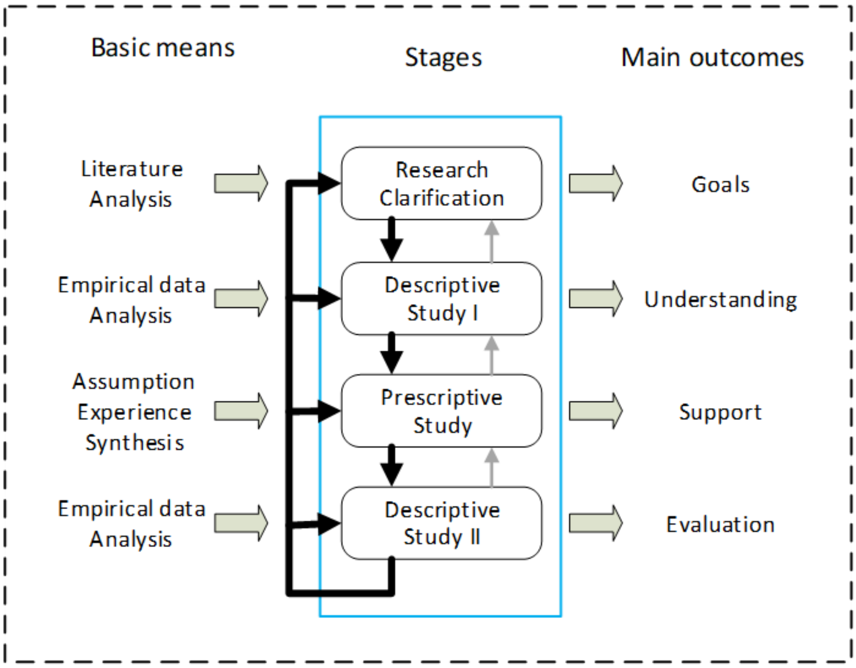
Source adapted: (URIBE OCAMPO, 2015)

2.2. GENERAL RESEARCH SCHEME

As pointed out by (BLESSING; CHAKRABARTI, 2009), the creation of methods to support product design can be based on deduction or induction deduction of bibliographic research and induction of case studies. In addition, these authors indicate a Design Research Methodology (DRM) framework, which is made up of four phases: Research Clarification, Descriptive Study I, Prescriptive Study, and Descriptive Study II, The DRM is shown in Figure 2.1, which relates the four phases of Design Research Methodology with their corresponding outputs.

In the ‘Research Clarification’ phase, the academic and practical reality is identified, from bibliographic research, by identifying topics of interest, activities, phases, or even areas of application of the design process. This clarification will allow us to discern gaps in knowledge, questions for which there are no answers or hypotheses.

Figure 2.1 - DRM framework



Source: (BLESSING; CHAKRABARTI, 2009)

The ‘Descriptive Study I’ phase is a description of the current situation, by highlighting problems and by indicating the relevance of the subject researched as well as an illustration of the main lines of argument which direct the attempt to improve the current situation. This phase can be carried out only with bibliographic review, or in a comprehensive form with bibliographic review and empirical research.

In the ‘Prescriptive Study’ phase, a support tool is developed for the project, supported by the previous phases. This phase can be carried out in an incipient manner - initial or preliminary proposal; comprehensive - its main functionality can be evaluated in its intended purpose; or by a bibliographic review - proposal of other authors.

The ‘Descriptive Study II’ phase in which the evaluation of the support tool developed is carried out, which can be carried out in an incipient manner - initial evaluation; or comprehensive - a much wider evaluation.

Similarly, Blessing and Chakrabarti (2009) perform a categorization of Design Research into seven types, depending on the scope and focus of research. This categorization corresponds to the way in which the indicated phases of the DRM framework are performed, as shown in Figure 2.2, indicating the authors how the first four types of research are focused on a particular phase and are proper of doctoral research.

Figure 2.2 - Design Research Types

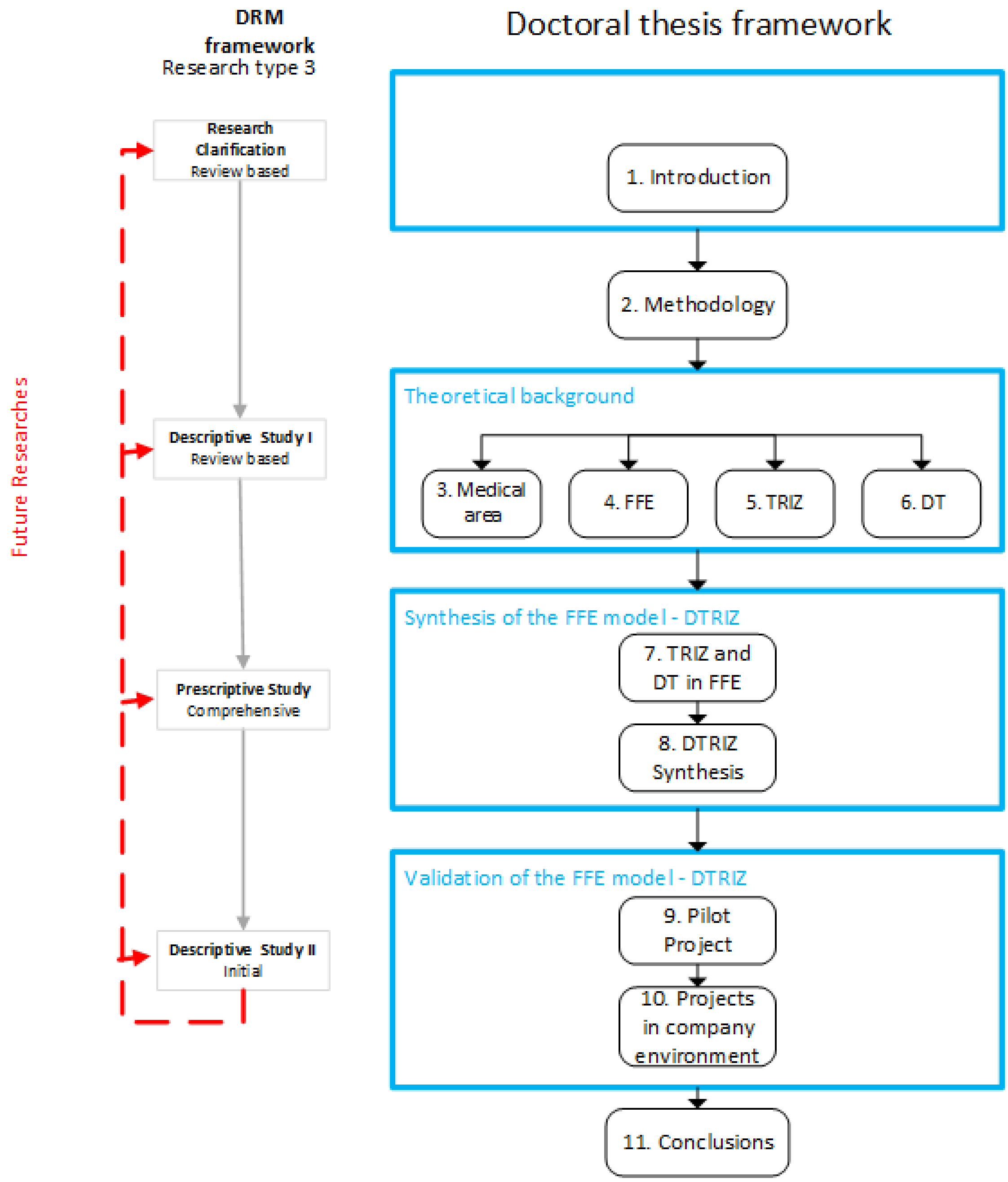
Research Clarification	Descriptive Study I	Prescriptive Study	Descriptive Study II
1. Review-based →	Comprehensive		
2. Review-based →	Comprehensive →	Initial	
3. Review-based →	Review-based →	Comprehensive →	Initial
4. Review-based →	Review-based →	Review-based → Initial/ Comprehensive ←	Comprehensive
5. Review-based →	Comprehensive →	Comprehensive →	Initial
6. Review-based →	Review-based →	Comprehensive →	Comprehensive
7. Review-based →	Comprehensive →	Comprehensive →	Comprehensive

Source: (BLESSING; CHAKRABARTI, 2009)

The present research is focused on the Prescriptive Study phase. In this way, it can be framed in research type 3 of Figure 2.2, the general objective being "to synthesize a Late FFE model, directed to high degree of innovation products, specific for industrial companies of PHE sector, by integrating TRIZ and Design Thinking methodologies". Thus, a general scheme of the current research is proposed, which relates the phases of research with the DRM framework as indicated by (BLESSING; CHAKRABARTI, 2009), which is shown in Figure 2.3. The structure of this research presents four phases, as follows: Research Clarification, Descriptive Study I, Prescriptive Study, and Descriptive Study II.

The first phase, Research Clarification, is based on bibliographic research, in which an initial understanding of the situation was conducted, as shown in Figure 2.3, which presents four axes, medical area, FFE, TRIZ and DT. The previous master's research contributes to the understanding of the medical area, regarding the product features, which make the development of these products different. In addition, practices in the companies of the sector, which showed a gap in the initial phases of product development with a high degree of innovation. The second phase, Descriptive Study I, is based on bibliographic research, which allowed a deep understanding of the four axes: medical area, FFE, TRIZ, and DT. It was determined that in the context of the high degree of innovation, there is a gap of FFE models, applicable to specific sectors, at a time of integrating methodologies and techniques, which facilitate the execution of key activities. TRIZ and DT methodologies were understood from the principles, which direct them, the process and the possible complement of these methodologies in the Late FFE.

Figure 2.3 - Doctoral thesis framework



Source: the author

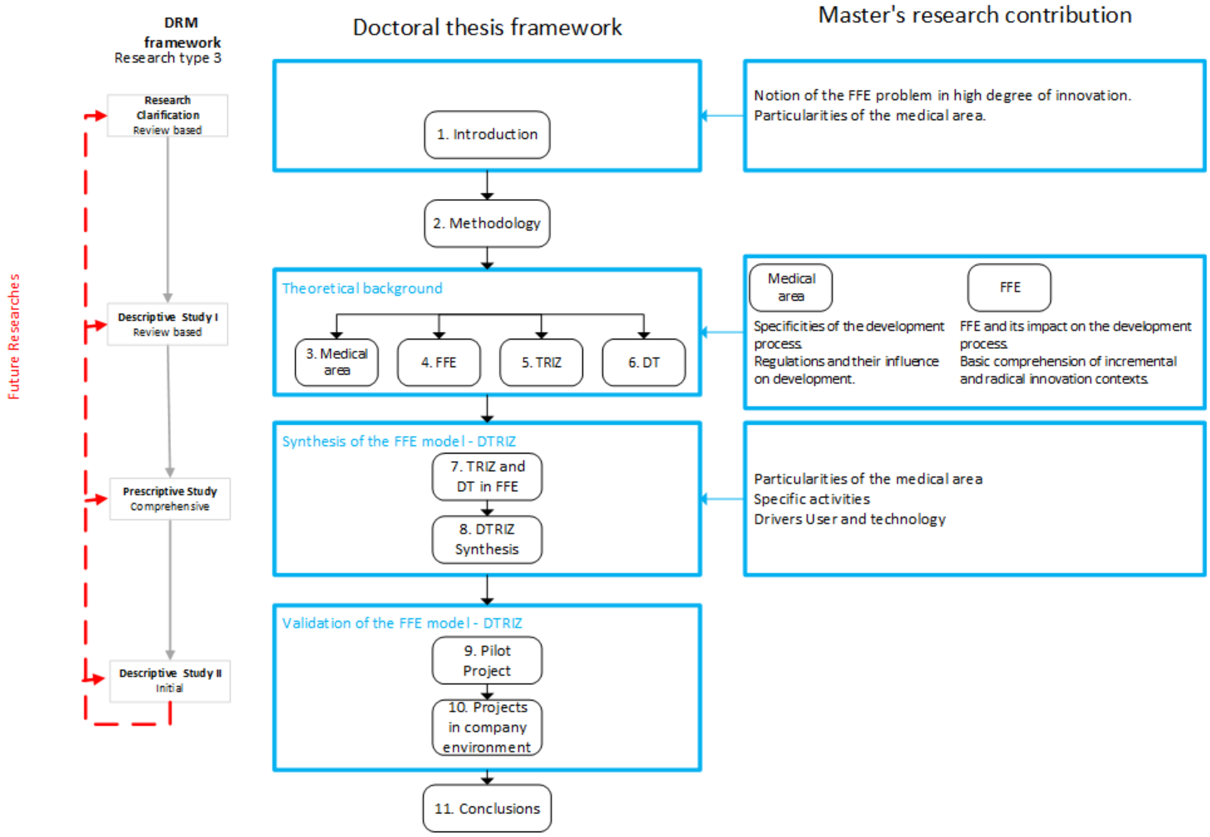
The third phase, Prescriptive Study, support methodology for Late FFE was developed specifically for products in the medical area and with a high degree of innovation, from the subsidies of the previous phases, this phase is the focus of the present research. Finally, the fourth phase, Descriptive Study II, corresponds to the validation of the proposed methodology. This validation was initial, meaning these case studies were carried out to understand how the proposed methodology supports companies in the PHE sector in the Late FFE.

Figure 2.4 indicates how the author's master's research contributes to the current research. It is worth noting that the author's Master's research focused on the Product Development Process in the PHE sector, framed in incremental innovation, and the present research focused on the Late FFE in the high degree of innovation paradigm.

The contribution of the previous master's research to the current research could be summarized as follows: finding the problem and reaching an initial understanding of it. Thus, the master's research allowed me to identify how the companies presented more problems with the most innovative projects. These companies did not understand that the most innovative projects presented different characteristics and tried to implement them with the usual practices, which generated technical problems, inadequate solutions, project delay, and abandonment.

Regarding the understanding of the problem, the master's research contributed to the understanding of the PHE sector, understanding the importance of regulations in this sector from the initial phases, as a driver of innovation, source of information and its influence on the PDP. Additionally, specificities of the medical sector were understood, which were explained in the introduction: type of users, regulations, technology, and development.

Figure 2.4 - Contribution of master's research to doctoral research



Source: the author

2.3. PROCEDURE DESCRIPTION

This item describes the research procedures performed in the thesis, in the bibliographic search phase, and how the validation of the synthesized model was performed.

2.3.1. Description of bibliographic search

Initially, bibliographic research was done with TRIZ, DT, and FFE thematic areas, by using the Web of knowledge database. They can be refined by selecting 'article' and language as being in 'English'. In the search for TRIZ, 376 articles were found. However, by reviewing their abstracts, some were discarded, except if they were related to the products of the PHE sector. As the idea was to deepen the knowledge of TRIZ, 33 articles were initially selected. In the case of DT, 426 of them were obtained. The abstracts were reviewed in order to determine the relationship with the topic, and 47 articles were selected, of which 45 were possible to obtain the full article, and then, reviewed in order to determine if the specific topic was DT. Finally, 21 articles were selected, of which 10 were DT reviews, while the other articles were focused on topics, such as user needs, reasoning in DT, teams, heuristics in DT, and iterations. In the case of FFE, the term "Fuzzy Front End" was used in the search. After reviewing the abstracts, 34 articles were selected.

With the articles in the three thematic areas having been reviewed, they were classified and analyzed. An important point to highlight in the analysis was the use of other relevant authors' bibliographic sources, by providing other types of search from different sources, such Google Scholar, and libraries. The classification and identification of relevant sources and authors allowed to focus the attention on themes and authors, for a more holistic understanding of the three thematic axes: TRIZ, DT and FFE. In the detailed examination of the texts, the qualitative analysis software Atlas TI, Version 8.1.27, was used.

2.3.2. Application of the proposed FFE Model

The object of study which will be measured is the application of the model to create new product concepts in a company's environment (the object of study is not the company itself). It is important to note that the focus of this research is the proposal of the model (Prescriptive Study). Descriptive Study II, is an initial type according to the DRM framework, which was proposed by (BLESSING; CHAKRABARTI, 2009).

The validation will have the following phases: preparation, the definition of variables to be measured, the selection of companies, the training in the model; project execution, the application of the model; project evaluation, the evaluation of project process and results; as well as the methodology application analysis.

2.3.2.1. The definition of variables to be measured

For validation, aspects of the way in which designs are carried out, were considered **- process variables**, and the main outputs **- result variables**, by having the proposed Late FFE Model as a prism. Therefore, as it is observed in Figure 8.12, the Late FFE Model proposal has three phases: Understand, Ideate, and Evaluate. The process variables are related to the quality of execution of design activities, which correspond to initial analysis and understanding the problem from the users' and technology's perspective; generation of concepts; and evaluation and selection of concepts. On the other hand, the results variables are the outcomes of processes: ideas and concepts. The evaluation of the ideas and concepts will be carried out according to: the amplitude

- in terms of different areas of knowledge; and the creative quality - defined by the adequacy of the concept to the problem and the novelty of concepts (AMABILE, 1996; LUBART, 2007).

2.3.2.2. The selection of companies

The selection of companies was based on their experience in product development in the PHE sector, it attempted to have companies with different features, and that companies had availability to participate in the current research.

Three companies were selected, predominantly, from the PHE sector. In this way, all companies applied the proposed model to development a product of the PHE sector, based on a detected opportunity or problem. Once the companies were selected, it was considered how they conducted the designs of new products.

2.3.2.3. The training in the model

The Late FFE model synthesized in this research presents two levels of understanding, the general methodology based on Spiral project, like principles of TRIZ and DT. Similarly, for each phase (Understand, Ideate, and Evaluate), a way of integrating TRIZ and DT was proposed. Also, an understanding of how to operationalize the model was proposed by listing the necessary techniques and procedures. In this way, it was chosen to carry out the training of the Late FFE Model in parallel with the application, keeping the general and focusing on the operative. Moreover, a didactic instrument was developed, which helps in the training and application of the model in companies. The didactic instrument is described in the item 9.1.3. The training time took 20 hours.

2.3.2.4. Project execution

Four projects were conducted. They are described in Table 9.4, where they are related to the three selected companies. The projects were proposed by the companies based on a previous identification of opportunity, for which a product development has not been performed in the company. In this way, it was possible to apply the methodology, starting from the analysis to find possible solutions. It was also suggested that the teams were from different areas of the company.

2.3.2.5. Project evaluation

The projects were taken until viable concepts were obtained, and as previously indicated, evaluations of the process and the results were carried out. For this purpose, workshops were held on key activities, and it was proposed that the team complement the activity. Besides, the deliverables were compiled, and some formats were suggested to facilitate the execution of the activities and the compilation of information. In addition, the designs were permanently monitored through unstructured interviews with development team personnel. With these instruments, the proposed variables were measured. The evaluation was focused on the key previously determined activities, as well as general aspects of the model.

2.3.2.6. Methodology application analysis

With the evaluation of the results of the methodology applications, a reflection of the adherence and consistency of the Late FFE model to the objectives of the thesis was carried out, as well as some adjustments to the model were suggested.

3. PERSONAL HEALTH EQUIPMENT

The present research is focused on Personal Health Equipment (PHE) which, as indicated, are classified in this thesis into three groups: Hospital Furniture, Medical Devices (MD) and Assistance Product for People with Disabilities. There are really no clear boundaries, which differentiate these three groups of products. Thus, some hospital furniture and Assistance Products for People with Disabilities are classified as MD, which may vary according to the regulations in different countries. The three groups of PHE will be explained, as well as the regulations, which have an influence on PD in the PHE sector.

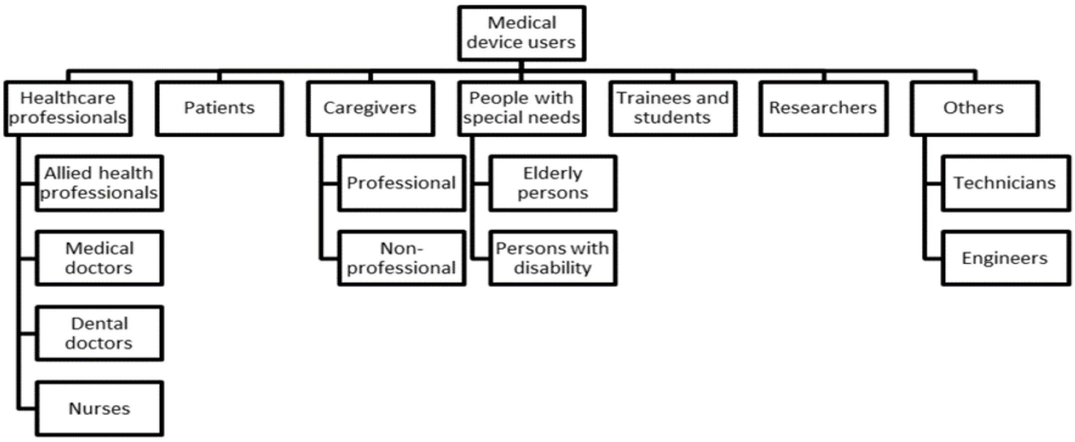
3.1. MEDICAL DEVICE

Medical device is any instrument, apparatus, implement, equipment, computer program or material intended by the manufacturer to be used, separately or in combination, in human beings for one or more specific purpose(s) of: diagnosis, prevention, control, treatment, or attenuation of a disease or injury. It is also used in research, replacement, modification, or support of the anatomy of a physiological process, support, or life-sustaining, design control, disinfection of medical devices, provision of information for medical purposes by in vitro examination, of specimens derived from the human body, (INTERNATIONAL STANDARD, 2016a), and includes various technologies and applications, from hand tools to computerized equipment for surgeries, or from an implant screw to an artificial organ (FOOD AND DRUG ADMINISTRATION, 1997; SANTOS et al., 2012).

Medical devices are classified according to the risk posed during their utilization. In Brazil, the European classification is used and this is performed by the Brazilian Health Regulatory Agency (ANVISA) for its acronym in Portuguese, which classifies the equipment in Class I (low risk); Class II (medium risk); Class III (high risk); and Class IV (maximum risk) (ANVISA, 2017).

People involved in MD are health professionals (health care assistants, doctors, or specialists), support personnel (cleaning or maintenance), patients and their companions, practitioners or students, people with special needs, researchers and engineers, as shown in Figure 3.1 (SANTOS et al., 2012).

Figure 3.1 - People involved in medical devices



Source: (SANTOS et al., 2012)

3.2. HOSPITAL FURNITURE

Hospital furniture is an artifact used to facilitate or to assist people in regular tasks of a hospital, and it is related to its main function, which is to preserve or to improve people's health. However, it has no active or invasive function in relation to the patient. There is no universal classification. Nevertheless, hospital furniture can be grouped according to their function. The basic groups are hospital beds, stretchers, examination tables, surgical tables, hospital cars, and other complementary products. Table 3.1 shows the classification of the main furniture and the main technology used to manufacture them, which were made based on catalogues and manufacturer's files.

The basic functions of hospital furniture are to accommodate patients during procedures and their recovery; to transport the patient; to transport, to support, or to preserve MD, medications, or supplies; to help medical staff in their functions, such as meeting the patients’ needs, diagnosing, performing procedures, and so on.

The evolution of hospital furniture follows the evolution of medical requirements and regulations. For example, new diagnostic equipment requires the development of new furniture, which can assist the patient according to new equipment or treatment requirements. However, in recent years hospital furniture have tended to integrate Information and Communications Technologies (ICT) to the extent that it has proposals for integration with hospitals' IT systems.

Table 3.1 - Classification of hospital furniture

Group	Type	Basic technology to power movement
Bed	Hospital bed Intensive Care Unit (ICU) bed Childbirth bed	Manual and electric
Stretcher	Patient transport stretcher Patient recuperation stretcher Emergency stretcher	Manual, electric, and hydraulic
Examination table	General examination table Gynecological examination table Pediatric examination table	Manual and electric
Surgical operating table	Universal Ophthalmology Orthopedics	Manual, electric, and hydraulic
Hospital trolley	hospital infusion trolley Hospital crash cart hospital medication trolley	Manual and electric
Complements	Auxiliary table Serum support Hospital food table	Manual

Source: (URIBE OCAMPO, 2015)

For the manufacture of hospital furniture, metallic and plastic materials are mainly used. The technology used for the movements is manual, electrical, pneumatic, and hydraulic. The technological trend is to manufacture them in plastic materials because they are more aseptic and withstand molded production processes. In addition, the operating technology tends to make it easier for the user to operate with the use of electrical systems in combination with electronic controls.

3.3. ASSISTIVE PRODUCTS FOR PERSONS WITH DISABILITIES

There are several definitions of Assistive Products for Persons with Disabilities. On the one hand, the World Health Organization -WHO (2001) defines assistive products and technology as any product, instrument, equipment or technology adapted or especially designed to improve the functioning of a disabled person. On the other hand, International Standard (2016a) defines them more broadly as any product (including devices, equipment, instruments, technology and software) especially produced for the prevention, compensation, monitoring, relief, or neutralization of disabilities, activity limitations and participation restrictions of the person, assisting physiological functions of body systems (including psychological function).

Disability, in the context of the ISO 9999 - International Standard (2016b), is an umbrella term for impediments, activity limitations, and participation restrictions, denoting the negative aspects of interaction between an individual (with a health condition) and the contextual factors of that individual (environmental and personal factors). In this sense, assistive technology is a tool to increase independence and participation (UNICEF, 2015).

The ISO 9999 International Standard (2016b) makes a classification, which is based on product function, and it consists of three hierarchical levels: classes, subclasses and assigned divisions.

The first level-classes classification is:

- 04 Support products for personal medical treatment;
- 05 Supporting products for skills training;
- 06 Orthoses and prostheses;
- 09 Assistance products for personal care and protection;
- 12 Products to support personal mobility;
- 15 Auxiliary products for cleaning service;
- 18 Furniture and adaptation for residences and other facilities;
- 22 Ancillary products for communication and information;
- 24 Assistive products for handling objects and devices;
- 27 Products to support environmental improvement, tools and machines; and
- 30 Products to support recreation.

With the introduction of the three groups, which make up PHE, it was possible to establish that, despite the different definitions, there are no clear and defined boundaries between these groups. However, their great difference consists of basic objectives for what they are designed, and, in summary, these are: Medical device, to treat, to diagnose, and to prevent, or to alleviate people's diseases; Hospital furniture, to support and to protect people, medications, and artifacts in the hospital context; and Assistance Product for People with Disabilities, to enable independence and participation of people.

3.4. PHE SECTOR REGULATIONS

Regulation has a strong influence on the development of MD, as shown by (URIBE OCAMPO; KAMINSKI, 2019). This can be extrapolated to PHE since there is no clear limit for the three groups of PHE. These regulations, in general, seek to ensure the safety and effectiveness of PHE, based on prior knowledge and experience, and are constantly evolving, following the evolution of innovation in the medical sector. In PHE development, regulations play different roles, such as providing guidelines for the PHE development process; as a source of knowledge, standards are based on scientific and empirical knowledge, which can be used in PD; and as a driver of innovation, the evolution of PHE standards (and even other standards) presents new challenges, this of standard evolution, offers opportunities for improvement and new PHE. Table 3.2 shows a compendium of some of the main standards related to the safety and effectiveness, which are indicated for MD, in general.

Table 3.2 - Safety standards

Standard	Scope
ISO 14971 Medical devices Application of risk management to medical devices (INTERNATIONAL STANDARD, 2019)	It establishes procedures for risk analysis and management in MD development. It includes basically risk identification, evaluation, control, and reduction, for further monitoring
IEC 62366-1 Medical devices -- Part 1: Application of usability engineering to medical devices (INTERNATIONAL ELECTROTECHNICAL COMMISSION, 2015)	It specifies usability requirements in MD in order to mitigate risks associated with the poor use of MD. Analysis, design, verification, and validation of usability through the MD development cycle, in relation to their safety.
IEC/TR 62366-2 Medical devices -- Part 2: Guidance on the application of usability engineering to medical devices (INTERNATIONAL ELECTROTECHNICAL COMMISSION, 2016)	It is a guideline for usability in MD, being a complement of part 1
Applying Human Factors and Usability Engineering to Medical Device (FOOD AND DRUG ADMINISTRATION, 2016)	It represents the thinking of the FDA on human factors and usability in MD development since these human factors can harm users, and they are not easily detectable.
ISO 16142-1 Medical devices — Recognized essential principles of safety and performance of medical devices — Part 1 (INTERNATIONAL STANDARD, 2016c)	It identifies and describes requirements and tenets for safety and effectiveness, which should be considered during the development and manufacturing of MD, in general, beyond risk management, by gathering specific topics, such as chemical, biological, physical, working environment, and conditions of use, which also include MD aspects different from in-vitro diagnosis.
ISO 16142-2 Medical devices — Recognized essential principles of safety and performance of medical devices — Part 2 (INTERNATIONAL STANDARD, 2017)	It identifies and describes requirements and principles for MD safety and effectiveness, in general, by including in-vitro diagnosis, which is a supplement of part 1.
IEC 60601-1 Medical electrical equipment - Part 1: General requirements for basic safety and essential performance (INTERNATIONAL STANDARD, 2005)	IEC 60601 is a series of technical standards aimed at the safety and essential performance of medical electrical equipment. It consists of a general standard IEC 60601-1, collateral standards and particular standards. The general standard IEC 60601-1 describes the safety requirements for medical electrical equipment to ensure the protection of patients, operators, and the working environment. Collateral standards are broad requirements, which can be applied to one or several MD. They have specific objectives, such as homecare, electromagnetic compatibility, and usability. They have a horizontal integration with the general IEC 60601-1 standard. Particular standards define conditions for specific MD, such as hospital bed IEC 60601-2-52, infant incubators IEC 60601-2-19. They have a vertical integration with the general IEC 60601-1 standard.
The evolution of MD safety standards has morphed from patient safety to MD safety and effectiveness, by considering that in addition to the patient, there are different users and the environment in which MD operate. Key issues of the standards include: safety, risk management, effectiveness, usability, and ultimately, human aspects.	

Source modified: (URIBE OCAMPO; KAMINSKI, 2019)

Institutions have proposed process standards, which indicate features of the PD process, in its different phases, such as development, production and distribution, marketing, use and even discontinuation – development provisions. On the other hand, product standards recommended conditions, which need to be met by the product in order to perform its function effectively and safely - source of knowledge. About the former, several institutions have published standards or guidelines, which provide conditions on how to develop medical products. The most relevant are the European and United States standards, for their utilization in several of the world's major medical device markets. In addition, the United States in 1976 and Europe in 1993 were the first ones to regulate medical devices (SANTOS et al., 2012; SGS, 2012). The main product and process standards, which shape the medical device development process are presented below.

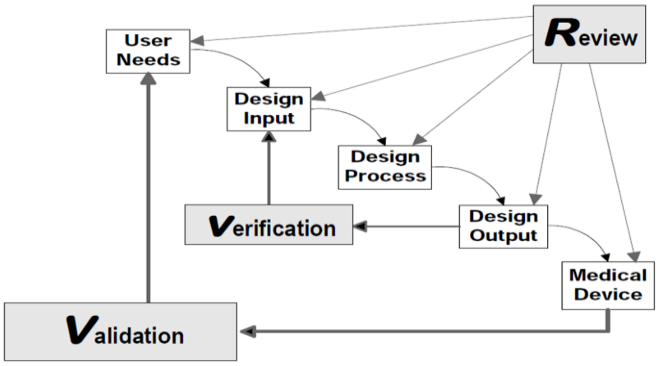
3.4.1. FDA guidelines

The United States Food and Drug Administration (FDA) has published a manual for the development of MD, in which it proposes a control that extends from product design, manufacturing, distribution, use, maintenance to obsolescence. FDA suggests the Waterfall model, by emphasizing the need for reviews of each phase, revisions that are of a technical order; verification of design results with users' initial needs, and product validation before transferring the product to production. Figure 3.2 represents the FDA Waterfall Design Process.

Food and Drug Administration (1997) emphasizes device risk management, in which the development process needs to integrate an assessment system to identify unacceptable risks in early phases of the design, and procedures for risk analysis, control, and monitoring. The type of risk depends on the nature of the product. Therefore, the FDA classifies medical devices into three categories, by depending on risk level. Category 1, moderate risk is the lowest, in which hospital furniture are generally classified. FDA guidelines do not establish a model as such, they are a set of guidelines to improve the safety of users and companies. In addition, they emphasize the need for change control and documentation during the life of the product.

The main points established by Food and Drug Administration (1997) are: i) the revision of the product design inputs, being these functional - function requirements, performance - accuracy, speed, time, among others, interface - compatibility requirement with external systems; ii) development control at all stages, from the beginning of product design to discontinuation; iii) defined and logical stages in product development phases; iv) risk management process, which ensures identification, analysis, control, and monitoring of potential risks, a risk is defined as a possible hazard to the integrity of people, by interacting with the device in use; v) review of the process phases, verification of project results against specifications, and validation of the product developed; vi) control of changes in the product; vii) document control; viii) definition of the interfaces between groups; ix) communication policies and procedures of team members; and x) identification of responsibilities in activities.

Figure 3.2 - FDA Waterfall Design Process



Source: (FOOD AND 2DRUG ADMINISTRATION, 1997)

3.4.2. ISO 13485

In Europe, Directive 93/42/EEC for Medical Devices regulates general medical devices. The requirements for the development of these products are indicated in the (INTERNATIONAL STANDARD, 2016a), it proposes a series of measures for the organization, which develops MD to implement them in order to guarantee the quality of products.

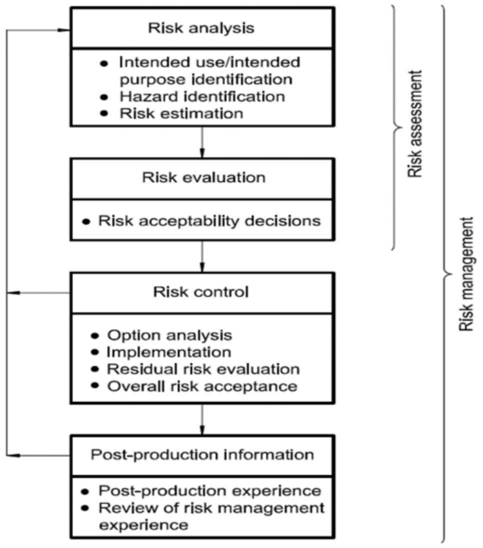
The standard establishes the general conditions of product design, which are, in general terms, project planning; the documented procedure, with its phases and activities; review of the process stages, verification of the project results against specifications, and the product validation; definition of the interfaces between the groups involved in product design, identification of responsibilities and assurance of effective communication; by having human resources with the knowledge and skills necessary for the tasks, by having evaluation and training plans, and risk management.

Planning outputs must be documented and updated as development is designed and continued. In general, the standard does not determine a specific methodology, and it is similar in several points to the ISO 9001 Standard, although it has its own elements for medical products.

3.4.3. ISO 14971

The International Standard (2019) - ISO 14971, establishes procedures for the analysis and rink management in the MD development, by defining a risk as situations, which can endanger different users of medical devices. It basically covers the identification, evaluation, control, and reduction of risk for subsequent monitoring. Figure 3.3 shows the risk control process diagram.

Figure 3.3 - Risk management diagram



Source: (INTERNATIONAL STANDARD, 2019)

The process standards and guidelines, considered in the theoretical framework, provide the elements indicated in Table 3.3, which support the proposal of this research. 22

Table 3.3 - Elements of the standards

IT	Description	Application
1	Importance of defining clinical and regulatory requirements, as well as functional type design inputs, performance, and environmental compatibility, and other equipment.	FFE PDP
2	Take into consideration the different users involved, who interact with MD.	FFE PDP
3	Identification and management of MD risks for different users, from the initial phases and throughout the PDP, which include identification, evaluation, control, and subsequent monitoring.	FFE PDP
4	Documentary control of MD throughout the entire life cycle, as well as change control.	PDP
5	Define interfaces between working groups in order to ensure the transfer of outputs between project phases.	FFE PDP
6	Effective communication strategy between departments involved in the development.	PDP
7	Clear definition of responsibilities.	PDP
8	Human resources with sufficient knowledge and skills for design tasks.	FFE PDP

Source: the author

4. FUZZY FRONT END

The concept of FFE is related to the undefined, ambiguous and even chaotic nature of the initial phase (KOEN et al., 2001). This diffuse phase can be extended from opportunity identification to the concept creation, or even, during the basic project definition until product architecture. FFE is more relevant for high degree of innovation products due to high uncertainties and the insufficient design definition present in this stage (KOEN et al., 2001; MARKHAM, 2013; TATIKONDA; ROSENTHAL, 2000). In a broader sense, FFE could be defined as all activities, which are done before the formal and structured process of the new product (Development) begins, even though there is a continuity of FFE to Development.

The classic authors of product development in their models propose phases or activities before product design. Although not all of them indicate FFE, these authors recognize the relevance of the initial phases and suggest how in the design progress, product's features are defined in the first phases, which have a small investment. However, they strongly influence the final features of the product.

About the differences of FFE and Development stages, in Table 4.1 a comparison is established, in which it is possible to perceive how the different aspects compared move from the undetermined and flexible FFE to the determined and rigid Development. As indicated by (KOEN et al., 2001), FFE is experimental, ambiguous, and sometimes chaotic and with great uncertainties, in contrast to the structure, which looks for efficiency and orientation to the objective of Development.

Table 4.1 - Difference between FFE and Development

Factor	FFE	Development
Idea status	Probable, diffuse, easy to change	Clear and specific; defined to develop, difficult to change
Nature of work	Experimental, chaotic, and difficult to plan	Structured; goal-oriented with a project plan
Nature of the information for decision	Qualitative, informal, and approximate	Quantitative, formal and precise
Easiness to reject idea	Easy	Difficult
Degree of formalization	Low	High
Marketing date	Indefinable	Definable
Billing Expectation	Uncertain, it can be done as speculation	Can be estimated with some accuracy
Activities	Individuals and in teams, to reduce risk	Multifunctional teams in development
Method of management	Unstructured, experimental, creativity required	Structured and systematic
Visible damage, if abandoned	Usually small	Substantial
CEO Committee	Small or non-existent	Usually large

Source modified: (KOEN et al., 2001)

4.1. FFE MODELS

As previously indicated, different authors have proposed activities and ways of relating them in order to structure FFE. The following authors stand out because of their relevance in the literature: Cooper (1988), Khurana and Rosenthal (1997) and Koen et al. (2001) in incremental innovation. On the other hand, other authors have recently proposed models to implement FFE for high degree of innovation (FRISHAMMAR et al., 2016; REID; BRENTANI, 2004).

Table 4.2 and Figure 4.1 show the synthesis of the FFE proposals consulted, chronologically organized into three groups, from the incremental to the most radical. Table 4.2 shows the main activities and features of these models, while Figure 4.1 indicates the graphic representation of each model. The models in Figure 4.1 were placed to indicate their orientation with the Early or Late FFE.

By analyzing these studied models, it is possible to observe how the proposals are becoming more refined, and include new elements: ideation (COOPER, 1988), identification opportunities (KHURANA; ROSENTHAL, 1998), influence of external factors and top management (KOEN et al., 2001), internal and external involvement and the importance of the ideas transfer (RIEL; NEUMANN; TICHKIEWITCH, 2013), information flow and interphases (REID; BRENTANI, 2004), clear definition, understanding and creation of the problem - Early FFE, and the problem solution - Late FFE (FRISHAMMAR et al., 2016), and cycles of divergence and convergence, by focusing on the problem and solution (VIZIOLI, 2019).

It was also identified how the FFE models went from being based on SG, in incremental innovation, characterized by rigidity and decision gates as part of their essence, to more flexible models, in which more than activities and gates, elements are presented and their relationship with the process.

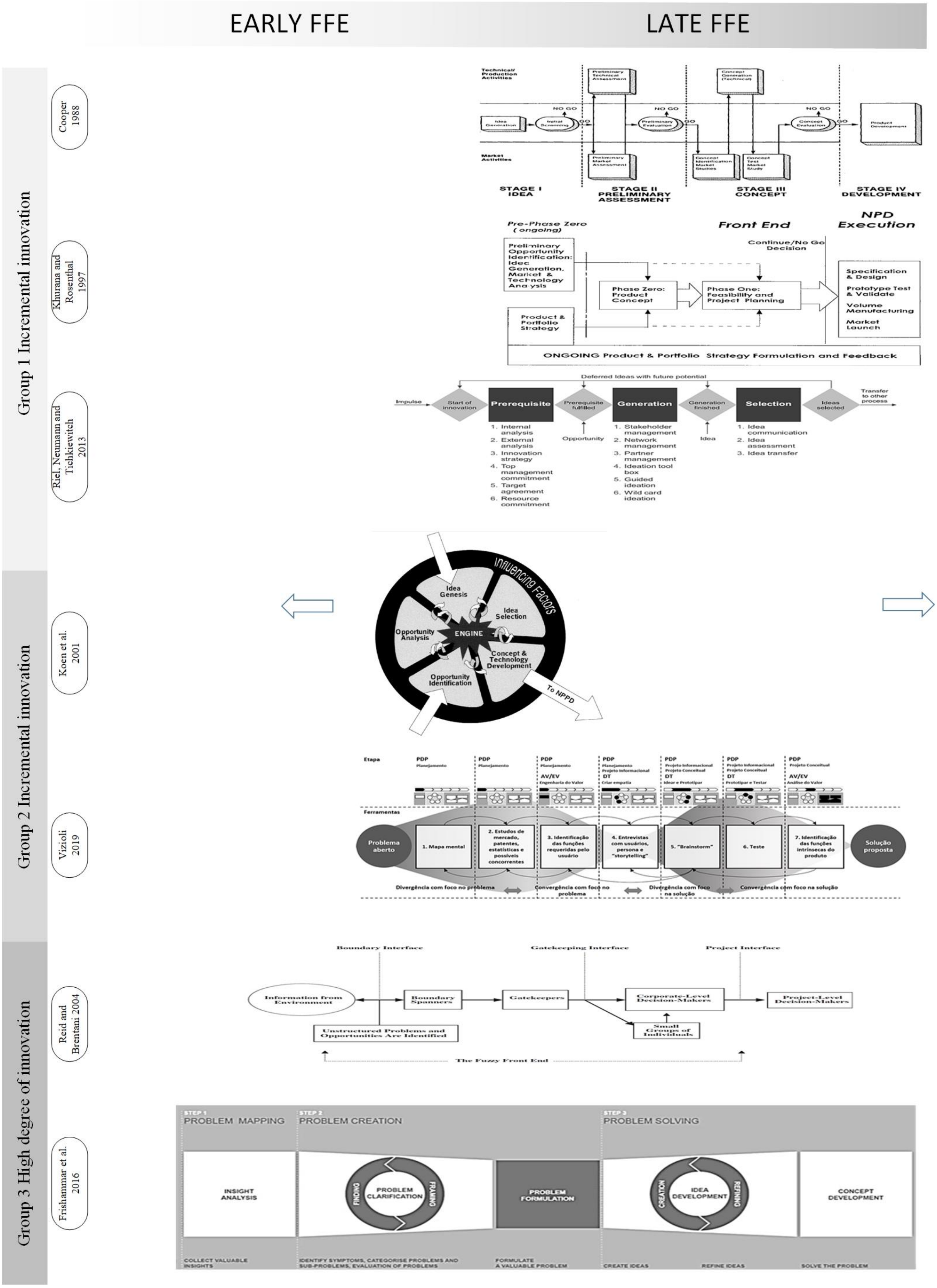
Some authors focus on specific aspects of FFE, Riel, Neumann and Tichkiewitch (2013) in the generation and selection of ideas, which integrate different stakeholders. Besides, by proposing phases, the authors indicate information flows and interfaces as essential elements, Vizioli (2019) proposes a way of solving the problem (Late FFE), by integrating the Value Analysis and Design Thinking methodologies, to understand the problem and to propose solutions in divergence and convergence cycles.

Table 4.2 - FFE Models Summary

	Author	Activities	Key Concepts	Comment
Group 1. Incremental innovation	Cooper 1988 (COOPER, 1988)	Idea generation Preliminary Evacuation Concept definition	From Idea to the concept	Linear model, based on Stage Gate. The author identifies the importance of technological and market evaluation
	Khurana y Rosenthal 1997 (KHURANA; ROSENTHAL, 1997, 1998)	Preliminary identification of opportunity Concept definition Product and plan definition	From opportunity identification to concept. Product strategy during the process.	Inspired by Cooper (1988) Existence of iterations The authors identify problems in FFE Based on case studies and literature review.
	Riel, Neumann and Tichkiewitch 2013 (RIEL; NEUMANN; TICHKIEWITCH, 2013)	Prerequisites Idea generation Idea selection	Generation, selection, and transfer of ideas, integrating internal and external stakeholders	Based on SG, the model only focuses on the ideation process. Originated from case studies of the automotive sector and interviews with specialists
Group 2	Koen et al. 2001 (KOEN et al., 2001; KOEN; BERTELS; KLEINSCHMIDT, 2014)	Opportunity identification Opportunities analysis Ideas Genesis Idea selection Concept definition	Consideration of external influences, strategic, top management and organizational culture. Few details on how to operate the activities.	Nonlinear model, based on interactions. In essence it is an evolution of the Cooper y Khurana & Rosenthal models. It emerges from a longitudinal study with 8 companies, later evaluation (2014) with 19 companies
	Vizioli 2019 (VIZIOLI, 2019)	Plan: Mental map, market research, patents, and Identification functions, Informational project: Interviews with users Conceptual design: Brainstorm, testing and identification of intrinsic functions	Two cycles of divergence and convergence, focusing on the problem and focusing on the solution, respectively. Integrates Design Thinking and Value Analysis in FFE.	Based on SG, with interactions, the model indicates DT and Value Analysis domains, resulting from literature analysis and academic applications.
Group 3. High degree of innovation	Reid and Brentani 2004 (BRENTANI; REID, 2012; REID; BRENTANI, 2004, 2010)	Boundary interface: detection and interpretation of unstructured opportunity by the individual Gatekeeping Interface: the individual's step to organizing the most structured opportunity Project Interface: From Organization to Formal Project	Early FFE identification of the problem and gather information, Later FFE generation of ideas and development of the concept	The authors are more interested in the inter-phases and the flow of information. Strictly theoretical does not present practical results. Originated from a succession of studies on radical innovation.
	Frishammar et al. 2016 (FLORÉN et al., 2017; FRISHAMMAR et al., 2016; FRISHAMMAR; FLORÉN; WINCENT, 2011; FRISHAMMAR; LICHTENTHALER; RICHTNÉR, 2013)	Mapping problems: customer analysis, values, culture, current situation and external environment. Problem creation: finding and formulating the customer's problem, being iterative steps. Problem solving: creating and refining ideas, iterative steps. Select the appropriate solution and develop the concept	Part of the user's understanding and his surroundings, to define the problem and proceed to its solution and development of The concept in successive phases.	Based on studies of seven cases of radical innovation and previous longitudinal study of 4 years. No real application of the model.

Source: the author

Figure 4.1 - FFE Models



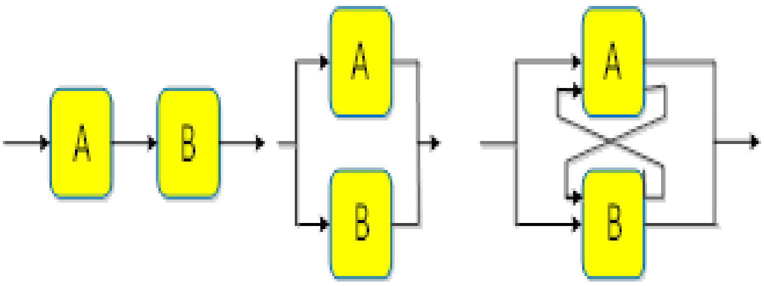
Source: the author

Similarly, FLORÉN et al. (2017), Frishammar; Lichtenthaler; Richtnér (2013), and Koen et al. (2001) highlight the importance of the participation of senior management to legitimize, to facilitate, and to evaluate. Frishammar et al. (2016) indicate open and divergent thinking, flexibility, market vision - the ability to identify and to capture gaps. Besides, Frishammar et al. (2016) and Koen et al. (2001) propose determining aspects such as culture, organizational climate, vision, resources, and leadership.

4.2. FLEXIBILITY, ITERATION, AND DEGREE OF INNOVATION OF THE NEW PRODUCT

In order to understand flexibility, and iterations in product development, the possible relationships of activities in this process are illustrated, which can have three relationships, as shown in Figure 4.2: i) dependence, task B requires information from task A, by requiring serial organization; ii) independence, tasks A and B have no information relationship, which can be executed in parallel; and iii) interdependence, task B requires information from task A, and task A requires information from task B to be completed. Therefore, they must be executed iteratively, with successive advances of both tasks with communication between them (EPPINGER et al., 1994).

Figure 4.2 - Relations of activities



Source: (EPPINGER et al., 1994)

Interdependency or dependency relationships may be weak when the information needed for task A can be estimated with an adequate level of accuracy to complete task B, or it is difficult to estimate, but the information has little impact on the subsequent task. The relationship may be strong if the information from task A has a high impact on the subsequent task and it is not possible to estimate this information with the degree of accuracy necessary to complement task B. Thus, the relationship or independence, as well as the intensity of this relationship, determines whether the activities need to be performed sequentially, in parallel, or iteratively.

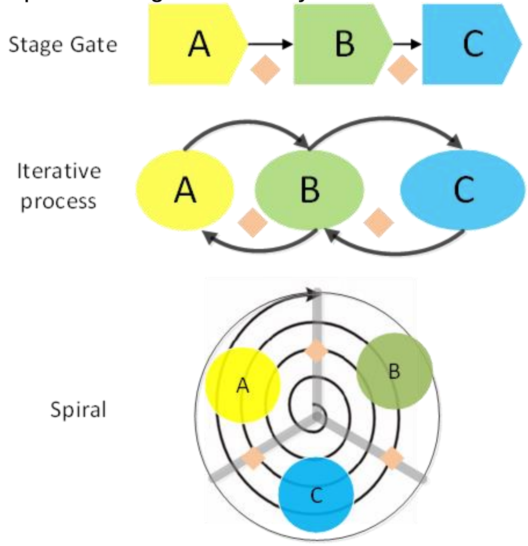
In FFE, it is expected that for more innovative products, there is no much prior information and, on the contrary, great uncertainties - lack of knowledge. This lack of knowledge causes situations that cannot be controlled by the development team. Then, activities tend to have greater dependence or interdependence. On the contrary, to develop a less innovative product, some relevant information is already known or can be estimated with sufficient precision to continue design so that activities can be more independent and the process can be defined with activities in series or in parallel. In other words, the increase in the degree of innovation determines the level of unstructuredness of FFE.

In Chapter 1, it was indicated as for FFE in the context of high degree of innovation, a model based on SG, which is not adequate or needs to have adaptations in order to deal with the uncertainties inherent in this context. Also, authors like (MARKHAM, 2013; TATIKONDA; ROSENTHAL, 2000; UNGER; EPPINGER, 2011), propose flexibility in the design and tentative - error, as ways of reducing uncertainties, facts that were verified when analyzing the proposals of FFE, which were more focused on high degree of innovation. The analysis made in Figure 4.2 in relation to activities can be extrapolated to phases. This is basically the conceptual underpinning of the growing need for flexibility with the increase in the degree of innovation of new developments.

Flexibility of the design process consists of the iteration between activities and even between phases, characterized by the number of iterations and by the short or long iterations. That is, iterations between adjacent activities or between distant activities (UNGER; EPPINGER, 2011). Thus, for short and few iterations, the project structure can be indicated as phases with constant iterations, by obtaining an iterative SG process. However, whenever it is necessary constant iterations short and long the Spiral structure can be more convenient for its iterative nature, which proposes constant iterations in the project progress (UNGER; EPPINGER, 2011).

The Spiral has been proposed for the engineering area by (EVANS, 1959; KAMINSKI, 2000), and for the software development area (BOEHM, 1988). It has different interpretations, in the version of (BOEHM, 1988), which consists of the idea that each Spiral run passes through different phases. The radius represents the resources of time and money invested and the angle traveled represents the accumulation of knowledge. With each run, more than repeating the activities, based on the results of the previous run, the project is taken to a higher level. Its high interactivity allows the project to be understood as a successive advance of several aspects, but it is difficult to manage it due to the high level of flexibility (UNGER; EPPINGER, 2011).

Figure 4.3 - Activity Relationship According to Flexibility



Source: the author

4.3. CREATIVE PROCESS

Creativity is defined as a new and context-adaptable production according to (AMABILE, 1996; LUBART, 2007). Novelty can have different degrees from minimal deviations to something completely different, and adaptability refers to satisfying the difficulties of the situation, which gave origin to production. There is no absolute norm, which evaluates how creative a specific production is.

Several authors have described the creative process, by giving relevance to different important aspects in this process. From a review of texts by some authors (ALENCAR, 2003; AMABILE, 1996; LUBART, 2007; SAWYER, 2012; STERNBERG, 2010), different views and descriptions of the Creative Process are indicated. Figure 4.4 shows a comparison of the stages of the cited authors, which are presented chronologically, and these are classified into three major stages: Analysis, Synthesis, and Verification.

Figure 4.4 - Creative process

	Analysis			Synthesis			Verification	
Poincaré		Preparation		Illumination			Verification	
Heltmholtz		Saturation		Incubation	Illumination			
Wallas		Preparation		Incubation	Illumination		Verification	
Amabile	Task identification	Preparation		Generating alternatives			Validating and communicating	Verification
Sawyer	Finding and formulating problem	Acquiring relevant knowledge	Gathering information	Incubation	Generating ideas	Combining ideas	Selection idea	Communicating idea

Source: the author

More contemporary authors present more detailed descriptions of the Creative Process. However, as indicated in Figure 4.4, it is possible to summarize the phases of the different authors in three stages: Analysis, Synthesis and Verification.

Analysis, conscious phase in which the problem is defined and clarified and the relevant information collected. In this phase relevance of knowledge or baggage in the field of the problem is highlighted; Synthesis, the authors propose that this phase has an unconscious part (incubation), where the mind makes multiple combinations of the problem elements with prior knowledge in order to generate solutions, as indicated by (SAWYER, 2012), in an "unexpected" way, and a conscious part (illumination or generation of ideas) in which the most pertinent combinations are identified, which can address the problem; and Verification, in this phase the most appropriate ideas are verified and selected, which is also represented and communicated.

Other authors indicate Creative Process as a confluence of factors. Among them (AMABILE, 1996), who relates determining factors to the proposed phases. There is no definitive theory, which explains Creative Process in detail, but from those in the know, it was possible to define a basic sequence and to identify certain influencing Creative Process elements.

In this way, the Creative Process can be understood as the result of individual and environmental factors and involve cognitive, affective, social, cultural, and historical aspects. The Creative Process does not occur systematically, it requires favorable conditions. Intrinsic motivation is a preponderant factor, as well as the baggage of knowledge on the issue, and the strategies for monitoring and evaluation (ALENCAR, 2003).

Synthesis is one of the phases of the creative process according to cited authors. The researchers relate synthesis with conscious and unconscious processes. Thus, the mind continues working on the problem even if it is in other tasks, by going through moments of relaxation and forgetting fixed ideas, which can block the mind. The subconscious mind makes random combinations of elements of the problem and past memories, and the conscious mind identifies feasible ideas.

However, in the real world, it is difficult to establish the process accurately. Researchers believe that creativity is related to finding the problem and solving it creatively. Thus, finding and determining the problem is a fundamental part of solving it, which implies divergence and convergence progresses.

4.4. ANALYSIS OF FFE MODELS

Different proposals for FFE models were presented, to have a historical context and to understand the evolution of FFE construction over time, as well as the interest of the academy in FFE in high degree of innovation was evident. Also, the flexibility of the design and the creative process were discussed, these last topics will support the analysis of FFE models and the synthesis of the model of this research.

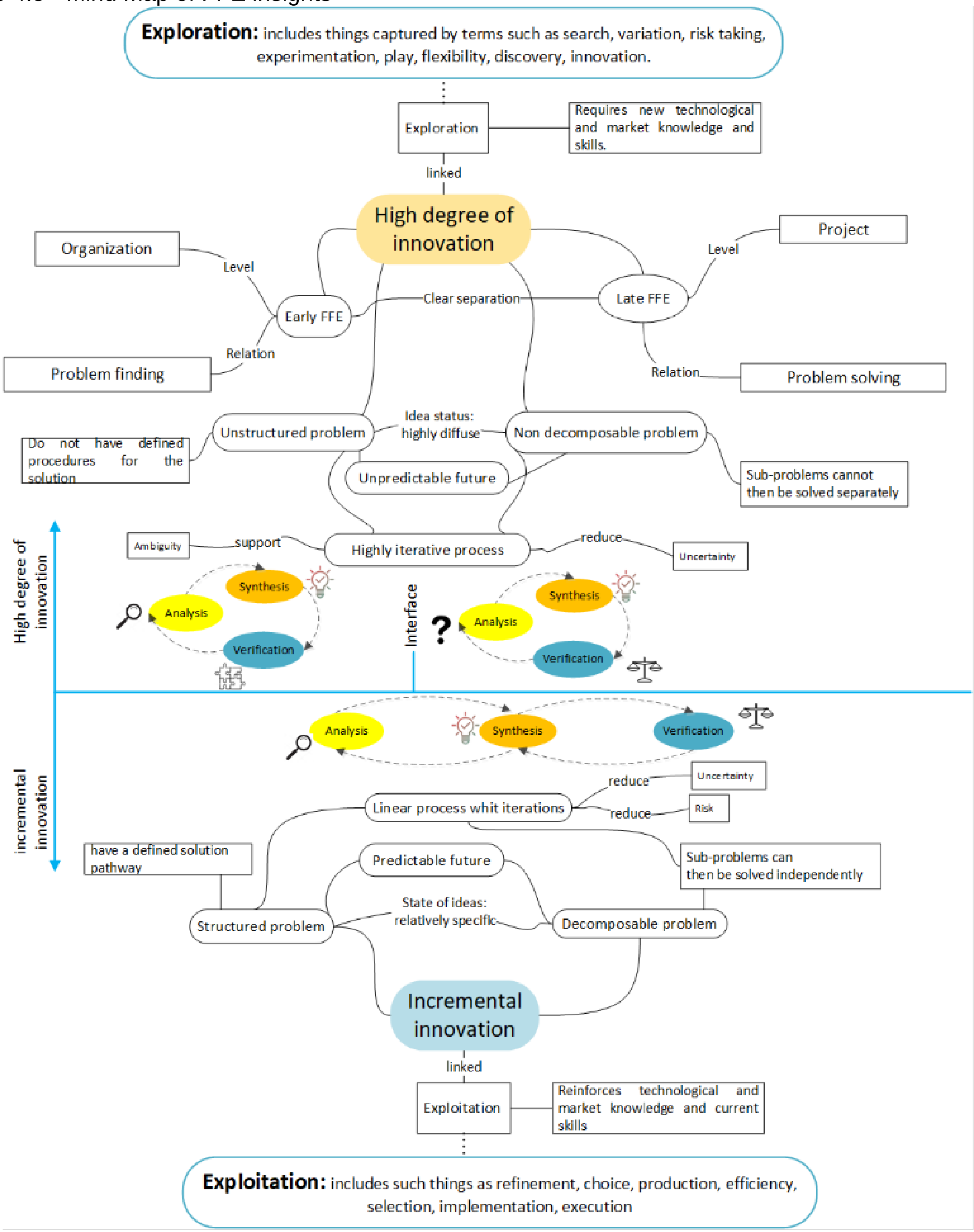
Therefore, in FFE models, the essential subject has passed from the generation and selection of ideas (Cooper 1988), to the detection of opportunities and generation of ideas about these opportunities (Khurana and Rosenthal 1997, 1998), and to transfer of ideas, by integrating internal and external stakeholders (Riel et al. 2013), in process based of SG, in the context of incremental innovation, group 1 Table 4.2. In the group 2, Table 4.2, the essential subject of FFE are opportunity identification, opportunities analysis to concept definition. Integrating external, and internal influences, business strategic, top management, and organizational culture (Koen et al. 2001), cycles of problem understanding and problem solution Vizioli (2019). The last two models propose an iterative process in essence, and they do not have a clear separation of Early and Late FFE.

On the other hand, in the high degree of innovation, group 3, Table 4.2, the models have a clear separation of Early and Late FFE (Frishammar et al. 2016; Reid and Brentani 2004). On the one hand, Reid and Brentani (2004) propose a model based on information flows considering three levels: environmental, individual, and organizational. The authors have been more interested in how information flows in the process and interfaces, rather than in the FFE activities. On the other hand, Frishammar et al. (2016) propose a four-phase model, which is shown in Figure 1.1, the first two phases: Mapping problems and Problem creation - Early FFE, and he phases: Problem solving and Concept development - Late FFE. Early FFE and Late FFE are two independents' cycles.

Figure 4.5 is a mind map in which the main ideas of FFE are organized, below incremental innovation and above high degree of innovation. As indicated by March (1991) "Exploitation includes such things as refinement, choice, production, efficiency, selection, implementation, execution. Exploration includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery, innovation." These two sentences summarize the difference of FFE in both incremental and high degree of innovation contexts.

By focusing on high degree of innovation, as indicated in Figure 4.5, FFE presents a clear separation of Early and Late FFE. The Early FFE identified with an organizational level – Problem finding, is concerned with exploring, determining, and structuring new product ideas. Late FFE, which is identified with a project level- Problem solution, begins with a specific opportunity and aims to take it to a product concept, which responds to this opportunity. Each one is an independent and highly iterative cycle of analysis, synthesis, and verification, with its own objectives, to achieve a complement.

Figure 4.5 - Mind map of FFE insights



Source: the author

Early FFE - Problem finding, begins with an exploration of the environment - technology and market, by identifying possibilities - idea genesis, by structuring them with the objectives of the company, after an interface in which the company prioritizes the ideas to be developed. Late FFE - Problem solving, begins with an articulated idea and through a cycle of understanding, ideation of solution alternatives, and evaluation of alternatives to determine which the most promising solutions are.

As indicated in Figure 4.5, FFE in the context of high degree of innovation is Unstructured and Non-decomposable problem. Thus, the solution path is not clear, and it is not possible to solve the subproblems independently. A process defined by high uncertainties, which are reduced with a highly flexible and iterative process, more related to project spiral than to SG. In this way, Figure 4.5 summarizes FFE in the contexts of incremental innovation and high degree of innovation, understood: first, from the authors who have studied the FFE, second, from the relationship of activities and phases, which can be of independence, dependence, and interdependence, and finally from the analysis of the creative process.

The overview shown in Figure 4.5 help to understand how in the context of incremental innovation the process has as its mandate an efficiency in execution, and, on the other hand, in the context of high degree of innovation, the process has as its mandate to explore and experiment to discover new possibilities.

In Summary, in the context of HDI the FFE models are less linear and more iterative, according to the theoretical support indicated in section 4.2; have an emphasis on first to understand the problem and before to propose solutions; they present a clear division of the spaces: exploration of opportunities and structuring of these - Early FFE and understanding of a specific opportunity and its subsequent solution - Late FFE. In Addition, by relating Early FFE and Late FFE to the analysis of the creative process, it is possible to define each cycle with three phases: analysis, synthesis and verification. this division between phases provides greater consistency to each cycle, tending to improve the quality of the output. The phases in turn are broken down into activities specific to each cycle.

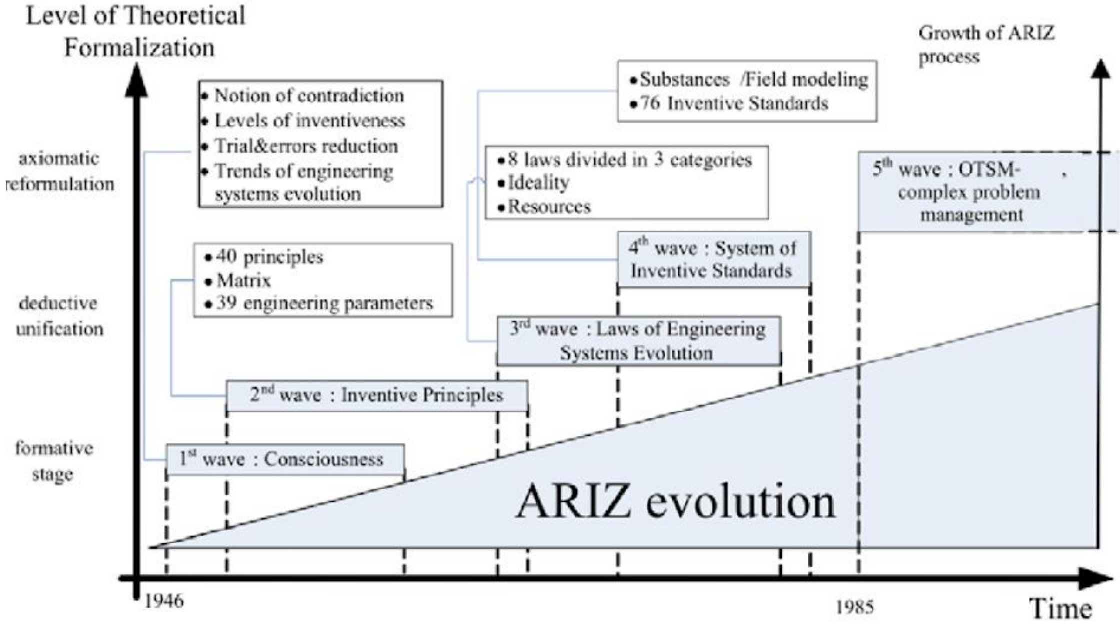
5. THEORY OF INVENTIVE PROBLEM SOLVING

The TRIZ acronym comes from Russian, and in English it could be translated as Theory for Inventive Problem Solving. It is a systematic methodology to solve inventive problems effectually, effectively, and creatively, based on the body of knowledge with human orientation (SAVRANSKY, 2000). It has been described as a methodology, a toolbox, science, philosophy, among others (ILEVBARE; PROBERT; PHAAL, 2013). However, it is a systematic methodology to find solutions to technical problems and to generate innovative technical systems (ALTSHULLER, 2007; SAVRANSKY, 2000).

TRIZ was initially developed in 1946 by the Russian engineer and scientist Genrich Altshuller, although the first text was published in 1956 (ALTSHULLER, 2007). Subsequently, TRIZ has been developed by his colleagues. In the West, TRIZ was known in the 1990s after the Perestroika in the Soviet Union, and it spread quickly to different countries. Initially, TRIZ was designed for technological problems. However, over time, its field has expanded to other areas, such as the social sciences, biology and the like (ILEVBARE; PROBERT; PHAAL, 2013).

Altshuller's initial work was dedicated to refuting how to solve problems, through trial and error, and the development of a scientific method to create inventions. From the beginning, with the study of patents, it was evident that high-level inventions did not permit a commitment between conflicting requirements - Contradictions. The creation of new paradigms was the manner to eliminate or to mitigate these contradictions (ALTSHULLER; SHAPIRO, 1956) Apud (CASCINI, 2012). Then, the existence of patterns of evolution of technical systems was evident. Figure 5.1 shows the evolution of TRIZ according to (CASCINI, 2012). The figure differentiates five phases in the development of TRIZ, by highlighting how from the initial notions of contradictions, patterns of evolution, and levels of invention, the authors of TRIZ proposed techniques, which made these notions operational. Thus, this methodology is being developed and refined.

Figure 5.1 - TRIZ evolution



Source: (CASCINI, 2012)

The most important sources for developing TRIZ have been patents and technical information. Initially 200,000 patents were studied. However, in subsequent developments, TRIZ experts analyzed approximately 2 million patents (SAVRANSKY, 2000). These patents were classified into five levels according to inventive level. As shown in Table 5.1, Altshuler (2007) indicates that in level 1 problems have few elements, require basic knowledge and a simple analysis in order to formulate solutions, and the time for its solution is short. On the other hand, level 4 problems have a large number of elements, which requires the application of a broad knowledge. It is difficult to make an analysis of the problem, by separating the different elements of knowledge, which require a long-term solution. However, level 2 and level 3 problems are at an intermediate level. Level 5 problems have already been solved with new scientific findings. TRIZ is proposed for levels 2, 3, and 4 problems according to (TERNINKO; ZUSMAN; ZLOTIN, 1998).

TRIZ offers the possibility of solving problems, by using some heuristics, functionally consists of techniques based on how inventors solved problems in the past, and respond to fundamental principles of how technical systems evolve. Carvalho (2017) indicates how the acronym TRIZ appeared in the 1970s and ended up being widely adopted, by becoming an umbrella term, which serves to designate the Classic TRIZ, proposed by Altshuler, as well as the techniques developed later on, based on the fundamental principles of TRIZ.

Table 5.1 - Patent Inventive Levels

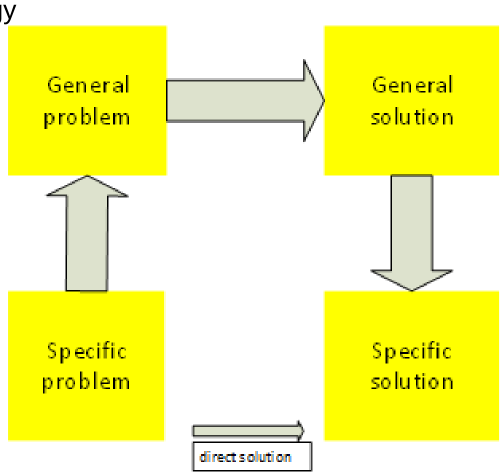
Level	Description	Context	%	#T & E
1	Conventional solution	Problems solved, by using basic specialized knowledge of the problem.	32	1-10
2	Small inventions within paradigms	Problems solved, by using knowledge within the industry of the problem.	45	10-100
3	Notable inventions inside the technology	Problems solved, by using knowledge outside the industry of the problem.	19	100-1.000
4	Inventions outside existing technology	Problems solved, by using knowledge outside the area of science where the problem originated.	4	1.000-10.000
5	Discoveries	Problems solved, by using new knowledge of science	0.3	10.000-1.000.000

%: percentage of inventions
#T & E: number of trial and error
Source: the author based on (ALTSHULLER, 2007)

5.1. TRIZ FOUNDATIONS

TRIZ methodology make it possible to find solutions to inventive problems, in different areas of knowledge, in a systematic way and surpassing what has been called by Altshuller as Psychological Inertia. This methodology basically starts from the specific problem. It analyzes the problem situation, by reaching an abstraction, which allows to find a generic problem, free of technical terminology. Soon, the generic solutions are found and finally, the solutions are particularized to the specific problem. As indicated in Figure 5.2, the step from the problem to the direct solution is proposed in intuitive methods, and it is based on trial and error, which is effective for problems with few elements - inventive level 1. For more complex problems, TRIZ provides the possibility of reformulating the problem, by taking it to a higher level of abstraction. The generic solutions are found in the abstract and, later, these solutions are taken to the specific problem, by lowering it to the real plan.

Figure 5.2 - TRIZ basic methodology



Source modified: (SAVRANSKY, 2000)

The general principles of TRIZ, according to (SAVRANSKY, 2000), are Ideality, Contradictions, Evolution, and Resources. Philosophically speaking, Ideality and Contradictions are the major pillars of TRIZ (SAVRANSKY, 2000), However, operationally, the patterns of evolution of technical systems, the resources of the problem situation, and the ideality, are the foundation of most of TRIZ techniques. Ideality helps to determine the direction of the solution and contradictions indicate the hurdles, which should be resolved (ALTSHULLER, 2007). In this way, Altshuler proved with the analysis of patents, how parts of the technical systems are developed, by seeking the ideality throughout their successive versions, in a non-uniform way, which causes the existence of contradictions, and the future evolution of such systems involves the overcoming, or the solution of these contradictions. Adequate use of TRIZ implies understanding the principles, which are the basic pillars of TRIZ, and mastering the techniques, which are the operational form of TRIZ, and as indicated in numeral 5.4 are numerous

The principles of TRIZ, Ideality, Contradictions, Evolution and Resources will be defined from these authors (ALTSHULLER, 2007; SAVRANSKY, 2000; TERNINKO; ZUSMAN; ZLOTIN, 1998).

Ideality is the fact that technical systems evolve over time, by increasing useful functions and, by decreasing harmful or neutral functions or cost. Ideality is derived from the "ideal machine," a system in which all the parts execute the maximum possible capacity, an idea introduced by (ALTSHULLER, 2007), - First edition published in 1969, from the identification that the objective is not the system. It is the function that makes up the system, such a pillar, mathematically, Ideality is expressed as, Ideality= Benefits/(Costs + Harms).

Benefits are the desired functions of the system, while the harms are the functions not expected or desired by it. TRIZ indicates the direction of the Ideal Final Result (IFR), a technical system tends towards ideality, by improving benefits, by decreasing the cost or harms, or a combination of these aspects. Likewise, ideality conceptually takes into consideration the optimization in the use of resources (associated to cost).

Contradictions are situations, which oppose each other in order to lead the system towards ideality. These contradictions are indicative of an inventive type problem because of the apparent incompatibility of desired features with the system, by solving the contradiction, the problem is solved. There are two main types of contradictions: technical and physical. Authors such as Savransky (2001) indicate other types of contradictions. Technical contradictions occur when an attempt to improve certain attributes or functions of a system leads to the deterioration of other attributes of that system; and physical contradiction when there are inconsistent requirements for the physical condition of the same system.

Evolution indicates how technologies evolve according to trends and understanding of these trends. It is possible to predict how the system will evolve and determine its maturity. Altshuller observed that technical systems generally follow certain regularities in their evolution, and these regularities were synthesized in evolution trends, and they are used to determine how different technologies evolve and to develop technical solutions (ALTSHULLER, 2007; SAVRANSKY, 2000). These authors propose laws and postulates of technological evolution, an issue to be expanded later.

Finally, Resources, which are the elements of the problem situation or its environment, which can be restructured to improve the technical system. Any problem is part of a super-system, and it is part of nature. It exists in space and time, consisting of and/or uses substances and fields, and. Resources can, therefore, be grouped according to natural or environmental resources - any material or field, which exists in nature; and time resources - time intervals before the start, after completion and between cycles of a technological process, which can be partially or completely wasted. One way of applying resources is to use the differential or gradient, such as pressure or temperature differentials or material properties, which serve to achieve the desired effect.

In summary, resources are everything in the system and in the environment. They usually remain in the problem or super system, but sometimes they are hidden from the problem solver.

5.2. EVOLUTION OF TECHNICAL SYSTEMS

Research in several areas of science and engineering have shown that the general character of the system development is essentially the same for any biological, technical, information, social system, among others. While research on evolution in biology and economic systems is well established, similar studies on techniques are just beginning (SAVRANSKY, 2000). Based on technical information and patents, authors, such as Altshuler, Savransky, Mann, Petrov, among others, have proposed laws, evolutionary patterns, S curves, evolution trends, and evolution paths of technical systems, among other names used in the literature. There are similarities among authors, but also differences, which generate confusion (GADD, 2011). For the present research, these concepts will be called Trends of Evolution (TEs).

Carvalho (2017)points out how the laws of evolution were obtained by induction or abduction, not by formal logic, and qualifies them as heuristics, too, Carvalho et al. (2005) show examples and against examples of TEs, which reinforces the idea that these are heuristics, indicates the likely future of evolution of technical systems. However, they are not deterministic pathways, or as indicated (GADD, 2011), TEs are simple, approximate guides, which indicate the directions that technical systems and products could follow to better meet human needs.

Thus, TEs in the context of FFE allow: to facilitate the understanding of the technology by indicating possible directions of technological evolution; to support the process of idea and concept generation of new products; and finally, to evaluate possible new solutions from the technology. Appendix C, shows in summary form the TEs proposed by the authors Altshuler, Savransky and Mann. This material was used in the elaboration of the FFE model proposal and in the training of the teams that carried out the projects indicated in chapter 10.

5.3. TRIZ PROCESS

Once Altshuller understood that there are patterns in solving inventive problems, the objective proposed was to create a general algorithm for the resolution of these types of problems "ARIZ" which had successive versions from ARIZ 61, until and ARIZ 85 C (CASCINI, 2012). The ARIZ 85C version has nine sections with 40 steps, making it difficult in applications. According to (TERNINKO; ZUSMAN; ZLOTIN, 1998), ARIZ is defined for very complex problems, approximately 5% of inventive problems justify its use. The use of ARIZ to solve inventive problems is the subject of controversy in the TRIZ community (CASCINI, 2012). Actually, ARIZ is one of TRIZ's least used techniques in practice (ILEVBARE; PROBERT; PHAAL, 2013; MOEHRLE, 2005), However, ARIZ was proposed to solve inventive problems, not for technological forecasting or product development.

Thus, the general process of using TRIZ, in its operative form, varies from one author to another. For example, Cascini (2012) identifies process proposals, as such the wave of (Salamatov, 1991) Apud (CASCINI, 2012); the evolution scheme of (Zlotin

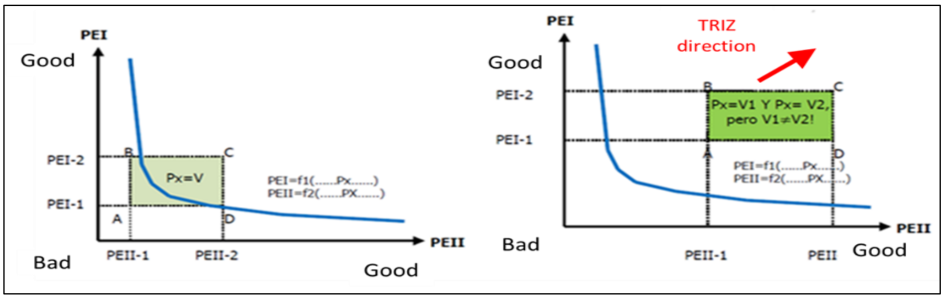
& Zusman, 2001) Apud (CASCINI, 2012)); the potential for evolution of (CAVALLUCCI; WEILL, 2001); the trees of evolution of (Shpakovsky, 2006) Apud (CASCINI, 2012), among others. Also, different authors have proposed variants of TRIZ, which are easier to use, such as SIT (BOYD; GOLDENBERG, 2013), WOIS, I-TRIZ (CASCINI et al., 2009).

Figure 5.2 indicates the basic method of TRIZ. It starts from a specific situation to a general situation, from an understanding of the problem. In this sense, TRIZ offers several ways of modeling the problem situation in order to facilitate its understanding and solution. The most indicated models in the literature are Contradiction Model, Minimum Technical System Model and Substance and Field Model (SuFi), which will be explained below.

5.3.1. Contradiction Model

The Contradiction Model is based on understanding the problem from the contradictions of technical parameters, which are opposed to achieving a higher level of Ideality than the present. Figure 5.3 represents two parameters of a technical system: EP-1 and EP-2, which are linked by a Px parameter, which wishes to improve - higher level of ideality. In order to improve Px, it is possible to modify EP-1 and/or EP-2. However, when one of these parameters is modified in the direction of improving Px, the other parameter changes by worsening Px. The blue line in Figure 5.3 represents the values that the current technology achieves for the EP-1 and EP-2 parameters. Thus, in Figure 5.3, on the left, the ABCD table is represented, which is the area of compromise solution between both parameters with the current technology, and in Figure 5.3, on the right, a new solution is shown, by reaching a higher level of Ideality - a new paradigm in technology. This is the purpose of TRIZ.

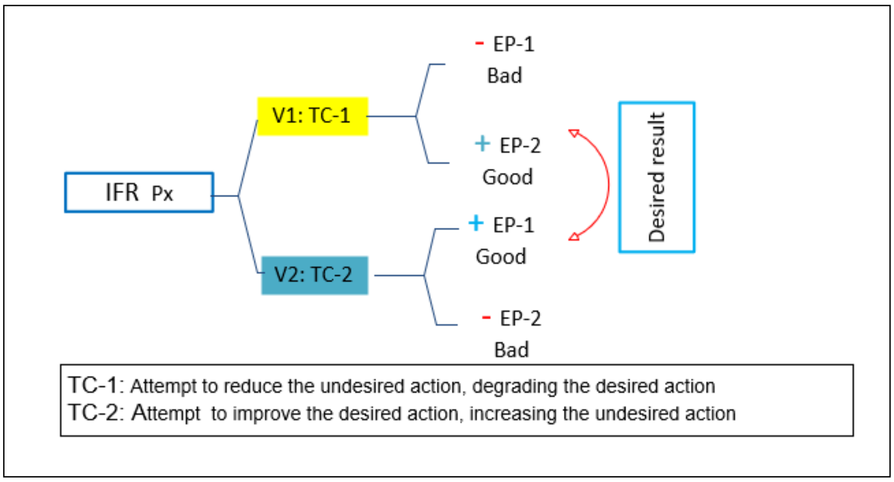
Figure 5.3 - Contradiction Model



Source: (CASCINI et al., 2009)

In addition, the following process is suggested to analyze and to schematize Contradictions (CASCINI et al., 2009), Figure 5.4. Select features or evaluation parameters: EP-1 and EP-2, which oppose the Ideal Final Result (IRF), and identify the common parameter Px, which links them - a feature, which should be improved. By linking EP-1 and EP-2 to Px, it can take the values V1 and V2, which are mutually exclusive. If EP-1 and EP-2 are not linked means that they are independent and there is no contradiction between these parameters.

Figure 5.4 - Contradiction diagram



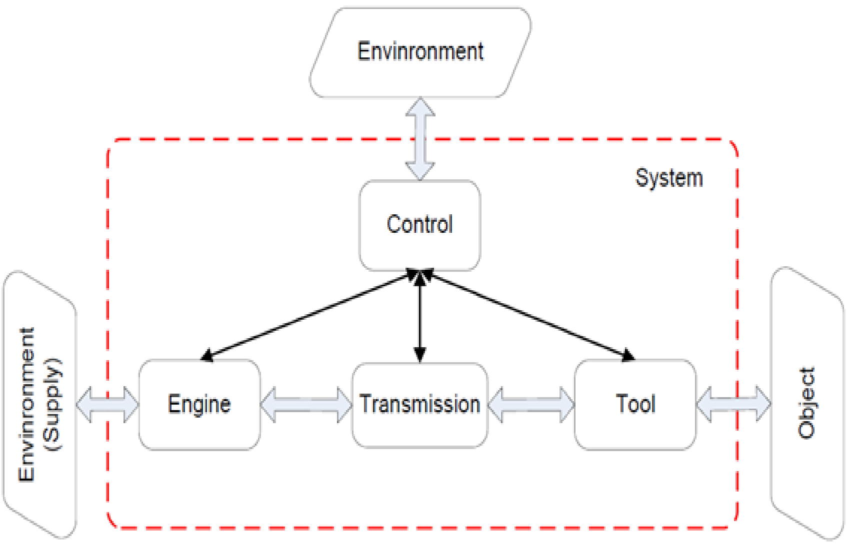
Px: common parameter, which links EP-1 and EP-2
V1 and V2: mutually exclusive Px values
EP-1: evaluation parameter 1, desired action
EP-2: evaluation parameter 2, undesirable action
TC-1: attempt to reduce the undesirable action (EP-2), by degrading the desired action (EP-1)
TC-2 attempts to improve the desired action, by increasing the unwanted action.
Source: adapted (CASCINI et al., 2009)

Values V1 and V2 represent the Contradictions CT-1 and CT-2, the desired result as indicated in Figure 5.4 is to improve PEI and PEII parameters, by obtaining values other than V1 and V2, which is not achieved with the current technical level of the system. TRIZ can direct us towards the desired result, by reaching a new level of the technical system - Innovation. PEI and PEII evaluation parameters are parameters of the problem situation and need to be expressed in simple terms. Once the problem is diagrammed, it is suggested to change these (PEI and PEII) for TRIZ Engineering Parameters, which are listed in Appendix F. This facilitates the transition from the problem analysis to the solution, and it is possible to use Contradiction Matrix and the 40 PI.

5.3.2. Minimum Technical System Model

The Minimum Technical System is based on the First Law of Altshuller's technical systems evolution - Completeness of parts, which establishes that a technical system in order to properly perform its function, is integrated by some minimum subsystems: tool, engine, transmission, and control, as illustrated in Figure 5.5. The tool is the working element, which performs the function of the technical system on the object. The engine is the element, which receives the necessary energy from the environment in order to perform the expected function. The transmission is the element, which transfers the energy from the engine to the tool, and the control is the element, which regulates, at least, one of the previous elements.

Figure 5.5 - Minimum Technical System



Source:(CASCINI, 2012)

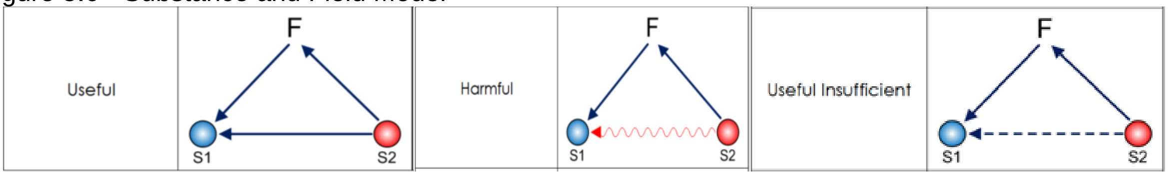
Thus, the first three Altshuler´s Technical Systems Evolution Laws, permit to analyze the Minimum Technical System Model, from the completeness of the system, the efficient energy flow between the parties, and the coordination of the rhythm of the parties. In this way, the Minimum Technical System Model according to Figure 5.5, and initially, by verifying the first three Altshuler's Laws, permits to understand the technical system of the problem, and to concentrate the attention on specific subsystems or to find Contradictions.

5.3.3. Substance and Field Model

The Substance and Field Model (SuFi) is a way of representing the problem situation in a functional and controllable way, which provides clues on the possible solution of the problem, without going into considerations of Contradictions (SALAMATOV, 2005). The system is represented by, at least, two substances and one field. According to Figure 5.6, a substance is a physical element and the field represents an interaction between both substances, characterized by a flow of energy of any kind, information, mechanical force, etc. Figure 5.6 shows how the iteration of the substances can generate a sufficient desired effect, an unwanted effect, or an insufficient desired effect, among other possibilities. Depending on the type of iteration, various solutions can be proposed, such as adding another substance, another field, or changing the substance.

For problem solving, the approach is to model the problem with SuFi and to propose solutions with the 76 standard solutions technique. This approach being an alternative to the classic Contradiction Approach, (CASCINI, 2012; SALAMATOV, 2005). Although SuFi is explained in the main TRIZ references (ALTSHULLER, 1984, 2007; PETROV, 2019; SALAMATOV, 2005; SAVRANSKY, 2000), and it is used in ARIZ 85C instead of the Contradiction Matrix, it is a less widely used TRIZ tool (ILEVBARE; PROBERT; PHAAL, 2013; MOEHRLE, 2005).

Figure 5.6 - Substance and Field Model



Source: (CASCINI, 2012)

5.4. TRIZ TECHNIQUES

The basic principles of TRIZ, as shown above, Ideality, which indicates the direction of the solution; Contradictions, which are the hurdles to be overcome in order to find solutions in the direction of Ideality; Evolution, which shows pathways that follow technology; and Resources, which are the elements in the problem situation, sometimes hidden, and can serve to solve the problem. However, the above principles need to be operational. Thus, functionally, TRIZ is supported by techniques, which are based on the basic principles.

Different authors have proposed classifications of TRIZ techniques (CARVALHO, 2017; ILEVBARE; PROBERT; PHAAL, 2013; MOEHRLE, 2005), being the classification based on the function of techniques. Really, there is no rule. For the current research, the techniques were classified according to the three major stages of Creative Process: Analysis, Ideation, and Evaluation, which is shown in Table 5.2.

In the Late FFE model proposed in Chapter 8, in the operational part, TRIZ techniques specific to the tasks are suggested. In this way, the model starts from an abstract theoretical concept to a usable model, with the incorporation of techniques in the critical activities.

Table 5.2 - Explanation of TRIZ techniques

	Technique	Description
Analysis	Ideal Final Result (IFR)	Imagine how the ideal solution would be, if it is not considered an achievable goal, to go back to a less ideal formulation than the ideal solution, but more ideal than the current solution.
	System Operator (SO)	A matrix has three rows and three columns, the rows represent the supersystem, the system and the subsystem and the columns, the past, the present and the future of the analyzed system. The filling of this matrix starts at the center (system in the present) and continues first in the column "present" and then in the columns "past" and "future". OP offers a matrix that describes the problem in time: past present and future, and space: sub system, system and super system.
	Size, Time, Cost Operator (STC)	It involves imagining what the situation would be like if the size, time and cost were extremely small or large.
	Trends of Evolution (TEs)	These are the standards of evolution of technical systems expressed in laws and postulates
	Substance-Field modeling (SuFi)	It is a way of modeling the technical system as a chemical formula with minimum elements that are Substance and Field and the desired or unwanted effects are indicated.
	Algorithm of Inventive Problem Solving (ARIZ)	It is a series of steps using a set of TRIZ tools to find problem solutions and innovations.
	Method of Smart Little People	It consists of finding solutions to a problem by personally identifying the object of the problem. The EPP method replaces the effects necessary to make a function, by small imaginary people, who would perform the tasks necessary to solve the problem.
	Analysis of system resources	This is the systematic search and analysis of resources into and out of the system, which can help find solutions on the way to the IFR
Ideation	Trends of Evolution (TEs)	These are the standards of evolution of technical systems expressed in laws and postulates
	40 Inventive Principles . (40 IP)	40 IP is based on the fact that the same generic inventive solutions, which have been successfully used to solve problems in the past, can be used successfully in similar situations in the future.
	Scientific Effects	These are databases of scientific principles that perform standard functions, which are extracted from the body of engineering and scientific knowledge and can be applied to problem solving
	Separation principles (SP)	The method proposes to solve a physical contradiction, to make separations, and these can be: in space (features are increased in one area and decreased in another), in time (features is increased in one period and decreased in another), separation of the parts of everything, the features increases or decreases according to some conditions.
	Method of Smart Little People	It consists of finding solutions to a problem by personally identifying the object of the problem. The EPP method replaces the effects necessary to make a function, by small imaginary people, who would perform the tasks necessary to solve the problem.
	Algorithm of Inventive Problem Solving (ARIZ)	It is a series of steps using a set of TRIZ tools to find problem solutions and innovations.

	Technique	Description
	76 Inventive Standards (76 IS)	76 IS to inventive type problems are classified into five groups.
	Contradiction Matrix	It is a matrix which relates the 39 technical parameters of TRIZ, with the 40 Inventive Principles. In this way, the intersections of the rows and columns mark the parameters in contradiction, and the inventive principles used to solve this technical contradiction.
Verification	Ideal Final Result (IFR)	Imagine how the ideal solution would be if it is not considered an achievable goal to to go back to a less ideal formulation than the ideal solution, but more ideal than the current solution.
	Trends of Evolution (TEs)	These are the standards of evolution of technical systems expressed in laws and postulates
	Algorithm of Inventive Problem Solving (ARIZ)	It is a series of steps using a set of TRIZ tools to find problem solutions and innovations.

5.5. CHAPTER CONCLUSIONS

The relevant TRIZ issues are presented and the main conclusions of the chapter are set out.

TRIZ is a methodology, which is based on simple principles, but it is extensive and complex in its forms of operationalization due to the various methodological proposals, ways of modeling the problem situation and techniques, which make its use require training and practice. Not having a defined way of acting; technologies are evolving, by following some general patterns. The understanding of these patterns helps in the determination of opportunities, generation, and evaluation of ideas. It should be noted that these patterns cannot be interpreted as absolute. There are more tendencies, which are based on prior knowledge, and TRIZ can be used with isolated techniques for specific problems, or it allows its use in a process, by employing various techniques, and by modeling the situation in order to achieve a better understanding and to help in generating solutions.

6. DESIGN THINKING

From the beginning of the 21st century, Design Thinking (DT) methodology has emerged as a "panacea" for product design and problem solving (BROWN, 2008; BROWN; WYATT, 2010), or as a competitive advantage in organizations (MARTIN; DUNNE, 2006; MARTIN, 2007; MOLDOVEANU; MARTIN, 2008). DT is more omnipresent in recent years in different media and private and public institutions (KIMBELL, 2009).

However, the term "Design Thinking" is confusing and the literature on which it is based is contradictory, with no single authority to define Design or Design Thinking (CARLGREN; RAUTH; ELMQUIST, 2016; HASSI; LAAKSO, 2011; KIMBELL, 2009). Thus, different types of discourse are clearly found, as well as lines from the origin of DT methodology (JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013; KIMBELL, 2011), and different process proposals, guidelines, and techniques (CARLGREN; RAUTH; ELMQUIST, 2016; FLEURY; STABILE; CARVALHO, 2016; HASSI; LAAKSO, 2011; ROSA, 2017).

The term "Design Thinking" emerges with the publication of Peter Rowe's Design Thinking, originally published in 1987 (DANTAS, 2005; DORST, 2011; KIMBELL, 2011), but the first person to put it at the center of the design process was Henry Dreyfuss (DANTAS, 2005; VIZIOLI; KAMINSKI, 2014). His basic postulate was "to design objects adaptable to people” (DANTAS, 2005).

From the academy, there has been a noted concern to clarify what Design Thinking really is, what its origins, theoretical foundations, operational proposals, and procedural guidelines are. Two lines of research on DT were found: the first one focused on clarifying the concept and its theoretical foundations.

The second line of research on DT is focused on the analysis of DT practices, the process phases, techniques used, and the guidelines which support this methodology.

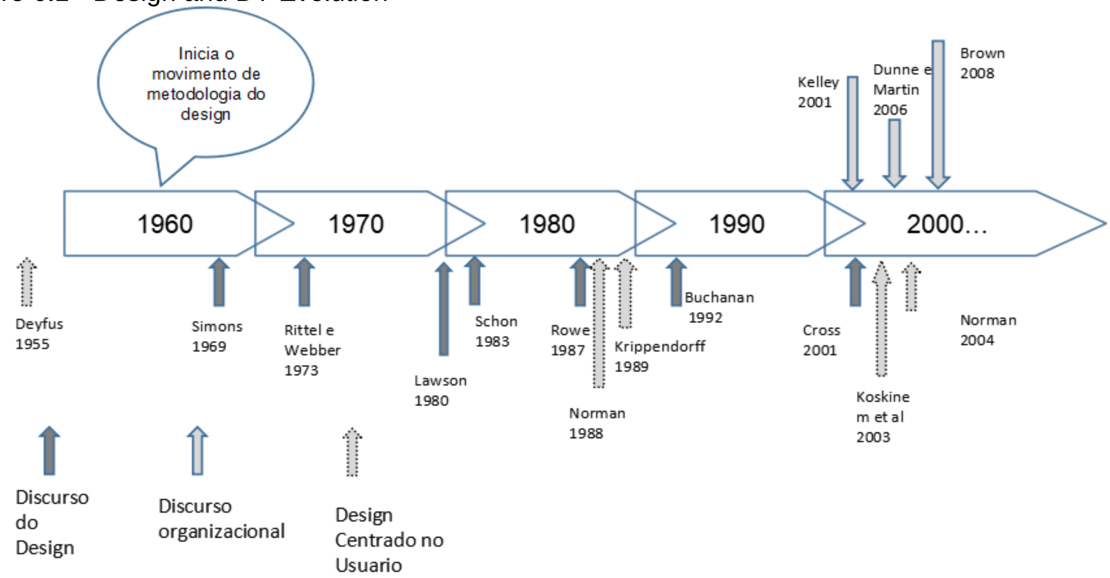
Table 6.1 shows the main references used in research on DT classified into four groups: i) design, these are texts which, although indicate DT as a central issue, deal with design - evolution or methodological framework; ii) DT fundamentals, focused on the theoretical foundations of DT; iii) DT process, texts focused on procedural elements of DT; and iv) institutional authors, these are the most representative educational institutions and diffusion of DT due to their reference in the scientific literature. The institutions were analyzed based on several texts, which are indicated in Table 6.1

Hassi and Laakso (2011) starts from the previous identification of the academic and organizational discourse of DT. It traces a timeline of the evolution of both academic and organizational types of discourse of DT, from the main authors. In the current research, the evolution of the User Centered Design (UCD) line was added. From Figure 6.1, it is possible to warn the evolution of designer thinking to Design Thinking. Kimbell (2011) indicates how the public presentation of DT is linked to the IDEO consultant, by ignoring the extensive research on the way designers work in recent decades. However, the history of DT is more complex, an argument, which can be partially supported in Figure 6.1.

Table 6.1 - Main references used in DT analysis

	Author	Comments
Design	(JOHANSSON; WOODILLA, 2008)	The article does a bibliographic research on the evolution of design for DT, to try to clarify what DT is.
	(RAZZOUK; SHUTE, 2012)	The purpose of the article is to frame the design process and the way of thinking used in the process, by identifying features that the design needs to have.
	(D'IPPOLITO, 2014)	The article reviews the literature on Design in the organization as a source of competitive advantage, by identifying trends and gaps.
	(SHEARER, 2015)	The proposed framework indicates when designers can make one, how about that? Which is how designers can change the world. The author is interested in the designer's way of acting, for which he proposes a framework
	(KIMBELL, 2012)	This article explores what designers' theories of practice can contribute to the understanding of professional designers and the cultures in which they have experience. The main contribution is to propose a new analytical artifact to discuss design based on theories of practice
DT fundamentals	(KIMBELL, 2009, 2011)	The first article does a bibliographic research on the evolution of design for DT, to try to clarify what DT is. The second article focuses on the origin of the DT concept, identifying three lines of the DT literature: DT as cognitive style, DT as design theory and DT in organization.
	(JOHANSSON-SKÖLDBERG; WOODILLA, 2009; JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013; JOHANSSON SKÖLDBERG; WOODILLA, 2013)	From an analysis of Design literature, articles, books and commercial literature, two basic discourses of academic and organizational DT were identified, each with several alignments.
DT process	(DORST, 2011)	Analysis of the Design and DT process, the author proposes a classification of the problems in Design and the form of reasoning used, and in which types of DT problems are most used.
	(HASSI; LAAKSO, 2011)	From the analysis of DT literature and interviews with experts, three domains of DT practice were determined: practices, thinking style, and mindsets. Each domain has several elements that help to understand the DT process.
	(CARLGREN; RAUTH; ELMQUIST, 2016)	The article conducts a field research with six companies that use DT, complemented with bibliographic research. Focus on essential elements of DT, divided into three categories: principles, mindset, practices and techniques.
	(FLEURY; STABILE; CARVALHO, 2016)	From a literature review, from the Web of Knowledge base, the authors establish some basic phases of DT and the techniques used in each phase
	(ROSA, 2017)	In the research, a DT analysis is carried out in relation to the process, in several categories, phases, guidelines, and techniques used
institutional	IDEO	(BROWN, 2008, 2009; BROWN; WYATT, 2010; IDEO, 2011; KELLEY, 2001)
	Stanford University	(PLATTER, 2009; STANFORD UNIVERSITY, 2012)
	Rotman School of Management	(MARTIN; DUNNE, 2006; MARTIN, 2007; MOLDOVEANU; MARTIN, 2008)

Figure 6.1 - Design and DT Evolution



Source modified: (HASSI; LAAKSO, 2011)

6.1. DT FOUNDATIONS

Contemporary writers Alexander and Herbert Simon have tried to understand and to describe design. On the one hand, Alexander approaches design as a way of shaping things, by focusing on doing, by focusing on materiality (KIMBELL, 2009). On the other hand, Simon defines a designer's act as abstract. His work is to create a desired state of things. The term design being extensive to professions, such as engineering and architecture (SIMON, 1996). He points out that: "the sciences of nature deal with how things are, the sciences of Design about how they should be"[2]. The tension between both concepts prevails in Design Theory to date (KIMBELL, 2011).

Three subjects emerged from the research of (KIMBELL, 2009, 2011), being: i) the explanation of DT, with a dualism between doing and thinking, and between the designer and his surroundings; ii) several design schools, which wonders about the generalization of DT of the design practice; and iii) description of DT, which is sometimes contradictory regarding the nature of design.

In her research, Kimbell (2011) identifies three lines in the description of designer thinking: i) cognitive style, associated with authors, such as Cros, Lawson, and Dorst, based on the practice of designers in which it is indicated how design problems are unstructured, the problem and the solution coexist, emphasis is made on designer's

[2] The first edition of “The sciences of the artificial” was published in 1969, which is considered the foundation of Design Theory. The third edition was used as a reference

ability as a form of thinking, and abductive thinking; ii) general design theory, associated with Buchanan, by identifying how social problems, which designers grapple, are Wicked Problems, in this manner, Buchanan indicates the way of approaching these problems, which is different from step-by-step analysis and synthesis; and iii) organizational resource, associated with Brown and Martin, its focus is on organizational problems and innovation, which are approached with designers' skills. For these authors, concepts, such as visualization, prototyping, empathy, and integrative thinking are the essence of DT.

In this way, the first line is focused on the designer, as they think and do. To summarize, Designer Thinking has been used to characterize what individual designers know, and how they approach and make sense of their own work, just as they truly do. In addition to describing designers' practices, the term also offers a design theory, which amplifies Simon's ideas. In this context, design does not only shape things, but it also refers to action and the artificial. In the second line, Buchanan (1992) focused on defining the field of design rather than the design process. For Buchanan, design is the broad context of the practice of engineers, architects, and designers. And in the third line, the authors take the concepts of both initial lines into the organizational context, as a methodology to product design and problem solving.

In their research, (JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013), by using a linguistic analysis of academic and commercial publications about design, identified the evolution of Design for DT with two strands, each one with several lines, as shown in Table 6.2. i) Academic - academic literature of design area corresponds to Creation of artifacts, Reflective practice, Problem solution, Form of reasoning, and Creation of meanings; and ii) Organizational - organizational literature corresponds to Way of innovating, Competitive advantage, and Organizational theory. The lines are detailed in Table 6.2.

The authors referred to the academic approach as "Designerly Thinking" - the academic construction of designer's practice and skills, and theoretical reflection on the practice of design; and the organizational approach as DT - practice and skills used in the context of design (art and architecture). Thus, the organizational approach or DT is a simplification of Designerly Thinking, according to the authors. Table 6.2 presents the lines from the academic and organizational discourse according to (JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013), and by relating them to the proposals of (KIMBELL, 2011); the latter in grey. The theoretical aspects presented offer an overview of the DT base, from design theory, which contributes to the understanding of the essence of DT methodology.

Table 6.2 - Lines of DT discourse

		Line	Relevant authors	Concept	Features
Academic	Cognitive Style	Creation of artifacts	(SIMON, 1996) first edition 1969	Artificial science	Design as the transformation of the existing conditions, for some preferable, by distinguishing between the professional, who deals with creation - design sciences, and what deals with analysis - nature sciences.
		Reflective practice	(SCHON, 1983)	Reflection in action	Reflective practice: Schön is critical of Simon's positivist perspective. From the designer's practice, he focused on the relationship between creation and reflection of creation, based on the work of architects and psychoanalysts because the core of design work was found there.
		Creation of meanings	(KRIPPENDORFF, 1989, 2000, 2006)	Creation of meanings	The author proposes design as more than the creation of artifacts, the creation of meanings. For the author, meaning is the core of design and the artifact is the medium, unlike Simon for whom the core is the artifact and meaning is perhaps an attribute.
		Form of reasoning	(LAWSON, 2005) first edition 1980 (CROSS, 1982, 1999, 2001, 2006)	Forms of designer’s knowledge	Larsson and Cross start from Schön's reflective tradition, but focus on the direct study of design work. Each of the authors suggests a model of the design process. From the way things are done and felt, Larson - from reflection on the architect's work, from psychology and creativity - researches ways designers can do it; and Cross, from ethnographic research, studied what designers actually do in the design process.
	Design Theory	Problem solving	(RITTEL; WEBBER, 1973) (BUCHANAN, 1992) (COYNE, 2005)	Wicked Problems	Introducing the Wicked Problem - originally indicated by (RITTEL and WEBBER, 1973) - or Wicked Problem, which does not have a singular solution, where creativity is required to find solutions. Buchanan indicates that for this type of problem, it is necessary to configure the situation, by identifying the point of view of all the participants in the related issues and the intervention from the beginning, working with the hypotheses and the exploration, allowing to intervene in the definition and the solution of the problem simultaneously, as opposed to the classic step-by-step, with phase of analysis and synthesis.
Organizational	Organizational Resource	Form of innovation	(BROWN, 2008, 2009; BROWN; WYATT, 2010; IDEO, 2011; KELLEY, 2001)	Form of innovation	How IDEO works with new products and innovation processes.
		Competitive advantage	(MARTIN; DUNNE, 2006; MARTIN, 2007; MOLDOVEANU; MARTIN, 2008)	Competitive advantage	How to solve organizational problems and competitive advantage
		Organizational Theory	(BOLAND; COLLOPY, 2004)	Organizational Theory	Application of design perspectives in the organization

Source modified: (JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013)

The lines of creation of artifacts, reflective practice, form of reasoning, and problem solving, are a group of views or theories of design practices. The different authors have contributed to the understanding of Design, being one of the pioneers (SIMON, 1996), whose first version was in 1969, and it is considered the founding author of Design Theory (JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013), Simon did not enter into the practice of design, but in its reflection. From his contributions, contemporary authors have criticized his reflexive approach, which is from a purely theoretical perspective. These contemporary authors have made their contributions from the real practice of Design, by using the relationship between creation and the reflection of creation (SCHON, 1983), and proposals from the actions of designers, Lawsosn and Cross, who from the analysis of designer's real practice, have proposed models of how these designer's work.

Buchanan's paper (1992) can be considered to found a theory on Design Thought, which later evolved to DT according to (JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013). It indicates Buchanan (1992) how from encyclopedic education, in the areas of arts, natural sciences, mathematics, philosophy, among others. Knowledge was divided into parts, each with its own methods. Thus, in the evolution of knowledge, it was divided and sud-divided until it reached specialization, leading to the progressive loss of the connection between the areas, by differentiating the methods of analysis of day-to-day problems. Consequently, the integration of knowledge has been one of the greatest issues since the 20th century

Buchanan adopts the idea of the Wicked Problem, originally proposed by (RITTEL; WEBBER, 1973), which is a type of social problem, undetermined, which does not have a singular solution, where creativity is required to find solutions. Buchanan indicates that for this situation, the classic step-by-step thinking, with the separate analysis and synthesis phases, is not adequate. Thus, he introduces the "placements" (techniques) for orientation in specific situations, and generates new perceptions of them, and tests new possibilities, by identifying all participants' points of view on relevant themes. In this way, from the beginning it works with hypotheses and exploration, by allowing to intervene in the definition and solution of the problem, at the same time. As opposed to the linear step-by-step designer's thinking, which is based on deterministic problems. These problems have defined conditions. Thereby, the designers' task is to determine the conditions and to calculate the solution. In the Wicked Problem approach, there is a fundamental indeterminacy, which implies that definitive conditions or boundaries of the design problem do not really exist.

In this context, Design Thinking (DT) emerges as a way of acting for the Designer, concerned with connecting and integrating useful knowledge of both arts and sciences. However, in a manner appropriate to the problems and purposes of the current time. An important point indicated by Buchanan (1992) is that confusion persists over the different modes of argument employed by different design professionals, such as industrial design, engineers, and the marketing professional. Industrial design tends to emphasize the possibilities of conception and product plan. Engineers tend to emphasize the appropriate materials, mechanisms, structures, and systems, and marketing considers contingencies with the changing attitudes and preferences of potential users. Perhaps because of the different approaches, the three professions, which are important in product design, are in practice irreconcilable opponents, by presenting irreconcilable differences.

6.2. USER CENTERED DESIGN

User Centered Design (UCD) is one of the fundamental pillars of DT, from the theoretical foundations, and the guidelines, being a concept strongly related to the practice of DT. For this reason, UCD occupies a prominent place in the discussion or decoding of DT. Four lines about UCD were identified: Design for usability; Creation of meaning; Empathic design, and Emotional, Table 6.3 show UCD lines. In Figure 6.1, the evolution of UCD is highlighted within the evolution of Design Thinking.

Table 6.3 - UCD lines

lines about UCD	Definition	comments on UCD line
Design for usability Norman 1969 (NORMAN, 2013)	Product-person interaction for the realization of the function for which the product was designed.	Interaction of users with artifacts, in more than just the ergonomic aspects; how people interpret artifacts to perform functions, and how people determine what the artifact does. In addition, how people understand what they are expected to do in order to perform functions and what should happen when the functions are being performed.
Creation of meaning Krippendorff 1989 (KRIPPENDORFF, 1989)	Design starts from understanding the meaning of technology for people, before understanding product technology. Concepts: sense, meaning, and context.	A contraposition to the premises, "form follows function" or "design as the creation of artifacts," by SIMON. For Krippendorff, the premise is design as the creation of meaning - "design is making sense of things." And indicated two manners of understanding the problem or object; the designer's understanding of the object, which can be clear, and the designer's understanding of the understanding of the object by the person, which is more confusing and inexplicable.
Empathic design koskinen; battarbee; mattelmäki 2003 (KOSKINEN; BATTARBEE; MATTELMÄKI, 2003)	Product research is really about trying to feel what other people feel. “To feel what someone feels, you really need to become that person. Three ways to explore the problem: Observation, participation and immersion.	Refers to direct contact with real users in order to understand aspects of the problem, as opposed to imagining or representing people. Understanding of the way users experience the material environment and people in it, from direct contact with real users.
Emotional design Norman 2004 (NORMAN, 2004)	How people respond emotionally to products, beyond aesthetic and usability. Three levels: visceral, behavioral, and reflective	Emotional design is a refinement of design to usability. The two previous concepts are complementary. Norman starts from the concept of usability, which goes beyond the ergonomic and aesthetic, and later proposes the emotional. Usability complements the emotional and the emotional is partly based on usability

Source: the author

Norman (2013) - first edition1969, points out that, "The paradox of technology is that it offers the potential to make life easier and more enjoyable; each new technology increases the benefits, but at the same time adds complexity, increasing difficulty and frustration with this technology."

In this approach, the functional physical aspects, as well as the aesthetic ones, and the person's emotional aspects with respect to the artifact are also important and are involved in how the product will finally perform in users' context. For the author, ergonomic aspects are determinant in the product. However, user's interaction with the product goes beyond ergonomic aspects. Questions like indications of the artifact about its function, which the author calls natural maps, finally influence the use or frustration in the artifact-user interaction. Product development involves coordinating different disciplines, each one with its own priorities and interpretations of the relative importance of various aspects of the product: usable, attractive, manufactural, reliable, price. Conflicts between certain aspects will necessarily be presented. However, the ease with which the user does the job for which the product is designed, is relevant and must be a postulate.

Creation of meaning, due to radical changes in recent decades, in the society in which the design is practiced, poses Krippendorff (2006). The author indicates how humans do not respond to the physical qualities of things, but rather react about what things mean to them.

Design problems have evolved, by distinguishing six stages: products, defined by utility, functionality, and a universal aesthetic; material goods, information, and identity, diversity, and local aesthetics; interfaces natural interactivity, reconfiguration and adaptability; multi-user networks, accessibility, connectivity, and information; planning, linked to the concept of projects, directionality, commitment, and social viability; and discourse, the posture of a community, or the tension between using the established and looking for other ways of doing things.

The trajectory of design problems is manifested with a gradual increase in the inclusion of human/social aspects, where the participation of "science of culture" is requested for a "cultural design." In this sense, cultural design as a form of directing design from the technological to the human/social condition. In the industrial era, the beneficial character of technology was the premise. Users felt they had to adapt to technology and designers were concerned with aspects, such as cost, efficiency, and expansion of markets. Nevertheless, in the creation of meaning, design is understood as a way of narrating imaginable and realizable worlds in order to be able to re-frame or to look at a familiar situation with other eyes. That is, the conception of the present in order to make the imaginable achievable (KRIPPENDORFF, 2000).

The author indicates three concepts: sense, meaning, and context. Sense, it is the feeling of having contact with the world, without reflection or explanation, directly related to the senses. It is the desirable feeling of conformity with the world itself, which relates to specific person, not verifiable by instruments, and follows learned patterns, being in the present, not in the past or in the future, It does not distinguish the cause or the expectation; meaning, it indicates the difference between what is sense and what is perceived as being realized. On a more complex level, it is how feeling is incorporated into other feelings. The manifestation of meaning is the perceptions, which are the possible ways of feeling or interpreting the occurrence or the object. Meaning is a structured space, a network of feelings, or a set of possibilities, communication of meaning is not always possible. It involves the interaction between the object and the person. It is not an intrinsic attribution of the physical features of the object; meaning is constructed in interaction from the person’s past experiences; and context, it basically limits meaning; objects, as well as words can have different meanings. Context is a designer's tool in order to assign meaning to objects, so artifacts mean what the context allows them to mean.

Empathic design, according to (KOSKINEN; BATTARBEE; MATTELMÄKI, 2003), refers to direct contact with real users in order to understand aspects of the problem, as opposed to imagining or representing people. Kolko (2014) defines empathic design as acquiring feelings, or to feel what it would be like to be someone else. Then, product research is really about trying to feel what other people feel. Thus, the authors of empathic design proclaim “to feel what someone feels, you really need to become that person.”

In the designer-centered approach to design, users, circumstances, and perceptions are imagined. Techniques like persona and the day in a user's life are used to represent the user, but without his participation. In the Empathic approach, the user has a real participation, by having three ways of researching him: observation through the use of ethnographic techniques, such as observation or interviews; participation, which can be a real participation of designers in users' lives, or observations based on how people use future product prototypes; and immersion, where the designer creates an understanding of user's world, by participating as users rather than just observing users.

Finally, Norman's Emotional Design (2004) distinguishes three levels: visceral, behavioral, and reflective. Visceral level - unconscious, which is a rapid judgment about what is good or bad, safe or unsafe, to react from this judgment, being unconscious and prejudiced, related to the initial impact and appearance, it is very identified with the natural; behavioral level – unconscious, which is determined by experiences, training, education, and it is related to the experience with the product, and various functional aspects, include, the function that the product performs and how the product accomplishes it, and usability, which refers to the ease with which the user understands the product, how it works, and how it achieves performance; and reflective level - conscious, which is slower to be processed by the user and is related to the cognitive and emotional, and the way in which emotions are experienced, which is susceptible to change through education, previous experiences, culture, and individual differences. It is identified with sophistication, the reflective level, remembering satisfaction in the past and contemplating the future, makes a long-term relationship.

The four presented lines of UCD are not exclusive. They seek to guide the design process, from the center in technology to a user center. In this way, emotional design is a refinement of design to usability. On the other hand, the creation of meanings and emotional design are the views of two authors on the complexity of the product-person (user) relationship. Both authors identify how people react to products through their senses, by creating a quick response, and then by making a relationship slower and more durable with processing, in Norman's case, reflection is based on behavior and previous experiences, and, in Krippendorff's case, by creating meaning through context and previous experiences. Empathic Design, on the other hand, is not an approach to how people react to the product. It is an approach to understand how people react to the product, or it determines their needs, or the so-called Second Order Understanding by Krippendorff.

The cited authors, who deal with DT, indicate that the User-Centered approach is one of the pillars; and the techniques described by the institutional authors are based on representing or approaching the user directly. In their research, Carlgren, Rauth, and Elmquist (2016) find out how companies use DT according to their specific features. Some of them indicate empathy as an important point, but approach users as imagined or represented. In this sense, the way of leading DT methodology can cause a dilution of the concept, with the risk of using speech much more than DT practice itself. This is a question that can only be answered with real research on the use of DT in companies, as well as success cases, and critical studies.

6.3. DT GUIDELINES

The term guidelines, in this research, refers to non-structural notions of the DT process, but which are determinant in the application called mindset (PLATTER, 2009), dimensions, and elements (HASSI; LAAKSO, 2011), issues (CARLGREN; RAUTH; ELMQUIST, 2016), and guidelines (ROSA, 2017). As defined above, guidelines are tenets on which the DT methodology is based. These guidelines are essential elements and can be explicitly expressed by the institutional authors, or be implied in the discourse of the methodological proposal. by which it was chosen to compile the result of previous research, and make an analysis of the institutional authors from the sources indicated in Table 6.1, in order to identify the implicit guidelines.

Appendix I shows the guidelines based on the following authors (HASSI; LAAKSO, 2011) (FLEURY; STABILE; CARVALHO, 2016), (CARLGREN; RAUTH; ELMQUIST, 2016) (ROSA, 2017). As a complement to the cited papers, an analysis of the content of the institutional authors IDEIO, Stanford University; and Rotman School of Management, based on the references indicated in Table 6.1, was performed. The analysis was performed, by using the Word Cloud technique, with the qualitative analysis Atlas TI software version 8.1.27. Additionally, a synthesis was made based on the reading of texts, by looking for explicit and implicit guidelines. The results are indicated in Table 6.4 -. These guidelines proposed by the different academic and institutional authors are related to and grouped into seven general guidelines, by seeking to synthesize what is defined as the guideline, by differentiating them from practices or ways of doing.

Table 6.4 - Synthesis of DT Guidelines

(HASSI; LAAKSO, 2011)	(FLEURY; STABILE; CARVALHO, 2016)	(CARLGREN; RAUTH; ELMQUIST, 2016)c	(ROSA, 2017)	IDEO	Stanford University	Rotman School of Management	Summary of Guidelines
Human-centered approach 1	Focus on human 1	Focus on human 1	Focus on human (empathy) 1	Focus on human Consumer Involved Needs 1	Focus on human (empathy) 1	Integrative 7	**1. Human-centered approach:** stakeholders Empathy, detecting needs
Thinking by doing 2,3	Prototypes 2	Reformulate problems 6	Experimentation 2	Prototypes 2,3	Show, don't say it 3	Abdutive	**2. Interactivity**: Experimentation Prototypes Multiple options Feedback Learning
Visualization 3	Wicked problem or unstructured problem 6	Visualization 3	Explore multiple options 2	Team 6	Clarify disorderly problem 6	People Users 1	**3. Visualization:** Show, don't say it Prototypes Experiences and sensations Thinking by doing Way of refine ideas
Divergent and convergent thinking 4	Divergent and convergent reasoning or deductive mode 4	Experimentation 2	Show, don't say it 3	Insight 6	Experimentation 2	Understand 6	**4. Divergent and convergent thinking:** to explore and to materialize.
Collaborative work style 5	Visual techniques to explore ideas 3	Diversity 5	Keep in mind the process 7	Learning 2	Keep in mind the process		**5. Collaborative work style**
Abducitive thinking	Teams, interdisciplinary, collaborative 5		Predisposition to action 2	Understand 6	Predisposition to action 2,3		**6. Problem solution**: Reformulating problems Wicked problem Start with the unknown Insight Ambiguity
Reflective rewording 6			Begin with the unknown 6	Iterative 2	Radical collaboration 5		**7 Integral thinking**: Holistic vision Desirable, feasible and viable
Holistic perspective 7			Observe details and the general	Positive 8	Prototypes 2,3		
Integrative thinking 7			Project based on how people think 1	Inspired 8	Insight 6		
Experimental and explorative 2,				Feedback 2	Understand the Problem 6		
Ambiguity Tolerance 6				Divergent and convergent thinking 4	Divergent and convergent 4		
Optimism 8				Visual thinking 3	Learning 2		
Future orientation 7				Desirable, feasible and viable 7			

Source: the author

These guidelines are: i) Human-Centered Approach, as shown in Table 6.4, as all references allude to this issue, which is considered the fundamental pillar of DT, related to empathy, to detecting users' needs and to taking into account the different stakeholders; ii) Iterativity, a form of the non-linear process, related to the exploration of multiple options and the learning of experimentation with prototypes, which allows redirecting the process constantly; iii) Visualization, ideas and concepts are materialized with prototypes in order to communicate, to refine, to learn, and to allow those involved to experience the concept; iv) Divergent and Convergent Thinking, which is the way of working in design, with divergence in order to enlarge spaces, either of problem or of solution, and converging in order to focus on the subject or to choose a way of solution; v) Collaborative Work Style, DT process is based on activities performed on teams, with different backgrounds and perspectives, by expanding the possibilities, and the inclusion of those involved in the solution; vi) Problem solution, social problems, or product development are rarely algorithmic or structured problems, where it is possible to define a route from the very beginning, by deepening the search for a solution to the problem, it is possible to understand the problem, which influences its solution, furthermore, ambiguity, as opposed to determinism allows to enlarge the space of the problem and, in turn, the space of possible solutions; and vii) Integrative thinking, the parts of the process are not isolated, the problem and the solution, the artifact and users, users and their context, and the solution and the business are integrated.

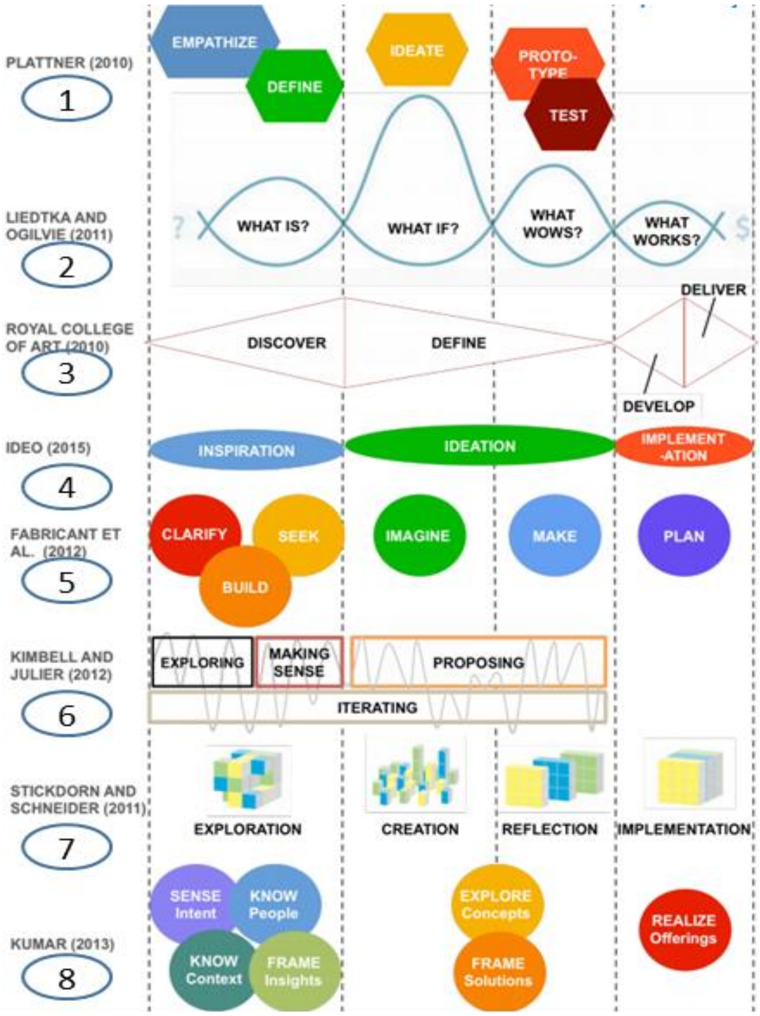
6.4. DT PROCESS

One of the criticisms from academia to DT is that there is no clear consensus on what the stages of DT are. The different academic authors and institutions propose various configurations of DT. (FLEURY; STABILE; CARVALHO, 2016), make up an analysis of the body of knowledge, which is the scattered knowledge in the literature. The authors find six proposed DT phases, of which they summarize three phases, by covering the overall process: i) immersion, which consists of the structuring and understanding of the problem; ii) ideation, which is the creation of concepts; and iii) prototyping, which is the incorporation of concepts in concrete prototypes to be tested by users.

Rosa (2017) based on a comparison of eight proposals from DT process, summarizes four phases, as shown in Figure 6.2, in which the eight models analyzed are contrasted. The four phases are i) generation of empathy and definition of the problem, an understanding and synthesis of the problem, which is being performed, it is based on empathy with users; ii) ideation, generation of new possibilities, and definition of ideas to be tested; iii) prototyping and testing, ideas are tested with users involved, prototypes are simple and serve both to test and to explore ideas and to gain empathy with users and inspiration and; iv) implementation, which consists of preparation and determination of activities for the final development of the solution, which involves the business case, business model, testing, and strategic plan.

IDEO, which is an institutional author cited by Figure 6.2, is represented by model 4 as shown in Figure 6.2. Its DT proposal has the following phases: Inspiration, Ideation, and Implementation. Inspiration is the discovery of the problem or opportunity, in which an understanding of the problem is made from those involved, as opposed to starting the project with narrow restrictions, which leave room only for small improvements. The understanding of the problem is based on researching the involved people, the closest to the natural environment, and by analyzing the information in an iterative way, until obtaining perceptions -Insights, which will direct the subsequent process.

Figure 6.2 - Comparison of DT Models



Source modified: (ROSA, 2017)

Ideation is a process of synthesis in which ideas are condensed, based on what they have seen and heard from users. These ideas can lead to solutions or opportunities for change. This approach helps to multiply the options in order to create choices and different points of view about human behavior. Ideation can offer alternative visions of new products or choices among various ways of creating experiences. By testing competing ideas, the likelihood that the outcome will be more daring and attractive increases since ideation, divergent thinking, and multidisciplinary teams help to explore multiple options (BROWN; WYATT, 2010).

Finally, Implementation, phase in which, once one has varied ideas, it is necessary to test and to refine ideas, by using prototypes, in principle simple, but according to the progress, they are more sophisticated and similar to the real product, until, according to (BROWN, 2008, 2009; BROWN; WYATT, 2010), a real and definitive product is obtained. The authors indicate that the process is not necessarily performed in all phases in a linear way.

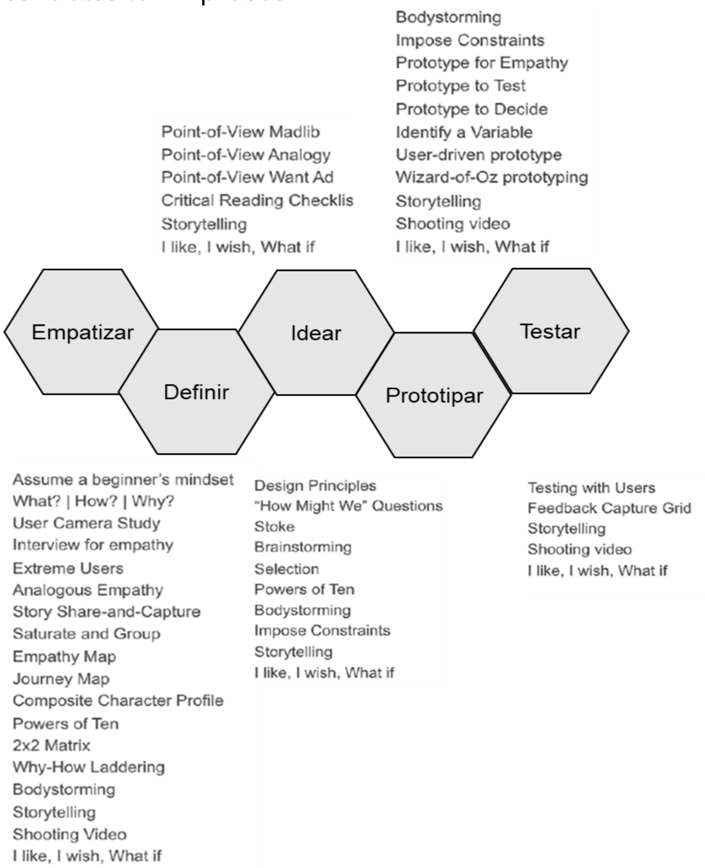
The Stanford University model referred by (FLEURY; STABILE; CARVALHO, 2016; ROSA, 2017), is represented by model 1 in Figure 6.2. The phases of the proposal are the following: Empathize, Define, Ideate, Prototype, and Test, which will be described. Empathize is to observe in order to understand users' behavior in their context in order for the observer to be identified with the users, it consists of an immersion in order to experience what users feel, by observing them and verifying how they interact with the environment, it can capture physical situations and intangible meanings, what can, in turn, lead to innovative solutions; Define consists of synthesizing empathy findings into needs and insights, an understanding of the user and the problem space is realized, by making a statement oriented, centered on the user and his needs; Ideate is a phase in which radical alternatives are generated in order to solve the defined problem, by emphasizing on a variety and quality of solutions, and teamwork; Prototype is the exploration of ideas in the physical world, a prototype is some physical representation of the idea, a sketch or models in three dimensions, the purpose of the prototype is to allow the team, users, and others involved to experience the idea, initially, the prototypes are simple and are gradually improved with the advancement and depuration of ideas; and Test is the opportunity to get feedback on the proposed solution, to refine it, and to learn from users, being an iterative process from low resolution prototypes, the key is to test in the context of users' lives and to test, by looking if there is something, which is not right.

Rotman School of Management, which is Martin's DT proposal, is directed to the use of designers' actions in the organization, and as indicated above, it does not present a set of phases, as such.

6.5. DT TECHNIQUES

The authors of DT propose techniques to assist in the different phases. However, each author indicates different techniques for the same phase, or the same techniques with different names. In Figure 6.3, as an example, tools are given for the Stanford University Model phases, summarized by (ROSA, 2017). The author made this analysis for the eight proposals presented in Figure 6.2, and, in general, the techniques to effectively generate ideas (concepts) are few. This result is recurrent with the results of the authors (FLEURY; STABILE; CARVALHO, 2016), who analyzed six DT processes, as well as the research of (CARLGREN; RAUTH; ELMQUIST, 2016), which made use of bibliographic research and case studies, by indicating some techniques related to DT guidelines, as shown in Table 6.4. Besides, by making an analysis of the institutional authors Stanford University and IDEO, it is noted how most of the techniques are focused on user's understanding, prototyping, and testing. On the other hand, these authors make emphasis on sharing and teamwork for the generation of ideas.

Figure 6.3 - Techniques related to DT phases



Source: (ROSA, 2017)

6.6. CHAPTER CONCLUSIONS

DT methodology was presented, by exploring its theoretical foundations and procedural elements: guidelines, processes, and techniques. Some specific points will be highlighted, as conclusions of the current chapter.

Based on concepts disseminated in designer's practices, which have implicit foundations of Design Theory, institutional authors proposed a methodology with a structure, tools, and guidelines - DT. Although none of the elements is new, the structuring does present a new form. Another important aspect of DT novelty is the use of the designer's thought in other contexts: organizational, engineering, among others, which have shown validity in practice.

DT process can be performed with different phases, but maintaining the essence, which is an iterative process, from the generation of user's insights, generation of ideas, and testing, in which the use of visual representations and physical prototypes help to work the multidisciplinary teams.

DT places the user in the center in order to solve problems, in contrast to starting from technology or the organization as its center. The teams wonder "how about it?" in order to imagine the future more than to accept the situations as they are today.

Two aspects that have been pointed out previously are the lack of use of techniques to generate ideas, and the lack of techniques to analyze the data observed with users. The following question is posed, can teamwork with different fields of knowledge, the proposal and testing of multiple options, the environment of optimism, and the way of considering the problem as a challenge, make up for DT lack?

DT methodology, in the context of Product Development, is basically defined at the beginning of the process. The solution, which is determined by DT, needs to go through the subsequent phases of Development, roughly speaking: product design, production design, and product launch.

Finally, it will be indicated how the media show DT as a panacea, which is really an exaggeration. However, the packaging proposed by the institutional authors allows practitioners to use some tenets, which are separate and difficult to operate, by allowing them to find out and to explore new possibilities, by making DT an appropriate methodology for FFE in innovative products.

7. DISCUSSION OF TRIZ AND DT IN THE FFE CONTEXT

In this chapter, TRIZ and DT will be discussed in the FFE context, by focusing on products from the PHE sector, with a high degree of innovation. Initially, a comparison between both methodologies was made and, later, a discussion was held on how both methodologies converge or diverge in the FFE context; converge in the way of complement or compatibility, and diverge while being incompatible or difficult to complement each other.

7.1. COMPARISON BETWEEN TRIZ AND DT

As indicated (HENTSCHEL; CZINKI, 2013), the terms systematic and innovation seem contradictory. However, the speed with which products are introduced into the market today, and the necessary increase in the originality of these products, require systematic innovation. These two aspects are present in TRIZ and DT methodologies; both methodologies break the archetype of the solitary genius struck by an idea. In this way, they present a process, at the same time, there exists time for creativity, and tries to converge to a solution with a combination of analysis, generation of ideas and verification. In addition, both methodologies are based on techniques for their operationalization.

However, as explained above, both methodologies are very different in their fundamental principles and processes. TRIZ tries to make an optimum problem analysis, from the product space, by making an abstraction of the problem in order to obtain a solution, while DT is more focused on knowing users' specific needs in their context and from successive iterations, based on prototypes and tests, until reaching a desirable, viable, and feasible solution.

Savransky (2000) indicates how TRIZ has a human orientation. However, the author does not defend this statement. Along with his book, as well as classic TRIZ authors, in general, it is possible to see how, effectively, human orientation in TRIZ is determined by the beneficial and harmful effects from the human point of view. However, these benefits and damages, although for many situations, can be easily defined by the designer. Nevertheless, there are product categories or situations in the design where it is difficult to determine what is really beneficial and harmful for a group of users. In this context, (NORMAN, 2013), the author who deals with usability, sets an example, in which, by totally eliminating the noise (undesired effect) of a bathroom extraction system, it is clear that too much noise causes discomfort. However, when it is completely eliminated, the feedback that indicates that the system is in operation, is lost, by causing discomfort to the user. Therefore, the system loses usability, in the attempt to evolve towards the technological ideality.

On the other hand, DT contributes to a deep understanding of users' needs and perspectives. However, one of the criticisms they make to DT from the academy, is the weakness in the generation of innovative ideas from technology. Table 7.1 shows a comparison between TRIZ and DT, which is based mainly on (PELT; HEY, 2011), who make a comparison between TRIZ and DCU; (HENTSCHEL; CZINKI, 2013), who make a comparison between TRIZ and DT; and complemented with elements of the theoretical reference used. The comparison categories were taken from (HENTSCHEL; CZINKI, 2013).

Table 7.1 - TRIZ and Design Thinking Comparison

CATEGORY	TRIZ	Design Thinking	
Origin	Derived from analysis of patents and technology	Derived from experience and commercial success of designs	
Objective	Focused on technical feasibility and/or economic viability Centered on technological and economic	Focused on human needs and desires Human-centered	C
	Probable technological advance	Probable advance in acceptance by the target in those involved	C
Initial situation	Complex technical problem	Wicked problem, with the people involved	C
	Declaration of the problem based on contradictions and technical and/or economic i	Declaration of the problem based on the detection of those involved and their needs	C
	As complete as possible	Compilation and selection of relevant aspects of those involved	D
	Initial system analysis	Initial analysis of those involved	C
Process	The approach is highly structured sequential and procedural, in which there is an analysis phase, followed by a solution phase and an evaluation phase	Unstructured and/or highly iterative approach, in which there is an analysis phase, followed by a solution phase and an evaluation	D
	Step-by-step process (for the general TRIZ as a process and for the individual techniques)	Vivid process, which is a spontaneous sequence of tools and phases, guided by a reference/iterative and evolutionary process	D
	Process driven by cause and effect analysis	Process driven by empathy	C
	Based on knowledge and accurate data	Based on creativity and ambiguity	D
	Systematic process with intensive use of techniques	Systematic process, with intensive use of techniques	C
	Defining the most appropriate technique to be used in real cases may be difficult	Defining the most appropriate technique to be used in real cases may be difficult	
	Different procedural proposals make it difficult to understand and to reach a consensus	Different procedural proposals make it difficult to understand and to reach a consensus	
	The application, more than the use of techniques, is an understanding and application of some principles	The application, more than the use of techniques, is an understanding and application of some guidelines	
Results	The best technical solution	The most desirable solution	C
	Initial solution presented at abstraction level	Solution presented as an example, a basic prototype, or a scenario	C
	The result is often clearly definable and tangible	The result often has features of a vision, a scenario, or a desire	C
Philosophy	Prescribes "what" and "how"; problem definition	Describes "why"; finds the problem	C
	Deep understanding of technological evolution	Deep understanding of human desires and needs	C

CATEGORY	TRIZ	Design Thinking	
	Links the development team to other areas of knowledge	Multidisciplinary team in order to integrate different perspectives	C
	Very rational, seeks heuristics	Very intuitive, seeks insight	D
	Seeks to find an optimal solution direction, by reducing trial and error in order to save labor	Seeks many solution directions, by making many trial and error cycles, early in the process in order to save labor	C
	May be teamwork, but it is not a condition; teamwork generates shared knowledge in the process	Teamwork oriented, with which the generated knowledge of both the product and the development process is shared	D
	Emphasis on problem abstraction in order to avoid psychological inertia and to understand the essence of the problem	Emphasis on observation and analysis of those involved and the context in order to understand the essence of the problem	C
	Most suitable for technical uncertainties	Best suited for user/market uncertainty	C
	Strong in search of solutions, technical direction	Weak in the search for solutions. Are the solutions by Brainstorming without direction by randomness?	C
	Considers ideality of the solution, but is it from the designer's perspective?	Considers the appropriate solution from user's perspective	C
	For those who will use this methodology, it is clear that they need to learn and to be trained.	For those who will use the methodology, it may not be clear that one has to learn and to train, and to be trained, and it may underestimate learning	
Learning	Difficult to learn	Easy to learn	
	Difficult to learn how to apply	The process and its techniques are didactic	
	For a deep knowledge, it requires a significant amount of time and is complex	Comparatively easy to achieve in-depth knowledge; the amount of techniques can be confusing	

Source: the author based (HENTSCHEL; CZINKI, 2013)

The fourth column in Table 1 indicates convergences (C) or divergences (D) of TRIZ and DT. By analyzing each category, the complements are: i) the objective, the technological ideal of TRIZ, along with the needs and desires of those involved in DT; ii) the initial situation, perspective, and technical analysis of TRIZ, complemented with the analysis of those involved in DT; iii) the process, it has in common the notion of process, but are very different views, being more the divergences than the convergences in this category; iv) the results, TRIZ looks for the best technical solution, and from the DT, the desired solution, while the way of expressing the result, TRIZ indicates a result, which can be transformed into user's vision with DT; v) philosophy, can be marked as complements in this category, first, with DT it is possible to find the problem from the emphasis on the observation of those involved, and with the use of TRIZ, it is possible to define or to clarify this problem, from the analysis of technology, second, with the use of TRIZ, it is possible discover the problem, from the understanding of technology, and with DT, this problem can be defined or clarified from the understanding of those involved, finally, TRIZ presents a solution direction, by making links with other areas of knowledge, complemented with the multidisciplinary team of DT and the intensive use of Brainstorming in order to find tangible solutions. In the philosophy category, there are divergences related to the rationale of TRIZ and the intuitiveness of DT, for the team, it can be difficult to balance the use of both methodologies in Late FFE.

To conclude the discussion of both methodologies, two citations illustrate their complementing potential. Pelt, Hey (2011) indicate that TRIZ practitioners define the problem space often based on insufficient information. This is due to management requirements and marketing perspectives. Thus, they use their experiences in place of effective research with users, which may leave the project at risk, and Gurtner, Reinhardt (2016) indicate how an exclusive user orientation can neglect the technological side of innovation. By imposing a cognitive lens on idea generators and managers, by bearing in mind that in the opportunities, which arise from technology, it is sometimes unclear how users can benefit from it.

These two citations summarize the weak points of TRIZ and DT, which as shown in Table 7.1, can be a complement. Obviously both methodologies have differences in procedure, focus, form of problem analysis, structuring of the solution, and even, in the hemisphere of the brain that they use. However, as observed in Table 7.1, both methodologies have a high potential to complement each other.

7.2. TRIZ AND DT COMPLEMENTS IN FFE

Once the complement of TRIZ and DT have been discussed, the next step is to discuss how these two methodologies can be integrated and complemented in the FFE, specifically for products of the PHE sector in the context of a high degree of innovation. First, a discussion will be carried out to contextualize the use of TRIZ and DT and then, an analysis of both, from the perspective of the creative process will be conducted.

Several authors have proposed a different way of integrating TRIZ with DT or DCU. Akay, Demıray, Kurt (2008) suggest an identification of human parameters in problem situations, and, later, in the analysis. These parameters are considered in the TRIZ process, being its proposal more focused on solving specific problems than generating product concepts. Another aspect is that the authors do not indicate methodologies in order to determine the human parameters of the problem.

Pelt, Hey (2011) indicate the combination of TRIZ and DCU in order to develop consumer products. From the DCU, users' needs are identified, and TRIZ allows to generate product concepts to these needs. The authors indicate how a DCU approach is most suitable in products driven by *usability* and *meaning*, and TRIZ is most pertinent on products in which *use* is the predominant one. However, for products with various considerations, both combined methodologies can bring about positive results.

Hentschel, Czinki (2013) indicate how DT can be the gateway to using TRIZ. At the beginning of the design, the problem is diffuse, its elements and their relationships are difficult to identify. In this context, DT provides a "playing" approach to challenge mode, by accumulating knowledge about the problem, which is a systematic method easily understandable and usable, in which TRIZ provides a technical understanding directed to the generation of ideas. The authors indicate that TRIZ could provide high level Brainstorming.

Silva, Kaminski , Armellini (2020) propose TRIZ and DT integration to improve the conceptual phase of product development. The proposed model is a non-linear one, which is made up of three phases: Problem Definition, Problem Treatment, and Solution Verification. Problem Definition, which is supported by DT in order to understand the problem and to define the project scope; Problem Treatment, which is supported by TRIZ in order to analyze the problem and to propose solutions. This phase comprises four tasks: technical system description, functional analysis, contradiction matrix application, and comparing solutions with IFR; and Solution Verification, which is supported by DT in order to prototype and test the solution with the user.

The aforementioned authors show a pathway in complementing TRIZ with DCU or DT. In general, these authors consider the creation of concepts with two phases: analysis and synthesis. In the analysis phase, DCU or DT provides an understanding of the problem from the users, and in the synthesis, TRIZ is utilized for concept generation to solve the needs found. In principle, this is the natural complement of both methodologies, and right solutions can be achieved in this complement.

Highlights, the research of (SILVA; KAMINSKI; ARMELLINI, 2020), which TRIZ and DT integration have three phases: Problem Definition, Problem Treatment, and Solution Verification. It is important to remark that the Problem Treatment phase, which is supported by TRIZ, constitutes a cycle of analysis, synthesis, and evaluation.

Nonetheless, considerations, in the context of product development, user, and technology, are not similar. It was discussed how a product can be more than an artifact, which plays a function. Three classic examples of product development will be cited, which will serve as a scenario in the discussion (See Appendix D EXAMPLES).

The products to be developed may be of different nature according to various aspects, the degree of technological novelty, and the way the user interacts with the product, among others. As discussed in DCU, (NORMAN, 2004, 2013) indicates the use, usability, and emotional aspects in the product-person interaction, while Krippendorff (2006) indicates the meaning as the important relationship, which is mediated in the context.

In Example 1, the product (the bicycle) has a Use that is central, but the way the product is used (Usability) and child's memories create a Meaning, which is crucial to the product's success. Thus, the determined direction of the solution from the users is not aligned with the technological ideal. In Example 2, the important thing of the product is its function (Use), the interactions of users (Usability), or Meanings are not relevant. Here, technological ideality is the relevant aspect, the user little or nothing influences the decisions made. In Example 3, it can be noted that it is an innovation led from technology. However, users' expectations play a preponderant role. Users have given more relevance to VHS higher recording capacity than to BetaMax higher video quality.

Therefore, the question that comes up is, under what circumstances should TRIZ or DT be used? The answer is by taking into account the relevance of Use, Usability, and Meaning in products. When use is very important, and usability and meaning are not very relevant (as in Example 2) the problem is strongly technical, TRIZ methodology may be more appropriate. However, when user-product interaction is very direct and usability and/or meaning take relevance (as in Example 1), DT is more appropriate in order to identify gaps and to make evaluations.

However, in FFE of PHE products, the problem is driven by technology, user, and regulations. Although for specific problems, a driver can be more relevant, in the early stages, in products with a high degree of innovation, it can be difficult to make this separation. In this context, a complement to both methodologies, for products in the PHE sector, improves the execution of FFE.

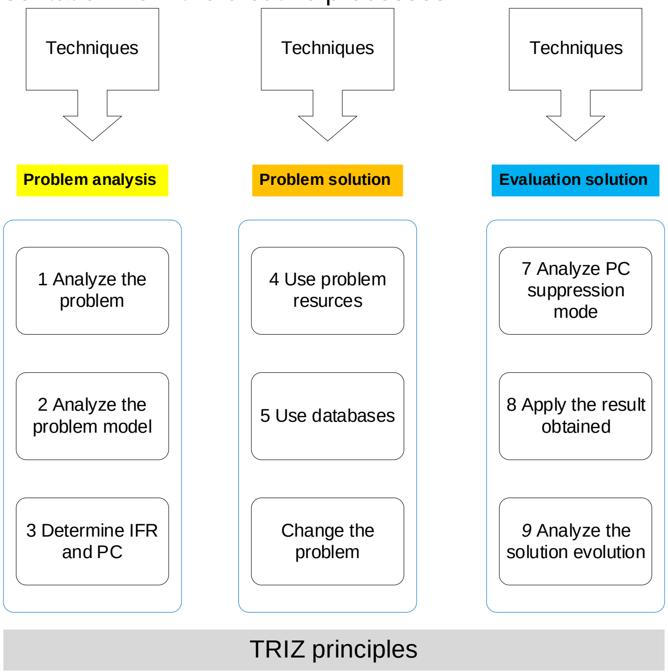
In this sense, it was indicated how the development of products in the PHE sector has some specificities that differentiate them from other sectors: i) User, multiple, and varied users, with sometimes contradictory needs. These needs can be framed into the function of the artifact - Use, the manner and ease of use - Usability, and the emotional or symbolic - Meaning; ii) Technology, the PHE sector is dynamic from the perspective of innovation and integrates a variety of technologies in its products; iii) Regulations, these are based on previous knowledge and experiences and play the roles of source of knowledge, guidelines in the product development, and innovation opportunity - Driver; and iv) PD, for product development in the PHE sector. For this propose, several areas of knowledge with different language and priorities are required, which must interact to generate solutions.

Once the complement of TRIZ and DT have been approached, a discussion of both methodologies in the context of FFE will be carried out. In section 4.3 an explanation and vision of the PC was presented, which will be used as a reference to contrast the TRIZ and DT methodologies in the FFE.

As discussed in Chapter 5, TRIZ presents several process proposals, even in PD literature shows examples of the use of TRIZ techniques without process context. However, Altshuller proposed ARIZ - inventive problem-solving algorithm, which as indicated in Chapter 5, is for complex problems. Thus, for the integration of TRIZ in the FFE, from the process point of view, ARIZ will be partially used. ARIZ is explained in Appendix B. Table B.1 presents the nine phases of ARIZ succinctly, by indicating how they can be divided into Analysis, Synthesis, and Verification phases.

Table B.2 shows the ARIZ process in more detail, by indicating the process of each phase and some TRIZ techniques that can support the process. It was also indicated how TRIZ is based on principles, which guides the process. Figure x shows the nine phases of ARIZ clustered in the stages of analysis, synthesis, and verification. Also, by indicating how the process is supported by techniques and guided by general TRIZ principles.

Figure 7.1 - ARIZ representation from the creative processes

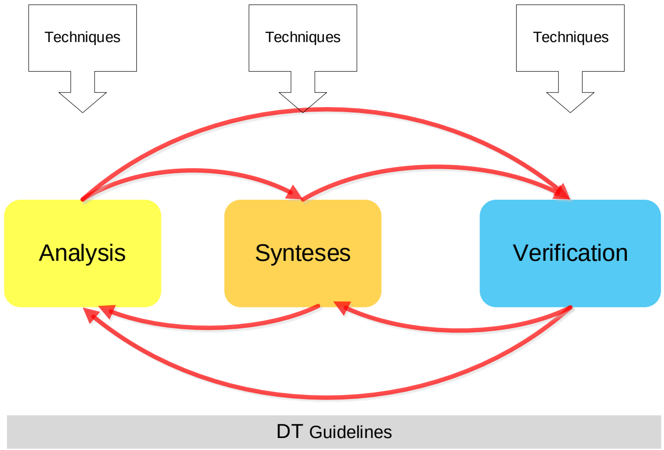


On the other hand, chapter 6 presented how different academic and institutional authors have proposed various DT processes. According to the three stages identified in the Creative Process in Chapter 4, a DT process with three stages is proposed: analysis, synthesis, and verification.

Analysis, the process of DT starts from the understanding of the problem situation, from the point of view of the different involved, by expanding the problem space (divergence), to define the problem (convergence), which corresponding with the inspiration of IDEO (2011) and to empathize and to define from (PLATTER, 2009; STANFORD UNIVERSITY, 2012); synthesis, in this phase multiple solutions are generated (divergence), ideation of IDEO (2011) and (PLATTER, 2009; STANFORD UNIVERSITY, 2012); and verification, ideas are prototyped and tested quickly in order to determine the pathway of the solution (convergence), implementation of IDEO (2011) and prototype and test of (PLATTER, 2009; STANFORD UNIVERSITY, 2012).

The solution is refined, and with new and more refined prototype-tests in iterative cycles, variants are evaluated until a suitable solution is obtained. Some authors emphasize certain aspects, but this is the synthesis of DT process of the cited authors. It can be noticed from Figure 7.2 how the overall process is guided by the guidelines, which are aspects that give meaning to DT. In turn, each phase is supported with a set of techniques.

Figure 7.2 - DT Model from the Creative Process



As a complement to the comparison of TRIZ and DT with PC, Table 7.2 draws a parallel between both methodologies, as seen from the creative process.

Table 7.2 - Comparison of the Creative Process with TRIZ and DT

	Creative process	TRIZ	Design Thinking
Analysis	Finding the problem Acquiring knowledge Gathering potentially Useful information Saturation Gathering data, acts, and sensations	Understanding the problem: purpose, resources, and elements in conflict, Schematizing the problem Analyzing the problem in the context of time and space Determining the direction of the optimal solution Understanding the essence of the problem from technology to eliminate psychological inertia. Identifying the problem as a generic type of problem.	Understanding the problems from stakeholders. Structuring and understanding the problem Empathizing with users to synthesize the problem Immersion and user understanding
Synthesis	Illumination Incubation Idea generation Idea Combining Associations to generate and to combine ideas	Use and modify resources to solve the problem Separate in time, space, condition, or system. Use ways of solving problems in the past: inventive principles, scientific effects, 76 standard solutions	Creation of concepts Generation of new possibilities Alternative views Definition of ideas and test
Verification	Verify Validate Communicate Idea selection	Verify if the solution goes in the direction of ideality Check the possible use of existing resources Check possible sub-problems that may arise Check if the solution can be generic Verify if the solution goes in the direction of the evolution of technology	Prototyping and testing Testing with users Visualizing scenarios
Elements	Influence of social environment, motivation, and elements, such as problem dominance skills, and creative methods.	Principles that direct the technique application, and several techniques to be used, in the stages of analysis, synthesis, and evaluation.	A guideline that directs the process, and several techniques to be used, in the stages of analysis, synthesis, and evaluation.
Process	The process is stated in general terms, and it is indicated that there may be iterations.	ARIZ presents a structured process, but TRIZ does not offer a specific process. The techniques can be used individually.	The process is one of the basic elements of DT, with the phases of analysis, synthesis, and evaluation, performed with multiple iterations.

Source: the author

In sum, the chapter supports how in the PHE sector the FFE is driven by the Technology and/or User, and how the integration of TRIZ and DT methodologies can support the FFE. Likewise, in the comparison of TRIZ and DT with CP, it was exposed how each methodology can be used in the analysis, synthesis, and evaluation, by taking into account that TRIZ focuses more on the technological driver, and DT on the User/market driver. In addition, the comparison of both methodologies in numeral 7.1 indicates potential complementarities in the categories of objective, initial analysis, process, philosophy, and results, although divergences are noted. These reflections imply that for products in the PHE sector, it is possible and convenient to integrate TRIZ and DT in the three main stages of the FFE: analysis, synthesis, and evaluation.

Finally, in Chapter 4 it was pointed out how in the HDI context, the Early and Late FFE cycles require to be executed in a highly iterative manner because of the ambiguities and uncertainties inherent in this context. These cycles are in essence complex problems - there are a large number of problem elements, which have multiplex interactions; unstructured problem - there are no established solution procedures; and non-decomposable problems - it is not possible to solve partial problems (See Figure x). In this sense, TRIZ and DT are integrative methodologies, which allow to understand the problem as a whole and to attempt to bring together distant elements, TRIZ from Technology and DT from the User.

One difficulty identified in the application of TRIZ is the long time and training required to use it (HENTSCHEL; CZINKI, 2013; ILEVBARE; PROBERT; PHAAL, 2013). In this context, another line of argument of TRIZ and DT complement is the one implemented by (HENTSCHEL; CZINKI, 2013), who indicate that through DT, a company can understand the advantages of systematic innovation, it is easy to implement it and, for problems where a higher level of abstraction is required, begin to use TRIZ. Thus, DT can be a door to TRIZ.

8. FFE MODEL SYNTHESIS

As indicated in the introduction and research limitations, the present thesis is based on previous master's dissertation results. In it, a model of PDP for SMEs of hospital furniture and MD of the large mechanical-electronics area was proposed. Once the Assistance Product for People with Disabilities are analyzed, it is verified that the proposal is valid for the three groups of PHE. In fact, most of the personal care products are, by definition medical devices. In this research, the focus is on products with a high degree of innovation and emphasis on Late FFE. Chapters 4, 5 and 6 have provided elements, which allow reformulating the FFE of the Master's PDP proposal, and integrating TRIZ and DT, they will let the operationalization of Late FFE, by indicating what to do and how to do it, without turning the Late FFE model into a limited guide to just perform some techniques.

8.1. FFE MODEL PROPOSAL

The review of FFE models, proposed by different authors, indicated in Chapter 4, provides important elements for understanding and structuring a proposal for products with a high degree of innovation. Figure 4.5 shows a synthesis of how FFE evolves from incremental innovation to HDI, as well as, a clear separation in the context of HDI from Early and Late FFE, which are usually executed by different teams. The Early FFE is linked to the company's strategic plan, in which the objective is to have many possibilities of products to develop - project ideas. On the other hand, the Late FFE is the beginning of the development of a specific idea.

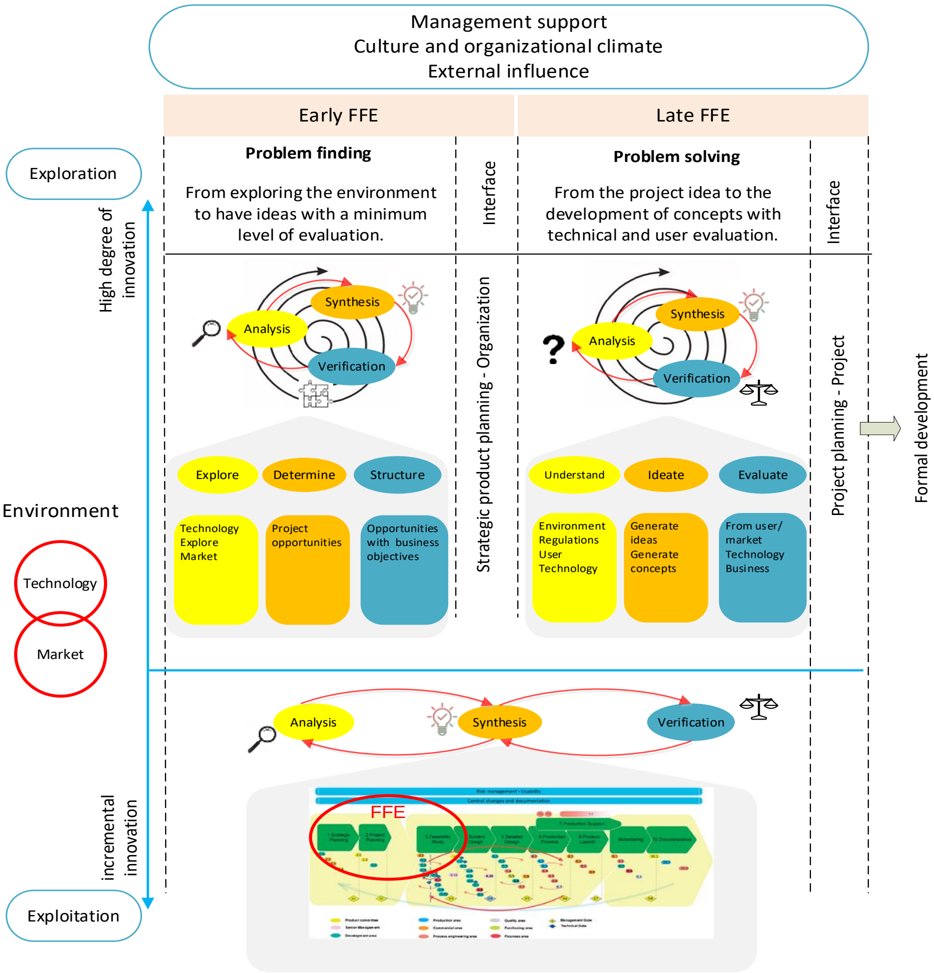
Based on the theoretical background, and the analysis of Figure 4.5, an FFE framework in incremental innovation and HDI is proposed to clarify contexts of incremental innovation and HDI, which is shown in Figure 8.1. Incremental innovation is explained, by indicating a methodological proposal, which can be read in appendix A, and HDI where the main activities are indicated at a general level.

By focusing on HDI, Early FFE is organized into three phases, which are performed iteratively: Explore, Determine, and Structure. The Explore phase involves an analysis of the environment, in the external, and internal domains to determine opportunities in the company's field of interest. The Determine phase involves the initial ideation of possibilities for new products in the company's field of interest. Finally, the structuring phase consists of linking these possibilities to the company's strategy.

On the other hand, Late FFE, as indicated in Figure 8.1, shows a structure with three iterative phases: Understand, Ideate, and Evaluate. The Understand phase involves an exploration of the problem based on the environment, user/market and technology. The problem is understood based on the idea of the new project or the problem, to provide a clearer formulation of the problem and necessary information. The Ideate phase involves the generation of ideas to solve the problem. These are debugged until new product concepts are conceived.

The Evaluate phase involves the evaluation of initial ideas and concepts from user/market, technology, and business perspectives, to determine the best alternatives. Thus, Late FFE provides new viable product concepts, as indicated in Figure 8.1—Problem solving—, Which is identified at the product project level.

Figure 8.1 - FFE framework in incremental innovation and HDI



Source: the author

Finally, a number of points are indicated by contrasting Figure 8.1 with the discussion on flexibility, iterations, degree of innovation of the new product, and the creative process. In terms of the relationship among phases, As the degree of innovation increases, the interdependence relationship becomes stronger. In this sense, there is no information or approximation, which would allow an estimation of what is necessary to carry out the next phase. Thus, to complete one phase, progress has to be made in the subsequent phases. In this way, the process will be more iterative as the degree of innovation increases.

On the other hand, when considering the Creative Process. In the context of a high degree of innovation, the problem to be solved is not algorithmic. It is an unstructured problem, or as defined by (Frishammar et al. 2013), a non-decomposable problem, for which there are no clear solution pathways, and the sub-problems cannot be solved separately. Moreover, as the degree of innovation increases, this unstructured problem tends to be stronger, and creativity is fundamental to propose solutions. It is possible to observe how Early and Late FFE indicated in Figure 8.1 are consistent with the creative process with analysis, synthesis, and evaluation. Finally, in Figure 8.1, it can be noted that Early and Late FFE are different processes. They are complementary, though separated by an interphase, which is the strategic plan of the set of products, in which designs are prioritized.

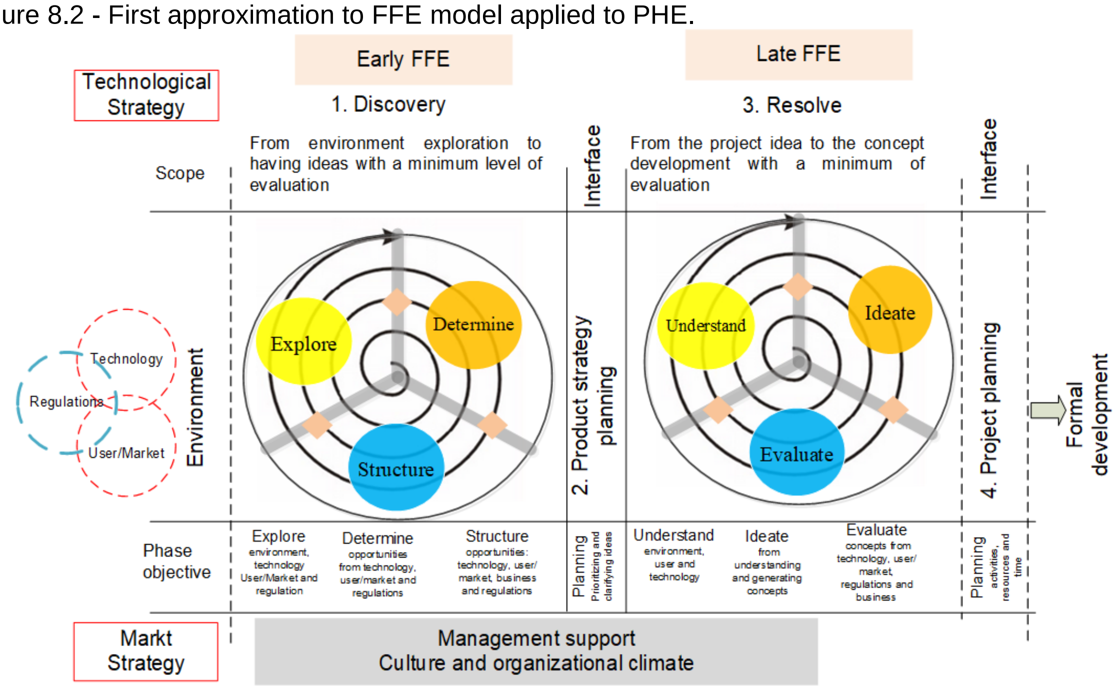
Chapter 3 focused on products in PHE sector, which are developed to help people in vulnerable situations. Likewise, it was shown how regulations have a marked impact on the development of PHE products, these regulations mainly look after the safety and product effectiveness, and they, recently, integrate usability and human aspects. It was also indicated how regulations in PHE product development play several roles: process guidelines, source of knowledge, and innovation drive.

On the other hand, the master's research synthesized a proposal model to MD development (URIBE OCAMPO; KAMINSKI, 2019) (See Appendix A). This model was addressed to incremental products. However, it provides elements to be taken into account in the specific FFE for the PHE sector, as follows: i) regulations, which are determinant in all phases of medical device development; ii) users, medical devices have multiple users, each with different requirements, by having to consider both explicit functional needs and symbolic or latent ones; iii) a high tendency to integrate new technologies in products and different areas of knowledge. In addition, specifics in terms of activities, which are required to develop PHE, (See Appendix A).

In this way, regulations, users, and technology will be present in all phases of FFE, from the exploration of opportunities, in which changes in regulations, new technologies, or User/market behavior provide opportunities. Thus, these elements constitute the basis for the understanding of the problem, the generation, and evaluation of ideas, and product concepts.

Figure 8.2 is the first approach to the FFE model, which is based on the discussion on FFE regulations; the previous analysis of the FFE, which is summarized in Figure 8.1; and the author's master's research.

Figure 8.2 - First approximation to FFE model applied to PHE.



Source: the author

The FFE proposal, as indicated in Figure 8.2, is a refinement for the sector and specific conditions of the current research, and it consists of four defined phases. In the Early FFE: i) Discovery –problem finding, which consists of three activities, Explore the spaces of technology, user/market and regulations, the results of exploration allow, Determine project opportunities, and finally, Structure the opportunities generated with the business objectives. This is done in Spiral cycles, which allow moving from a basic initial understanding to a refinement of the opportunity; ii) Strategic product planning, every organization has more project ideas than resources, by having as input, the results of the Discovery phase and the company’s technological and market strategy, the projects to be developed are prioritized and defined; in the Late FFE: iii) Resolve -

problem solving, here begins the solution of specific problem or opportunities encountered, with cycles of Understanding -environment, regulations, user, and technology, Ideate -generate ideas and concepts, and Evaluate - from user/ market, technology, regulations, and business. Each Spiral cycle is an accumulation of knowledge about the problem and the solution, until satisfactory solutions are obtained; and iv) Project planning, with the concepts evaluated, it is possible to estimate the activities, resources, times, and those involved in the new product design.

In this way, the overall proposal is framed in the SG concept, while the Discovery and Resolve phases are structured in a highly flexible way, under the Spiral concept. The SG concept facilitates the progress and management of the overall process of FFE. On the other hand, the Spiral facilitates continued iterations in activities, which by their nature, are interdependent in a high degree of innovation context, in Discovery and Resolve phases.

The Late FFE, which is the focus of the current research, can be related to the Feasibility Study phase of the previous master's degree research (URIBE OCAMPO, 2015). In this phase, the understanding of the problem, proposed solutions and evaluation of them is carried out. The activities of the Feasibility Study, as can be observed in Appendix A, are: validate the existence of market for the future product; identify the basic users' needs; define clinical and regulatory requirements; gather the relevant information for the PD; determine the target specifications of the product; create concept proposals; analyze the product economically and financially; define potential risks for users; classify the product according to regulations of the target market; determine the types of tests required, the conditions for validation in use of the product; and verify possible actions to manage intellectual property.

Some comments on these activities in the master's proposal. First, validate the existence of market, for incremental products, elements, such as price, or purchase intention can be determined with a degree of precision, but for a new and even not perceived problem, or a new way of solving an existing problem, it will be difficult to establish the market data, with sufficient precision. It may even, if the idea is not well understood in the identification phase, it may not be clear what the market is. Here it is evident the importance of Early FFE, particularly for products with a high degree of innovation, as well as the need to carry out an iterative process for these types of products. In these cases, it is recommended to first make some rounds in the Spiral in the Late FFE in order to accumulate enough knowledge, to allow determining which problem is being solved and who benefits from it. A deficient accomplishment of this activity can bring as consequence "Developing a product for a market that does not exist".

Second, identify the needs, for the problem identified, it is asked what the expectations and needs of those involved are. Remembering that, to the extent of novelty, these expectations and needs can hardly be determined because sometimes people are not aware of the problem until they have a solution for it. Another point in the PHE sector is vulnerability and the object-person inter-relationship, in which not only is it functional, based on use and usability, but also emotional aspects or meaning can be important. A deficient realization of this activity can bring as a consequence "Developing a product for a need that does not exist";

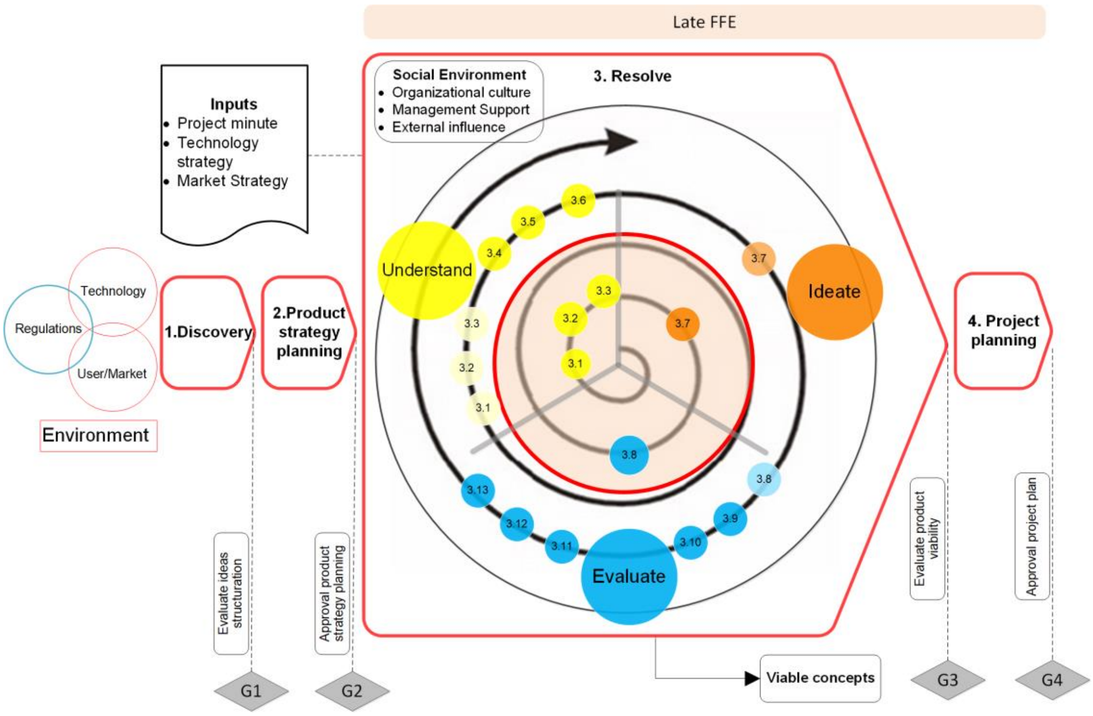
Finally, generate concepts, once the problem and the needs and expectations of the users and the stakeholders are defined, concepts are generated for possible products. At this point, creativity is crucial to synthesize solutions in the form of an appropriate artifact, and, in the case of products with a high degree of innovation, original. A deficient realization of this activity can bring as a consequence "Develop a product that does not meet the needs and expectations of users".

In this way the master's research provides elements to be taken into consideration for the PHE sector, in the activities of Understand, Ideate and Evaluate in Late FFE. Thus, a detailed Late FFE is performed as shown in Figure 8.3 and will be explained below.

The proposal in Figure 8.3 presents a Spiral structure in two levels, the activities indicated in numbers are detailed in Table 8.1. Level 1 (inside the red circle) is the beginning for a project with a high degree of innovation, and when one has a degree of understanding of the problem and the solution with sufficient maturity, one moves to Level 2. On the contrary, for an incremental project, it starts with Level 2, and more than a Spiral it would be a linear process with many iterations.

In this way, Level 1 of the Spiral constitutes the most diffuse part of the Late FFE. In this level, the loops are many and fast, by providing some cycles of Understand, Ideate, and Evaluate. At this level, the integration of TRIZ and DT will be determinant. The Spiral allows the accumulation of knowledge about the development. The first loops are simple ideas, and as the phase progresses, concepts of the product to be developed are generated. At this point, the activities of Level 2 of the Spiral begin to operate, which are activities to be taken into consideration when the process has a high level of understanding, and concepts have sufficient degree of maturity. It is expected that there will be fewer loops of the Spiral in Level 2, and even slower, if the problem already has a high level of understanding. In other words, it is at Level 2 of the Spiral, when the process tends to be less diffuse and more concrete. It should be noted that the activities of level 2 will also be carried out first in an expedited way because at this point, one can be evaluating numerous concepts, with the turns of the Spiral refining the solution for more mature concepts and the activities of level 2 will be more refined.

Figure 8.3 - Late FFE detail



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The Resolve phase of the Late FFE consists of three blocks of activities, as shown in Figure 8.2 and Table 8.1, which are Understand, Ideate, and Evaluate.

Understand, related to the search, clarification, and discerning, which starts with learning about the environment, user, and technology, and it culminates with the definition of target specifications of the product, which will lead to the subsequent process; Ideate, from the prior information, possible concepts are generated in order to integrate technology and to meet users' needs. Concept generation implies an effort of synthesis, which requires integrating elements of the problem, such as users´ expectations and needs, and company´ market and technological strategy, among others. This activity is the heart of the Late FFE, and even the PDP for products with a high degree of innovation; and Evaluate, synthesized several concepts, which integrate technological possibilities of solution, are evaluated initially from user and technology drivers. Afterwards, they are submitted to different evaluations, such as economic, financial, potential risks for users, regulations and intellectual property. In this block, the evaluations are only at a level, which allows comparing the alternatives and determining whether a concept is really feasible and promising.

PHEs products require some specific activities in the Understand and Evaluate blocks: by defining clinical and regulatory requirements, and by incorporating them in the specifications, by determining possible risks for the different users, by classifying the possible product according to the regulations, and determining the types of tests required for homologation and validation. These activities, at this stage of the process, are important due to the high impact of regulations, which may even make a concept that in principle looks promising, unviable. On the other hand, understanding regulatory changes can be a source of opportunities for new products. For products classified in high risk levels, homologation may be more complex than its development, and this understanding provides a better assessment of concepts (URIBE OCAMPO, 2015).

One of the inputs of Late FFE is the project minute, which will have an initial description of itself. This description can be detailed or still vague, depending on the results of the identification phase, and the degree of innovation of the design. In products with a high degree of innovation in relation to the technological novelty and with the users, the design begins more open and ambiguous. On the other hand, in evolutionary designs, they can start more closed and defined, with an idea of the solution direction. The technological and market strategy will also be important input. The process will be inserted in the social environment, which constitutes a support to the phase, being the organizational culture, management support and external influence particularly important. It should be noted that regulatory aspects for products from the PHE sector will be present from the initial phases.

The process shown in Figure 8.3 presents the Spiral structure because for products with a high degree of innovation, at this stage, the process is unstructured and there is a strong interdependence of the three blocks - Understand, Ideate, and Evaluate. Thus, the Spiral will facilitate the interaction of activities in the advancement of the phase.

Table 8.1 shows the different activities of the phase, in which for the Resolve phase, the respective level of Spiral is indicated for each activity. The level 1 activities are executed in both the initial turns of the Spiral - Level 1, and the advanced turns - Level 2, but as it can be represented in Figure 8.3, these last activities in Level 2 tend to be weaker.

Table 8.1 - Late FFE activities

			ACTIVITIES OF PHASE	DESCRIPTION
1.Discovery	Explore		Explore	Explore environment, technology User/ market and regulation
1.Discovery	Determine		Determine	Determine opportunities from technology, user/market and regulations
1.Discovery	Structure		Structure	Structure opportunities: technology, user/market, business and regulations
G1			Evaluate ideas structuration	
2.Product strategy planning			Product strategy planning	Prioritizing and clarifying ideas
G2			Approval product strategy planning	
3.Resolve	Understand	N1	3.1. Understand environment	Gather the relevant information for product development
3.Resolve	Understand	N1	3.2. Understand user	Understanding of users' wishes and needs – Insight
3.Resolve	Understand	N1	3.3 Understand technology	Understanding the essence of the problem from technology
3.Resolve	Understand	N2	3.4 Validate market	Verify the existence of market for future product
3.Resolve	Understand	N2	3.5. Define requirements	Define clinical and regulatory requirements
3.Resolve	Understand	N2	3.6. Determine specifications	Determine the specifications required for product
3.Resolve	Ideate	N1	3.7. Create concept	Create ideas and concepts to solve the problem
3.Resolve	Evaluate	N1	3.8. Evaluate	Evaluate solutions from user and technology
3.Resolve	Evaluate	N2	3.9. Define risks	Define the potential risks for the different users of product
3.Resolve	Evaluate	N2	3.10. Classify product type	Classify the product according to the regulations of the objective market
3.Resolve	Evaluate	N2	3.11. Determine tests	Determine the types of tests required and the conditions for validation in use of product
3.Resolve	Evaluate	N2	3.12. Analyze product economically and financially	Analyze product economically and financially, by taking into consideration the market potential
3.Resolve	Evaluate	N2	3.13. Manage intellectual property	Determine, execute, and control possible actions to manage intellectual property
G3			Evaluate product viability	Evaluate the viability and decide the future of project

	ACTIVITIES OF PHASE	DESCRIPTION
4.Project planning	4.1 Define scope of product and project	Define the goal and scope of product, and about the project, its length or resources that can be consumed
	4.2 Prepare project plan	Determine project management, in terms of time, resources, quality, and objectives
	4.3 Define development team	Determine the areas and people needed and interested in the project and make up a development team
	4.4. Allocate resources	Determine and separate the resources needed to execute project
G4	Approval project planning	Approve project plan and decide the start of project

At level 2, as indicated, an understanding of the problem is expected, yet, with the new elements of evaluation, market, regulations, economic, and financial analysis and the like. It may be necessary to make new generations of concepts in order to improve or to combine existing concepts. An important point to highlight, when at Level 2, the generated concepts are not being well evaluated, or the team realizes that the solutions are not adequate, one can return to Level 1, by starting from the accumulated knowledge. The logic behind this is that if at Level 1 the results are deficient, to continue the project may be precipitated.

As mentioned above, it can be difficult to establish limits for the termination of the Late FFE phase. Therefore, management can be difficult, and since it is a strategic phase, the monitoring of senior management is required in order to provide support in the understanding and articulation of solutions in order to contribute to strategic alignment, and in order to require convergence of the phase.

8.2. TRIZ AND DT INTEGRATION INTO THE FFE

A preliminary overview of the FFE model was presented in the context of a high degree of innovation and a more detailed description of the Late FFE, which is the focus of the current research, with specificities for the PHE sector. In the same way, the theoretical reference about the creative process, TRIZ, and DT methodologies was treated, and a comparison of both methodologies was established in order to determine their complement in the Late FFE.

The integration of TRIZ and DT methodologies in the proposed Late FFE model will be discussed below, by focusing on the synthesis of a conceptual and operational model, which can be used for products with a high degree of innovation in the PHE sector. The authors of FFE and PDP indicate how the technological and market/user direction can generate fields of product innovation. TRIZ and DT provide an understanding of the problem from both perspectives. The challenge is to incorporate both into the Late FFE.

Some points of TRIZ and DT methodologies will be mentioned, which are: i) both TRIZ and DT can be seen as a methodology, which operationally use techniques, it can be difficult to decide which technique to use in practical situations; ii) TRIZ and DT do not present a single form of process; iii) the essence of TRIZ and DT include some principles in the former and some guidelines in the latter. Moreover, the use of both methodologies presupposes the understanding of these principles and guidelines, as well as the use of techniques; and iv) both methodologies can be used to solve problems and to generate innovative solutions, TRIZ, to solve complex problems of the inventive type, and DT, to solve wicked problems, which involve human understanding.

The object of study of the current research is the PHE, in which for its development, it is necessary to interpret the needs of different people involved and regulations in order to propose solutions with the use of technological possibilities of several sectors, - "User and Technology".

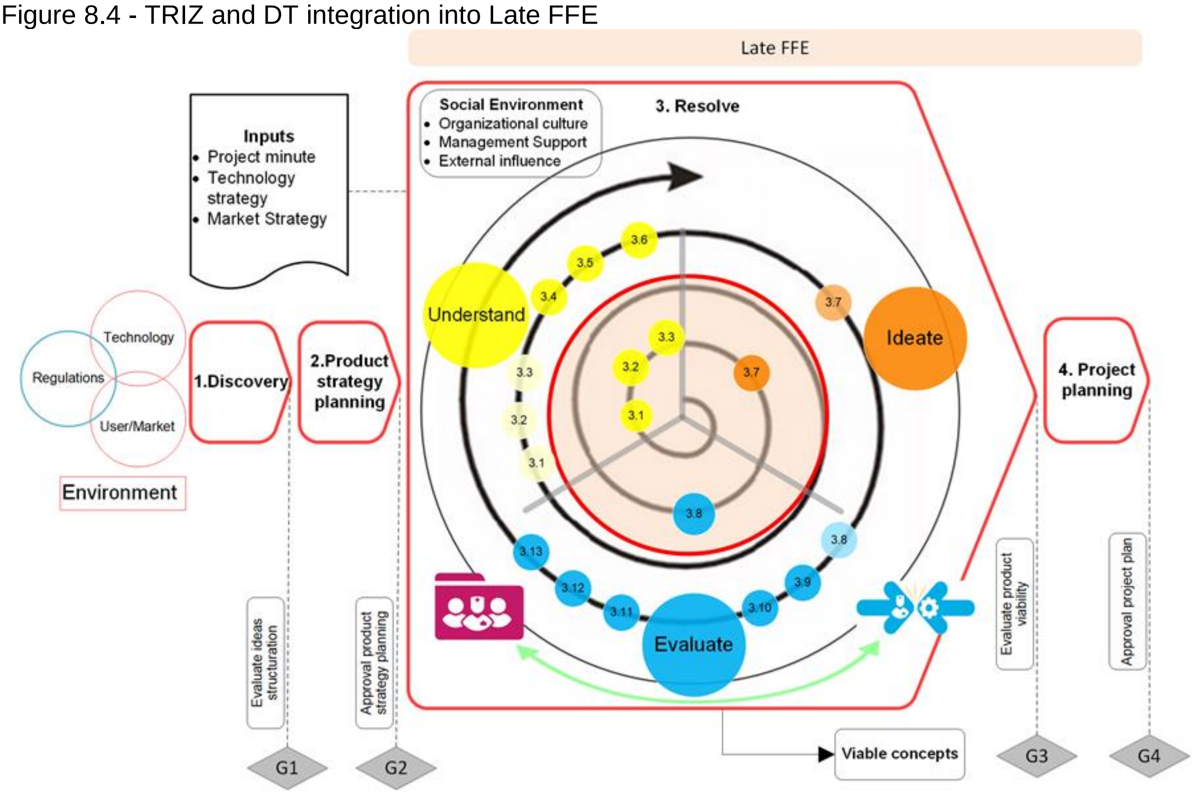
It is possible to conclude how TRIZ, (at least ARIZ) and DT can be understood from the three phases of the creative process: analysis, synthesis, and evaluation, as indicated in Table 7.2. In DT, even if the different academic and institutional authors call these phases differently, along with guidelines, DT is defined by the notion of the process. On the other hand, in TRIZ, ARIZ proposes a structured process (See Appendix B), However, it is complex because ARIZ is used for highly complex problems. Besides, the individual techniques of TRIZ, in the context of product development, do not have this notion of process.

In this way, the Late FFE model is proposed with the general Spiral structure, which is closer to the DT structure, by combining in each, the Understand, Ideate and Evaluate, elements of ARIZ. In the same way, the general process of Late FFE will be addressed for DT guidelines and by fundamental principles of TRIZ. Also, the most desirable characteristics of both methodologies will be combined in each phase. Figure 8.3 illustrates the general relationship of both methodologies in Late FFE.

An initial look could indicate TRIZ just in the idea generation phase, excluding it from the other phases, as proposed by authors, such as (AKAY; DEMIRAY; KURT, 2008; HENTSCHEL; CZINKI, 2013; PELT; HEY, 2011). However, the in-depth study of TRIZ has made it possible to understand that it can offer a complement in all phases of analysis, synthesis, and evaluation. This conclusion is consistent with the research of (SILVA; KAMINSKI; ARMELLINI, 2020), which used TRIZ in analysis, synthesis, and evaluation, but, in an independent cycle.

In this way, the structuring of the integration of DT and TRIZ has as essential elements. On the one hand, the analysis of the process of DT, and on the other hand, the analysis of ARIZ, but does not use ARIZ in the strict sense of the word because as indicated above, ARIZ can result rather laboriously. However, the general structure of ARIZ provides a reasoning direction in the TRIZ process, which has been incorporated into Late FFE. Figure 8.4 shows the Late FFE Spiral model, and it represents the insertion of TRIZ and DT into the overall process, and how both methodologies rather than being inserted independently, they complement each other.

Figure 8.4 - TRIZ and DT integration into Late FFE



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This integration is also different in each of the Understand, Ideate, and Evaluate phases. In summary, the integration of TRIZ and DT into Late FFE, aims to integrate the user and technology in the overall process, in a conceptual model. Furthermore, it proposes a way of operationalizing and instrumentalizing the phases and activities. The following will describe the integration of TRIZ and DT in each of the phases in order to have an understanding with sufficient detail in order to apply the model, and lastly a description of the final general model will be made in order to maintain the overall concept.

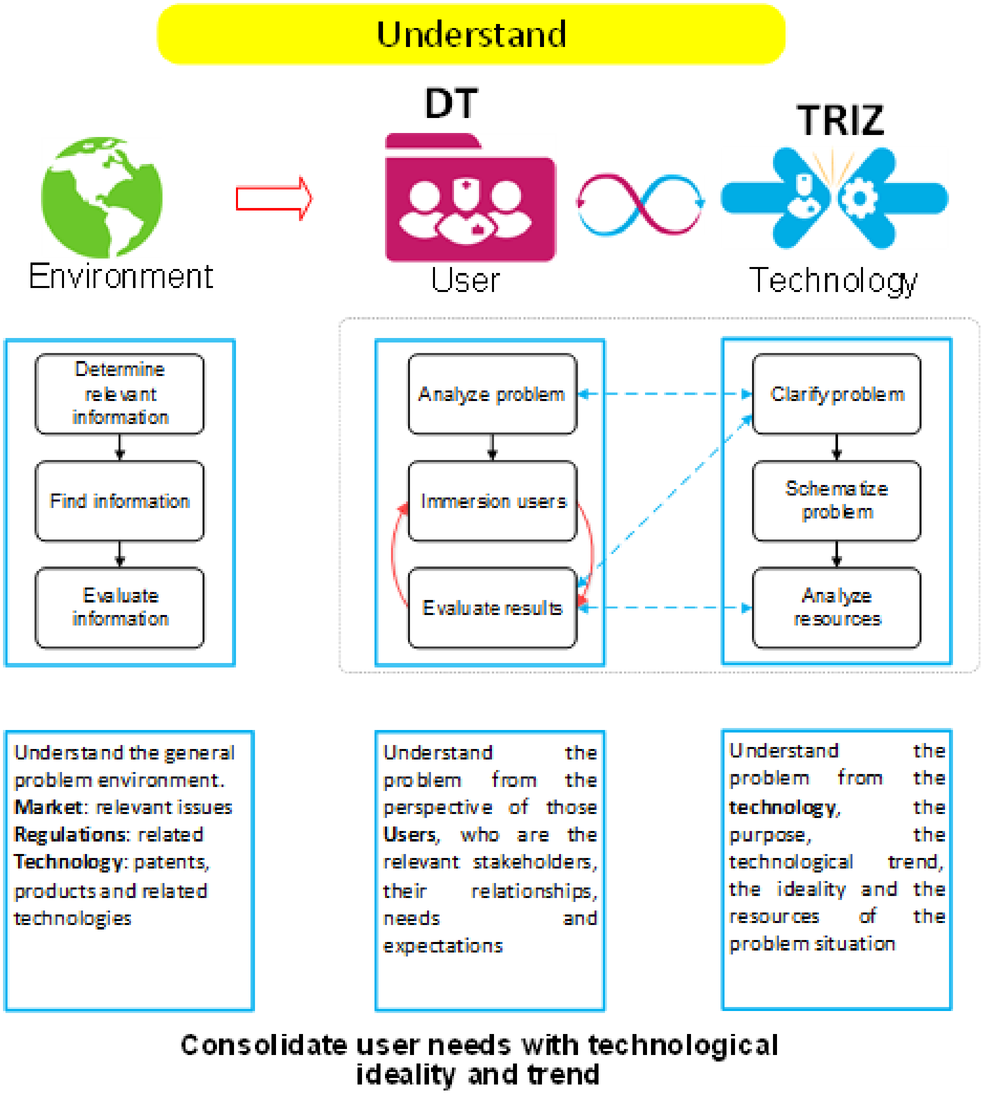
8.2.1. Understand phase

In the Understand phase, TRIZ and DT methodologies present a complementary relationship by interdependence. Thus, activities 3.2 and 3.3 which are about the understanding of the user and technology, from DT and TRIZ methodologies respectively, are performed with a strong interdependence, as indicated in Figure 8.4. In this way, a deep understanding of the problem from the users' perspective supports the problem clarification from the technological perspective, and vice versa. Thus, the results of scanning the relevant users from DT, allows clarity in defining the purpose of the system. What is desirable and what is not desirable, from users' perspective. These results support the definition of the ideal final result of TRIZ. On the other hand, the clarification of the problem, which allows extending its vision, the schematization of the problem, and the analysis of the resources from TRIZ, provides elements or analysis categories in the immersion with users.

In this way, 3.2 and 3.3 are two separate activities, but they need to evolve over time to facilitate the two forms of analysis of TRIZ and DT. And even they allow the possibility of having two independent teams, by performing each activity, with fluid communication. This allows for complex projects to incorporate experts from both TRIZ and DT.

Figure 8.5 shows how the activity understands the environment -3.1 provides support for subsequent activities. It should be noted that relevant project information is sought as the project progresses. The team can even begin the project from activities 3.2 or 3.3, and in the evolution of understanding of the problem, search for relevant information. In this way, the search for information is an activity, which will be carried out along the project. Understanding the environment has various aspects according to the project in question. Some of the most relevant ones are demographic, economic, regulatory, environmental, social, and technological. However, the development team determines what information is crucial at the project stage.

Figure 8.5 - Relation of activities Understand on level 1



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Demographics - population growth, birth rate/mortality, population density, age distribution; Economic - growth, economic prospects; Regulations - relevant local and international laws and regulations, recent changes and trends in regulations; Environmental - environmental regulations, industry impact, novelties; Social - lifestyle, values, and desires, income distribution, access to services; and Technological - patents, local and international commercial products, technological-related novelties.

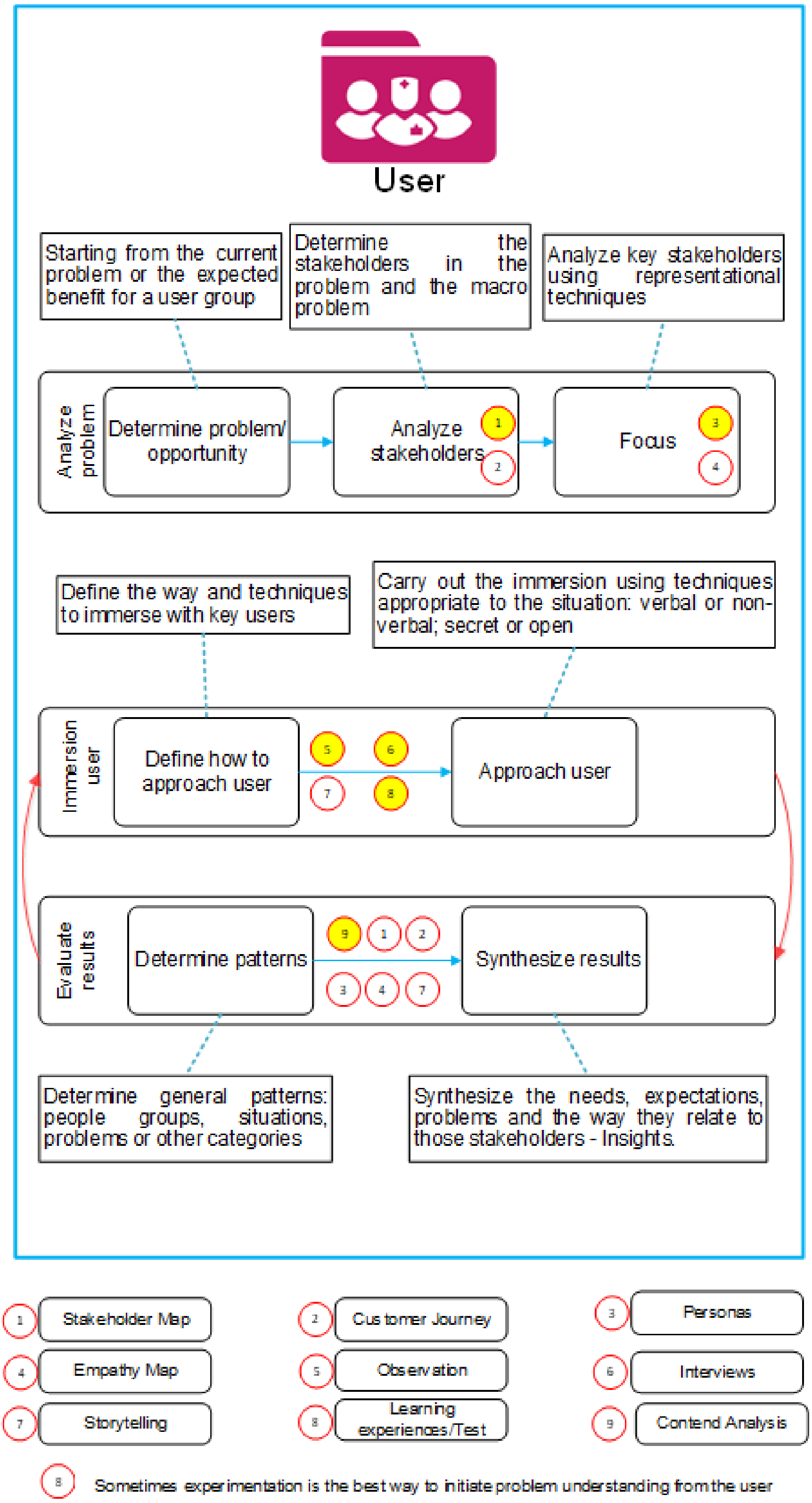
8.2.1.1. Understand User

In this activity, from immersion, or interaction with real potential users, the intention is to define which the relevant stakeholders of the problem are, their relationship with the problem, determine insights, needs, desires, and expectations. Figure 8.4 shows the basic flow of the Understand user activity while Figure 8.6 specifies each task, and additionally it recommends some techniques, which assist the task, which are listed in the numbers in circles in Figure 8.6. The Understand user activity is divided into tasks: Analyze problem, Immersion users, and Evaluate results.

Analyze problem, it consists of an expeditious understanding of the problem and the stakeholders. Determine the problem or opportunity, begin from the current problem or expected benefit for a user group in order to clarify the problem; Analyze stakeholders, determine the stakeholders in the problem situation and the macro problem, people or entities are considered stakeholders; and Focus, to make a preliminary analysis of the key stakeholders, by using representational techniques in order to initiate user understanding and facilitate immersion.

Immersion with users, it consists of performing immersion with users and relevant stakeholders, to determine their explicit and latent needs, desires, and expectations. It is important to remember the concepts of use, usability, and meaning in order to clarify the immersion. Firstly, Define how to approach stakeholders, by determining the techniques to be used and the manner to realize immersion by taking into consideration the expected results category, which can be functional or symbolic, explicit or latent. The user's immersion approach, the more natural and closer it is to the problem, the results of this immersion will be more reliable. Finally, Approach users, apply the appropriate techniques for immersion with users, which can be verbal or non-verbal, secret or open observation. Sometimes, it is possible to carry out the immersion, from tests with a prototype, which can be a very basic solution. It is necessary to be recursive in order to wonder where the real users are, and how their interactions could be used in order to know their needs, wishes, and expectations.

Figure 8.6 - User Understand Flow



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Analyze results, it consists of performing an immersion analysis. These results allow determining relevant issues, which will drive the solution. The analysis is complementary to data capture. Firstly, Determine patterns, are determined general patterns, groups of people, situations, or other categories. It is recommended to graphically represent the results of data captured with the techniques of user representation, which were suggested in the Problem analysis, as indicated in Figure 8.5. Synthesize results, are determined insights -needs, desires, expectations, and problems. Similarly, it is defined how these insights are related to stakeholders. The analysis of content of social sciences can help in this task.

It is notorious in the analysis of DT literature how the analysis of results is performed in teams, determining insight, the techniques offered by the social sciences are scarcely mentioned. Here is a reflection: the determination of Insights in DT could be at random. Moreover, the teamwork and the guidelines of DT will allow going beyond a superficial look. On the other hand, for more complex problems and when the necessary resources are available, there are professionals of social sciences and companies, who help in understanding the user. It should be noted that the immersion and analysis are carried out in an interdependent way in order to determine new actors, scenarios, or points in which it is necessary to deepen into.

8.2.1.2. Understanding technology

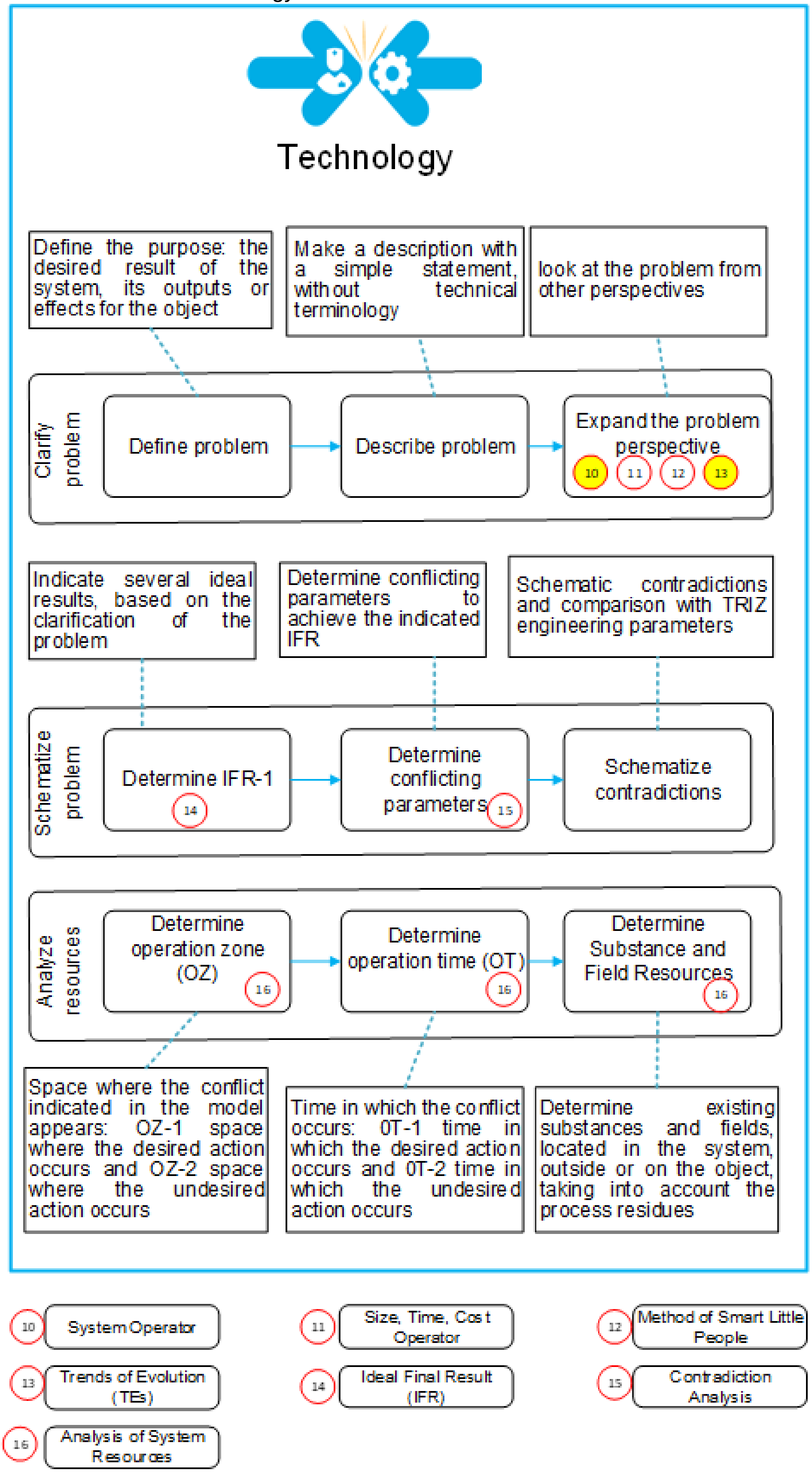
This activity is expected to understand and to interpret the problem from the technological point of view. The natural evolution of technology, understanding the problem in time and space, schematizing the problem in order to simplify its understanding, and analyzing the resources involved in the problem. These can be sources of solutions without complicating the system. This phase has a direct influence of ARIZ. Figure 8.5 shows the flow of activity 3.3, which is detailed in Figure 8.7. This activity is divided into three tasks: Clarify problem, Schematize problem, and Analyze resources.

Clarify problem, it consists of defining the purpose, clarifying, and broadening the problem view. Firstly, Define the problem, the purpose is defined, which is the desired result of the system, its outputs or effects for the object (the one which receives the function, not to be confused with the user) something like: eliminate impurities from the air. Secondly, Describe the problem, this description is a simple statement, without technical terminology. Finally, Broaden the view of the problem, look at the problem from different perspectives, which allow a more holistic understanding, TRIZ offers techniques, which support this task, some of which are indicated in Figure 8.7.

Schematize problem, as indicated in numeral 5.4, TRIZ proposes several ways in order to schematize the problem. The contradiction model was chosen, but it is feasible to use other ways to schematize the problem. Firstly, Determine IFR, starting from Clarify problem, and the analysis of activity 3.2, which implies a TRIZ - DT integration, several forms of Ideal Final Result (IFR) are presented, see explanation in Appendix H. It is relevant that the IFR integrates an understanding of both technology and users. Secondly, Determine conflicting parameters, which are opposing parameters to achieve the different manners of IFR. In order to achieve the IFR, it is necessary to solve Technical Contradictions (TC) or Physical Contradictions (PC). Finally, Schematize TC or PC and link the conflicting parameters, with the 39 TRIZ Engineering Parameters. See Appendix H for an explanation of how to determine contradictions.

Analyze resources, it consists of making an analysis of space, time, substance, and field resources in order to understand the resources and to determine the spaces and times in which contradictions arise. Firstly, Determine operation zone (OZ), space in which the conflict occurs, OZ-1 space where the desired action occurs and OZ-2 space where the undesired action occurs, OZ-1 and OZ-2 can be separated or overlapped. This analysis makes it possible to determine different spaces as resources. Secondly, Determine operation time (OT), time in which the conflict occurs, OT-1 time in which the desired action occurs, and OT-2 time in which the undesired action occurs, OT-1 and OT-2 can be separated or overlapped, consider the times: before, during, and after the conflict. This analysis makes it possible to determine different times or intervals as resources. Finally, Determine substance and field resources, which are existing substances and fields, located in the system, the environment, or the object. Take into consideration the residues of the process and derived resources, which are resources obtained, by transforming some resources.

Figure 8.7 - Flow Understand Technology



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As shown in Figure 8.5, activities 3.2 and 3.3 are interdependent. Thus, the analysis of the problem from DT and the clarification of the problem from TRIZ are complementary. It can also be seen in Figure 8.5 how the analysis of the immersion results, the clarification of the problem, and the analysis of the resources, are mutually supportive. The understanding of key stakeholders allows a better understanding of the purpose of the system and the possible FRI and vice versa. In the same way, the contradictions determined can be contrasted with users, until these contradictions are categories of analysis in the user's understanding.

8.2.2. Ideate phase

In the Ideate phase, TRIZ and DT methodologies present a complementary relationship by integration. This means that the ideation is carried out in one activity by integrating both methodologies in the same space, time, and team. Under the principles of TRIZ and DT guidelines, a large number of techniques of both methodologies are available. Figure 8.8 shows a representation of the Ideate phase, in which it is shown how there is no defined separation between both methodologies.

It is commonly said that "understanding the problem is half the solution." Also, authors of creativity from the area of cognitive psychology indicate that for non-algorithmic problems, the problem analysis is determinant for the solution. Thus, in the understanding of the problem from the environment, user, and technology, it is perceived that already, at this stage, the solutions come out of the analysis itself. This fact is indicated by TRIZ authors like (CASCINI et al., 2009; PETROV, 2019). The suggestion is to register these ideas, to complement the solutions generated in the Ideate phase.

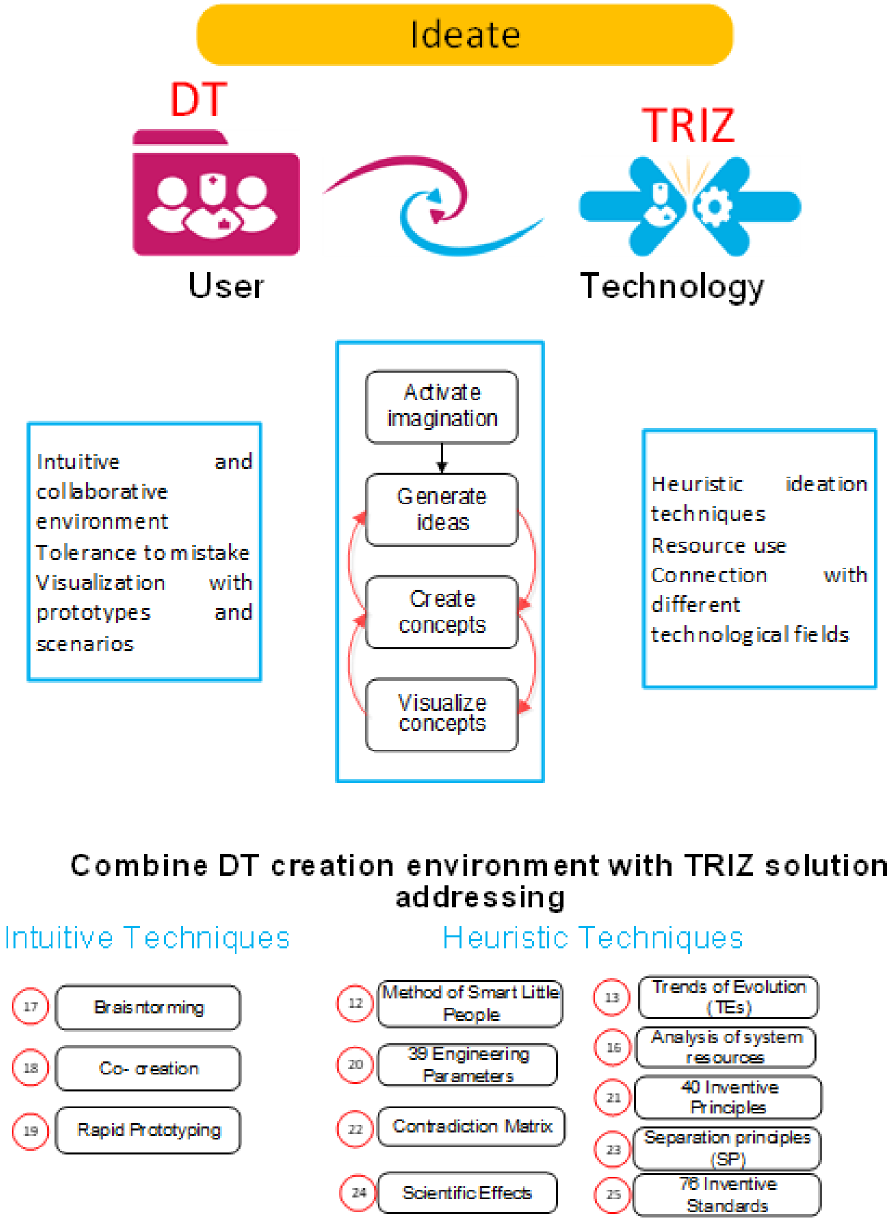
For products with a high degree of innovation, ideation can be difficult because it is a synthesis in the form of possible products of the results of the Understand phase, which has a great number of options and elements of the problem, sometimes distant. It was established in the study of the creative process, how once the problem is understood, and under the proper conditions, the mind makes an unconscious Incubation, which is a combination of the elements of the problem and prior knowledge. In an "unexpected" way, by generating possible solutions to then generate ideas in a conscious way - Illumination, which is the identification of valid combinations for the situation.

The integration of TRIZ and DT aims to potentiate both mechanisms of Incubation and Illumination. In Incubation TRIZ has the capacity to link elements of the problem with knowledge of the person and other technological areas, by directing the generation of ideas with the techniques indicated in Figure 8.8. On the other hand, DT stimulates the creation of an appropriate environment of ideation, while collaborative work and techniques such as, brainstorming, co-creation and the use of prototypes as ideation (not only for communication) stimulate the Incubation, as indicated Hentschel, Czinki (2013) the integration of TRIZ and DT leads to high potential brainstorming.

Regarding, Illumination – "Eureka," is a conscious mechanism, which depends on the person's skills, dexterity, and expertise. TRIZ and DT, with its principles and guidelines facilitate this Incubation, but do not replace personal capabilities. The principles of TRIZ ideality, evolution, and resources indicate appropriate directions, while teamwork, integrative thinking, user-centered approach of DT help the Illumination.

In this way, the Ideate phase indicated in Figure 8.8 represents a sequence, which assists in obtaining valid concepts having the subsidies of the Understand phase. Figure 8.9 indicates a form of flow of the Ideate phase. This flow is the way the author suggests the integration of TRIZ and DT methodologies in order to generate ideas. By maintaining the generality of Late FFE model, the flow could vary, in Item 8.5, the theme of the pathway and the generality of the model, will be discussed.

Figure 8.8 - Ideate Phase



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DT presents a series of techniques for ideas generation, such as brainstorming, co-creation, scenarios. And within these techniques are used other support, storytelling, affinity map, roleplay, story boards. One can summarize the general orientations of these DT ideation techniques, such as combining team ideas and even users, in a relaxed and positive context; by showing the possible future to users, team and decision takers; by exploring multiplex options in a fast, easy, and economic way, to determine appropriate directions. All in the context of the user as the focus of the problem, which allows directing the solution from the user and the business perspective.

TRIZ offers a number of techniques for generating solutions such as PPE, resource analysis of the problem, Separation Methods (MS), Scientific Effects, 40 inventive principles (40PI), SuCa, and standard solutions. In general, the technical orientations are the use and optimization of resources of the problem situation; by using solution strategies, which succeeded in the past, for isomorphic problems (accumulated knowledge), all within the context of the simplification of the problem, ideality, and evolution trends (TEs) of technical systems, which allows directing the solution from the perspective of technology.

Figure 8.8 indicates how concept generation is supported by both TRIZ and DT methodologies. Based on understand results, it has several techniques from TRIZ and DT, which can support the generation. On its turn, Figure 8.9 details the activity, which is composed of four tasks: Activate imagination, Generate ideas, Create concepts, and Visualize concepts.

Activate imagination, it consist of moving from understanding the problem to generating ideas, two forms are proposed, which are adopted from ARIZ. Intensify the conflict, by indicating the state or limit action of the elements TC-1 and TC-2, TC-1 eliminate the undesired action, but the desired action is not carried out, and TC-2 the desired action is fully accomplished, but the undesired action increases as much as possible, determine the contradiction that best represents the problem TC-1 or TC-2, and model with PPE, imagine that the particles or resources are Small Smart People capable of both thinking and taking action to create conditions that eliminate TC-1 or TC-2. If the action is in time, it can be represented in a drawing sequence. In this step, it is intended to understand the effects required to solve the problem independent of technology.

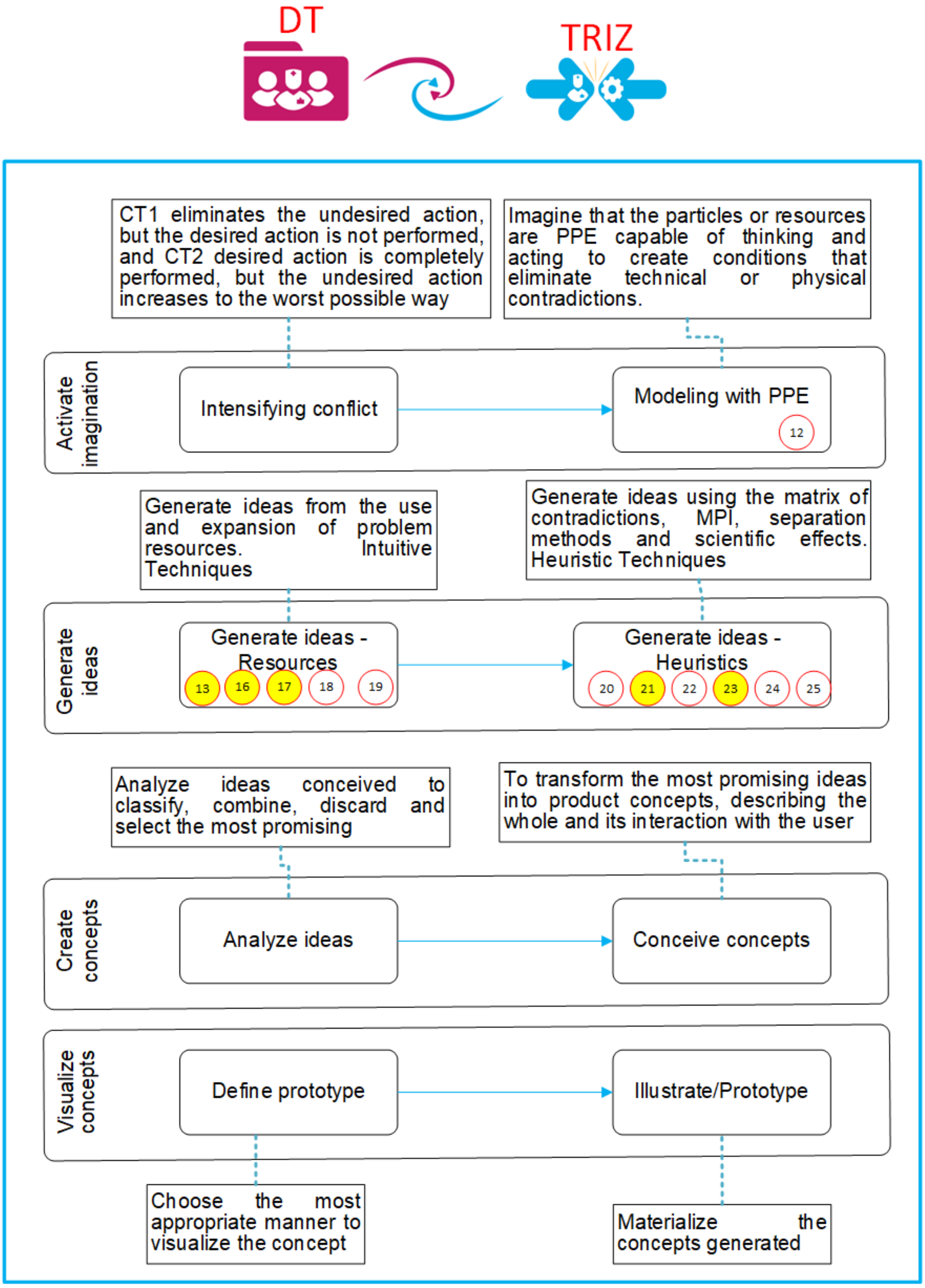
Generate ideas, this task is geared to generating solution ideas with user focus. When analyzing the ARIZ process shown in Appendix B, it can be noted that the solution of the problem is performed in several phases. In Phase 4 of ARIZ, solutions are proposed with emphasis on the problem resources, and in Phase 5, problem-solving strategies, used by inventors in the past, are used - heuristic techniques, such as standard solutions, separation methods, scientific effects, and in the ARIZ version of Marconi (1998) also uses the 40 inventive principles. The current proposal starts from this principle. Thus, activity 3.7 creates ideas from the use of resources, and later, from heuristic techniques.

Generate ideas - resources, apply the resources of the problem situation, consider residual resources of the processes, change two homogeneous substances by a heterogeneous one, change existing substances by vacuum, apply derived resources and introduce electric fields and new substances and fields. The generation of ideas is based on intuitive techniques, such as brainstorming, co-creation and prototyping as a form of synthesis, and as indicated in Figure 8.8 the Resource Analysis, TEs and IFR will support this generation, as they help to determine general direction of solution.

Generate ideas - heuristics, in the Understand phase an analysis was proposed and schematization of the problem, by determining technical or physical contradictions and were linked the parameters in contradiction with the engineering parameters of TRIZ, with this analysis, it is easy to propose solutions, by using the matrix of contradictions and 40 IP, or the methods of separation for physical contradictions. Other ways to approach generation is to use the 40 IPs independent of the Contradiction matrix, to use the 76 standard solutions from a SuFi analysis, or the use of Scientific effects.

Techniques do not need to be used in the sequence indicated in Figure 8.9, it will depend on the experience of the participants and the problem. In the literature, it is found how some TRIZ tools are little used, by predominating the use of the 40 IP and contradiction matrix (ILEVBARE; PROBERT; PHAAL, 2013; MOEHRLE, 2005). The generation of ideas with heuristic techniques could be supported by the indicated intuitive techniques. By pointing out that in the methodology synthesized in the current research, TRIZ principles and DT guidelines are a common thread, which maintains a notion of process in the integration of TRIZ and DT rather than using isolated techniques.

Figure 8.9 - Flow Ideate



Source: the author

Create concepts, with the conceived ideas, solution concepts are generated, initially by making an analysis of the generated ideas in order to create concepts about refined ideas. Firstly, Analyze ideas, a process of analysis of the conceived ideas is carried out in order to classify, to combine, to discard, and to select the most promising ideas. Remembering that an idea is the most embryonic form of a new product or service, sometimes consisting of a high-level vision of the solution envisaged for the problem, by which the idea may lead in one direction, but it is not yet explicit how to solve the problem. Then, Conceive concepts, from the previous analysis are structured solution concepts. Remembering that the concept is a well-defined form, by including a written and visual description, which contains the main characteristics and benefits for the user, along with a broad understanding of the technology required, or as indicated Ulrich; Eppinger; Yang (2019) a concept is a concise description of how the product will meet users´ needs, and it contains technology to be used, working principle, and product form.

Visualize concepts, DT guidelines indicate a highly iterative design process, through interactions of users with the solution. In this context, the visualization concept is key in the process, as a natural way of interacting and evaluating the solution with users. Firstly, define prototype, choose the most appropriate way of visualizing the concept in order to improve its understanding, to communicate with the development group and/or to interact and to evaluate the concept with the users of interest. It is convenient to remember that initially, it may be necessary to test many concepts, which is only viable with simple prototypes, techniques, such as sketches, storyboard, cardboard prototypes, and even additive manufacturing can help in the initial phases. Then, Illustrate/prototype, concepts are materialized, with the techniques defined.

8.2.3. Evaluate phase

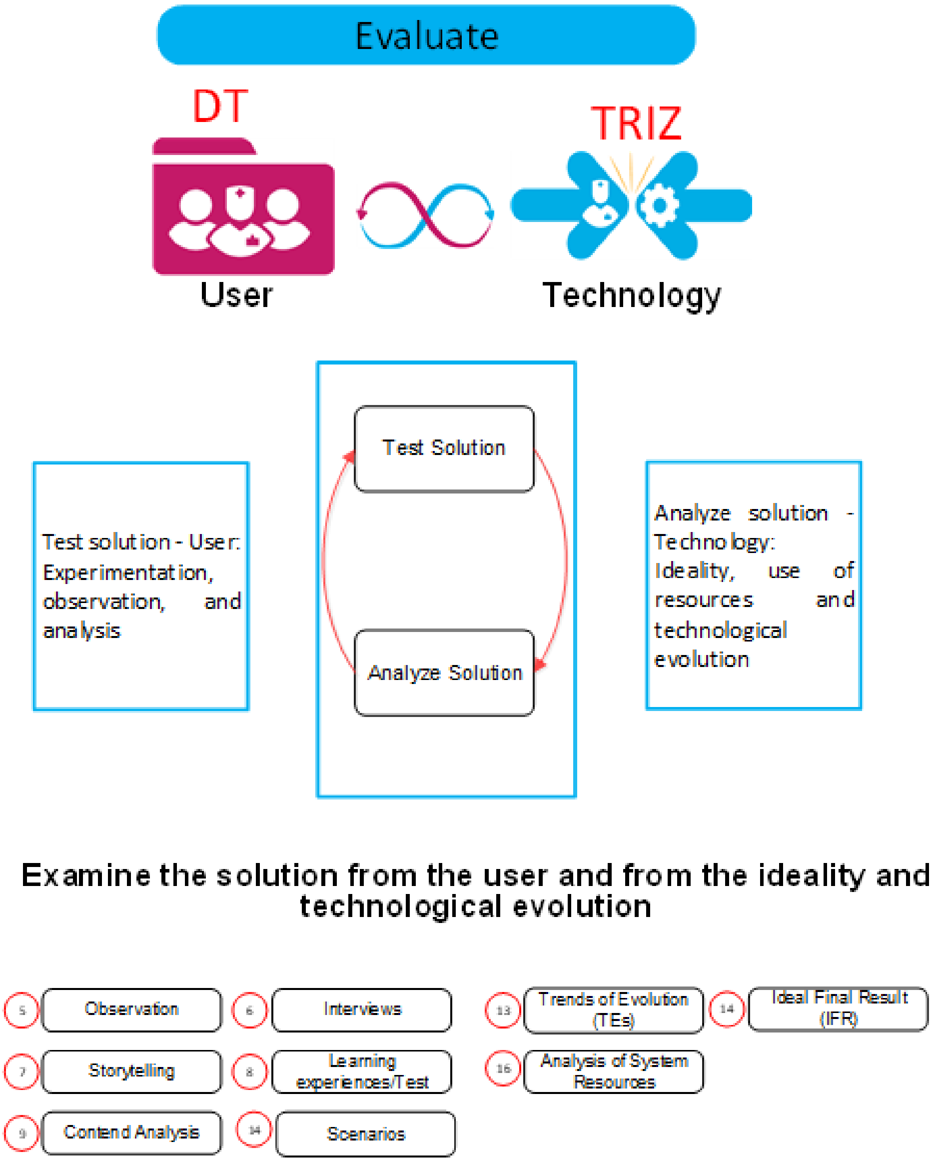
Chronologically, the Late FFE process indicates Understand, Ideate, and Evaluate. This last phase of the present proposal, the concepts generated from the understanding of the problem, from users and technology are initially evaluated, by using these two perspectives, by discerning the most promising solutions. In this way, by doing several cycles of the Spiral, from the model indicated in Figure 8.3, achieve a refinement, a combination, or a rejection of solution concepts, and move to Level 2 in which other important evaluation elements for the PHE sector, are incorporated, as can be seen in Table 8.1 - Late FFE activities.

In the Level 1 of the Spiral, in the Evaluate phase, the relation of TRIZ and DT is a complement by interdependence, as well as in the Understand phase. In this case, tests of the solution are carried out with users, and analysis is carried out from technology with separate tasks, by looking for a mutual complement in both perspectives. Thus, the tests with users provide human perceptions, but of a small group. On the other hand, the analysis of technology offers a wider perspective, but without human consideration. Remembering the concepts of Use, Usability, and Meaning discussed in numeral 7.2. For some projects, the team can have clarity at this level about the relevance of these concepts and direct the evaluation either from the user or from technology. However, keeping the generality for PHE, both drivers are relevant and at Level 1, it is expected that the project is still in a diffuse condition.

Figure 8.10 shows the representation of activity 3.8. In which the objective of the Level 1 phase is indicated, examine the solutions from user's perspective and the ideality and evolution of technology. Similarly, some techniques that can support this activity are indicated, from both TRIZ and DT. The Evaluate Solution activity is divided into two tasks. Test solution and Analyze solution, which are supported from DT and TRIZ methodologies, respectively. Figure 8.11 shows a detailed description of the activity.

Test solution, concepts are tested, to be evaluate from users' point of view - the desirable. The task is related to the human center, iterativity, and visualization. According to Figure 8.11, the task to test solution comprises Define how to approach user, Experiment solution, and Analyze results.

Figure 8.10 - Evaluate phase



Source: the author

Define how to approach user, is determined how to approach the user, which is influenced by the concept, the prototype, what is wanted to be tested, and the possibilities to interact with users. It is intended that initially, it will be easy and fast, similar to the first prototypes. However, as the solution is refined, by performing several turns of the Spiral, it is expected that prototypes will be more elaborate. Then, more specific, detailed and multi-user tests are carried out to verify the hypotheses, which are implicit in the solution.

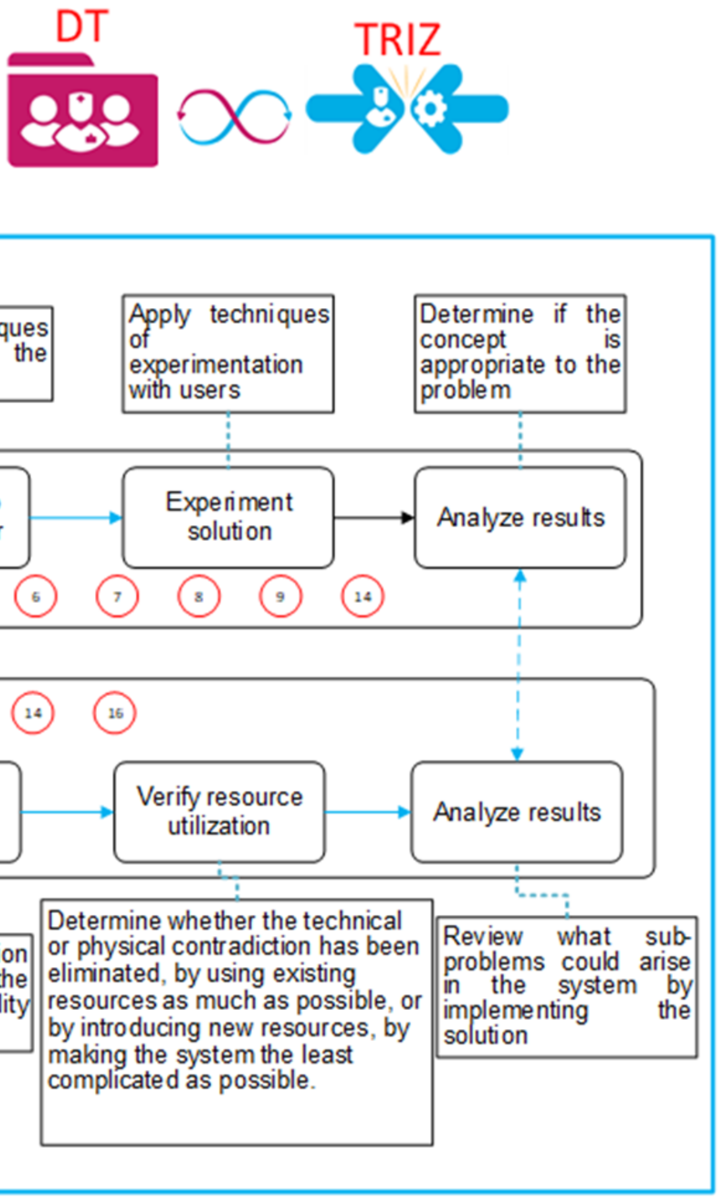
Experiment solution, once the approach with the user has been determined, the test is carried out, seeking to make it as natural and plural as possible. In this point, it is necessary to determine how the user assimilates the solution, which positive or negative situations it causes. The objective is not to convince the user to adopt a suitable solution. DT indicates that more than testing with users to show that the concept is right, on the contrary, testing to find defects in the concept, from potential users' perspective. The immersion techniques used to understand, users help in this task.

Analyze results, tests with users will provide different situations. An analysis of these results is performed in order to refine the proposed solutions. As in the Understand user, in Analyze results, the content analysis of social sciences could support this task. In the same way, DT provides a form of analysis of tests with the user, in a collaborative and iterative way. As consequence, the analysis can require new tests to verify conjecture, being this iterative mode of DT, a powerful instrument in the testing of the solution.

It is important to highlight how in activity 3.2 understand user, it was exposed how sometimes the best way of understanding the user is to try possible solutions. In this sense, the three phases Understand, Ideate, and Evaluate as a chronological sequence can be mixed in practice, particularly, in the first turns of the Spiral, and with projects with a high degree of innovation.

As shown in Figure 8.10, the Evaluate solution task complements Tests solution, with a technology-driven analysis. Also, Figure 8.10 indicates how the Test solution and Analyze solution tasks are interdependent. The latter is linked to the principles of TRIZ: Ideality, Evolution, and Resources. The objective is to analyze the solutions from the technology's ideality, and evolution, and the use of resources of the problem situation. This task is made up of Verify IFR and TEs, verify resource utilization, and Analyze results, as shown in Figure 8.11.

Figure 8.11 - Flowchart of Evaluation at Level1



Source: the author

Verify IFR and TEs, the purpose is to verify that the proposed solutions are in accordance with the direction of ideality and technological evolution. IFR and TEs techniques can be used. In activity 3.3, various forms of IFR were determined from the user's understanding. The proposed solutions are considered to determine whether these are in the direction of IFR. On the other hand, it was indicated, in the problem understanding and in the solution proposal, how TEs could indicate directions of the solution. In this way, the solutions are verified from the perspective of the TEs. The technique of Radar evolution can facilitate this verification (See Figure C.0.1).

Verify use of resources, the proposed solutions are verified with the analysis of resources, the following questions can be any help with this analysis: can the resources of the problem situation simplify the solution generated? Are current or modified resources used?

Analyze results, verify which sub-problems could arise in the system when implementing the solution. In addition to the previous results, analyze if the solution is in the direction of technological evolution, the ideality, and the use of resources. These three issues seem isolated. However, they are related.

The analysis of the results of the tests with users and the analysis of the solution with TRIZ need to have an interaction. By taking into account that in the PHE sector, the directions of both technology and user are relevant, each project is different, and in some cases, a driver may be more relevant.

8.2.4. FFE global model

In numeral 8.1, the Spiral concept of the model of current research was described, with levels 1 and 2. Likewise, the integration of both TRIZ and DT methodologies was detailed, in Understand, Ideate, and Evaluate phases. In each phase, the generality of the integration of TRIZ and DT was discussed, at the time that a possible pathway of this integration was detailed, based on the understanding of the process, TRIZ and DT methodologies, and the techniques applicable to each phase.

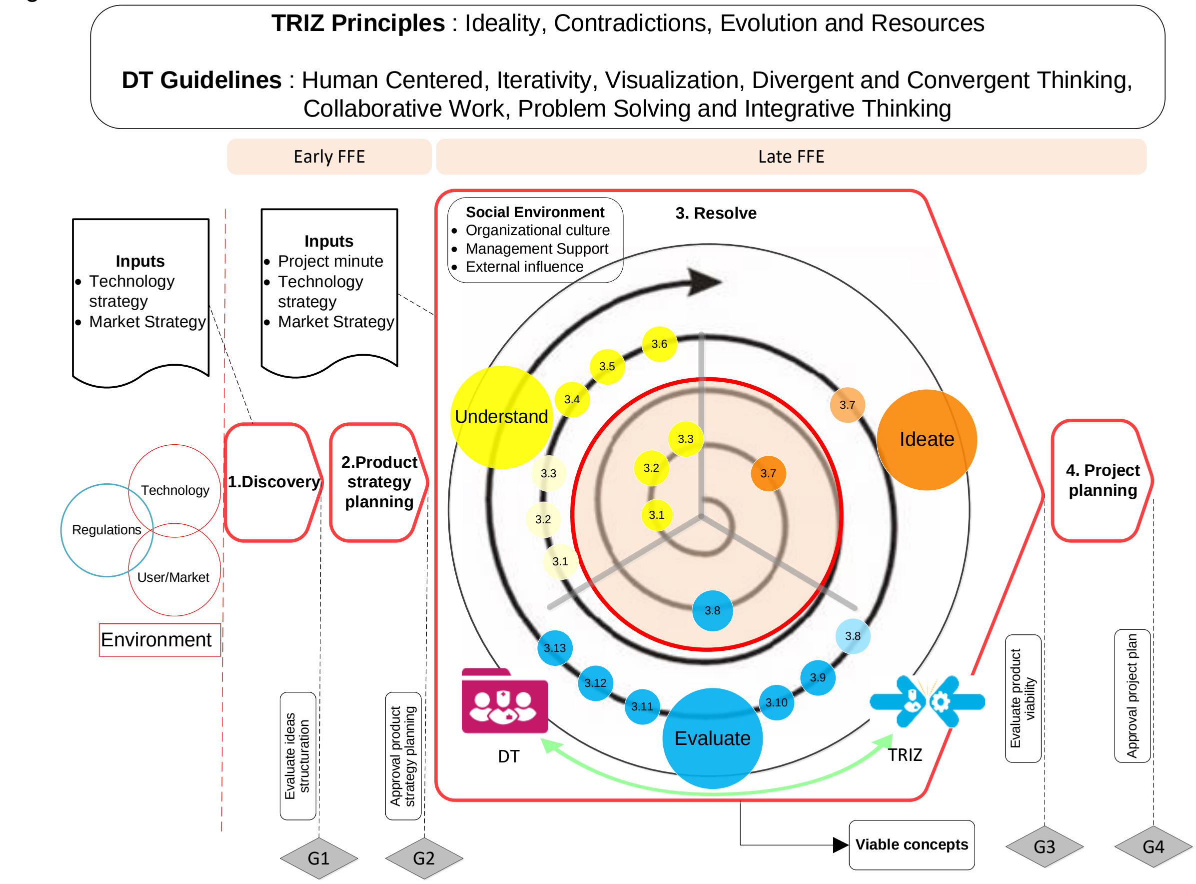
Similarly, it was indicated how the integration of TRIZ and DT in the Late FFE is different in the Understand, Ideate, and Evaluate phases at level 1, as shown in Figure 8.12. In the Understand and Evaluate phases, there is an interdependent relationship. In this way, each methodology performs a separate procedure in principle, in the sense that the respective activities could be carried out in different spaces, times, and by different teams. However, these activities are connected by the results so that the understanding of the problem or the evaluation of the results from TRIZ will serve as a reference point for the respective activities from DT, and vice versa.

Otherwise, in the Ideate phase, the relationship between TRIZ and DT is one of fusion. Thus, the creation of concepts is supported in both methodologies with a complement by integration in the same space, time, and team. Each methodology offers aspects from its foundations and techniques. Figure 8.12 indicates the relationship in the three phases of Understand, Ideate, and Evaluate, as well as the purpose of integration for the phase. Thus, in the Understand phase, the purpose is to conciliate the user's needs with the ideality and TEs; in the Ideate phase, the DT creation environment with the TRIZ solution direction are combined; and in the Evaluate phase, the solution from the user and from the ideality and technological evolution are examined. Also, in Figure 8.12, for each phase, the objectives, key activities, main outputs, and main techniques used by TRIZ and DT are indicated.

In Figure 8.12, it could be warned how Late FFE is inserted in the social environment. This point is important because the methodological proposal of the current research is for products with a high degree of innovation. In this context, organizational culture, management support, and external influence are relevant aspects to the process. This social environment is mentioned and highlighted. However, it is not a topic developed in this research.

Another point, indicated in Figure 8.12, is as technology, user/market, and regulations are relevant into environment to the PHE sector. Additionally, it is highlighted how FFE process is guided by the principles of TRIZ and DT guidelines, which is indicated in the upper part of Figure 8.12. Thus, we have a general process of FFE with TRIZ and DT methodologies inserted with three major phases, as it has been described before.

Figure 8.12 - Late FFE model overview



	Understand	Ideate	Evaluate
Integration TRIZ - DT	Interdependence Complement Environment ⇨ DT User ∞ TRIZ Technology Market: relevant issues Related regulations Technology: patents, products and related technologies User immersion Identifying patterns, needs, and expectations Technological Understanding Model problem Resources analysis	Fusion Complement DT User – TRIZ Technology Intuitive and collaborative environment Error tolerance Visualization with prototypes and scenarios Heuristic Ideation Techniques Resource utilization Connect with different technological fields	Interdependence Complement DT User ∞ TRIZ Technology Test User solution: Experimentation, observation, and analysis Analyze Technology solution: Ideality, resource use and technological evolution
Phase objective	Understanding the environment, User, and Technology to consolidate user needs with technological ideality and trend	Combine DT creation environment with TRIZ solution addressing to Create concepts	Evaluate the concepts of technology, user, regulations, and business
Main outputs	Perception of the problem from Users Understand the problem from Technology Understand the resources of the problem	Solution Ideas Solution concepts	Viable concepts
Key activities	3.1. Understand environment 3.2. Understand user 3.3 Understand technology 3.4 Validate market 3.5. Define requirements 3.6. Determine specifications	3.7. Create concept	3.8. Evaluate 3.9. Define risks 3.10. Classify product type 3.11. Determine tests 3.12. Analyze product economically and financially 3.13. Manage intellectual property
Main techniques	Stakeholder Map Customer Journey Persona Empathy Map Observation Interviews Storytelling Learning experiences/Test Contend Analysis System Operator Size, Time, Cost Operator Method of Smart Little People Trends of Evolution (TEs) Ideal Final Result (IFR) Contradiction Analysis 39 Engineering Parameters Analysis of System Resources Evolution potential radar	Brainstorming Co- creation Rapid Prototyping 40 Inventive Principles Separation Methods (SP) Contradiction Matrix Scientific Effects Trends of Evolution (TEs) 76 Inventive Standards 39 Engineering Parameters Analysis of System Resources Method of Smart Little People	Learning experiences/Test Observation Scenarios Interviews Storytelling Contend Analysis Ideal Final Result (IFR) Trends of Evolution (TEs) Analysis of System Resources Evolution potential radar

Source: the author

The Understand, Ideate and Evaluate phases have been described above, and as indicated in Figure 8.12, they are the operational part of the model. In this way, a flow of activities, tasks, and procedures was suggested for each of the phases, and some TRIZ and DT techniques were recommended. At this point, it is necessary to present a discussion between the generality of the proposed Late FFE model and the indicated flows of the phases, which constitute a pathway.

The proposed Late FFE model, which is indicated in Figure 8.12, shows a perspective of the overall process, how the phases are related, as well as the integration of TRIZ and DT methodologies. This is the essence of the proposal of the present research. On the other hand, by detailing each phase, the proposed flow is a way of interpreting the integration of TRIZ and DT methodologies. In this way, in order to achieve the objective of integrating both methodologies in Late FFE, other techniques, or forms of flow can be used. For instance, in the Understand phase, the schematization of the problem is indicated, and it is suggested to schematize the contradiction model. However, it was indicated in Chapter 5, that TRIZ proposes several ways of model or schematize the problem: Contradictions model, minimum technical system, and substances and fields model. Also, it is possible to use contradictions to generate solutions without making a schematization of the problem.

In the same way, in the Ideate phase, consequent on the scheme of contradictions, it was proposed to use the matrix of contradictions and the 40 IP, to generate solutions. Another way of proceeding could be to model the problem with substance and field and use the 76 standard solutions. Similarly, DT offers various techniques and ways of proceeding, applicable in the Understand, Ideate, and Evaluate phases.

To sum up, the model proposed in this research which is represented in Figure 8.12 at the operative level could be carried out in various ways. The proposed flow is one way of making the model operational. However, it is crucial not to lose the generality of the process, by applying isolated techniques, or by neglecting the TRIZ or the DT. The power of the model is based on complementing both methodologies, in a general Spiral process. The Late FFE model proposed integrated TRIZ and DT methodologies, is named by the author as DTRIZ methodology. Thus, during the validation the terms DTRIZ methodology or Late FFE model will be used, depending of context.

9. PILOT PROJECT

Validation of the late FFE model was realized first with a pilot project, and then four applications of the model were carried out in the context of companies in the PHE sector. The pilot allowed to understand and adjust the process flow of the proposed late FFE model - DTRIZ methodology. In addition, this example was used to illustrate the application of the model and adjust the training material used with the companies.

The authors (BLESSING; CHAKRABARTI, 2009) indicate how validation or SD II, (See Figure 2.3), can be initial or comprehensive. Initial validation is based on applications of the methodology, and the comprehensive validation is based on the desired results (success criteria). The present research is based on a high degree of innovation. The success criteria are to develop products in line of disruption, that customers require and desire, with high aggregate value, that can have higher margins, and generate barriers for the market competition. A validation of success criteria would take years. The validation will be of an initial type, in which the emphasis is on the process and the results are measurable criteria that are directly related to the success criteria, as indicated by (BLESSING; CHAKRABARTI, 2009) "To identify whether the Actual Support can be used for the task for which it is intended and has the expected effect on the Key Factors".

The process refers to how the proposed model was applied to the different problems indicated. On the other hand, the measurable criteria directly are related to the success criteria at this level of the process are: ideas and concepts. These are evaluated in terms of: quantity - total number, creative level - appropriateness and novelty - and technological breadth - exploration of various technological areas. Table 9.1 shows the aspects to be measured separated into process and results (measurable criteria).

Additionally, (BLESSING; CHAKRABARTI, 2009) indicates how the focus of the validation should be defined, by taking into account that the results are influenced by aspects, such as the proposed model may not be useful, incorrect hypotheses, possible failures in the introduction-training, competencies, and beliefs of the team that are not in consonance with the model, insufficient resources, and inadequate environment. Validation - the Pilot Project and the four subsequent applications, focused on verifying the model and its underlying assumptions. The other indicated aspects were not the focus of attention, although they are mentioned. It should be noted that the validation focused on level 1 of the spiral of the proposed late FFE model, see Figure 8.12, because it is the most diffuse stage of the project, in which the problem is extremely unstructured and complex. At the same time, it is at this stage that the ideas and concepts that will guide the subsequent process are conceived. For this reason, it is at level 1 of the spiral where the integration of TRIZ and DT methodologies have the potential to support the Late FFE, from the technology and user drivers respectively, which, as previously explained, are determinant in the PHE sector.

Table 9.1 - Summary of aspects to be measured in the validation

		Category	#	Variable
Process variables	Aspects of how projects are carried out.	Understand	1	Understanding the problem from the user's point of view
			2	Understanding the problem from technology
		Ideate	3	Process of idea generation
			4	Process of concept generation
		Evaluate	5	Ideas evaluation
			6	Concept evaluation
		Overall process (Links)	7	Spiral process
			8	TRIZ and DT complement
Result variables	Tangible process results	Ideas	9	Number of ideas generated
			10	Creative level of ideas
			11	Technological breadth of ideas
		Concepts	12	Number of concepts conceived
			13	Creative level of concepts
			14	Technological breadth of concepts

Source: the author

The pilot project was conducted in an engineering company and the author worked as a user of the Late FFE model. The documentation of the implementation of the pilot project is completed after its execution, which implies the difficulty of documenting a non-linear process - Spiral, in a linear way due to the limitations of the "paper." In this way, the first two and most defined turns of the spiral will be presented graphically, and, then, the sequence of the three phases of Understand, Ideate, and Evaluate will be developed in a linear way.

Hospital and home care beds are required by regulation to have bed rails, which are one of the main safety devices for these beds. There is a tendency to improve the safety for different users and to utilize these bed rails with complementary functions.

The project aims to explore new possibilities for the bed railing-mechanism system, it is intended to provide benefits to different stakeholders. The rail is the upper part that acts as a barrier to prevent patient falls, and the mechanism allows the fixation and movements of the rail, which is a determinant device in its safety and effectiveness, (See Figure 9.1).

Figure 9.1 - Bed rail-mechanism system

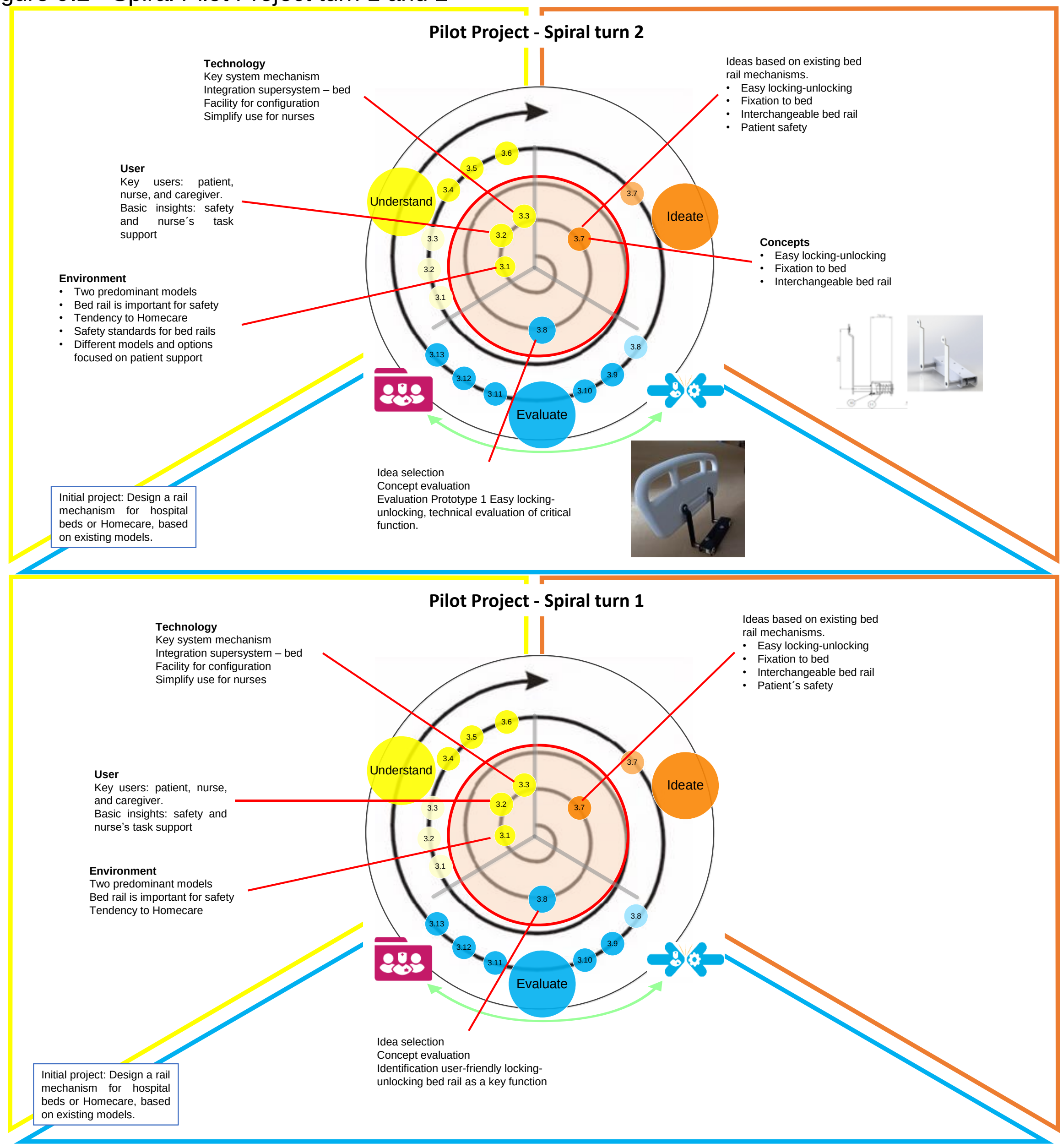
Source modified: (METAHOSPITALAR, 2019)

In Chapter 8, Figure 8.12 and Table 8.1 respectively describe the Late FFE model and explain the different activities indicated in the Spiral. The activities of level 1 of the spiral that are the focus of this application are 3.1. Understand environment, 3.2. Understand user, 3.3 Understand technology, 3.7. Create concept, and 3.8. Evaluate, which are indicated in Figure 9.2, and Figure 9.3.

The first three turns of the spiral are shown graphically in Figure 9.2,and Figure 9.3. In addition, an indication is presented of how the project can proceed from the fourth turn of the spiral onwards. When the concepts are considered mature, it moves to level two of the Spiral, in which other elements are integrated into the Understand and Evaluate phases.

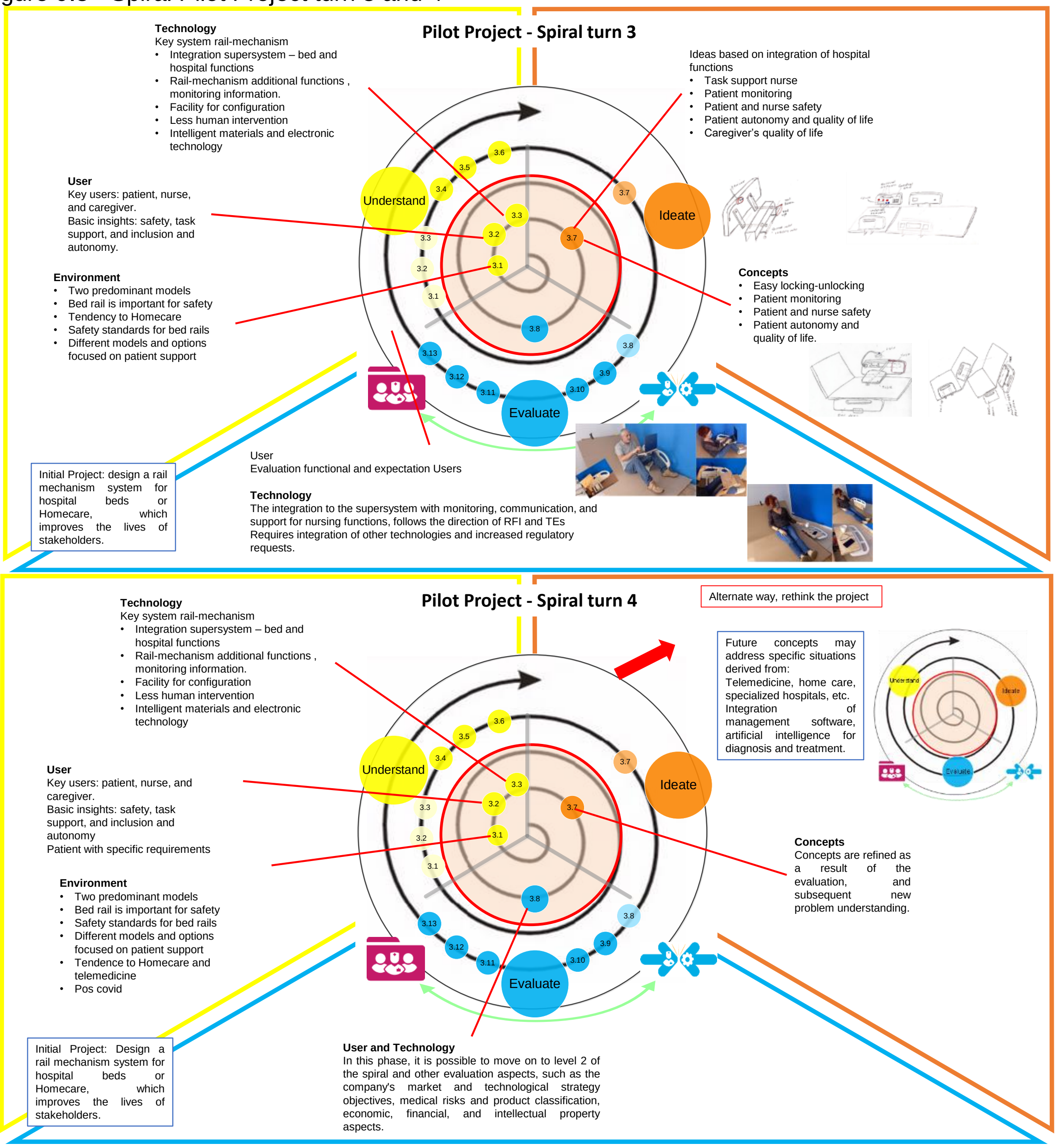
The following sections describe the process in detail, by keeping a parallel with Chapter 8, which describes the Late FFE model.

Figure 9.2 - Spiral Pilot Project turn 1 and 2



Source: the author

Figure 9.3 - Spiral Pilot Project turn 3 and 4

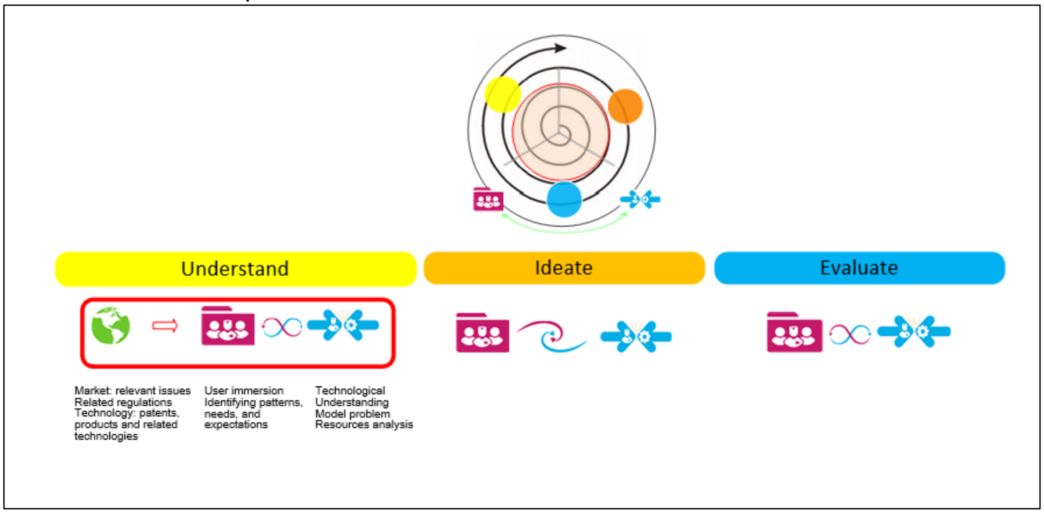


Source: the author

9.1. UNDERSTAND PHASE

The objective phase is Understanding the environment, User, and Technology to consolidate user´s needs with technological ideality and trend. Figure 9.4 shows in simplified form the Understand phase inside the Late FFE process. As indicated in Chapter 8, the activities to understand the user and the technology complement each other by interdependence, i.e., the progress of one activity determines the other. This concept is illustrated in Figure 9.2,and Figure 9.3,which summarize the first turns of the spiral.

Figure 9.4 - Understand phase



Source: the author

The activity of Understand environment provides an understanding of current issues surrounding the problem, and can be done gradually, so that as the spiral progresses, more detailed knowledge of specific topics, such as regulations, patents, technologies, etc., is required.

The format shown in Table 9.2 serves as a guideline for the Understand Environment activity. It is not about filling all the boxes. It is a guideline, which guides the main points to consider. For the specific project, the team determines, which information is most relevant to the project progress. The team could determine to start with Understand User and/or Understand Technology.

Table 9.2 - Study of the environment format

<table>
<tr><td>Study of the Environment</td><td>Project: Bed rail</td><td>Date:</td></tr>
<tr><td>Demographic: population growth, birth/mortality, population density, age distribution.</td><td colspan="2">Affordable: Growth, economic perspectives.</td></tr>
<tr><td>Regulatory: relevant laws and regulations locally and internationally, recent changes, and trends in regulations.

IEC 60601-1-52 standard, which deals with hospital beds, has a point on bed rails
NF standard in 1970, concerning adjustable beds for the disabled, has some points on bed rails

Studies of accidents caused by bed rails in FDA and French hospital beds</td><td colspan="2">Environmental: environmental, industry impact, novelties.</td></tr>
<tr><td>Social: Lifestyle, values, and desires, income distribution, access to services.</td><td colspan="2">Technological: patents, commercial products at the local and international levels, related technological developments.
It was decided to start exploring similar Products</td></tr>
<tr><td colspan="3">Conclusions:
The bed rail system mechanism is a safety element in the bed, safety standards and studies about accidents caused by these were found. There are different models in the market for hospital beds and/or homecare beds. Some models have functions, such as support to help lift the person, place objects, the bed rail can be extended, and easy to install.</td></tr>
</table>

Source: the author

In Table 9.2 it was decided to start exploring similar products, Table 9.3 shows the checked products.

Table 9.3 - Similar bed rail products

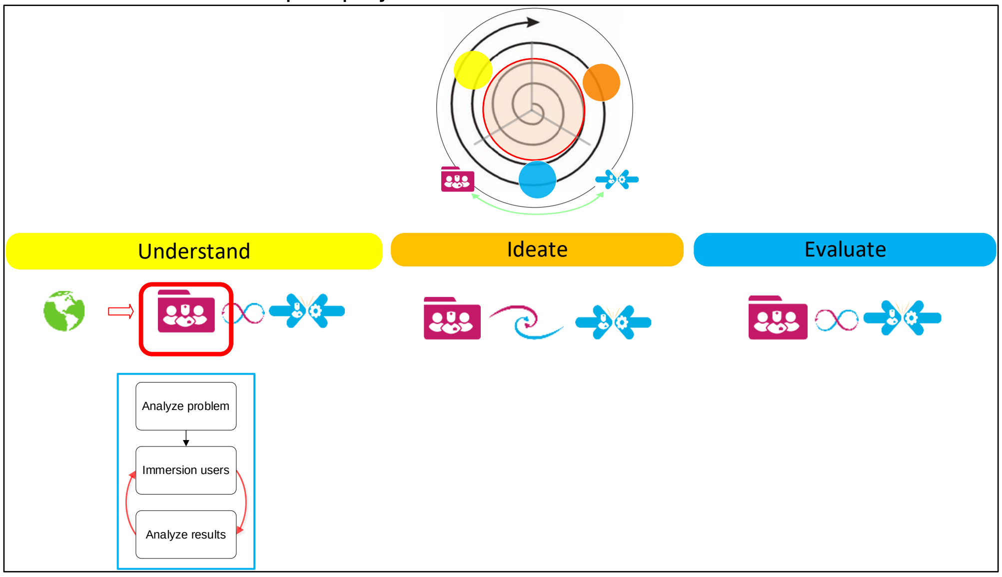
Annotations	Product	Annotations	Product
Bed rail with adjustable length		Bed rail with exterior object holder	
Bed rail with easy installation system for home beds and extendable length.		Single rail movement mechanism	
Bed rail system mechanism with outward movement of the bed		Bed rail system mechanism, with movement parallel to the bed	
Easy-to-use, single-section guardrail, which does not accommodate the movements of the bed backrest.		Bed rails that provide support to the patient to facilitate movement	 

Source: the author

9.1.1. Understand user

Understand the problem from the perspective of those Users, who are the relevant stakeholders, their relationships, needs, and expectations. Figure 9.5 indicates how this activity is positioned in the overall late FFE model and shows the flow of the tasks.

Figure 9.5 - Understand User on pilot project



Source: the author

First, an analysis of the problem was performed, which is summarized in Table 9.4, and then, the immersion was performed with the key users determined in the analysis, patient, nurse and caregivers, as shown in Table 9.5.

Table 9.4 - Analyze problem on pilot project

	Analyze Problem
Determine problem/opportunity	To explore new possibilities for the Homecare or hospital bed rail-mechanism system, which improves the life of the users, and it allows the manufacturer to develop value added products.
Stakeholders Analysis	Analysis with Actors' Map technique. Conclusions: Key users: patient, nurse, and caregiver. The bed-patient needs to perform functions, such as going to the bathroom, eating, reading and the nurse or caregiver needs to perform procedures, such as monitoring, giving medications, toileting, therapies, company and the like.
Focus	Representation techniques will not be used to engage with key stakeholders. Once the key users have been identified, an immersion will be conducted with these users, as explained in Table 9.5, to obtain a triangulation of results.

Source: the author

Table 9.5 - Immersion with users on pilot project

Immersion with users	
Determine how to approach users.	Because of the difficulty of directly observing patients and nurses in the problem context, it was initially decided to explore other ways of engaging them. • YouTube videos showing the activity of nurses; • Amazon's reviews of similar products – Users; • Nonstructured interview with caregivers of patients with special needs, which was conducted based on the previous results.
Approach user	YouTube Vídeos https://www.youtube.com/watch?v=bEy16Ix0Xy4 https://www.youtube.com/watch?v=hGiLZ_thNdA https://www.youtube.com/watch?v=3GzBKoCK3Ik https://www.youtube.com/watch?v=yUhojqm1N2Y Reviews from Amazon users, search words: Electrical bed, Hospital bed, Home Care bed, Hospital rail bed. Two nonstructured interview with caregivers of patients with special needs, the first is a middle-aged adult caregiver who cares for his sister, a middle-aged adult with mental health problems, and the second is an older adult who cares for other older adults with mobility problems.

Source: the author

Subsequently to the immersion with users, a content analysis was performed to determine patterns and later insights, as described in Table 9.6. The initial part of the table explains the analysis of user comments of two similar products in the Amazon store; initially a word cloud analysis was performed and then a content analysis. Additionally, Table 9.6 shows the consolidated results of the immersion approaches with users, separated by nurse, patient and caregiver.

Table 9.6 - Analyze Results on pilot project

Analyze Results		
	Product	Content analysis results
Reviews from Amazon users	Product 1 2 reviews	Ease of installation
	Product 2 290 reviews 230 very positive reviews. They were organized by date. 40 reviews were taken randomly out of 230 very positive ones.	**Word cloud analysis:** Useful Easy Strong **Content analysis:** Ease of installation Security Easy to use Fit any bed Generate patient protection Fear of failure Protect a loved one Protect the elderly Obese people Make it easier for the patient to get out of bed Hold on while out of bed Be sturdy
	17 Very negative reviews.	**Content analysis:** Unstable Manufacturing problems caused accident

Analyze Results	
	Quality problems Not very sturdy Not very resistant Not very safe
	Despite having many reviews of product #2, it reached a saturation from very positive and negative reviews. Several users are people with mobility problems, or elderly, other reviews are from users' children or family members.
Determine patterns	**Nurses** They perform a variety of patient procedures They use various devices They are always very busy They must clean their hands to do procedures, after touching objects They have a lot of contact with the patient They are very familiar with operating devices
	Patients They can be autonomous or non-autonomous They require safety They require ease of getting out of bed Bed rail can be a support when they are out of bed Difficult for them to perform their own life routines
	Caregivers They attend to patients' needs Perform procedures that require physical effort, such as lifting or laying the patient down They are concerned about patients' safety Difficult for them to perform their own life routines
Compile results - Insights	**Nurse** Facilitate the nurse's work To provide safety in the work Operate the mechanism without the nurse's hands touching the device **Patient** Safety, protection, stability Ease of use Support to facilitate getting out of bed and being out of bed Can be for the elderly or obese people to achieve other activities such as work or entertainment **Caregiver** Patients' safety, protection of loved ones Assisting in their work: monitoring, movements, administration of medications Very strong bed rail Possibility of increasing the standard height of the bed rail Helping to do other tasks while caring for the patient Have free time
Patients, caregivers and nurses expect the bed rails to be stable (strong and firm) and safety, reliable, easy to use, as well as help to make their lives easier. Patients should be able to get out of bed and carry out daily activities. For the companion, to help in the patient care tasks, to have free time for his/her activities and for the nurse, to help in the daily patient care tasks. Additionally, the bed rail to be promote inclusion and autonomy for patients and caregivers. The mechanism is operated by the patient when he is an adult and in full use of his faculties. In some conditions, such as children, elderly with mental problems or critical health conditions, the mechanism should not be operated by the patient.	

Source: the author

The analysis of the problem from the user's point of view allows to generate solution ideas, as recommended in chapter 8, these should be registered to be integrated in the ideation sections. The ideas that emerged from the user analysis are:

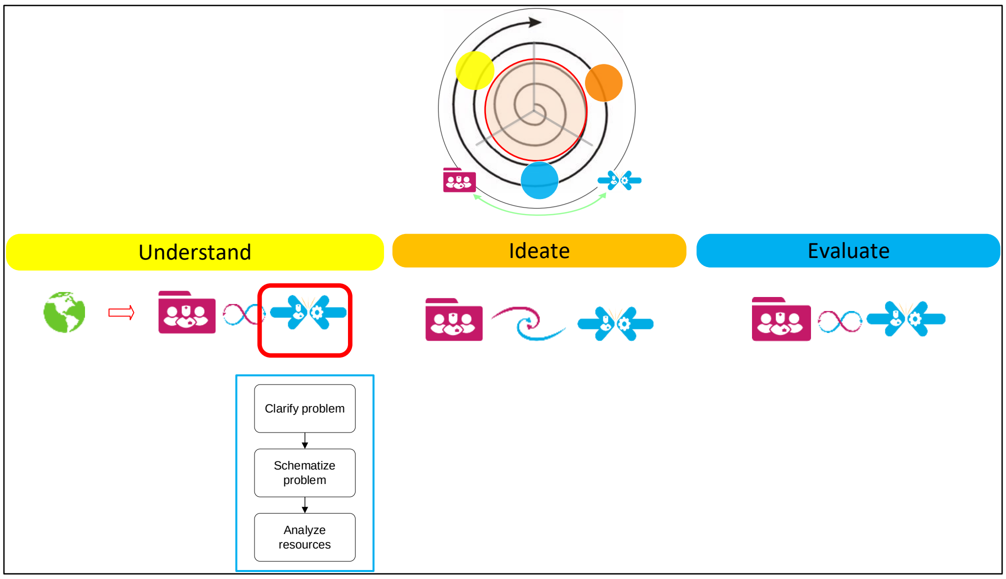
1) Mechanism, which can be hands-off operated;
2) Bed rail mechanism, which assists in the nurse's duties;

3) Bed rail mechanism, which monitors the patient;
4) Bed rail I mechanism that helps to support the patient to get up and even to provide motor power;
5) Bed rail mechanism, assisting the patient in life activities.

9.1.2. Understand technology

Understand the problem from the technology, the purpose, technological trend, the ideality and the resources of the problem situation. Figure 9.6 indicates how this activity is positioned in the overall late FFE model, and it shows the flow of the tasks, and Table 9.7, 9.9 and 9.12 indicate the sequence of the tasks that make up the activity: Clarify problem, Schematize problem, and Analysis of Resources.

Figure 9.6 - Understand Technology



Source: the author

Table 9.7 - Clarify problem

Clarify problem	
Define problem	Define the purpose: the desired result of the system, its outputs or effects for the object. The starting point is the problem/opportunity defined in Understand User and the subsequent analysis. Hospital bed rails are required for patient safety and used for other simple functions. From the user analysis is perceived that the key users: patient, nurse and caregiver in the context of patient care, have different needs in their life routines. The project is aimed at improving the life of these users with new proposals of the rail system mechanism.
Describe problem	Development of a bed rails-mechanism, which must be easy to use, safety, stable, and facilitate personal and work activities of patients, nurses, and caregivers, and advocating inclusion and autonomy for patients and caregivers.
Expand problem perspective	System Operator and TEs techniques were used in order to understand the problem from the technological point of view.
Conclusions about clarifying the problem	
By analyzing the SO and TEs, it is possible to determine the fields of innovation of the rail mechanism system such as noise elimination, integration with bed or hospital functions, no dependence on the use of hands to operate, setting options, use of intelligent materials, use of color, fluid or field-based systems, reduction of human intervention, increasing controllability, increasing transparence, and increasing asymmetry.	

Source: the author

The conclusions of the Clarify problem task indicated in Table 9.7, are supported by techniques for expanding the problem perspective, System Operator and - 31 Mann's TEs, which are explained in Chapter 5 - Table 5.2 and Appendix C respectively. Tables 9.8 and 9.9 indicate the application of both techniques.

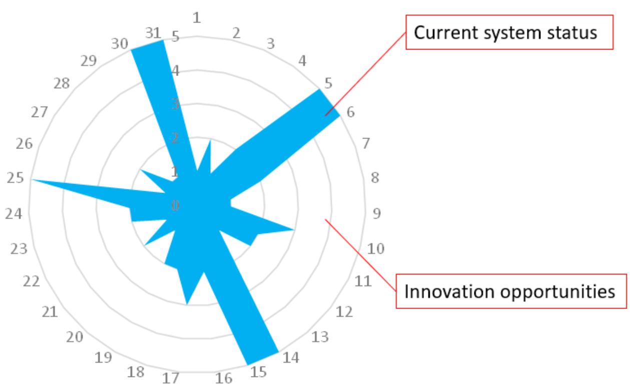
The 31 Mann's TEs were used because, as explained in Appendix C, in each TE the maximum potential of evolution is shown, which facilitates the evaluation of technology. Table 9.9 shows the evaluation columns of TEs, the blue color indicates the current status, and the yellow color indicates the potential of evolution of each TE. Some TEs could not be evaluated and are shown in white in Table 9.9, and Figure 9.7, which shows the 31 Mann's TEs in radar form.

Table 9.8 - System Operator application

Systems Operator			
	Past	**Present**	**Future**
Supersystem	Home-type bed with minor modifications Very difficult to operate: nurses performed all movements manually Few bed movements options	Bed Bed rail sets are manufactured with fixed specifications Institutions can request some functions Bed has many electrical and mechanical movements and functions	Integration of the bed to the supersystem: monitoring, control, and some actions on the patient Easy reconfiguration for specific institutions or patient conditions Mass customization Intelligent materials
System	Metal bed rails with very noisy mechanisms Difficult to operate Many parts Difficult to clean Cannot be installed on existing beds Caused accidents	Bed rail mechanism. Manually operated Makes noise when operated Requires two hands No adjustments or options Unlocking is easy from outside the bed, difficult from in bed can be installed on some existing bed types Accidents occur	Silent mechanism Easy to operate: one hand, or without direct contact Secure and reliable, complies with standards Aesthetic Few moving parts in sight Options and/or adjustments Assists the nurse in caring for or treating the patient
Subsystem	Position lock A lot of effort Difficult to maintain High maintenance Insecure Metal fabrication	Position lock Manually operated Mechanical system Makes noise Requires little effort Requires the use of both hands Metal and plastic manufacturing Other subsystems Bed rail Fastening system Kinematic bars	Position lock Integrates with bed functions Facilitates functions Replaceable Configurable and intelligent Effortless, no touching Hands-free Quiet Manufactured with intelligent materials

Source: the author

Figure 9.7 - Evolution potential radar 31 Mann's TEs applied to the problem



Source: the author based on (ISHI; CARVALHO, 2015)

Table 9.9 - 31 Mann's TEs applied to the problem

31 Mann's TEs applied to the problem		
	Evolution trend	Evolution potential
1	Smart materials	1) Passive material, 2) One-way adaptive material, 3) Two-way adaptive material, 4) Fully adaptive material
2	Space segmentation	1) Monolithic solid, 2) Hollow structure, 3) Structure with multiple hollows, 4) Capillary/porous structure, 5) Porous structure with active elements
3	Surface segmentation	1) Smooth surface, 2) Surface with rib protrusions, 3) 3D roughened surface, 4) Roughened surface with active pores
4	Object segmentation	1) Monolithic solid, 2) Segmented solid, 3) Particulate solid, 4) Fluid, 5) Segmented fluid, 6) Gas, 7) Plasma, 8) Field, 9) Vacuum
5	Macro-nano evolution	Continuous, smaller each time (1...10)
6	Webs and fibers	1) Homogeneous sheet structure, 2) 2D regular mesh structure, 3) 3D fiber, alignment according to load conditions, 4) Addition of active elements
7	Decreasing density	Continuous, smaller each time (1...10)
8	Increasing asymmetry	1)Symmetrical system, 2) Partial asymmetry, 3) Matched asymmetry
9	Boundary breakdown	1) Many boundaries, 2) Few boundaries, 3) No boundaries
10	Geometric evolution (linear)	1) Point, 2) 1D line, 3) 2D plane, 4) 3D surface
11	Geometric evolution (volumetric)	1) Planar structure, 2) 2D structure, 3) Axisymmetric structure, 4) Fully 3D structure
12	Dynamization	1) Immobile system, 2) Jointed system, 3) Fully flexible system, 4) Fluid or pneumatic system, 5) Field-based system
13	Action coordination	1) Non coordinated action, 2) Partially coordinated action, 3) Fully coordinated action, 4) Different actions during intervals
14	Rhythm coordination	1) Continuous action, 2) Periodic action, 3) Use of resonance, 4) Travelling wave
15	Matching to external non-linearities	1) Linear consideration of system, 2) Partial accounting of non-linearities, 3) Full accommodation of non-linearities
16	Mono-bi-poly (similar)	1) Mono-system, 2) Bi-system, 3) Tri-system, 4) Poly-system.
17	Mono-bi-poly (various)	1) Mono-system, 2) Bi-system, 3) Tri-system, 4) Poly-system.
18	Mono-bi-poly (increasing differences)	1) Similar components, 2) Components with biased characteristics, 3) Component plus negative component, 4) Different components
19	Reduced damping	1) Heavy damping, 2) Critical damping, 3) Light damping, 4) Un-damped
20	Increasing use of senses	1) 1 sense, 2) 2 senses, 3) 3 senses, 4) 4 senses, 5) 5 senses
21	Increasing use of color	1) No use of color, 2) Binary use of color, 3) Use of visible spectrum, 4) Full spectrum use of color
22	Increasing transparency	1) Opaque construction, 2) Partially transparent, 3) Transparent, 4) Active transparent elements
23	Customer purchase focus	1) Performance, 2) Reliability, 3) Convenience, 4) Price
24	Market evolution	1) Commodity, 2) Product, 3) Service, 4) Experience, 5) Transformation
25	Design point	Design optimized: 1) For single operating point, 2) At two operating points, 3) At several discrete operating points, 4) Continuously
26	Degrees of freedom	1) 1 Degree of Freedom (DOF), 2) 2 DOF, 3) 3 DOF, 4) 4 DOF, 5) 5 DOF, 6) 6 DOF
27	Trimming	1) Complex system, 2) Elimination of non-key components, 3) Elimination of non-key sub-systems, 4) Trimmed system
28	Controllability	1) Direct control, 2) Action through intermediary, 3) Addition of feedback, 4) Intelligent feedback
29	Reducing human involvement	1) Human, 2) Human and tool, 3) Human and powered tool, 4) Human and semi-automated tool, 5) Human and automated tool, 6) Automated tool
30	Design methodology	1) Cut & try, 2) Steady state design, 3) Transient effects included, 4) Slow degradation effects included, 5) Cross-coupling effects, 6) Design by Murphy
31	Reducing number of energy conversions	1) 3 conversions, 2) 2 conversions, 3) 1 conversion, 4) No conversions

blue color current system status, yellow color innovation opportunities.

Source: the author based on (ISHI; CARVALHO, 2015)

To schematize the problem TRIZ proposes several ways as it was indicated in numeral 5.3. It was chosen to use the Contradiction Model, which is based on understanding the problem from the contradictions of technical parameters, which are opposed to achieving a higher level of Ideality than the present. From Understanding User and technology, several forms of Ideal Final Result (IFR) are presented, by seeking to define IFR in terms of something that is desired as opposed to something that is not desired. It should be noted that the Ideality in this approach, is derived from the previous analysis of the technology and users. Table 9.10 summarizes the process of establishing different forms of IFR.

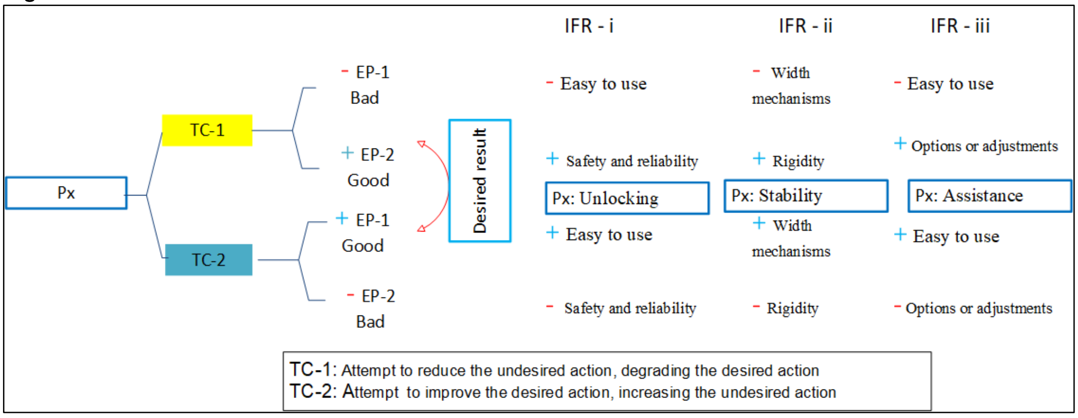
Table 9.10 - Process of IFR on pilot project

Schematize problem	
Problem: The bed rails-mechanism must be easy to use, safety, stable, and they must facilitate personal and work activities of patients, nurses and caregivers. advocating inclusion and autonomy for patients and caregivers.	
Benefits	
Primary	Secondary
Patient's safety and protection Easy to operate Assisting patients' life activities Assisting caregivers' life and work activities Assists in the work of nurses	Quiet operation Simple construction Options or adjustments Help lift the patient
Prejudice	
Primary	Secondary
Complex to use Not very rigid Very bulky Unlockable without requiring it	Wide bulky mechanism Complicated to operate
Ideal Final Result: i. The bed rail-mechanism must be 100 % secure and reliable, remain locked when not activated and unlock without any action when desired; ii. The bed rail-mechanism shall not add any width to the bed and shall support infinite weight of any user; iii. The bed rail-mechanism can assist the patient, caregiver, and nurse in their activities, and it is easy to use.	
Achievable result: i. The bed rail -mechanism must be very secure and reliable. It must remain locked when not activated and be easy to operate, desired unlocking; ii. The bed rail -mechanism must be fine so as not to add width to the bed and be very rigid to support the weight of users, including obese users; iii. The bed rail -mechanism should serve to make life easier for patients, caregivers and nurses, and be easy to operate; iv. The bed rail -mechanism should be easy to operate in order to perform the basic function without instructions, and several options and/or adjustments should be offered to make life easier for caregivers or patients; v. The bed rail -mechanism should be simple and inexpensive and configurable to be customized; vi. The bed rail -mechanism should be accurate in its operation and easy to snap into place.	

Source: the author

From the different IFR, the Evaluation Parameters (EP) are determined, which oppose the IFR. Technical Contradictions (TC), TC-1 and TC-2 are schematized, TC-1 try to reduce the undesired action, by degrading the desired action and TC-2 try to improve the desired action, by increasing the undesired action. Then, the EPs are related to the TRIZ Engineering Parameters and finally, Inventive Principles proposed by the contradictions matrix to solve these contradictions are identified. These inventive principles will be used in the Ideate phase. Figure 9.8 shows the schematization of the contradictions, by using the first three IFR. The method to schematize the contradictions in TRIZ was explained in numeral 5.1.1. Table 9.11 shows EP, which are in conflict to achieve the IFR, the TRIZ Engineering Parameters that are related (See appendix F) and the Inventive Principles that can be used (See appendix E). Additionally, Appendix G indicates how to use the Contradiction Matrix to determine the IPs.

Figure 9.8 - Technical contradictions scheme



Source: the author

Table 9.11 - IFR applied to pilot project

IFR		EP-1	EP-2
IFR- i	Px Unlocking	Safety and reliability	Easy to use
	Engineering Parameters	27 x 33, 13 x 33	
	Inventive Principles	27, 17, 40, 8, 32, 35, 40, 30	
IFR -ii	Px Stability	Width mechanisms	Rigidity
	Engineering Parameters	4 x 14	
	Inventive Principles	15, 14, 28, 26	
IFR -iii	Px Assistance	Easy to use	Options or adjustments
	Engineering Parameters	33 x35	
	Inventive Principles	15, 34, 1, 16	

IFR: Ideal Final Result
EP: Evaluation Parameters
Px: common parameter, which links EP-1 and EP .2

Source: the author

Table 9.12 - Analysis of resources IFR applied to pilot project

Analysis of Resources	
	Resource identified
Substance	Bed rail, mechanisms, bed, room, patient, nurse, and caregiver.
Field	Gravity, electricity, WIFI, cellular signal, patient strength, patient strength, patient heat, patient physical movements, patient voice, nurse´s strength (hands, feet, body) nurse voice, electrical bed movements.
Time	Unoccupied bed; Sleeping patient: rail up; Operation of the mechanism: t1 unlock rail, t2 lower rail, t3 perform some operation, t4 rail up and lock (automatic).

Source: the author

As with user understanding, in the process of Understanding technology, ideas for solutions are spontaneously generated and recorded:

1) Offer settings or set up options
2) Integrate functions, such as patient monitoring, patient exit detection
3) Actively assists patient’s movements

4) Use smart materials to perform functions
5) Mechanism, which climbs autonomously and self-locks
6) Use of voice to unlock and/or to lock
7) Use of another body part different from the hands to unlock and/or to lock
8) Mechanism generates noise when going down to indicate patient's exit
9) Semi-automatic motorized mechanisms with the possibility of feedback
10) Mechanism works without human intervention
11) Use of colors or signals to perform functions
12) use of active transparencies to facilitate patient monitoring

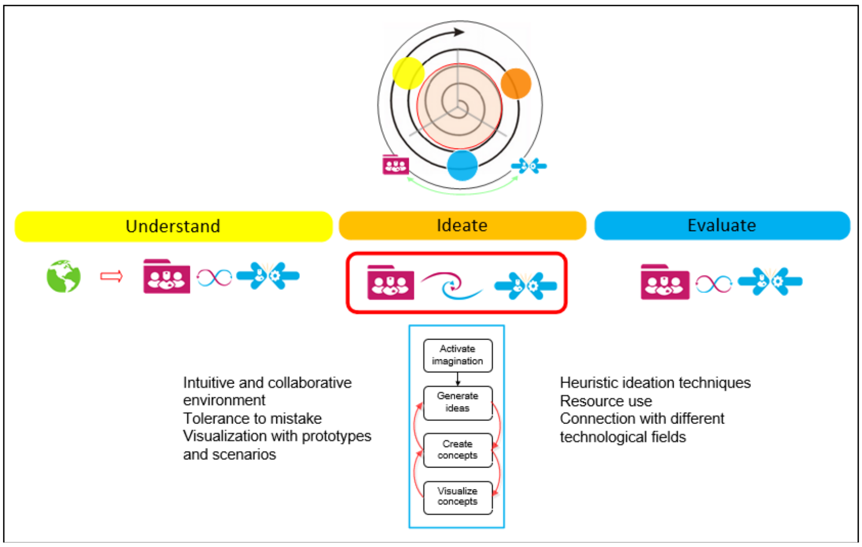
9.2. IDEATE PHASE

The Understand phase provides a new perspective of the problem from the users´ and technology drivers. Initial Project "The project intends to explore new possibilities for the bed rail-mechanism system, which will provide benefits to the different stakeholders." Users' analysis "Hospital and home care beds require safety rails. Patients, caregivers, and nurses expect the rails to be stable (strong and steady) and safe, reliable, easy to use, as well as help to make their lives easier. Additionally, the bed rail to promote inclusion and autonomy for patients and caregivers." And Technology analysis "possible fields of innovation of the rail mechanism system: noise elimination, integration with bed or hospital functions, no dependence on the use of hands to operate, setting options, use of intelligent materials, use of color, fluid or field-based systems, reduction of human intervention, increasing controllability, increasing transparent, and increasing asymmetry."

Ideate phase is based on the results of these analyses, and, it has as its premise to combine DT creation environment with TRIZ solution addressing. Figure 9.9 indicates how this activity is positioned in the overall late FFE model, and it shows the flow of the tasks.

The first task, Activate Imagination, is an element taken from ARIZ that seeks before generating ideas to broaden the perspective of the problem on the previous understanding. Table 9.13 shows the application of the task from the IFRs. ARIZ as well as Figure 8.12 indicate the use of the Method of Smart Little People technique, which was not used in this example

Figure 9.9 - Ideate phase



Source: the author

Table 9.13 - Activate Imagination on pilot project

	Activate Imagination
Intensifying conflict	Determine the contradiction that best represents the problem: CT-1 or CT-2, by indicate the limit state of the action of the elements. CT-1 eliminates the undesired action, but the desired action is not realized and CT-2 the desired action is fully realized, but the undesired action increases to the worst possible. IFR-i The mechanism must be very secure and reliable, remain locked when not activated and be easy to activate, desired unlocking CT-1 The mechanism is completely fixed, not unlocked. Therefore, it is impossible to operate. CT-2 The mechanism can be operated without any action, but it is not locked when required. IFR-ii The mechanism must be fine so as not to add width to the bed and be very rigid to support users' weight, including obese users CT-1 The mechanism is fully rigid, but it increases the width of the bed more than allowed CT-2 The mechanism does not increase the width at all, but it lacks rigidity. IFR-iii The mechanism should be easy to operate in order to perform the basic function without instructions, and various options and/or adjustments should be provided to make life easier for caregivers or patients CT-1 The mechanism can be operated without any action, but it does not perform any function CT-2 The mechanism is fully configurable, but it is almost impossible to control

Source: the author

9.2.1. Generate ideas

The generation of ideas as discussed in Chapter 8 is recommended to be done in two different spaces. First, an idea generation with intuitive techniques, and, then, another idea generation with heuristic techniques. According to the complexity of the problem, more ideation sections with heuristic techniques may be required, TRIZ offers several ideation techniques as shown in Figure 8.12. Another important point is that, for simple problems with previous user and technology analysis, ideation with intuitive techniques may be sufficient.

Table 9.14 indicates the Ideation process of the intuitive and heuristic sections in project pilot, and, Table 9.15 and 9.15 shows the ideas generated with intuitive and heuristic techniques, respectively.

Table 9.14 - Generate ideas in pilot project

Generate ideas	
Generate ideas - Resources	Create solution ideas, using intuitive techniques - brainstorming and performing a previous analysis of the results of understanding User and Technology: User insights, technological Ideality, IFR, TEs, Method of Smart Little People, System Operator. In this section we try to emphasize the utilization and expansion of the resources of the problem. Two people participated in the process, which was carried out in written form, by using post, in two 30-minute sections, a first ideation was carried out, and, then, with the results of the evaluation phase, a second section was carried out (turns 1 and 2 of the spiral). The generation of ideas was based on the DT guidelines and TRIZ principles, first round, second round.
Generate ideas - Heuristics	Create solution ideas, using heuristic techniques - 40 IP and performing a previous analysis of the results of User and Technology understanding: User Understanding, Technological Ideality, IFR, TEs, Method of Smart Little People, System Operator. The task Outline problem, identified several IFRs, an analysis of technical contradictions, and the following inventive principles that can be used to solve the problem: 1,4,8, 13, 14, 15, 16, 17,26,27,28,30, 32, 33, 34, 35 and 40. Previous to the ideation, the determined IP were analyzed by selecting the most appropriate ones for the problem. Two people participated in the process, which was carried out in a written form, by using post, in two 30-minute sections, a first ideation was carried out, and, then, with the results of the evaluation phase, a second section was carried out (turns 1 and 2 of the spiral). The generation of ideas was based on the DT guidelines and TRIZ principles, first round, second round.

Source: the author

An evaluation was made for each idea and concept shown in Table 9.15, Table 9.16, and Table 9.17 was made, according to their creative level and the influence of TRIZ and DT methodologies. Regarding creative level, column A indicates the adequacy of the idea or concept to the problem. Column N indicates the novelty of the idea or concept. These are rated from 1 to 5, being 1 the minimum score being 5 the maximum score. Column C is the product of A multiplied by N, and it indicates the creative level of the idea or concept. This evaluation was carried out by an expert in the PHE area, who is a mechatronic engineer, director of the design department of a company in the PHE sector with more than 20 years of experience in this sector.

Concerning the influence of TRIZ and DT methodologies, the tables listed have a column called integration, which evaluates the influence of TRIZ and DT graphically:

blank box no influence, yellow box low influence, orange box high influence. This evaluation was performed by the author based on their knowledge of both methodologies.

Table 9.15 - Intuitive technique ideas

	Ideas using intuitive techniques - Brainstorming	A	N	C	Integration	
					TRIZ	DT
1	Mechanisms with two states: 1, which is operated with one hand, and 2 which can be locked so that neither patient nor accompanying person operates it. F	4	4	16		
2	Mechanism with dampening so that it does not fall abruptly, accumulating the energy of the descent, which is used for lifting and locking. F	4	3	12		
3	Mechanisms, which make the bed rail, become an auxiliary table for a nurse.	4	4	16		
4	Very rigid and configured mechanisms and bed rails, to allow the patient to be supported in any situation: to sit up in bed, to stand up while sitting out of bed, to stand up while out of bed.	4	3	12		
5	Mechanisms, which help to actively lift the patient.	3	3	9		
6	Mechanisms, which when lowered, can be configured to make noise and indicate patient's exit. (F)	3	2	6		
7	Mechanisms, which send a signal to the caregiver's cell phone when lowering. (F)	4	4	16		
8	Mechanisms, which allow the patient to ask for help with voice, vibrations, temperature or shock and send a signal to the caregiver. (F)	4	4	16		
9	Bed rail mechanism, which is easy to transport and to install in other beds, patient's travel. (Cf)	3	2	6		
10	Bed rails with intelligent medication dispenser, which can remind and control patient and caregiver about medication supply. (F)	3	3	9		
11	Intelligent bed rail mechanism, with Wi-Fi signal, sensors and batteries, which can be configured for specific patients' needs: they require care and if they are left alone, have seizures, which need intervention, is not autonomous. My mechanism - bed rail as a companion.	4	4	16		
12	Mechanism with keys to lock it. (F)	3	3	9		
13	Integrate a cell phone with direct dialing to the caregiver by simple action, such as touching something or asking for help. (F)	3	3	9		
14	That patient's objects can be stored. (F)	2	3	6		
15	That patient can achieve autonomy and privacy.	3	3	9		
16	Rail bed- mechanism integrated with electronics: sound screen with the possibility of compatibility with the cell phone.	3	4	12		
17	Rail bed- mechanism for office work: USB connection, laptop support, and lamp for reading.	4	4	16		

Source: the author

Table 9.16 - Heuristic technique ideas

	Ideas using Heuristics techniques – 40 PI	A	N	C	Integration	
					TRIZ	DT
1	Bed rail-mechanism, which integrates the super bed system and the hospital supersystem or Home Care, by allowing: control bed movements, monitor the patient, help and supervise the caregiver, facilitate doctor work – communication, review, and monitoring.	4	4	16		
2	Mechanism that is unlocked without the assistance of hands, by mechanical action of the elbow, hip, or leg.	4	3	12		
3	Voice-operated mechanism, which lowers by gravity action, and it returns by shape memory effect. (F)	4	4	16		
4	Mechanisms, which are operated by non-contact body movements, and it returns and locks automatically.	4	4	16		
5	Mechanism, which is operated without using physical contact by the nurse and ease of operation by the patient, which can be locked, and patient exit and return indication can be activated.	4	3	12		
6	Mechanism that not only goes down and goes up to allow the patient to leave, but it also motorized operated in order to help the patient to sit in bed and to get up while being sitting outside the bed.	4	4	16		
7	Use light signals in order to indicate states: locked, free mechanisms, patient in or out of bed, patient with or without problems (F)	4	3	12		
8	Customizable bed rail mechanisms, by using elements or inlays with different colors or forms. (Cf)	3	3	12		

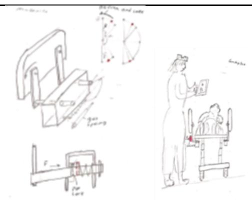
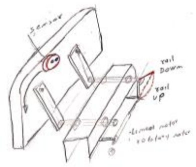
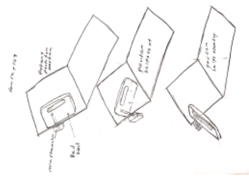
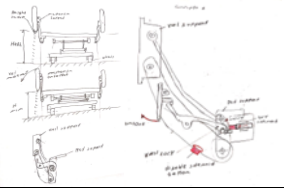
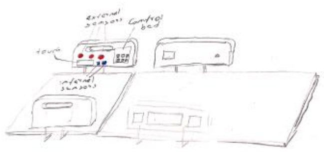
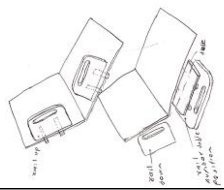
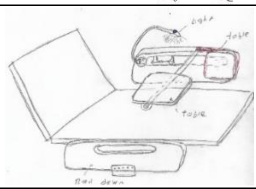
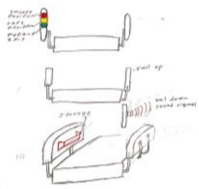
	Ideas using Heuristics techniques – 40 PI	A	N	C	Integration	
					TRIZ	DT
9	Bed rail mechanisms that when the bed is in the minimum height position, it is unlocked by the patient, when the bed is in another height position, it is only unlockable by the person accompanying the patient.	4	4	16		
10	Divide the Bed rail Mechanism into modules, such as obstacle to patient falls, side table, compartments for storing medications, possibility of integrating electronic or control systems. (Cf)	3	4	12		
11	The movement of mechanism is operated by an electromechanics field.	3	3	9		
12	Instead of the bed rail going up and down, it can also rotate vertically or horizontally.	3	3	9		
13	Generate the movement of the mechanism by expansion or thermal contraction: bimetallic system, intelligent material. (F)	3	4	12		
14	Bed rail mechanism with programmed states: free, lock, monitor, send signal, auto function, up, and lock. (F)	4	4	16		
15	The operation mechanism instead of the nurse touching something may alternatively be a magnet that the nurse approaches a point of the mechanism, a bracelet. (F)	3	4	12		
16	Automatic descent, once the low mechanism is unlocked, without human action.	3	4	12		
17	The up and down action is performed by two thermo-controllable smart type wires – Shape memory effect.	3	4	12		
18	Mechanism, which returns automatically when partially operated to prevent accidental or unwanted unlocks. (F)	3	4	12		
19	Integrate in the mechanism dim light and reading light. (F)	3	3	12		
20	Mechanical and electronic modules can be added to configure the mechanism. (Cf)	3	3	9		
21	Bed rail can be easily changed, either for customization or reconfiguration. (Cf)	3	3	9		
22	Interchangeable rails, for specific users such as children, elderly, etc.	3	4	12		
23	Bed rails are fixed and the mattress changes height to provide protection for the patient.	2	3	6		
24	Inflatable accessories to be placed on bed rails to prevent entrapment	3	3	9		
25	Bed rail divided in two to adjust the height according to specific needs	4	4	16		
26	Bed rail rotates out of bed while remaining vertical, to support the patient when leaving or entering the bed.	4	4	16		
27	Bed rail with integrated motorized patient lifting assistance system	4	4	16		

Source: the author

9.2.2. Create concepts

By analyzing the ideas generated with intuitive and heuristic techniques, they are combined, discarded and some are classified into desirable functions (F) or configuration possibilities (Cf), as indicated in Table 9.15 and 9.15. Finally, some solution concepts are conceived and shown below. Concepts 1 and 2 are focused on the function of the rail-mechanism system and the following concepts are more oriented to improve the life of the users. The table shows the evaluation of the creative level of the concepts and the influence of TRIZ and/or DT in their conception, the size of the letters determines the greater or lesser influence of each methodology.

Table 9.17 - Concepts on pilot project

#	Concept sketch	Concept description	A	N	C	Integration
Concept 1		Mechanical operation mechanism, which is unlocked and lowered without the assistance of nurse's hand, they can use their elbow or any other body part and rises, and it locks with minimal force without the assistance of their hands. Also, when unlocked, if they lower it just a little bit, it returns to its up position, and it locks autonomously by means of springs, cams, or sprint gas.	4	4	16	
Concept 2		Electromechanical operating mechanisms. They are unlocked by voice, magnet, or body movement, without contact. To lower them, they move by gravity or motorized and they return (climb) by motor action: electric motor, or by shape effect memory.	4	3	12	
Concept 3		Mechanism, which not only raises and lowers to perform the main function which is to patient protection, in addition, it actively assists the patient in movements: sitting up in bed, standing up while sitting in bed and providing support to the patient while in or out of bed.	4	4	16	
Concept 4		Bed rail that the patient can unlock only with the bed at minimum height, and when the bed is in another position, only the nurse can unlock it. When the bed moves up a distance x a solenoid prevents it from unlocking, the nurse can disable the solenoid with a button.	4	4	16	
Concept 5		Intelligent bed rail, which integrates with the bed and hospital function - supersystem. It controls the mechanical movements of the bed and monitors the patient: patient presence, temperature, vital signs and assistance requirement. It can be connected to WIFI and cellular. Includes inclinometer and accelerometer sensor to indicate bed position information and possible occurrences with the patient.	4	4	16	
Concept 6		Bed rail that, in addition to the up and down positions, can assume the position of an auxiliary table, which allows for the nurse to place medicines or other materials.	3	4	12	
Concept 7		Bed rail that with accessories for patient office work, as for table for laptop, light lecture, USB connection.	4	4	16	
Concept 8		For all ideas, it is necessary to take into account the possibilities of optional functions and configurations, which constitute add-ons to reach solution concepts. • Bed rail with Audible Patient Abandonment Signal • Bed rail indicating: unsafe position - bed up and rail down, safe position: rail up and locked, patient exit position - bed down. • Bed rail with storage for patient´s objects.	4	3	12	

Source: the author

Table 9.18 - Prototype photos

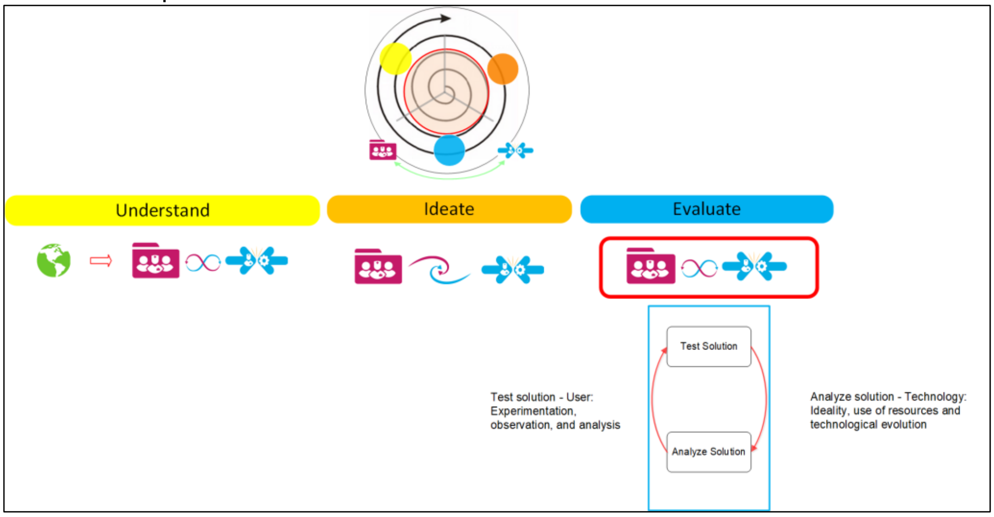
	Visualize concepts	Description
Concept 3		Concept 3 prototype allows one to visualize the bed rail movement outwards and how the user can support himself or herself to stand up.
Concept 5		The concept 5 prototype visually shows the bed rail with monorail systems.
Concept 6		Concept 6 prototype shows how the bed rail tilts to transform itself into a side table.
Concept 7		Concept 7 prototype shows how the bed rail can be accessorized as a laptop table, reading light and USB socket.
Concept 8		Concept 8 prototype shows an object holder for the bed rail.

Source: the author

9.3. EVALUATE

Objective phase is to examine the solution from the user and from the ideality and technological evolution. Figure 9.10 indicates how this activity is positioned in the overall late FFE model, and it shows the flow of the tasks, Table 9.19 and Table 9.20 indicate the sequence of the tasks that make up the activity, and Table 9.21 summarizes the evaluation of the concept.

Figure 9.10 - Evaluate phase



Source: the author

Table 9.19 - Test Solution on project pilot

Test Solution	
Define how to approach user	Based on the prototypes and concept sketches, an interview was conducted with a nurse practitioner.
Experiment solution	The interview was conducted virtually in a 60-minute section, each concept was explained, and those that had an associated prototype were also presented. The nurse was asked to evaluate each concept from the point of view of safety, facilitating the nurse's work and improving the patient's and companion's life.
Analyze results	The results of the concept evaluation synthesis show that, in general, the concepts present positive characteristics for the users (see Table 9.21); however, further refinement is needed, both evaluation in the hospital environment and conception of concepts that include suggestions and integrate several concepts.

Source: the author

Table 9.20 - Analyze Solution on project pilot

	Analyze Solution
Verify IFR and TEs	The results of concept evaluation synthesis indicate how the concepts are aligned with some of the TEs and from the IFR point of view some are more clearly aligned in this direction (see Table 9.20.).
Verify resource utilization	A resource utilization verification of the problem was not performed, due to the fact that the solutions focused on the utilization of TEs and selected Inventive Principles.
Analyze results	The evaluated concepts are seeking an increase in ideality and are going in the direction of some of the TEs, this itself is not enough to qualify a concept as good or bad, but it indicates whether it is on the right technological path. A point to take into consideration is that the concepts are adding new subsystems to perform complementary tasks, which could generate additional complications and loss of reliability of the bed rail system mechanism.

Source: the author

Table 9.21 - Concept evaluation synthesis

	Test Solution - DT	Analyze Solution - TRIZ
Concept 1	Nurses avoid some tasks and frequent glove changes. Can be difficult to operate the bed rail	Ideality: increased safety by facilitating the operation. Decreased human intervention
Concept 2	Nurses avoid some tasks and frequent glove changes. Facilitates bed rail operation	Ideality: increased safety by facilitating the operation. Decreased human intervention, - Human and semi-automated tool. Increased controllability
Concept 3	Seems like a good idea, but it is difficult to evaluate without a test There are patients for whom it would increase their autonomy The railing must be safe first and foremost	Increased controllability Decreased human intervention - Human and powered tool Geometric evolution, another dimension
Concept 4	It should allow the patient to lower the bed and unlock the rail with a single command. It should be programmed for specific patients	Increased controllability Decrease human intervention - Human and semi-automated tool
Concept 5	Must be integrated with the nurse's station Must be easily programmed for specific patients: post-operative, children, patients with mental diseases, etc.	Integration with the super system - Hospital Increased controllability - Intelligent feedback Decreased human intervention - Human and powered tool
Concept 6	It seems interesting Testing is required to evaluate The rail should not lose its safety function	Mono-bi-poly (various), By system
Concept 7	Many patients work at the bedside using cell phones, laptops and notebooks. They use the food table for support For lucid patients it would be a good idea	Mono-bi-poly (various), By system Integration with the super system - patient life

	Test Solution - DT	Analyze Solution - TRIZ
Concept 8	Some things are used in very specialized beds. Must be integrated with the nursing station Integrating these functions from the rail makes it possible to implement them in simpler beds.	Integration with the super system – bed Increasing use of senses 3 senses Mono-bi-poly (various) poly-systems Increasing use of color, Use of visible spectrum

Source: the author

9.4. PROJECT ANALYSIS

The evaluation of the application of the DTRIZ methodology in a specific application will be performed as indicated in section 9.1. Two issues relevant to the methodology will be addressed, the spiral process, and the integration of TRIZ and DT in the process.

9.4.1. Spiral process

About the spiral process, the first three turns of the spiral were shown graphically and how the fourth one could follow. The graphs show how the understanding of the problem, the maturity of the ideas and concepts, and even the focus of the project gradually evolve. It should be remembered that in a highly innovative context, the understanding and the solution are not separable.

It can be seen how the turns of the spiral allow each phase to be carried out from the previous knowledge, and how progress can be noted. Spiral 4 indicates how it is possible to converge to a refinement of the solution to move to level 2 of the spiral or an evolution of the project objective. This is one of the spiral characteristics, its flexibility makes the management of the project difficult. And it is precisely the presence of top management that is required to press and to decide on the project convergence or the continuation of the spiral.

9.4.2. Integration TRIZ and DT

The DTRIZ methodology process integrates TRIZ and DT in the three phases, which was extensively discussed and graphically represented during the methodology proposal stage. In this section, this integration will be discussed during the execution of the Late FFE. Figure 8.12, which represents the general process, emphasizes how the TRIZ and DT methodologies are integrated in the Understand, Ideate and Evaluate phases. Table 9.22 shows the highlights of the integration of TRIZ and DT in the three phases throughout the implementation of pilot project.

Table 9.22 - Integration of TRIZ and DT in the Late FFE

Understand phase Interdependence Complement	• Table 9.7 - Clarify problem: the activity of understanding the technology from TRIZ, starts with the previous analysis of the user - DT; • Table 9.8 - System Operator application: in the application of this technique, the present and future boxes are addressed with the previous analysis of the user - DT; Table 9.10 summarizes the process of establishing different forms of IFR. • Table 9.10 - The outline of the problem initiates with various forms of IFR, which are the result of understanding the user and the technology - TRIZ DT.
	• Table 9.15 - and Table 9.16 - show the ideas generated with intuitive and heuristic techniques respectively and evaluate the impact of TRIZ and DT on each idea, it is noticeable how in the two ideation sections TRIZ and DT are present; • Table 9.17 - Concepts: it shows the influence of TRIZ and DT in each concept, it can be seen how the concepts are influenced by both methodologies.
Evaluate phase Interdependence Complement	Table 9.21 - Concept evaluation synthesis, it shows the evaluation system of the concepts from TRIZ and DT, the interdependence relationship is not identified.

Source: the author

In the Understand phase, the integration of both methodologies is complementary, i.e. each methodology performs an independent activity, but the results of both are linked. Table 9.22 shows the main points of the TRIZ and DT complement, how the results of DT assist in addressing the TRIZ analysis. It is more noticeable in this example, the contribution of DT to the understanding of TRIZ technology is more noticeable. However, for another problem, it could be the other way around.

In the Ideate phase, the integration of TRIZ and DT is by fusion, which means that the contributions of both methodologies are not separable in different activities. Table 9.22 indicates how even though the ideation was performed with intuitive techniques – DT, and heuristic techniques - TRIZ, the results of both sections are influenced by both TRIZ and DT. It is remarkable how TRIZ shows solution paths from TEs and 40 IP - technology application, DT presents fewer technological, but more integrative ideas and concepts. The realization of the second section was more difficult because it was oriented from specific Inventive Principles and TEs, but the results are more concrete.

The Evaluate phase presents an integration of TRIZ and DT by complement, it can be seen how the evaluation of the concepts was performed from the user and the technology with separate activities, which could be performed by different teams, Table 9.22 indicates how the complement of both methodologies was not identified. This may be due to the fact that, for this pilot project, a more in-depth evaluation of the concepts was required.

Additional points on ideation are: i) the general dynamics of the ideation process was mediated by teamwork, user-centered, a holistic look at the problem, in both sections the DT guidelines were an integral part, TRIZ principles were mostly taken into consideration in the heuristic ideation; (ii) the visualization of the concepts in the form of prototypes constituted a significant contribution because it was possible to understand and communicate and discard some proposals; iii) some ideas of the intuitive section (3, 11 and 17) were more integrative from the user's point of view, these ideas would hardly be achieved with a look only from technology, and iv) it is observed that the ideas of the heuristic section go in the direction of proposing more concrete solutions and integrating technologies, some of them operationalize ideas from the first session.

9.4.3. OVERALL PROCESS EVALUATION

The overall process evaluation will be performed based on the variables defined previously, which were indicated in table 9.1. The evaluation was carried out by the author based on the documentation of the process and results of the project, (See Table 9.23).

Table 9.23 - Overall process evaluation

		Category		Variables	None	Incipient	Fair	Good	Excellent
Process variables	Aspects of how projects are carried out.	Understand	1)	Understanding the problem from the user's point of view	■	■	■	■	
			2)	Understanding the problem from the technology	■	■	■	■	
		Ideate	3)	Process of idea generation	■	■	■		
			4)	Process of concept generation	■	■	■		
		Evaluate	5)	Ideas evaluation	■	■	■		
			6)	Concept evaluation	■	■	■	■	
		Overall process (Links)	7)	Spiral process	■	■	■	■	■
			8)	TRIZ and DT complement	■	■	■	■	■
Result variables	Tangible process results	Ideas	9)	Number of ideas generated	■	■	■		
			10)	Creative level of ideas	■	■	■		
			11)	Technological breadth of ideas	■	■	■		
		Concepts	12)	Number of concepts conceived	■	■	■	■	
			13)	Creative level of concepts	■	■	■	■	
			14)	Technological breadth of concepts	■	■	■	■	

Source: the author

10. PROJECTS IN COMPANY ENVIRONMENT

An initial pilot project was carried out that is detailed in chapter 9, which allowed a better understanding of the process flow of the late FFE model - DTRIZ methodology. Additionally, it was indicated how the validation focused on level 1 of the model spiral. Subsequently, four projects were carried out in the environment of companies in the PHE sector, using the late FFE model proposed in Chapter 8. The general implementation procedure was carried out with the following steps: preparation, project execution, result evaluation, and application analysis of DTRIZ Methodology. as detailed below.

10.1. PREPARATION

For the application of DTRIZ methodology in four projects, a preparation was carried out, which consisted of defining aspects to be measured, selecting companies, designing support material, and conducting training on the methodology.

10.1.1. Definition of aspects to be measured

Before selecting the companies, it was determined that aspects - variables, should be evaluated throughout the project execution. In this way, aspects of how projects are carried out - **process variables**. On the other hand, tangible process results - **result variables**, were considered. Thus, process variables are related to the quality of activities for project implementation: Understand, analysis, and initial understanding of the problem from the user and technology; Ideate, the process of generating ideas and concepts; and Evaluate, evaluation and selection of concepts from the user and technology.

As indicated in Figure 8.12, the Late FFE is embedded in the social environment, which is not directly related to activities. However, it influences the development of projects. In this way, aspects, such as organizational culture, the interrelationship of the development team, managerial support, and external influence, are considered, albeit superficially, by the research limitations. On the other hand, the result variables are the ideas and concepts generated. These are measured concerning comprehensiveness in terms of utilization of different areas of knowledge and quality -

defined by its problem appropriateness and novelty. In Chapter 9 - Table 9.1, summarizes the aspects to be measured in the realization of the projects.

10.1.2. Company Selection

Initially, companies in the PHE sector located in Colombia were contacted. These companies were introduced to the intended objective and what the methodology would be like. Predominantly, PHE companies were chosen, for which the product development process is strategic. Likewise, companies devoted to developing products for third parties, with experience in PHE, were considered. In addition, these companies were chosen under the condition that they were willing to apply the proposed late FFE model, in at least one product, which should be a new concept. Table 10.1 summarizes the selected companies, and it relates to the four projects carried out.

Table 10.1 - Data of the enterprises studied

Enterprise A	Enterprise B	Enterprise C
Company description: A medium-sized company devoted to the development, manufacture, and marketing of hospital furniture. It, is 34 years old. It operates in the Colombian market and exports to Latin America countries. The basic technology is metalworking and electronics.	Company description: A small-sized company devoted to designing products for third parties, with some lines of its own. It has experience in the medical equipment sector. The company is 3 years old. It operates in the Colombian market. The main knowledge is in the mechanical and electronic areas.	Company Description: A small-sized company devoted to the development, manufacture, and marketing of gas management equipment in intensive care units and other hospital services. The company is 15 years old. It operates in the Colombian market, spatially in the region of Antioquia. The primary knowledge is in the mechanical and electronic areas.
Size: middle-sized company. Employees: 120. Export 50% of sales.	Size: micro company. Employees: 6. Export: no	Size: small business. Employees: 30. Export: approximately 5 %. of sales.
Design process: the company has a formal department and product design procedure. The team consists of eight people from different professions, such as mechanical engineering, industrial design, and graphic design. Electronic development is done in a separate department. They are continuously developing new, particularly incremental, products.	Design process: The company has a formal product design procedure. The team consists of three-six people, who make up the following areas: electronic mechanics, manufacturing, and bioengineering, as well as external advisors in specific areas.	Design process: The company does not have an area or formal product development procedure. The developments are carried out without formal procedure. They have a staff of two mechanical engineers and an electronic engineer. In general, designs are customization of pre-developed solutions and develop products sporadically.
Project 1: Elderly mobility Project 2: Mobility Bariatrics	Project 3: Medical environment asepsis	Project 4: Dental care

Source: the author

The three companies are heterogeneous in their size, field of action, and degree of maturity. Enterprise A is an average consolidated company in the Colombian hospital furniture market, which comprises four companies producing beds, stretchers, examination beds, and medical trolley. They are currently exporting 50% of their production to Latin America and the USA. The company has a separate mechanical and electronic design department, which designs new products and constantly customizes existing products for hospital projects. The process of product development is technical, connected to the marketing area. No methodologies or techniques are used to support the design process.

Enterprise B is a new micro-enterprise with only three years in the market. It is in the consolidation process. Its mission is to develop products for third parties and a specialized table line for the electronic gaming sector. The company members have experience of several years in the PHE sector, and the company has developed several projects in this sector. The company has a formal design procedure that focuses more on the customer service model than on its internal process. The company operates in the Colombian market, basically in the Antioquia region. As for the design process, they do not use methodologies or techniques to support the process.

Finally, enterprise 3 is an expanding small enterprise operating in the Colombian market, which is devoted to the market of gas handling equipment in hospitals. Initially, the enterprise offers gas systems from storage to the point of gas in the room or any other service, without contact with the patient or medical personnel. However, they have been offering products for four years, some of which are used by medical personnel in the ICU. Currently, they also develop products for direct patient use. The company does not have any formal development area. The projects are carried out by two mechanical engineers and one electronic engineer, the company's manager and owner, and actively participate in product development. Despite not using methodologies to support the design process, it should be noticeable that the company maintains contact with health professionals, some of whom collaborate directly in developments.

10.1.3. Support material for training

With the results of Chapter 8, and the theoretical reference, a material was made for training with companies to facilitate understanding and execution of DTRIZ methodology, and facilitate training with approximately 20 hours. Table 10.2 describes the materials created for training.

The material designed for the trainings aimed to facilitate understanding the methodology and its application in the projects proposed. In addition, a website was created in Moodle, which was used as a document repository. Table 10.2 indicates the appendices in which most of the materials are explained. The following will be discussed DTRZ Algorithm, TEs Summary, and Card game. This material was written in Spanish, which is the native language of the members of the different teams.

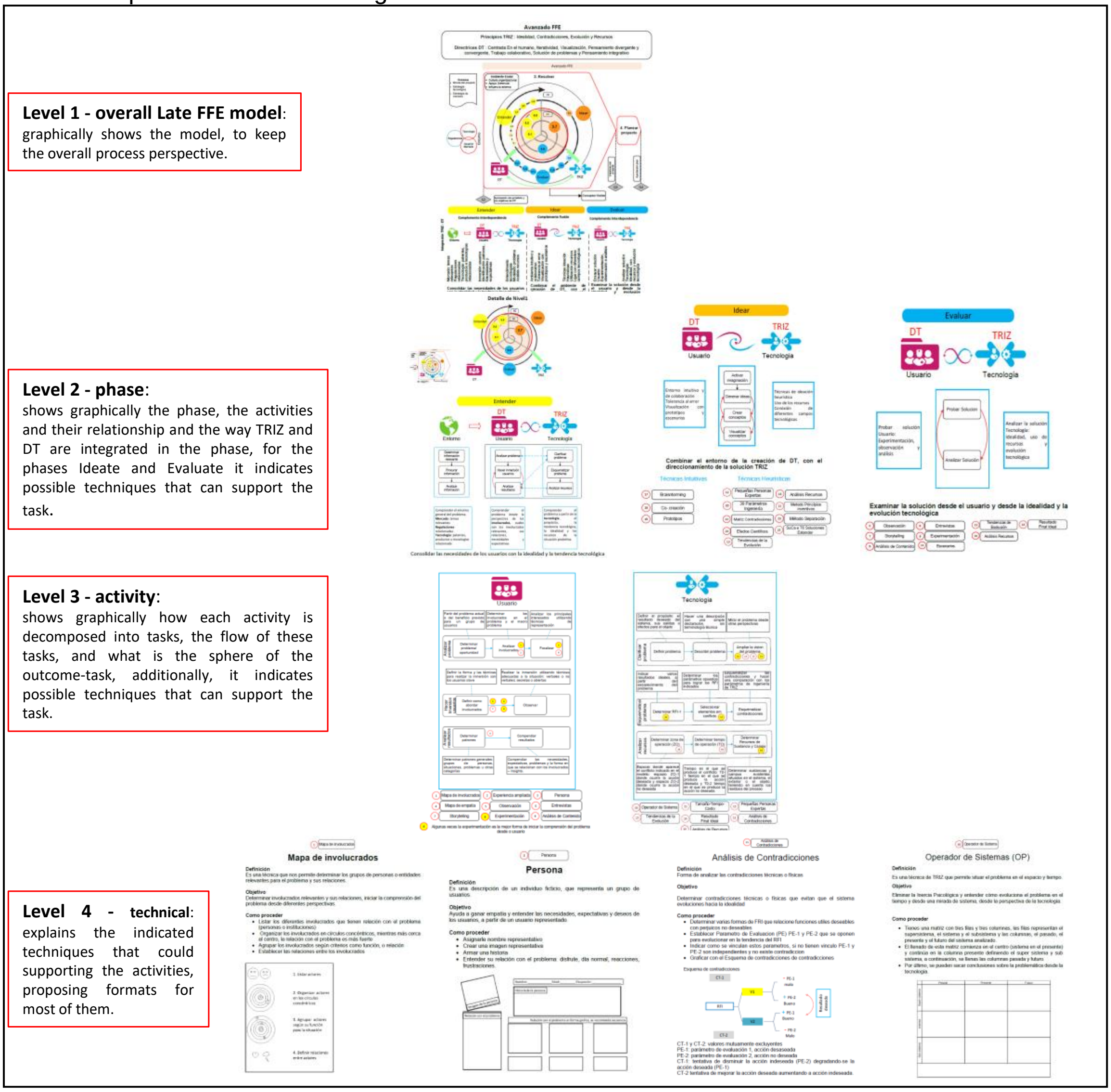
Table 10.2 - Materials used in the training

Material	Description
Algorithm DTRIZ	Document that graphically summarizes the DTRIZ methodology, and explains the techniques used.
Summary of TEs	Document shows the TEs of the authors cited in Chapter 5.
40 IPs	Explanation and examples of the 40 IPs, (See appendix E).
39 EP	Explanation of 39 Engineering Parameters of TRIZ, (See appendix F).
Matrix of contradicti ons	Graph of the matrix of contradictions explained, relating to Separation Methods, (See appendix G).
Separation methods	Explanation of Separation Methods with examples, (See appendix H).
Card game	The card game that facilitates the use of the Contradiction Matrix, 40 IPs, and Separation Methods.
Formats	Formats were created to facilitate the realization and summary of results of some of the techniques, (See Appendix J).
Application	An application of the DTRIZ methodology is described step-by-step – Pilot project, (See chapter 9).

Source: the author

The DTRIZ algorithm is a document that succinctly shows the methodology's flow proposed in Chapter 8, starting from the overall methodology to the flow of activities. Figure 10.1 shows as an illustration some fragments of the document. As the figure indicates, the document has four levels: Level 1 - FFE, shows the generality of the Late FFE process; Level 2 - Phase, focuses on the phases of the model, by indicating the flow of activities, and it emphasizes how to integrate TRIZ and DT in the specific phase; Level 3 - Activity, explains each activity and decomposes it into tasks. Additionally, by indicating some techniques that can support the task; and Level 4 - Technique, succinctly explains how to perform each suggested technique. In addition, it has hyperlinks, which relate the techniques proposed in the different activities or tasks, with their respective explanation to facilitate the project implementation.

Figure 10.1 - Explanation of DTRIZ Algorithm Document

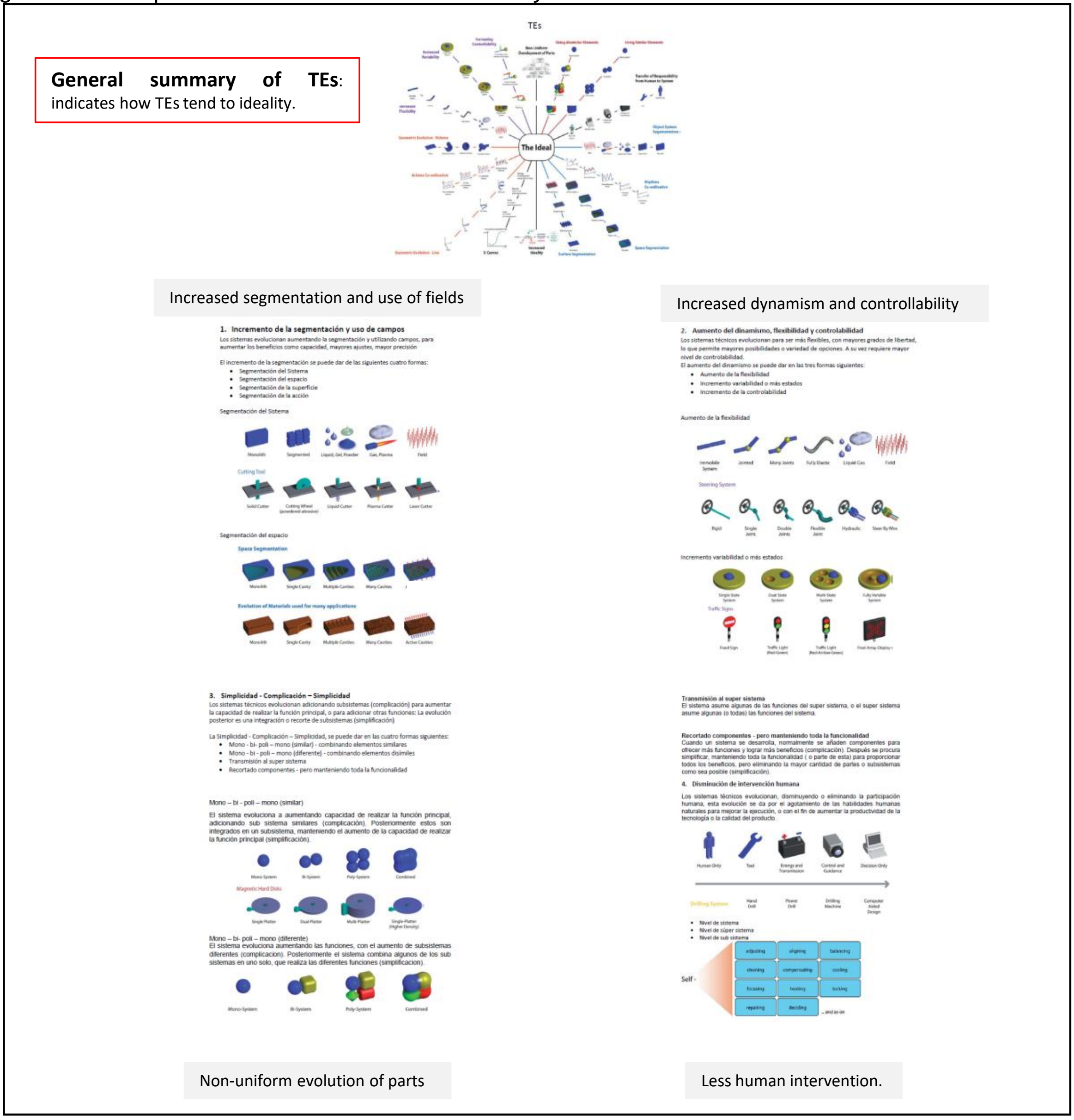


Source: the author

The summary of TEs is a document that concisely shows the TEs of Altshuller, Savransky and Mann and a compilation of the views of previous authors and others made graphically by (GADD, 2011), which performs a categorization of TEs, by facilitating their understanding.

Figure 10.2 shows some fragments of the document, by focusing on the compilation of (GADD, 2011), where it can be seen how from the graphs and a brief explanation each TE is explained, which facilitates its practical use in the Understand, Ideate and Evaluate phases. Additionally, Appendix C shows a summary of Altshuller, Savransky and Mann's TEs.

Figure 10.2 - Explanation of the document summary of TEs



Source: the author

Finally, the Card game, inspired by commercial card games used to apply TRIZ, developed a kit to facilitate project implementation, (See Figure 10.3). Each card has an inventive principle or separation method with a simple graphic representation, an explanation of the principle, and examples of the principles on the back. In this way, in the Ideation, by using the 40 IPs, the team can use the technical contradictions to determine the principles to use or, by reviewing the cards, the team could determine which principles to be used. Once selected, the respective cards are separated, and the team has only the principles cards of principles that it will use. In the Ideation, the teams were asked to review and comment on the principles to be used, by taking advantage of the respective cards.

Figure 10.3 - Card game image

Source: the author

The use of the methodology in real projects requires that the project team can easily apply abstract and difficult concepts to understand. In this way, the application itself is one of the best ways to contrast theory and to internalize concepts. The support materials created, in practice, are subjected to reality to verify whether they helped the team and to facilitate the implementation of projects and to verify improvements in these materials.

10.1.4. Enterprise training

The training was carried out on DTRIZ methodology, divided into four blocks: Introduction, DT, TRIZ, and DTRIZ. The training lasted approximately 20 hours, varying from project to project, for factors, such as the Covid-19 Pandemic, time availability, interruptions in the project, among others, as detailed below. The DT, TRIZ and DTRIZ blocks were divided into concept explanation and concept application, using the respective projects as examples. In this way, in the initial phase, the training was carried out in parallel with the implementation of the projects.

The introduction consisted of 5 hours where the FFE was shown in contrast to the PDP. Besides, it explained the context of a high degree of innovation in contrast to incremental innovation, and, finally, DT, TRIZ, and DTRIZ methodologies were introduced. Once the introduction was carried out, the teams introduced their projects as a problem intended to be solved in the form of a product. This problem was defined in the respective enterprises. The project was discussed and clarified before the second block, where, along with DT's explanations and examples, the teams began working on their projects.

As indicated, the training and execution of the projects were mediated by factors, such as the Covid-19 Pandemic, which had a marked impact for companies in this sector. Increased sales in products, such as beds and stretchers, need to develop some products quickly, health restrictions, which meant teleworking for some enterprises, and constant changes in schedules and work schemes. These situations forced us to adapt to the circumstances of each company. The project execution was not continuous and, even in some projects, team members changed throughout the project. Table 10.3 summarizes the training in the different projects.

Table 10.3 - Training summary

Project 1 Project 2	The training began in person because the pandemic was continued in virtual mode, requiring adapting material to the new situation, such as the Moodle platform. The team members were in remote work. Then, all the team interaction was held virtually. It was necessary to move forward with time intervals of up to one month. Once the measures of restriction for mobility by pandemic allowed and the company allowed, virtual meetings were combined with face-to-face meetings. In the conceptualization phase, it was possible to make meetings in a coworking space with the projects 1, 2, and 3.
Project 3	In this project, the training began virtually. The team was working remotely. Then, two face-to-face meetings were held, complemented by virtual ones, which improved the work dynamics. In the conceptualization phase, face-to-face encounters with teams 1, 2, and 3 in coworking.
Project 4	Training started virtually. Based on the previous experiences of the other projects, adjustments were made to the presentation form. The first two sections went well, but the workshops, as a complement to the theoretical classrooms, did not work out. The decision made was to stop for a while until a special mobility permit of the trainer was processed. In this way, the training was completed in person at the enterprise's facilities, with a better dynamic.

Source: the author

The virtual meetings had two components: theoretical exposition and application workshops. The virtual mediation hampered the latter, and the teams had little knowledge about technological tools for virtual work. It was necessary to explore and try different ways by combining synchronous and asynchronous meetings. Initially, what worked best was to use PowerPoint with a single person responsible for writing and participating orally. After exploring different tools, Jamboard was used. It is a tool that allows team members, in real-time, to participate in the implementation of the exercise by leaving the evidence of the result in a digital file, at the end.

In the final part of the project, it can be observed that companies are less interested in projects. In addition, most of the members of teams 1, 2 and 3, worked remotely. In this way, physical space was made available to work on the prototypes and have work meetings and clarify doubts. This strategy improved team communication and workflow.

10.2. PROJECT EXECUTION

As explained, the training was in parallel with project execution, at least in the early stages of Understand and Ideation phases. Then, support meetings for projects and concept clarification were scheduled. In the sequence, project execution will be explained.

The execution of the applications of DTRIZ methodology, it started from a problem, which was intended to be solved, by designing a product, which was part of the enterprises' strategic objectives as indicated in Table 10.4. For the makeup of teams, they were asked to have people from different company areas, mainly related to design, production, and marketing. However, the team was generally made up of technical staff, as can be appreciated in Table 10.5. As for projects, as it has been indicated, they were new to the company and some of them without any reference in the market. First, the projects and teams will be introduced. Then, the manner in which projects were implemented, will be addressed.

Table 10.4 - Project description

Project	Description	Comment
1 Elderly mobility Enterprise A	The starting problem was how to improve mobility for the elderly in bed, emphasizing the entry and exit of the patient to the bed in a hospitable environment or home.	The problem is related to the company's field of action, being an issue that has been indirectly addressed, which led to its identification. The project aims to explore solutions that can be implemented.
2 Mobility Bariatrics Enterprise A	The starting problem was how to improve the mobility of overweight people at the time of medical care within the hospital environment, with emphasis on medical examinations or minor procedures.	
3 Medical environment asepsis Enterprise B	The starting problem was how to reduce virus infections and other infections, which occur in medical environments, specifically in patient waiting rooms.	This problem existed before the Covid-19 Pandemic, and it is more relevant today than ever before. The company wants to explore the feasibility of offering a novel solution to the identified problem
4 Dental care Enterprise C	The starting problem is associated with the risk of the Covid-19 Pandemic and other pathologies during dental consultation, both for dentists and auxiliaries, as well as patients and companions.	This problem arises from the Covid-19 Pandemic. It is entirely different from what the company does today, but it is of strategic interest.
A general commentary for all projects is that once DTRIZ methodology was introduced to the management, the interest was to address a new problem or known from new approaches.		

Source: the author

Table 10.5 - Work team description

Project	Team description	Members and experience
1 Elderly mobility	The teams were made up of personnel from the company's mechanical and electronic design area. The members of electronics had a stake in projects 1 and 2, which was partial. Changes were made to the teams throughout projects. However, the team base remained.	Industrial designer: 8 years. Mechatronic technologist: 4 years. Mechanical design technician:1 year. Electronic engineer:15 years. Electronic engineer: 2 years. Graphic designer: 12 years.
2 Mobility Bariatrics		Mechanical engineer: 3 years. Mechanical engineer: 1 year. Industrial designer: 1 year. Electronic engineer: 15 years. Electronic engineer: 2 years. Graphic designer: 5 years.
3 Medical environment asepsis	The team consisted of members of the company, who are the ones who make the different designs, and an external electronic engineer, who participated in the initial phase.	Electronic engineer: 10 years. Mechanical technologist: 18 years. Mechanical technologist: 23 years. Mechanical technologist: 5 years. Biomedical engineer: 20 years.
4 Dental care	The team consisted of two people, who lead the production processes and project developments, and the general manager, who actively participates in the new projects.	Electronic engineer: 15 years. Mechanical engineer: 18 years. Mechanical engineer: 13 years.

Source: the author

The realization of each project presents its own characteristics in the process. Figures were made to show the evolution of the projects within the proposed spiral model, which are based on the elements that the teams delivered, the author's notes during the realization of the projects, and the interviews at the end of the project with at least one team member of each project. The drawings that represent the concepts or prototypes are not intended to go into detail. The intention is to show the notion of the process, in the following numeral these results are detailed.

In the projects it can be observed how the different elements evolve, such as the understanding of the problem from the environment, user and technology, the focus of the ideas and concepts and the maturity of the solution concepts, even in some projects (including the pilot project), the problem formulation evolves.

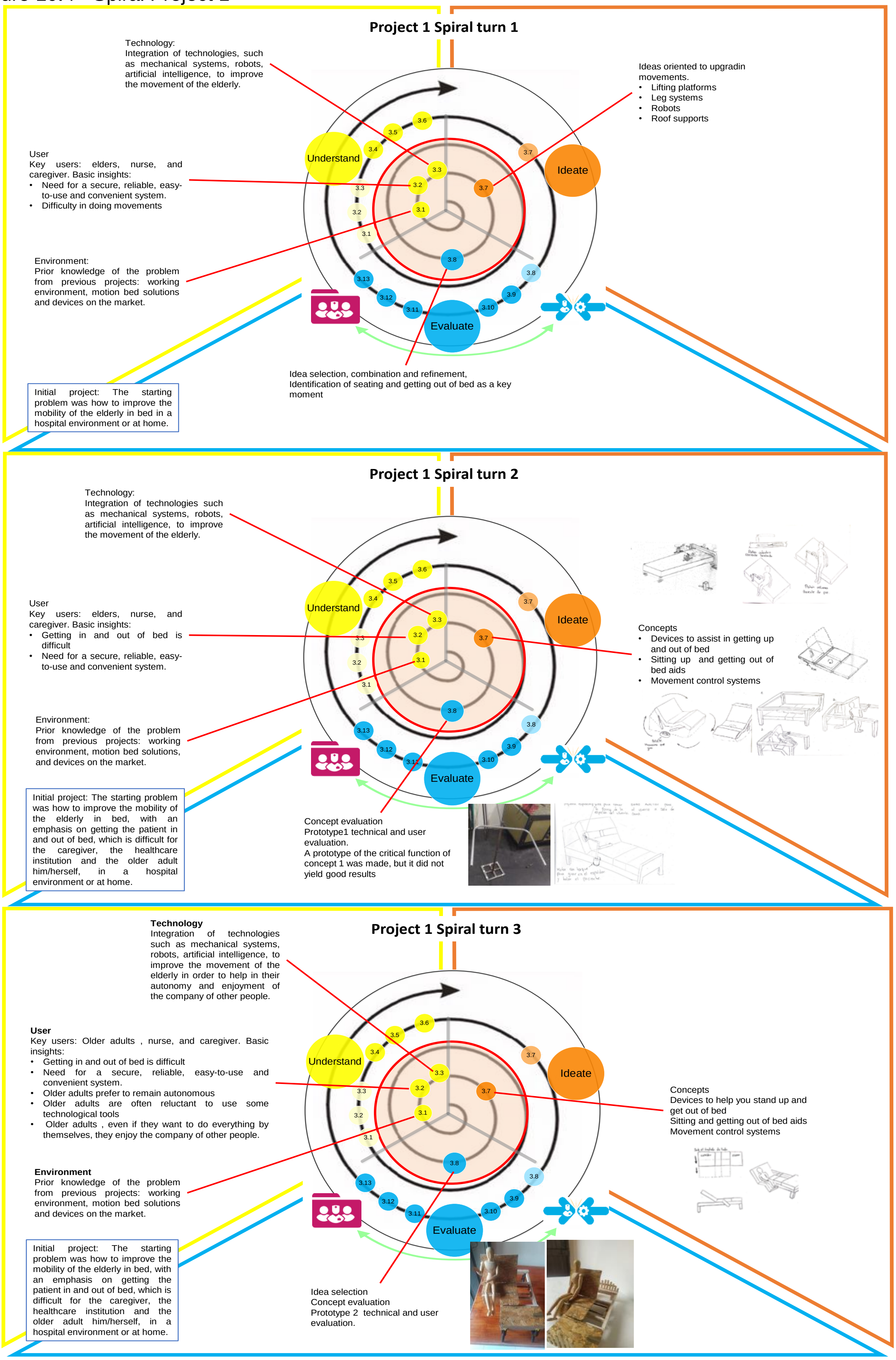
Figure 10.4 shows the process of Project 1, in which it can be seen how the project evolved from the understanding of the user, going from the difficulty of movement in bed, safety and comfort, to the understanding of deeper issues related to the needs of autonomy and enjoyment of the company. This allowed us to improve and to focus the solution concepts.

Figure 10.5 shows Project 2, the evolution of the project shows how it passed from the understanding the problem of mobility of obese people in a hospital environment to the focus on the moment of attention to minor procedures, such as examinations, in which access to equipment and movements of the procedures present difficulties for the patient and medical staff. The team focused its attention on functional aspects of the user.

Figure 10.6 shows Project 3, which shows how the team focused on technology. The user was not taken into consideration. The evolution of the project was based on the understanding of technology to solve an aseptic problem.

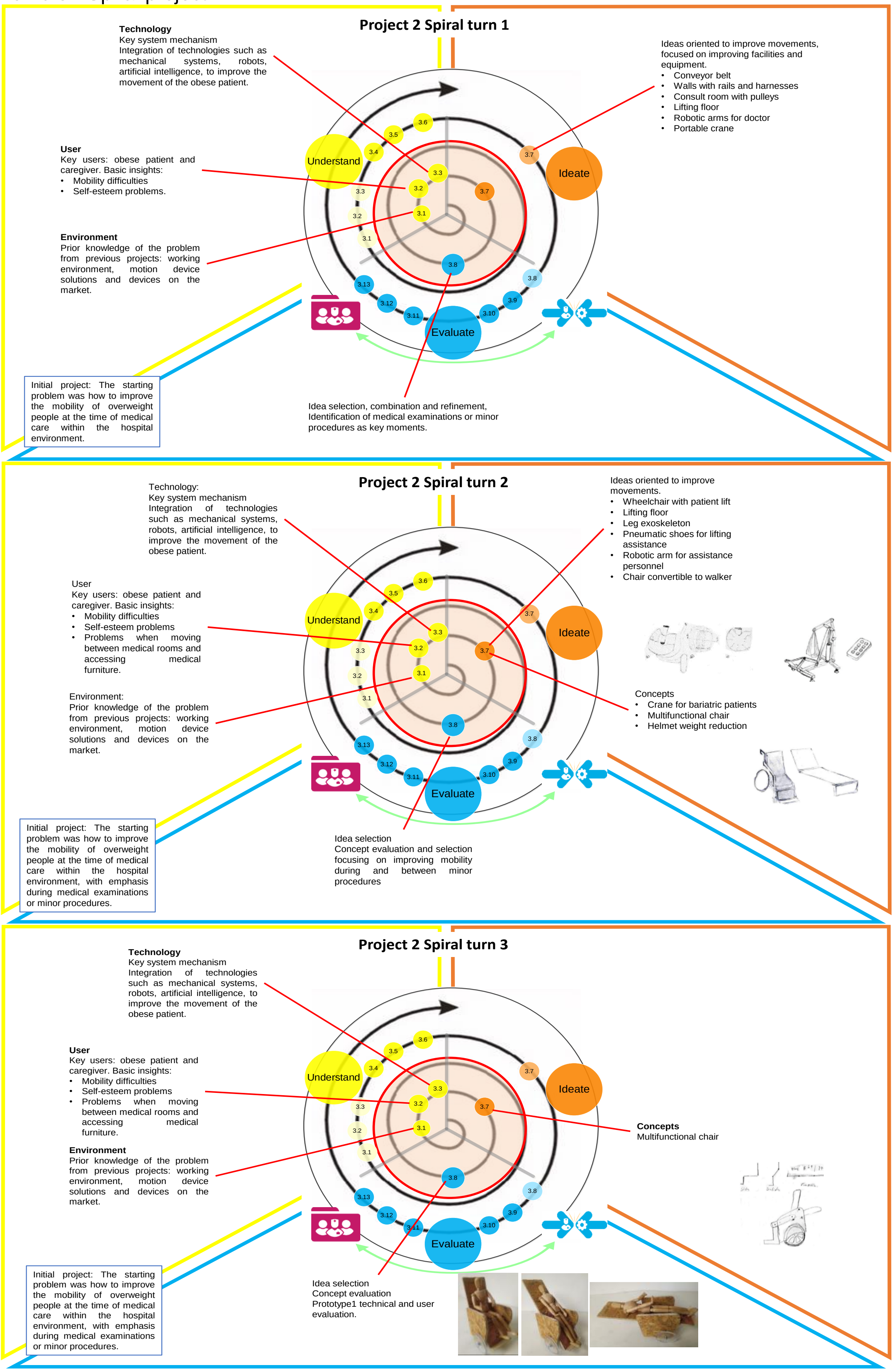
Finally, Figure 10.7 shows Project 4, which shows how the project presents few spiral turns, but it achieves an evolution of the understanding of the problem, going from the requirement to disinfect due to the dentist's and patient's fear of becoming infected, to the understanding functional aspects of the dentist's work, which focuses the ideas and concepts of the solution proposed.

Figure 10.4 - Spiral Project 1



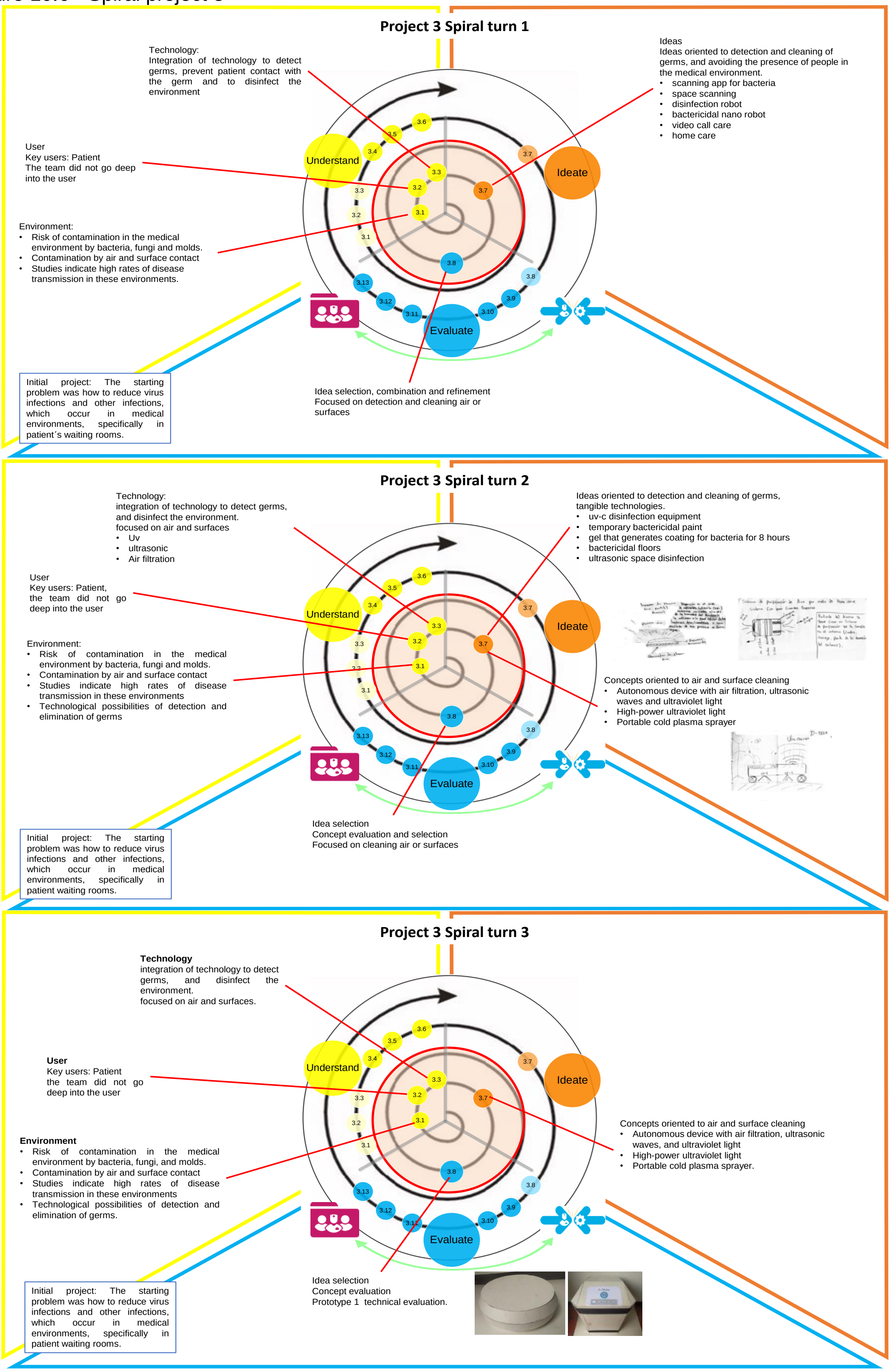
Source: the author

Figure 10.5 - Spiral project 2



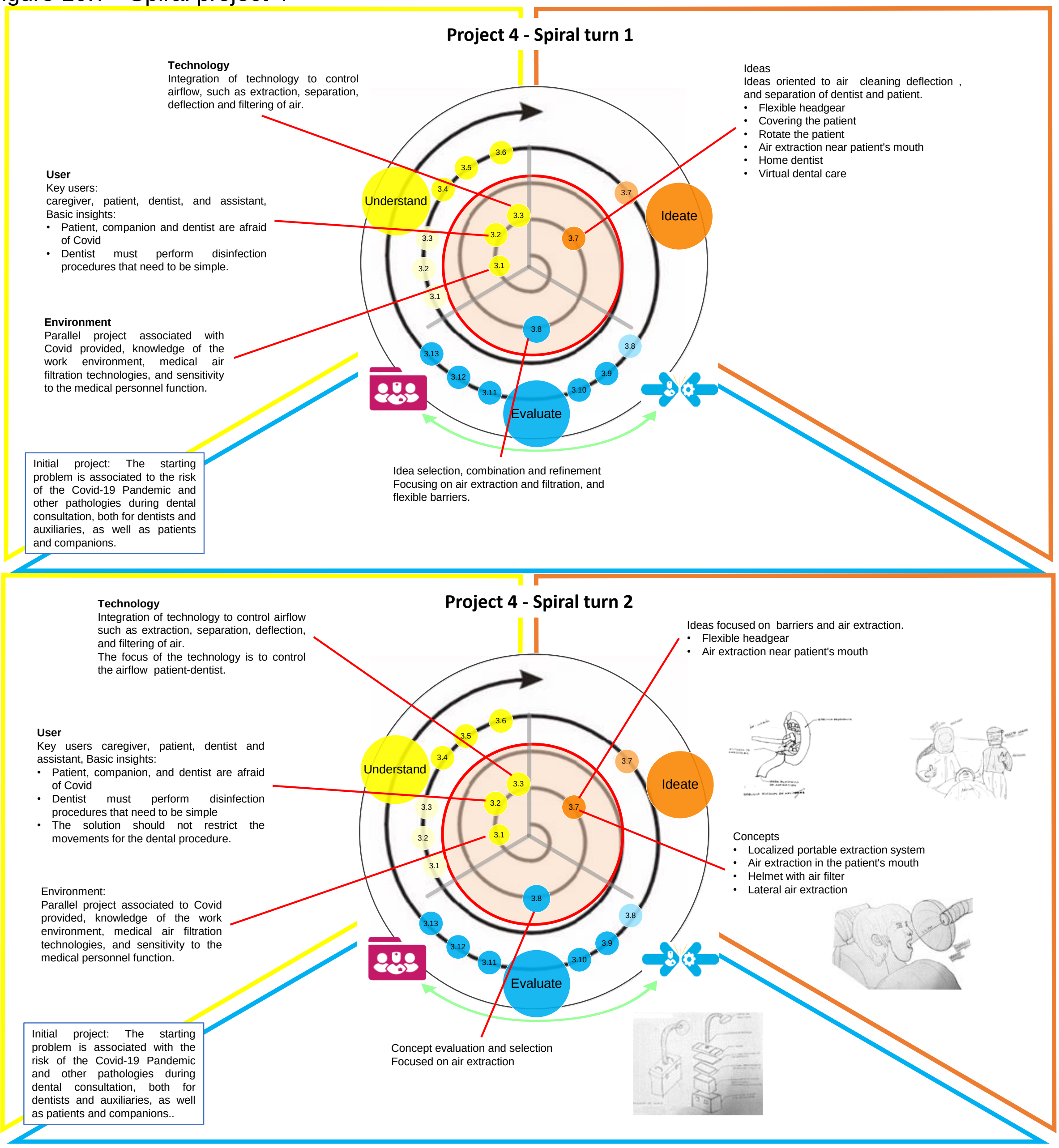
Source: the author

Figure 10.6 - Spiral project 3



Source: the author

Figure 10.7 - Spiral project 4



Source: the author

In addition to the graphical description of the projects, Table 10.6 shows the main features of project execution. In the sequence, there are a few more points to be discussed from the behavioristic point of view of the teams. Project 1 was led by a medium-experienced mechanical engineer. The team was compact throughout the project execution. This was noticeable in the participation of the sections, in which almost all the members were active in the project. Also, the members of the electronic area ceased participating in the project. Project 2 was led by an industrial designer with extensive experience in his field. The entire team enthusiastically carried out the initial part of the project. However, with the intermittency, it was observed that some team members had little participation, the members of the electronic area ceased participating in the project.

Table 10.6 - Summary of projects execution

Understand	Project 1	The team was familiar with the context of the problem by previous projects, user's understanding was made by using the Stakeholder Map technique, previous project experiences, and it was complemented by interviewing a user with mobility issues, which allowed them to determine insights: independence, company need, and users who were somewhat reluctant to use new technologies. SO, IFR and Resource analysis techniques were used to understand technology. The team was able to understand the problem from its purpose, not just as a set of mechanisms, as well as the notion of system, supersystem and subsystem.
	Project 2	The team was familiar with the context of the problem by previous projects, user's understanding was made, using the Stakeholder Map technique and from their previous experiences, they did not make direct contacts with the user. SO, IFR and Resource analysis techniques were used to understand technology. The team was able to understand the problem from its purpose, not just as a set of mechanisms, as well as the notion of system, supersystem and subsystem.
	Project 3	The team was unfamiliar with the problem, so to understand the situation, they conducted research on the problem. Its purpose was to visit sites, such as medical centers. Because of the pandemic, this was not possible. They conducted interviews with medical staff and medical service users. Nevertheless, the user's understanding was not evident. The Understanding the technology allowed to address the problem and find possible solution pathways.
	Project 4	The team was unfamiliar with the problem that arose from the pandemic. However, the company was collaborating with another Covid-related project. Therefore, they were sensitized and had some health professionals for consultation and interview. The user's understanding was realized in addition to the Stakeholder Map Technique, with an informal conversation with a dentist and experience of the problem of one of the team members. In short, the dentist is afraid of getting infected, must perform disinfection procedures which should be simple, the solution should not limit the movements for the dental procedure. SO, IFR, Resource analysis techniques were used to understand technology. The analysis of the users and technology allowed us to address the problem.
Ideate	Project 1	A section was virtually performed; another section, by using the 40 IP, in person, and the team, after performing the analysis of the ideas, made a third ideation virtually to expand their ideas and select the most promising ones. As for the generation of concepts, the team came up with their ideas to keep users' needs in mind. However, it was difficult for them to leave aside solutions they previously knew about. 11 concepts were posed. They selected Concept 1. Table 10.11. They manufactured a first prototype of the basic function, which showed problems. The team thought over the problem and came up with a new concept, which was prototyped, See Table 10.15
	Project 2	A section was supported virtually; another section, by using the 40 PI, in person, and the team, after performing an analysis of the ideas virtually, and performed the third section of Ideation and subsequent analysis in person. The approach to concepts was more rigid than the generation of ideas. They just generated three concepts.
	Project 3	Two ideation sections were virtually performed; one was directed, and the other was autonomous. Then, a face-to-face section was performed, in which an analysis of previous ideas was made. The team held a subsequent session of Ideation and analysis by starting from 75, discarding, and grouping. Finally, the team generated eight solution concepts, of which two were selected, and aesthetic prototypes of these were built. See Table 10.15.
	Project 4	Two face-to-face ideation sections were conducted, the team was noted to be rigid in Ideation. The previous analysis helped in the ideation, but it lacked depth to explore opportunities detected in the analysis. The team analyzed the most promising ideas and generated five concepts by selecting concept 1. See Table 10.14. No prototype of the selected concept was built.
Evaluate	Project 1	Ideas evaluation was carried out in independent sections of the Ideation, having as elements users' insights, which helped generate new and more refined ideas, and then, the most appropriate ideas were selected. The evaluation of the concepts was initially carried out with users' insights, and prototypes were also manufactured to evaluate the technical function.
	Project 2	Ideas evaluation was carried out in independent sections of the Ideation, having as elements users' insights, which helped generate new and more refined ideas, and then, the most appropriate ideas were selected. Concepts evaluation was essentially technical based on the team's engineering experience.
	Project 3	Ideas evaluation was carried out in independent sections of the Ideation. This evaluation was made from the technical possibilities. Likewise, the evaluation of the concepts was based on technical criteria based on the knowledge of the equipment, without user considerations.
	Project 4	Ideas evaluation was carried out in independent sections of the Ideation, users' insights were involved. The evaluation and selection of ideas showed the tendency for the air extraction technology, which was familiar to the team. Concepts evaluation was based on users and company criteria.

Source: the author

In projects 1 and 2, the company's head of unit approved implementing projects to explore problems where the company has possibilities to develop products, based on previous experiences. However, with the advancement of projects, these were not accompanied. Then, no managerial support was given. Project 3 was led by a mechatronic technologist, with extensive experience in product development and the PHE area. The team had changed throughout the project. Two of the original members no longer participated, and another member was added in the 'Understanding technology' activity, which forced them to review concepts. It was also noted that project execution was intermittent.

Finally, project 4, did not have a clear leader. The electronic engineer, who is the company manager, actively participated in the project from the start, and supported the execution. The other two mechanical engineers with extensive metalworking experience, actively participated in the project. Furthermore, we observed tiredness and less interest in the team in the final stages. The team seemed to be rigid; several ideas raised during the 'Understand phase' were not considered in the ideation phase.

10.3. PROJETS RESULTS

The main results of the execution of the project are the ideas and concepts. Thus, the ideas and concepts obtained from the four projects will be summarized. The methodology established that the evaluation of the results would be carried out according to quantity, creativity, and technological breadth. Likewise, creativity was defined by the adequacy and novelty of the solution to the problem posed. Thus, the ideas and concepts will be evaluated according to these parameters. As expressed by different authors, it is essential to consider that the degree of creativity of an idea is subjective. However, for this research, this evaluation allows to assess the results and help analyze the overall process of the project.

10.3.1. Ideas

About ideas, it is essential to keep in mind that these are the most embryonic form of a new product or service, which may consist of a high-level vision of the intended solution to the problem. Thus, the idea may lead in one direction, but it is unclear how to solve the problem. The DTRIZ methodology has a defined phase for Ideation - Ideate. However, during the Understand phase, solution ideas emerge because understanding the problem provides directions on how to solve the problem. (See Pilot Project Chapter 9). The ideas obtained in the four projects, which are the result of several processes of Ideation and analysis, will be presented in

Table 10.7, Table 10.8, Table 10.9 and Table 10.10. Similarly, the ideas are evaluated according to their creative level and the influence of TRIZ and DT methodologies.

Table 10.7 - Project 1 Ideas

#	Ideas	A	N	C	TRIZ	DT
1	Robot bed	4	4	16		
2	Mechanical hands integrated to the bed to lift the patient up	4	4	16		
3	Exoskeleton, which adapts to the shape of the older adult	3	3	9		
4	Leg system	2	2	4		
5	Voice commands for movements	3	3	9		
6	Patient detection	2	2	4		
7	Electric wheels	3	3	9		
8	Mechanisms with memory activation	2	3	6		
9	When the patient is unable to move, the product performs movements for the most comfortable position (programmed)	3	3	9		
10	Folding bed	3	2	6		
11	Gravitational field, which allows to make movements with the least effort of the patient	4	4	16		
12	Lift and lose weight	1	2	2		
13	Floor lift	4	5	20		
14	Reduce energy consumption through a counterweight	1	2	2		
15	Harness	3	2	6		
16	Levers	1	2	2		
17	Lift transfer chairs	4	4	16		
18	Material indicated for patients with sensitive skin	1	3	3		
19	Robot that does therapies to the patient	4	4	16		
20	Robotic mattresses	4	4	16		
21	Biometric commands	3	3	9		
22	Pneumatic gloves for the caregiver	1	4	4		
23	Sensors to prevent shock	3	2	6		
24	Wireless remote controls	2	2	4		
25	Reminder for medication	2	3	6		
26	Product has automated CPR devices without medical staff assistance	3	4	12		
27	Mat-type sectioned stretch - continuous	4	4	16		
28	Magnetic seat position sensor	3	3	9		
29	Lateral tilt hospital bed	4	3	12		
30	Distribute weight	2	3	6		
31	Mechanism for patients in isolation, the product has a field of protection and prevents contagion	2	3	6		
32	Bed props/supports	4	3	6		
33	Lightweight structure	2	2	4		
34	Belt system	2	2	4		
35	Easy-to-disassemble bed for home use	4	3	12		

Source: the author

Regarding creative level, column A indicates the adequacy of the idea or concept to the problem. Column N indicates the novelty of the idea or concept. These are rated from 1 to 5, being 1 the minimum score being 5 the maximum score. Column C is the product of A multiplied by N, and it indicates the creative level of the idea or concept. Concerning the influence of TRIZ and DT methodologies, the tables listed have a column, which evaluates the influence of TRIZ and DT graphically: blank box no influence, yellow box low influence, orange box high influence. This evaluation was performed by the author based on their knowledge of both methodologies.

Table 10.8 - Project 2 Ideas

#	Ideas	A	N	C	TRIZ	DT	#	Ideas	A	N	C	TRIZ	DT
1	Hydraulic crane to move patient	4	3	12			20	Adjustable walls	4	4	16		
2	Supports for patient entry and exit	4	3	9			21	Chair convertible to walker	4	4	16		
3	Independence to stand up	2	2	4			22	Patient care as a production line	2	4	8		
4	Mechanical arms integrated to the bed to lift the patient upwards	4	4	16			23	Electric skateboard with variable height and fall arrest system.	3	4	12		
5	Examination tables and beds with high and low headroom to facilitate entry and exit	4	4	16			24	Electric wheelchair with patient exit	4	3	12		
6	Patient lifting equipment	3	2	6			25	Mechano type furniture with configurable accessories	2	3	6		
7	Mattresses with pressure system to assist in patient manipulation	3	3	9			26	Aseptic Hospital	1	1	1		
8	Leg system	2	3	6			27	Pulley system to move patient	2	3	6		
9	Self-diagnosis by means of sensors and a screen	2	3	6			28	Floor lift	4	4	16		
10	Tactile system to measure pain or distress sensation	2	3	6			29	Counterweight system to lift the patient out of the chair	4	4	16		
11	Conveyor belt in corridors	2	4	8			30	Pneumatic patient lifting shoes	3	4	12		
12	Portable crane	4	4	16			31	Medical desk with lift	4	4	16		
13	Walls with rails and harnesses	4	4	16			32	Chair as bed accessory	4	4	16		
14	Monorail	2	3	6			33	Lift convertible into a chair	4	4	16		
15	Free-standing wheelchair	4	4	16			34	Bariatric care first floor hospital	3	4	12		
16	Doctor's mechanical arm	4	4	16			35	Baton with height change	4	4	16		
17	Articulating chair	4	3	12			36	Inflatable cushion to assist in patient movement	4	4	16		
18	Adjustable footrest - variable height	4	4	16			37	Entrance to the office by elevator	2	3	6		
19	Stretcher with patient stop system	2	3	6			38	Scale with electric height change	4	4	16		

Source: the author

Table 10.9 - Project 3 Ideas

#	Ideas	A	N	C	TRIZ	DT	#	Ideas	A	N	C	TRIZ	DT
1	scanning app for bacteria	2	3	6			17	temporary bactericidal paint	4	4	16		
2	medical doctor by means of an app for cell phone scanning, by scanning body symptoms and generating a diagnosis by means of software	4	3	12			18	disinfection booth	4	3	12		
3	smart cap head scanning	2	3	6			19	uv-c disinfection equipment	4	2	8		
4	space scanning	3	2	6			20	non-toxic bactericidal air	4	4	16		
5	camera or equipment, which scans the body and delivers patient diagnosis	2	3	6			21	portable uv air purifier	4	2	8		

#	Ideas	A	N	C	TRIZ	DT	#	Ideas	A	N	C	TRIZ	DT
6	generate special sanitation rooms, which create antibodies and kill bacteria	3	3	9			22	bactericidal floors	4	4	16		
7	patient self-assessment system	2	3	6			23	social networking facility	2	2	4		
8	Plants, which take up bacteria, deactivate them and generate antibodies	3	3	9			24	robotic care	3	3	9		
9	Internet of Things (IoT) chip to detect infections	4	3	12			25	disinfection robot	4	4	16		
10	infection and temperature scanning cameras in the city	4	3	12			26	portable equipment where in real time you have diagnosis of the virus in the patient	2	3	6		
11	video call care	4	3	12			27	home care	4	3	12		
12	antiviral patches to diffuse symptoms for immediate treatment	3	4	12			28	bactericidal nano robot	4	4	16		
13	gel that generates coating for bacteria for 8 hours	4	3	12			29	pre-diagnosis systems before arrival to the doctor to speed up processes	5	4	20		
14	bactericidal contact lens	3	3	9			30	Shower disinfection system (bath and disinfection)	3	3	9		
15	bactericidal smart cloth	4	4	16			31	ultrasonic space disinfection	4	3	12		

Source: the author

Table 10.10 - Project 4 Ideas

#	Ideas	A	N	C	TRIZ	DT	#	Ideas	A	N	C	TRIZ	DT
1	Home doctor	4	5	20			12	Robot	4	4	16		
2	Rinses for cleaning	4	3	12			13	Flexible barriers	4	4	16		
3	Disinfection lamps	4	3	12			114	Create vacuum or extraction close to the patient	4	3	12		
4	Personal offices - cubicles	4	4	16			15	Separate environment for patient and dentist	4	4	16		
5	Extract air	4	3	12			16	Dental chair, which can be swiveled to the side	3	4	12		
6	Air extraction near patient's mouth	4	4	16			17	Nozzle with air extraction	4	4	16		
7	Particle-trapping material	3	3	9			18	Reverse air flow	4	4	16		
8	Home dentist	3	3	9			19	Disposable gowns for patient and dentist	3	3	9		
9	Virtual dental care	4	4	16			20	Easy-to-handle patient-dentist barrier	4	3	12		
10	Not going to the dentist	3	3	9			21	Rotate the patient	3	3	9		
11	Covering the patient	3	3	9			22	Flexible headgear	4	3	12		

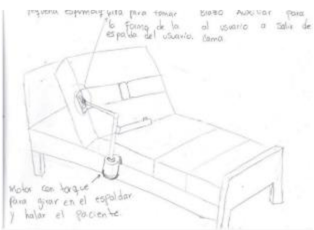
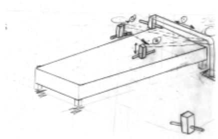
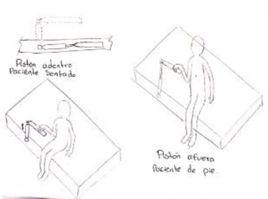
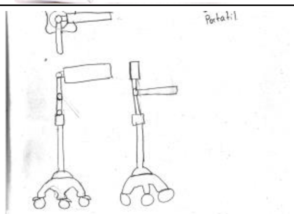
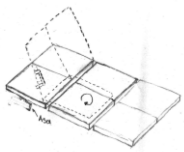
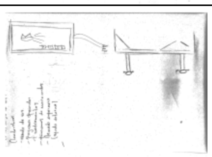
Source: the author

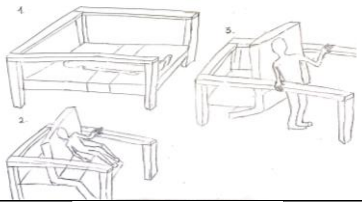
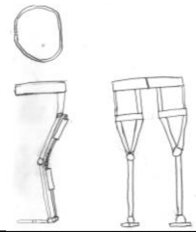
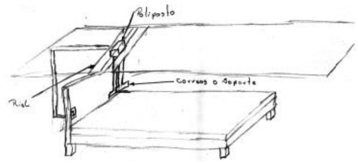
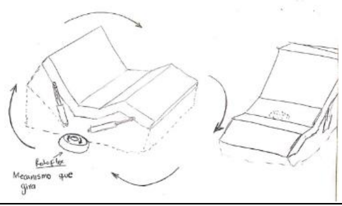
Each project presented its particularities in execution the understanding of the problem and the generation of ideas. It can be seen that in terms of the number of ideas, there are not many differences. Project 4, which generated the fewest ideas, was the one with the fewest members, with three members, two of whom were more active. In terms of quality, the ideas were varied in all the projects in general terms.

10.3.2. Concepts

The solution concepts generated will be presented, remembering that a concept is a well-defined form, which includes a written and visual description, containing the main features and benefits for the user, along with a broad understanding of the required technology and form. Table 10.11,Table 10.12,Table 10.13, and Table 10.14 show the concepts and an evaluation was performed, as explained for the ideas. Table 9.15 show the selected concepts, most of which were prototyped.

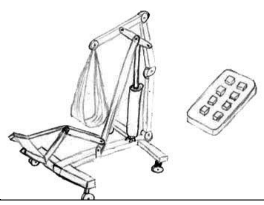
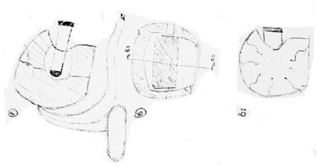
Table 10.11 - Project 1 Concepts

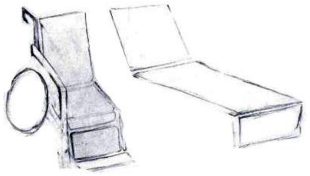
#	Concept sketch	Concept description	A	N	C	Integration
Concept 1		It consists of a sectioned mattress and a device, which can be placed on any bed. Its main function is to provide thrust and support to the patient, to assist in getting up and lying down. The device has a support, which adapts to the shape of the mattress and the bed frame, which offers support from the backrest and provides the elderly with an arm on which they can rest their hands to help them to get in and out of bed. Both arms, backrest, and handle, rotate at the same time, by means of an electric motor system.	20	4	5	DT, TRIZ
Concept 2		It is a device, which consists of an arm with handles, external to the bed, which rotates and changes height, thus allowing the older adult when holding on to the handles, to change height, rotation and thus pull him or her to the edge of the bed to help him or her to get in or out of bed.	16	4	4	DT, TRIZ
Concept 3		It is a folding and pneumatic armrest with height change. Its function is to support the patient, from the moment he or she is sitting on the bed until he or she stands up, by having it as a support during the whole journey.	16	4	4	DT, TRIZ
Concept 4		It is the portable version of concept 1. It is no longer assembled to the bed. It can be placed next to any bed. Both arms rotate at the same time, one for the backrest and the other as a handle. It does not change height and has wheels for its displacement. The upper arm, for the back, has a smaller foam thickness compared to concept 1 so that it is not uncomfortable for the patient. The lower arm serves as a handle for the older adult to lean on.	12	4	3	DT, TRIZ
Concept 5		It consists of a sectioned mattress, which allows the central section of the mattress, which is fixed to the bed, to rotate together with the backrest, thus leaving the feet of the older adult outside the bed and with the integrated handle, he or she can support him or herself to get out of bed. The rotation is made by an electric motor system.	16	4	4	DT, TRIZ
Concept 6		This concept is based on a bed, which makes the required movements by means of voice commands given by the patient: changing the angle of the backrest and legs, alarm to take medication, and call the nurse. In short, it is to adapt a voice recognition system to an existing electric bed.	6	3	2	DT, TRIZ

#	Concept sketch	Concept description	A	N	C	Integration
Concept 7		This concept allows to perform the different movements of the bed, by using a wireless headband so that patients, who have difficulty speaking, can control the bed with commands through brain-generated signals.	2	3	6	DT / TRIZ
Concept 8		It consists of a bed with actuators, which makes chair position to accommodate the patient and to prepare him or her to get out of bed. Once made the chair position, the bed continues to vertical position so that the patient is completely standing. The side supports are for the patient to lean on when the bed goes from chair to upright position.	5	4	20	DT / TRIZ
Concept 9		It is an exoskeleton, which supports the legs and hips of the elderly to give greater autonomy, from getting in and out of bed, as to go for a walk without the assistance of a companion.	3	2	6	DT / TRIZ
Concept 10		This concept consists of the implementation of rails on the ceiling above the bed, where a hoist slides, which has straps to hold the patient to lift him or her out of the bed and to help him or her to stand up.	3	3	9	DT / TRIZ
Concept 11		This concept is a mattress for platform type beds, which has integrated actuators to make degree changes in the backrest and legs. in addition, it has a system, which rotates on the lying surface to allow the patient to get out on one side of the bed.	5	4	20	DT / TRIZ

Source: the author

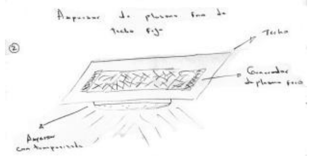
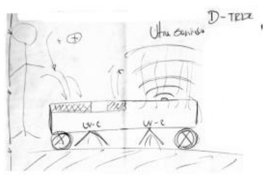
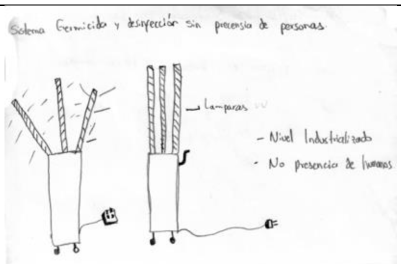
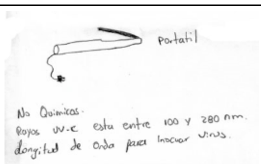
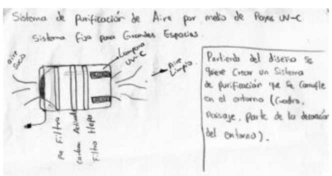
Table 10.12 - Project 2 Concepts

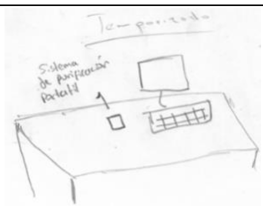
#	Concept sketch	Concept description	A	N	C	Integration
Concept 1		A crane for bariatric patients with possible operation by means of wireless control. The electro-hydraulic crane is operated by means of pedals and a manual remote control and possibility of wireless control, has a robotic arm, with rails for its displacement and transport, which is throughout the hospital, with a counterweight system for the exit of the patient and incorporates a solar charging system.	4	3	12	DT / TRIZ
Concept 2		The idea is to make a helmet, which is made of a very light, but resistant material, such as carbon fiber, which can read the person's thoughts when he or she feels the anxiety of overeating, which can read the pulsations and neuronal signals of the brain, in order to find a psychological and physical cure for the patient and help him or her with some good nutrition and improvements in eating habits to achieve weight reduction.	1	3	3	DT / TRIZ

#	Concept sketch	Concept description	A	N	C	Integratio n
Concept 3		Multifunctional chair, which can help the patient to transport, to get up, and to have a little more normal mobility being mounted on it, It is expected that this chair comply with the movements of chairs, extends horizontally to become bed, a chair, which helps the patient out, with motorized wheel to achieve move its high weight.	5	4	20	DT TRIZ

Source: the author

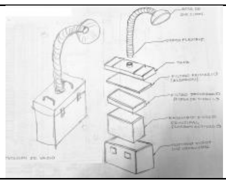
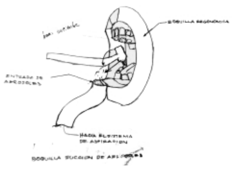
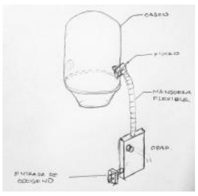
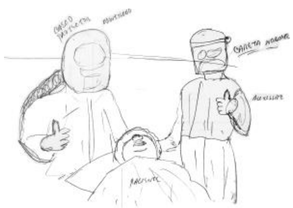
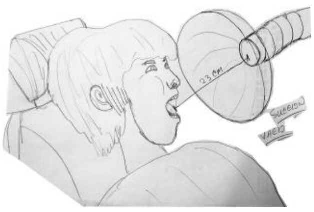
Table 10.13 - Project 3 Concepts

#	Concept sketch	Concept description	A	N	C	Integration
Concept 1		Portable cold plasma sprayer, the device filters the air and disperses hydroxyl OH radicals, which adhere to viruses or bacteria and produce an oxidation and deactivates viruses and eliminates bacteria present in the environment. These electrically charged particles are then attracted to each other, thus increasing their size and making it easier for them to be trapped by the filter.	4	4	16	DT TRIZ
Concept 2		Fixed cold plasma sprinkler, its operation is similar to the previous one. However, it is installed in the air conditioning system.	4	3	12	DT TRIZ
Concept 3		This concept seeks to integrate three disinfection methods in a single device, which can move autonomously over the floor of a given area, by avoiding obstacles. Trapping impurities and eliminating viruses and bacteria in the environment during their journey. The three disinfection methods are filtering the air, emission of ultrasonic waves, and emission of ultraviolet light (UV-C).	4	4	16	DT TRIZ
Concept 4		This concept refers to a germicidal and disinfection device by means of high-power ultraviolet light, which must be used in places with a large area and without the presence of people.	4	3	12	DT TRIZ
Concept 5		It is the portable version of concept 4, with less power to perform disinfection and cleaning processes in the presence of people.	3	2	6	DT TRIZ
Concept 6		This is an air purification device, which combines an air filtration system composed of 3 filtering stages and an ultraviolet light generator (UV-C). It is a fixed installation, suitable for large spaces.	4	3	12	DT TRIZ

#	Concept sketch	Concept description	A	N	C	Integration
Concept 7		It is the portable version of concept 6, to which a timer is added to control the working periods, according to user's needs.	4	3	12	DT / TRIZ

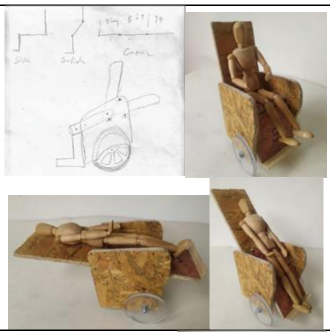
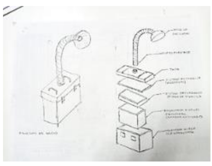
Source: the author

Table 10.14 - Project 4 Concepts

#	Concept sketch	Concept description	A	N	C	Integration
Concept 1		It is a localized portable extraction system, which by means of the tube, is positioned in the most convenient way and close to the patient's mouth. It has air filters and can be integrated chemical or physical systems to deactivate viruses, fungi, or bacteria.	4	4	16	DT / TRIZ
Concept 2		The concept is an extraction system, which is placed directly in the patient's mouth. Dentists use a flexible tube to extract saliva, which works by vacuum. This tube is modified to perform saliva extraction and to generate a localized air extraction.	4	5	20	DT / TRIZ
Concept 3		Helmet with air supply, a protective helmet to be used by the dentist and assistant. The helmet has an air supply with flexible hoses and can be connected to an oxygen supply.	4	3	12	DT / TRIZ
Concept 4		Helmet with air filter, which completely covers the dentist's head and filters the air that he mor she breathes. In this way, the dentist has no space limitations to treat the patient.	4	3	12	DT / TRIZ
Concept 5		Lateral air extraction system, which is manipulated by a flexible tube, which is positioned so as not to obstruct the dentist's job.	4	4	16	DT / TRIZ

Source: the author

Table 10.15 - Final concepts

	Concept	Comment	A	N	C
Project 1		The team called the concept "getting out of bed while in bed." Part of the elderly person's physical difficulty in moving and their need to get out of bed, receive visitors, or do things like reading, eating, or feeling out of bed. The bed has lateral movement. The bed has the back and feet movements. It performs a lateral movement to allow the patient to sit on the side of the bed and, from the chair position, raise it up to assist the patient in standing or sitting up.	5	5	25
Project 2		The selected and prototyped concept was a chair, which can be a transport and recovery stretcher, with tilt movements of the patient's back, feet, elevation, and exit. Unlike existing chairs, the multifunctional chair has motorized transfer, and it can be a comfortable stretcher to keep the patient lying down for several hours.	5	4	20
Project 3		The concept is an air purification device, which combines an air filtration system of 3 filtering stages and an ultraviolet light (UV-C) generator, which can be mounted in any environment without any modifications to the facilities.	5	4	20
		The concept is a stand-alone device, which integrates three disinfection methods: air filtration, ultrasonic wave emission, and ultraviolet light emission (UV-C).	4	4	16
Project 4		The concept is a localized portable extraction system, which, using the tube, is positioned most conveniently and close to the patient's mouth. It has air filters, and it can be integrated with chemical or physical systems to deactivate viruses, fungi, or bacteria.	4	4	16

Source: the author

The concepts generated in each project were more disparate than the ideas in terms of number and quality. Some teams explored the ideas further to conceive varied and valid concepts. In the end, all teams arrived at solution concepts evaluated as creative, or potential for products with a high degree of innovation.

10.4. PROJECT EVALUATION

The projects were carried out until product concepts were developed, and the ideas generated, the concepts conceived, and the concepts selected were compiled. An evaluation of the project´s results - ideas, and concepts, was made in this section. The ideas generated in the four projects are shown in

Table 10.7,Table 10.8,Table 10.9, and Table 10.10. Likewise, an evaluation of these ideas was carried out in order to determine the level of creativity of each one. The ideas with a creativity rating of 16 or higher are highlighted, which are considered highly creative ideas.

Table 10.16 shows a summary of the analysis of the ideas and concepts generated in the four projects, showing the number of ideas generated, the ideas considered of high creative level - rating of 16 or higher, the ideas considered of low creative level - rating less than 9, the number of concepts and the concepts of high creative level - rating of 16 or higher. Additionally, the table has the column interface, which mentions the issues that mediated between the generation of ideas and the conception of concepts.

Table 10.16 - Summary of project's results

	Ideas	interface	Concepts
Project 1	35 ideas, 8 HLCs, 24 LCL Greater predominance of TRIZ in ideation, the tendency to use technology to solve user problems can be noted. The ideas explored various technological possibilities	Problem approach: latent and functional. Highly iterative process, several spiral turns in the evaluation of ideas and concepts. A significant amount of time was dedicated to the project Cohesive team 6 members.	12 concepts 7 HCL, 4 LCL The concepts have a high integration of TRIZ and DT, integrating technology with functional and latent aspects of the users. The concepts with HCL are the ones that best integrate TRIZ and DT. The concepts explored various technological possibilities.
Project 2	38 ideas, 14 HCL, 17 LCL Greater predominance of TRIZ in ideation, the use of technology to solve user problems is dispersed. Ideas explored various technological possibilities	Problem approach: functional. Iterative process with more emphasis on idea evaluation and few on concepts. Time spent on the project was limited Team not very cohesive 6 members	3 concepts 1/3 HCL, 1/3 LCL The conception of the concepts showed little analysis of the technology, users, and previous ideas that indicated various solution paths. Limited technological breadth
Project 3	38 ideas, 7 HCL, 7 LCL Greater predominance of TRIZ in the ideation, the relationship of the technology to solve the problems of the users is not noticed, the focus is to disinfect. Ideas with focus on several technologies, scientific effects were used, lack of depth.	Problem approach: functional. Iterative process with more emphasis on idea evaluation and few on concepts. Time spent on the project was limited Team not very cohesive 6 members	8 concepts 3 HCL, 1 LCL Limited technological depth, although technologies were procured, user aspects were not present. Limited technological breadth.
Project 4	22 ideas, 9 HCL, 6 LCL Greater predominance of TRIZ in ideation, clear understanding of the problem, the tendency to use technology to solve user problems can be noted. Low technological breadth.	Problem approach: functional and partially latent. Not very iterative process Limited time was dedicated to the project Cohesive team 3 members	5 concepts 3 HCL, 0 LCL The concepts focused on two principles: separating the patient from the dentist and air extraction. Technological and user depth was lacking. Limited technological breadth.

Interface: the aspects that mediated the conception of concepts, starting from the creation of ideas.HCL: High Creative Level
LCL: low Creative Level

Source: the author

In Project 1, 35 ideas were generated, of which eight are considered highly creative ideas (22.9%) and 18 low creativity ideas (51.5%). As for the technological breadth, most of the ideas correspond to the mechanical and electronic technological domains, as expected because the problem is to help the movement of elderly people in the context of the bed, with emphasis on the entry and exit of the bed. The range of ideas varies from simple supports in bed to robots, or floor lift, which is opposed to raising and lowering the bed, with which according to the team, it is possible to adapt to existing beds and spaces.

As for the concepts in Project 1, 12 solution concepts were generated, of which 7 are considered highly creative (58.3%). It can also be seen in Table 10.11 that only three are considered low creativity. In general, a variety of solutions was presented, and a high degree of creativity was evident, from bed accessories to novel bed designs, some of which are unprecedented in the market, such as concepts 1, 2, 5, 8, and 11. The team selected concept 1 tested and discarded due to performance problems. From the proposed concepts, previous experimentation and analysis of the problem, they conceived a new concept, which was selected and prototyped as shown in Table 10.15. It should be noted that there is no known commercial precedent for this concept and it is adequate to the problem posed, from the functional - movement, and it integrates the needs of the users found by the team - needs for autonomy and companionship. Thus, the selected concept is considered to complement the technological and human in the sense that technical functions are integrated from the findings with the user.

In Project 2, 38 ideas were generated, of which 14 (36.9%) are considered highly creative ideas and 14 (36.9%) correspond to less creative ideas. As in project 1, most of the ideas come from the mechanical and electronic areas, since the issue is about the movement of obese people in the hospital environment. The team considered different approaches in the Ideation, accessories, new equipment, and facilities in the hospital. The team generated three solution concepts, one of which was considered highly creative. The concepts were few considering that 14 highly creative ideas were generated, several of these ideas were not explored to conceive new solution concepts. For example, elevating floor, adjustable footrest - variable height, integrated robotic arm, among others.

In Project 3, 32 ideas were generated, out of an initial 95, of which seven ideas (21.9%) are evaluated as high creative level, and 8 (25%) are evaluated as low creative level. The team considered several approaches to the problem: home care, pre-diagnosis, measurement device, air cleaning and surface device. In terms of concept generation, the team focused on air and surface cleaning as the essence of the problem. Of the seven concepts, there are four original concepts, the others are variants. The team approached the problem with a more technical than human approach, from the user's point of view, the relationship was mainly functional. For example, it does not affect or cause discomfort to people. It was necessary to go deeper in finding physical and chemical principles to solve the problem, since technology offers several possibilities to eliminate pathogens from the environment.

In Project 4, 22 ideas were generated, of which 9 (40.9%) were evaluated as highly creative and none as having a low level of creativity. The approaches proposed in the ideas were diverse: separating the dentist from the patient, barriers, helmets, extraction, and air flow, and even, turning the patient in order to facilitate the dentist's work and, by directing the air flow in another direction. Two directions of solution were explored: extraction with various concepts and separation for the dentist. Several of the ideas generated to conceive concepts were not fully explored, as well as the verification of other physical and chemical principles, which could help solve the problem. The team focused on the technical aspect of the problem and the functional aspect of the dentist, with little exploration of non-functional needs and desires.

It can be seen how the projects were disparate in the results of the ideas and concepts, the pilot project, and Projects 1 and 4, achieved results of high quality concepts. These projects were where the teams were more cohesive - plural participation and good communication, their perspective of the user was from the functional and latent - symbolic or emotional aspects. Projects 2 and 3, despite having a high number of ideas and some with high creative level, did not achieve high-quality solution concepts.

In Project 2, the Understand phase showed good results, as well as ideation, 38 ideas 14 with a high level of creativity. However, they did not achieve to adequately carry these ideas and problem understanding to conceive concepts with higher quantity and quality. As for Project 3, from the beginning, its analysis was focused on the function – disinfecting. They did not achieve a holistic understanding of the problem.

Finally, a process evaluation of the application of the Late FFE model and the results - measurable criteria, (See Table 10.17). This evaluation is supported by Table 10.6, which shows a summary of the implementation of the projects in the Understand, Ideate and Evaluate phases, and the indicated results of the projects.

Table 10.17 - Overall process evaluation

		Category	# Variable	Variable	Project 1	Project 2	Project 3	Project 4
Process variables	Aspects of how projects are carried out.	Understand	1	Understanding the problem from the user's point of view	5	4	2	4
			2	Understanding the problem from the technology	4	4	3	4
		Ideate	3	Process of idea generation	5	5	4	4
			4	Process of concept generation	5	2	3	4
		Evaluate	5	Ideas evaluation	4	4	4	3
			6	Concept evaluation	3	2	3	3
		Overall process (Links)	7	Spiral process	5	3	2	2
			8	TRIZ and DT complement	5	4	2	4
Result variables	Tangible process results	Ideas	9	Number of ideas generated	4	4	4	3
			10	Creative level of ideas	4	4	3	4
			11	Technological breadth of ideas	4	4	3	4
		Concepts	12	Number of concepts conceived	5	2	3	4
			13	Creative level of concepts	4	2	3	4
			14	Technological breadth of concepts	4	2	2	3

Source: the author

10.5. METHODOLOGY APPLICATION ANALYSIS

Up to this point, Chapter 9 has focused on showing the projects, from preparation and training to execution and results. The purpose of this section is to analyze and to reflect on the DTRIZ methodology application in the four projects beyond the results and finally propose adjustments to the DTRIZ methodology synthesized in Chapter 8. The information used for the analysis of the applications of the methodology is the materials generated during the projects, the results of projects, the classroom notes made throughout the sections, observations made in the face-to-face meetings to accompany the projects, and an interview at the end of the projects with a member of each team, one of the people, who participated most in each project was interviewed.

10.5.1. Analysis of project implementation

Table 10.6 shows the main characteristics of the project process separated by the three phases: Understand, Ideate, and Evaluate, in turn, Table 10.16 shows an analysis of the ideas and concepts, respectively. As indicated, all teams came up with at least one good concept, but the results were mixed. Again, aspects such as the social environment, motivation and even team composition, and leadership are determinants, but these aspects are beyond the scope of this research. Some relevant points of the three phases: Understand, Ideate, and Evaluate, will be discussed.

The proposed Late FFE model - DTRIZ, is based on the project spiral concept at the macro level and at the Understand Ideate and Evaluate phases it is based on TRIZ and DT methodologies. Figure 10.4, Figure 10.5, Figure 10.6, and Figure 10.7 show the evolution of each project as seen from the project spiral concept. When analyzing the realization of the four projects, it is noticed how the turns of the spiral provide accumulation of knowledge about the problem. By keeping the process in the spiral after creating ideas or conceiving concepts, it proposes a new formulation of the problem and refinement of the project.

All projects started with a general problem and ended with a more specific formulation of the problem, and ideas and concepts centered on this new formulation of the problem. In this way, the spiral provided the scenario for maturing the problem, by avoiding further development with seemingly good ideas or concepts when the problem was not yet clear.

Regarding the integration of TRIZ and DT methodologies in the process phases, in Projects 1, 2 and 4. This integration is notorious as support in the realization of key activities and to direct the process. In Project 3, this integration was less notorious. In the Understand phase, the integration of both methodologies was noticeable in Projects 1 and 2, with less intensity in Project 4 and few in Project 3. In Projects 1 and 2 the teams understood the problem from the user and directed the technology to solve the need, with greater success in Project 1. In Project 4 the team understood the problem from the technology and the understanding of the user refined the solutions, and Project 3 understood the problem exclusively from the technology.

In the Ideate phase, regarding the ideation process, the integration of TRIZ and DT methodologies was evident, even though two ideation sections were proposed with intuitive and heuristic techniques respectively, the influence of previous analysis with both methodologies was present in both sections.

On the other hand, as for the results, the tables which show the ideas of the projects indicate the influence of both methodologies, with TRIZ predominating. However, in the results of the concepts, both methodologies have a marked influence. It is worth mentioning that the ideas are basic proposals without structure, while the concepts require more elaboration and the linking elements of the problem. Finally, in the Evaluate phase, the DT challenge, and the visualization environment, and the TRIZ concept of ideality, complemented each other, although a deeper evaluation of the more mature concepts was missing in all projects (including the pilot project).

Additional comment, DTRIZ methodology greatly emphasizes the Understand phase, as it can be seen in 8.2.1. Therefore, in the training and projects execution, this phase was given relevance, for all teams to analyze the problem from the user and the technology was new, difficult to assimilate, and challenging. In all four projects, the emphasis on problem analysis was a new approach to dealing with the projects, as was the methodology used for such an analysis. Understanding the problem from the environment, user and technology, showed different directions to analyze the problem, which is essential. This approach contrasts with the more general practice found in different companies[3], for the design of a new product when there is no precedent of a previous product in the company or the market, the common practice is to conduct market research with emphasis on finding solutions, by defining specifications and generating one or more alternative solutions. The impact of the Understand phase for the teams could be summarized in the following sentence: the teams understood the power of problem analysis, discovered the user as an active entity, and found the analysis of technology as a source of solutions rather than the technology itself.

10.5.2. Reflections on the DTRIZ methodology

The DTRIZ methodology chronologically consists of three phases with defined objectives: Understand, consolidate users' needs with the ideal and technological trend; Ideate, combine DT creation environment with the TRIZ solution direction and Evaluate, examine the solution from the user's point of view, the ideality, and technological evolution. All within a project spiral concept, as shown in Figure 8.11.

[3] This is congruent with the results of the master's research in the PHE sector, where it was found that the companies investigated, for projects with a high degree of innovation, emphasized more on finding solutions than on understanding the problem.

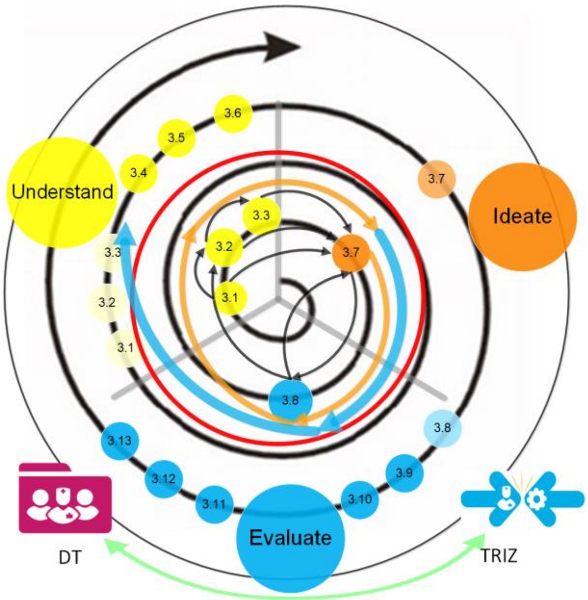
Level 1 of the spiral represents the most diffuse part of the project because at this level the team starts with a problem to be solved in the form of a product, but few elements of the problem are known. When the project is at level 2 of the spiral, it is already a mature project because the problem is better understood and there are product concepts. New elements of understanding and evaluation are introduced at this level, as explained in chapter 8.

PDP or FFE linear models start from the assumption of separating the problem domain and the solution - Analysis and Synthesis, as seen in Figure 4.1. On the contrary, the proposal synthesized in the present research starts from the fact that for some types of problems, it is not possible to separate the problem from the solution, social problems, or Wicked problems indicated by (BUCHANAN, 1992), or complex problems, defined by the number of elements and the relationships of these elements. Thus, at level 1, as it was corroborated in the execution of the project, it is difficult to separate the three phases: Understand, Ideate, and Evaluate. In the problem analysis, ideas arise. Also, during Ideation, an evaluation, analysis, and combination of ideas is made, which is the most basic and initial form of the Evaluate phase. However, this evaluation of ideas in the process flow outlined in Chapter 8 is in the Ideate phase.

In summary, the three phases in the first turns of the spiral represent domains rather than separate phases, and as the project achieves tangible results - clear ideas and solution concepts, and greater understanding of the problem, the subsequent turns of the spiral require each phase to be performed in a more complex and separate manner. Figure 10.8, shows the flow of reasoning in the project's execution studied. The black arrows represent the spiral flow in the first turn of the spiral - Understanding domain, the thickness of the arrows represents the level of maturity. Thus, from each activity of understanding the environment, user, and technology, ideas can be generated as to how the problem can be solved. During Ideation, ideas are evaluated to generate more consistent ideas, which improves the understanding of the problem situation and focuses attention on some aspects of the problem - problem refinement.

Figure 10.8 shows how the second turn of the spiral is represented by orange arrows - Ideate domain, which are thicker, indicating greater maturity of the process. Thus, more consistent ideas are refined, generated, and evaluated, starting from ideas and understanding. Next, we move to the third turn represented by blue arrows - Evaluate domain, conceived concepts. The concept conception is based on the ideas and previous understanding of the problem. Later, these concepts are evaluated, which, in turn, help improve the understanding of the problem, making it possible to conceive new solutions concepts. At this point, if the concepts are considered adequate, it is possible to move to level 2 of the spiral.

Figure 10.8 - Initial process evaluation



Source: the author

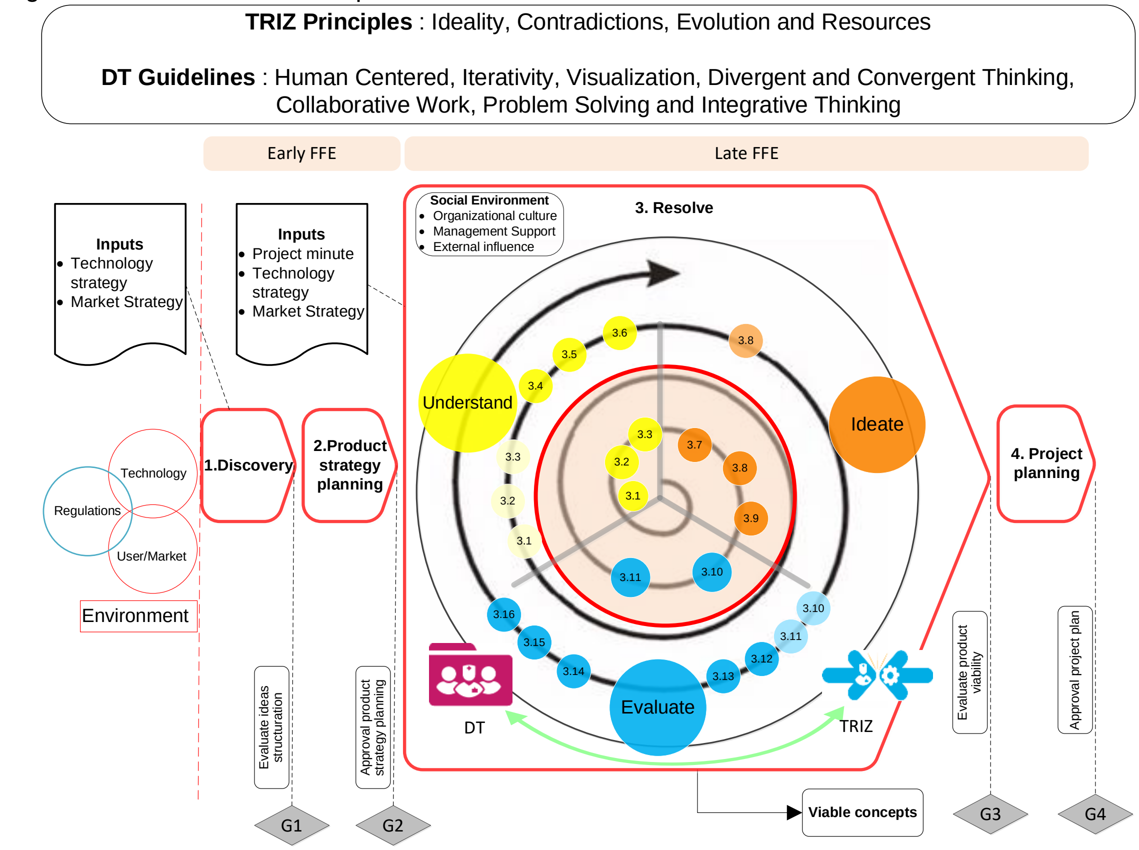
10.5.3. Proposals for improvement of the DTRIZ methodology

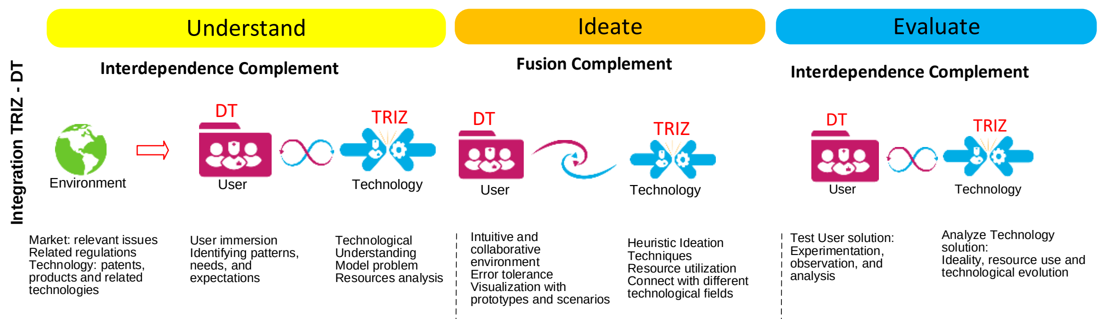
By analyzing the process flow of the DTRIZ methodology, presented in chapter 8, the analysis of the project's execution, and the reflection of numeral 9.5.2, some points emerge that could be bettered: improve the integration of the user and technology in the FFE; improve the generation of ideas in terms of quantity, novelty and technological breadth; enhance the conception of plural concepts from the understanding of the user and technology, visualize and evaluate them; facilitate that the insights from the user and technology are preserved in the Ideation and evaluation.

Some modifications to the DTRIZ methodology are proposed to improve the results and facilitate the implementation of the projects. The first modification is in the structure, which consists of modifying activities. The Ideate phase was defined as an activity with several tasks. See Figure 10.9. The project's execution indicates that this activity could be separated into the following activities: generate ideas, create concepts, and visualize concepts. In this way, the model separates what in practice is done separately, the generation and evaluation of ideas and the creation and evaluation of concepts. In addition, emphasis is being made on visualizing the concepts. As indicated, building prototypes allows better internal team communication, helps interaction with the user, and is a form of creation. Likewise, activity 3.8 evaluates the user and technology. In order to facilitate and emphasize the evaluation from both directions, it is clearer to separate it into two activities: evaluate from the user and evaluate from technology. Figure 10.9 shows the changes in the activities.

The second modification is more oriented to the self-reflection of the DTRIZ process. Structurally, the process is based on a spiral, and it presents some TRIZ principles and DT guidelines, as shown in Figure 8.12 and Figure 10.9. In practice, some teams tried to perform the activities in a linear process, a situation more noticeable in projects 3 and 4, perhaps due to the predominant linear structure in the PD processes. It was also indicated that the initial understanding of the problem was diluted in most of the projects except for project 1. Thus, it is proposed from the training to emphasize that the process is not linear, but based on a spiral, with the first turn focused on idea generation, the following turn on concept conception and the next turn in concept debugging until having, if possible, several alternatives of concepts initially evaluated from the user and technology drivers. The changes made in the activities tend to make the process in independent cycles of creation of ideas and conception of concepts, which facilitates the spiral structuring.

Figure 10.9 - DTRIZ model improved





	Understand	Ideate	Evaluate
Phase objective	Understanding the environment, User, and Technology to consolidate user needs with technological ideality and trend	Combine DT creation environment with TRIZ solution addressing to Create concepts	Evaluate the concepts of technology, user, regulations, and business
Main outputs	Perception of the problem from Users Understand the problem from Technology Understand the resources of the problem	Solution Ideas with intuitive and heuristics techniques Solution concepts driven by insights Concept visualizations in the form of prototypes	Viable concepts
Key activities – Level 1	3.1. Explore the environment and regulations 3.2. Make immersion with Users 3.3 Analyze technology and resources	3.7. Generate ideas 3.8 Create concepts 3.9Visualize concepts	3.10. Evaluate user 3.11. Evaluate technology
Key activities – Level 2	3.4 Validate market 3.5. Define requirements 3.6. Determine specifications		3.12. Define risks 3.13. Classify product type 3.14. Determine tests 3.15. Analyze product economically and financially 3.16. Manage intellectual property
Main techniques	Stakeholder Map Customer Journey Persona Empathy Map Observation Interviews Storytelling Learning experiences/Test Contend Analysis System Operator Size, Time, Cost Operator Method of Smart Little People Trends of Evolution (TEs) Ideal Final Result (IFR) Contradiction Analysis 39 Engineering Parameters Analysis of System Resources	Brainstorming Co- creation Rapid Prototyping 40 Inventive Principles Separation Methods (SP) Contradiction Matrix Scientific Effects Trends of Evolution (TEs) 76 Inventive Standards 39 Engineering Parameters Analysis of System Resources Method of Smart Little People	Learning experiences/Test Observation Scenarios Interviews Storytelling Contend Analysis Ideal Final Result (IFR) Trends of Evolution (TEs) Analysis of System Resources Evolution radar

Source: the author

Likewise, it is necessary to highlight the importance of drawing explicit conclusions from the activities to understand User Environment and Technology - Insights, by considering that these Insights will vary or evolve in the successive turns of the spiral, due to the new knowledge acquired. In order to facilitate the transfer of knowledge from the Understand phase during the process, it is proposed to create a simple format as support. During the execution of the projects, cards and formats were created to facilitate the implementation of the different techniques, which showed that it helped the teams carry out the activities and obtain tangible and summarized results.

Finally, as noted in the implementation of the projects, it can be seen that the predominant techniques for the generation of ideas were Brainstorm, Contradiction Matrix, and 40 Inventive Principles. In project 3, the Scientific Effects technique was also used. Figure 10.9 shows various techniques used in Ideation from TRIZ and DT. In order to improve the use of other ideation techniques, training could be improved, and examples of use could be included. For example, Chapter 9 shows how TEs are a source of ideas from understanding technology, as references are (AGUILAR-ZAMBRANO et al., 2012; CARVALHO, 2017). This does not constitute a change in methodology, and it is more of an improvement in implementation.

11. CONCLUSIONS

The academia shows interest in the FFE in HDI context. However, it is not a consolidated subject in the literature yet. In the introduction some gaps in the academy on the FFE were presented: lack of adequate practices for the implementation of projects in HDI context; the lack of specific, operable and balanced FFE models between what to "make" and "how" to do it; and the need to integrate engineering best practices to the PHE sector. Thus, the objective of this research is to synthesize a Late FFE model - DTRIZ methodology, for industrial companies in the PHE sector, by integrating TRIZ and DT.

Chapter 8 first proposed a procedural model of Late FFE, based on the previous results of the author's master's degree research. In addition to the bibliographic research on FFE, HDI, the creative process, and the relationship between the degree of innovation with the iterations and flexibility of the process. Later, based on this model and with the bibliographic research on TRIZ and DT, which allowed to understand its essence, these methodologies were integrated in the proposed model, to obtain a performative model for the indicated context.

The insertion of TRIZ and DT can be established at three levels: philosophy of the DTRIZ methodology, general process, and use of techniques in specific tasks. Regarding the philosophical level, TRIZ principles and DT guidelines constitute the guide for the process. In Chapter 7, a comparison of both methodologies was carried out and how both can complement each other in the FFE, aspects such as: emphasis on problem abstraction to understand the essence of the problem - TRIZ vs emphasis on observation and analysis of those involved and the context to understand the essence of the problem – DT, represent complements. However, other aspects, such as: very rational – TRIZ vs very intuitive – DT, represent divergences. In general, as it was stated in the proposal and evidenced in the projects carried out, the contribution of the insertion of TRIZ and DT to the DTRIZ methodology from a philosophical point of view is notorious and positive.

In terms of process, the DTRIZ methodology is based on the project spiral, and it is made up of three phases: Understand, Ideate, and Evaluate. The analysis of TRIZ and DT carried out in Chapter 7 indicates how the iterative process is congruent with the essence of DT. In contrast, the different procedural forms of TRIZ are sequential, the ARIZ analysis facilitated the insertion of TRIZ into the three phases of the project spiral-based FFE model. Regarding the techniques, as indicated in Chapter 8, TRIZ and DT provide numerous techniques for the different tasks. In the realization of the projects these techniques showed a support in the tasks, and complement of TRIZ and DT, which allowed the teams to facilitate the understanding, ideation, and evaluation, from both directional User/market and technology.

The underlying assumptions of the model are basically as follows: it is possible to propose a FFE model for the HDI context; the use of project spiral in two levels, level 1 with few elements for fast execution, helps to execute projects in the HDI context and to improve results; and the integration of TRIZ and DT in the three phases Understand, Ideate, and Evaluate, helps to operationalize the Late FFE model and to improve results, specifically for the PHE sector.

The model shown in Figure 8.12 - DTRIZ methodology, which was used for the realization of the described projects, shows that it is suitable for the proposed task: to support the realization of the initial and more diffuse phase of new product projects - Late FFE, in the context of high degree of innovation for the PHE sector. The results show that most of the projects resulted in numerous ideas and several concepts considered to be of high creative level (except project 2, only one concept of high creative level).

Thus, Project applications indicate that despite differences in procedures and results, the assumptions are correct. In this way, the objectives proposed in the research are achieved.

The main contributions of the present research to academia are: first, an explicit clarification of the FFE construct from the dimension degree of innovation - incremental innovation vs HDI and project stage - Early FFE vs Late FFE. This is a relevant contribution due to the fact that FFE is a construct that has evolved since its introduction in the last decades of the 20th century and, consequently, there is literature from different areas of knowledge, such as engineering, management, and design and at different times, which generates different terminologies and certain confusions.

Second, the DTRZ methodology aims to reduce some of the knowledge gaps about FFE, by inserting creativity techniques in the process, proposals for specific sectors and conditions, and conceptual and usable models of FFE.

For companies that need to develop incremental products and HDI in a systematic process. The research results clarify both processes, see Figure 8.1 - FFE framework in incremental innovation and high degree of innovation. In the case of projects framed in incremental innovation the academy presents consolidated proposals. In the context of HDI, the present research indicates a detailed procedure - DTRIZ methodology.

The results of the current research are limited by the number of studies carried out - five in total; the focus only on level 1 of the spiral for reasons of availability of the companies; and the cross-sectional nature of the study, which made it impossible to evaluate Key Factors - degree of innovation of the developed product, market acceptance and profit margins. A point to highlight, as indicated above is that the realization of the projects was affected by the Covid 19 pandemic, which forced intermittency in the projects, sometimes for weeks, and change of team members - projects 1 and 3.

FFE linear models start from the assumption of separating the problem domain and the solution. DTRIZ methodology at level 1, which proposes three essential and non-separable elements: analysis, synthesis, and evaluation. Based on the fact that for complex problems, these elements are not separable. The implementation of projects showed how the different elements of the problem evolve simultaneously to reach level 2 of the spiral, by achieving solution concepts, also a better understanding of the problem.

The theoretical referential indicated how, from different areas, understanding the problem is fundamental to its solution. From TRIZ and DT, all authors highlight understanding as a fundamental element. From TRIZ - emphasis on problem abstraction to understand the essence of the problem, and from DT - emphasis on observation and analysis of those involved and the context to understand the essence of the problem. From creativity in the organization (AMABILE, 1996; AMABILE; PRATT, 2016) and, from design (BUCHANAN, 1992; RITTEL; WEBBER, 1973). The DTRIZ methodology emphasizes the understanding of the problem. In this way, the projects carried out show how this understanding helps to generate solutions in different directions, and provides elements to evaluate ideas and further concepts. Something to highlight is how the understanding of the problem evolves with the turns of the spiral, which helps to generate more innovative solutions.

Innovation can be understood as the successful implementation of an idea within the context of the organization. The processes of ideation and implementation are separated, but related. The former mediated by creativity, and the latter mediated by aspects of teamwork, organizational, processes, and social environment (UMMAR;

SALEEM, 2020). Therefore, it is not enough to generate good and numerous ideas to design innovative products, but to implemented them. In the execution of the projects, these two processes were observed: the ideation and the implementation of the ideas up to the level of solution concepts. It could also be established how DTRIZ methodology not only supports the generation of ideas, but also the implementation - conception of concepts. However, this process is mediated by aspects of the environment as shown in Table 10.6.

Additionally, the realization of the projects allowed to understand the flows of the process activities, which helped to make some adjustments at the activity level. Figure 10.9 integrates these changes, which are minor: separation of the activities Generate ideas, Create concepts, and Visualize concepts, which initially consisted of a single activity; separation of the activities Test Solution and Analyze Solution, which initially consisted of a single activity. These adjustments are aimed at making the key activities explicit, in order to prevent their dilution in the process.

Validation of the methodology obtained in the present research was indicated to be of the initial type - evaluation of measurable criteria. Future research could improve the validation, optimize the DTRIZ methodology process, facilitate the application of the methodology in companies, and verify the application in other industrial sectors.

Thus, the following further research are suggested: new applications with projects in PHE and academic environments, by using research instruments to improve the understanding of the process and result variables, (See Tables 10.16 and 10.17), eventually with the assistance of experts in TRIZ and DT, which allows to improve not only the applications, but also the methodology; longitudinal studies to perform the FFE process, subsequent product development and reach the product performance evaluation, which will allow to move from evaluating measurable criteria to key factors - comprehensive validation; study and use DTRIZ methodology in other sectors to validate its application and make the appropriate adjustments; and design and implement software, or applications, or gamify the DTRIZ methodology, to facilitate project execution.

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Appendix A. SPECIFIC PDP MODEL FOR PHE AREA.

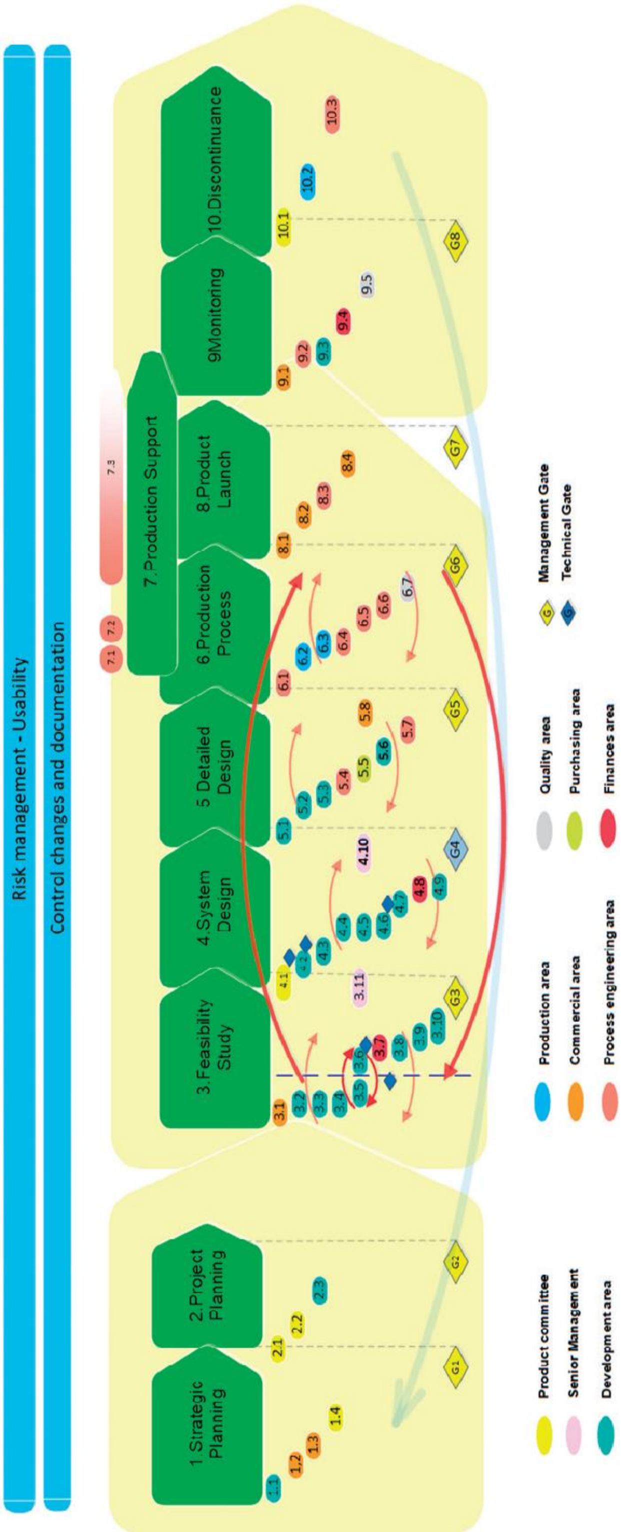
In the appendix, the PDP model resulting from the author's master's dissertation will be presented in general form. Table A1.1 indicates the activities of the phases related to the product design and Figure A1. 1 shows the general model.

Table A.0.1 - Phases and activities of Development – part I product project

Phase	Objective of the phase	Gate	Activities of the phase	
3.Feasibility Study	Validation of market existence; attainment of a set of concepts of feasible solutions related to technical, economic, and financial issues	G3 Project feasibility	3.1. Validation of the existence of the market for the intended product	D
			3.2. Identification of users' basic needs	D
			3.3. Definition of clinical and regulatory requirements	O
			3.4. Gathering of pertinent information for PD	
			3.5. Determination of the specifications and goals of the product	
			3.6. Elaboration of proposals of concept	D
			3.7. Economic and financial analysis of the product	D
			3.8. Definition of potential risks for users	O
			3.9. Product classification based on the target market regulations	O
			3.10. Determination of the types of necessary tests and the validation conditions for the use of the product	O
			3.11 Evaluation of the possible actions to manage intellectual property	
4.System Design	Selection of the final concept, deepening of the product description and design of an analysis of responsiveness, compatibility, and stability	G4 Approval of the solution	4.1. Selection of the final product concept	D
			4.2. Definition of product architecture	D
			4.3. Analysis of systems, subsystems, and main components	
			4.4. Analysis of the responsiveness of the product	
			4.5. Analysis of the compatibility of the product	
			4.6. Analysis of the stability of the product	
			4.7. Product optimization	
			4.8. Calculation of the costs of the product	
			4.9. Appraisal of risks for users of the product and tests	O
			4.10. Management of the intellectual property	
5.Detailed Design	Definition of a fully reliable product and of the manufacturing processes	G5 Product approval	5.1. Product modulation	
			5.2. Elaboration of preliminary or partial tests	
			5.3. Definition of details	
			5.4. Definition of manufacturing processes	
			5.5. Determination of suppliers	
			5.6. Consolidation of the information of the product	
			5.7. Elaboration of tests and homologation of the product	O
			5.8. Clinical validation of the product	O

D: activities linked to critical factors
O: activities have a strong influence on MD regulations
Source: (URIBE OCAMPO; KAMINSKI, 2019)

Figure A.0.1 - Proposed PDP model



Source: (URIBE OCAMPO; KAMINSKI, 2019)

Appendix B. ARIZ

A summary of the ARIZ is given in this Appendix from the following authors (CASCINI et al., 2009; FUNDACIÓN G.S.ALTSHULLER, 2019; GADD, 2011; MARCONI, 1998). Table B2.1 shows an overview of the ARIZ phases, and how they can be framed as: Problem analysis, Problem solution, and Evaluation solution. Table B2.2 details each phase.

Table B.0.1 - ARIZ Phases

1	Problem analysis	Analyze the problem
2		Analyze the problem model
3		Determine the Ideal Final Result (IFR) and Physical Contradictions (PC)
4	Problem solution	Mobilize and use the resources of the problem
5		Use databases
6		Change the problem
7	Evaluation solution	Evaluation of the obtained solutions
8		Expanding the application
9		Analyze the solution evolution

Source: the author

Table B.0.2 - Explanation of ARIZ phases

Phase	Objective	Explanation
1. Analyze the problem	Moving from an unclear problem to a clear problem scheme.	a) Describe the current system; the purpose and the parts, without technical terminology. b) Select conflicting elements, the object and the tool. Object: element that requires action and tool: element that interacts with the object. c) Schematize the problem, CT1: attempt to decrease the unwanted action, by degrading the desired action and CT2 attempt to improve the desired action, by increasing the unwanted action, use SuCa. Go back to a) to determine the consistency of the scheme with the problem situation). d) Determine the best scheme of the CT1 or CT2 problem. e) Intensify the chosen CT conflict: indicate the state and limit action of the elements. CT1 eliminates the undesired action, but the desired action is not done and CT2 the desired action is fully accomplished, but the undesired action increases to the worst possible. f) Model the intensified problem. g) Check standard solutions.
2. Analyze the problem model	Analyze the resources of the problem: time, space and sustenance, and field.	a) Determine operating zone (ZO): space from which the conflict indicated in the model occurs. ZO-1 space where the desired action occurs and ZO-2 space where the unwanted action occurs, ZO-1 and ZO-2 can be separated or have over position. b) Determine operation time (TO): time in which the conflict occurs, T0-1 time in which the desired action occurs and T0-2 time in which the undesired action occurs, TO-1 and T0-2 can be separated or be in over position, consider the times before, during and after the conflict.

Phase	Objective	Explanation
		c) Determine Substance and Field Resources (RSuCa): substances and fields already existing, located in the system, exterior, or object, take into consideration the residues of the process.
3. Determine the Ideal Final Result (IFR) and Physical Contradictions	Determine the Ideal Final Result (IFR) and the Physical Contradictions that impede achieving it.	a) Formulate IFR-1: The "X resource" will eliminate the negative effect without complicating the system at the time it performs the beneficial action, in the Z0 zone and in the T0 time. (MARCONI, 1998): indicates Replace "Resource X" with tool, object, system, super system, or environment. b) Reinforce IFR-1: Aggregate IFR-1 formulation to condition, no new substances or fields should be added to the system and RSuCa must be used, this order is suggested, use of RSuCa within tool, object, system, super system, or environment. (CASCINI et al., 2009), indicates using the resources identified in phase 2 for IFR intensification, so several versions of IFR-1 are proposed. c) Formulate Physical Contradictions (PC) at Macro Level: Formulate CF-1 and CF-2 at macro level, Zo and T0. Physical conditions that oppose to eliminate CF-1 and CF-2. d) Formulate CF at the micro level: formulate CF1 and Cf2 with the opposing physical conditions in terms of particles, in Zo and To, if it is not possible to formulate CF at the micro level, then the solution will be at the macro level. e) Formulate IFR-2: in Z0 and To the resource must itself provide CF-1 and CF-2, indicate at the micro and macro levels, by leaving several versions of FRI-2. f) Apply the standard solutions: use SuCa and Standard solutions, if the problem is solved, move to phase 7, otherwise, follow the sequence.
4. Mobilize and use the problem resources.	Expanding the Resources Sustenance and Fields of the Problem.	a) Model the IFR-2 problem with Method of Smart Little People: Imagine that particles or resources are PPE capable of thinking and action to create conditions that eliminate CF-1 and CF-2. If the action is in time, it can be represented in a drawing sequence. b) Back from IFR: the final system (IFR-1) is represented and small changes are made to reach it. c) Apply existing RSuCa, consider the replacement of two homogeneous substances by a heterogeneous one. d) Change the existing RSuCa: consider solving the problem with the exchange of substances by vacuum or mixing them with vacuum. e) Apply Derived RSuCa: Consider solving the problem with the application of SuCa Derivatives (or vacuum mixtures) of the initial RSuCa. SuCa derivatives are obtained by modification of the state or decomposition of SuCa at the macro or micro level, e.g. water: vapor, ice, hydrogen, oxygen. Another way is to build new substances with substances present. f) Introduce electric field: consider solving the problem with the introduction of one or several electric fields. g) Enter pair SuCa. According to (MARCONI, 1998): i) Apply the four Separation Methods (SM): to remove the FC. Separation in time: To separate the opposite physical states in time. Separation in space: to separate the opposite physical states in space. Separation in the system: to separate the opposite physical states between the system and its components. Condition separation: to separate opposite physical states, in different conditions. ii) Apply SuCa and standard solutions. iii) Apply Method of Smart Little People. iv) Go back to FRI-2, by doing backward analysis.
5. Use of databases	Use known databases to	a) Application of standards: formulate the IFR-2 problem and apply RSuCa and its derivatives.

Phase	Objective	Explanation
	solve the problem.	b) Use and apply analogous problems: apply solutions to previously solved analogous problems. c) Use Separation Methods (SM): Separation in time: To separate the opposite physical states in time. Separation in space: to separate the opposite physical states in space. Separation in the system: to separate the opposite physical states between the system and its components. Condition separation: to separate opposite physical states, in different conditions. Use phase transition: use phase changes. Use physical-chemical transition: appearance or disappearance of a substance by physical-chemical phenomenon. d) Physical Effects Indicator: use scientific effects. According to (MARCONI, 1998): i) Apply scientific effects. ii) Apply 40 inventive principles. iii) Apply SuCa and standard solutions.
6. Change the problem	Reformulate the problem	If no satisfactory solutions have been identified, the reformulated problem is analyzed starting again from the first part of ARIZ
7. Evaluation of the obtained solutions	Review the Solution and Analyze the Removal of the Physical Contradiction	In this step, the solutions are evaluated from the TRIZ point of view and to strengthen the solution obtained. In the course of this evaluation, new ideas may appear that specify or improve the solution obtained, for example, by eliminating secondary problems. a) Review introduced substances and fields into the system. b) Review the obtained solution.
8. Expanding the application	Expanding the application scope and standardizing a creative solution.	In this step the solution is extended, checked whether the proposed solution can be applied to solve other problems, including those in different subject areas. This makes it possible to give the solution a more generalized standard form for subsequent practical application. a) What is the modification of the suprasystem? b) New application of the system (of the suprasystem). c) Use of the obtained answer in the resolution of other problems.
9. Analyze the solution evolution	Analyze the evolution of the resolution of the problem, to increase the creative level.	According to (MARCONI, 1998): a) Review what your actual steps were in applying ARIZ. b) Note how the solution is different from other scientific effects or standards solutions. c) Add the solution to Your Knowledge Database.

Source: the author

RSuCa: They are the resources of substances and fields existing in the problem situation.

SuCa: It is the technique for analyzing the resources of substances and fields of the problem.

Appendix C TEs of TRIZ

The Altshuler, Savransky and Mann TEs will be shown below.

Table C.0.1 - Altshuller's Evolution of Technical Systems Laws

Type Law	#	Description
Static They allow to evaluate the structural and functional completeness of the technical system	1	Completeness of the parts: establishes that a system will adequately perform its main function when presenting its four parts (engine, transmission, tool, and control). Corollary: Each element should participate fully in the correct functioning of the system. At least one of the parts must be controllable to adapt to variations.
	2	Energy flow: establishes that there should be a free and efficient flow of energy through the four elements of the system. Losses can be estimated with the difference between input and output energy
	3	Coordination of the rhythm of the parts: it establishes that a system should have synchronization in its frequency, vibration and periodicity of all its parts. A difference in coordination between the elements can cause losses, and other harmful effects, throughout the system.
Kinematics They allow us to observe the system in a space-time view from the past to analyze its technological evolution.	4	Ideality: establishes that every technical system tends towards ideality. The ideal system is the one that carries out its main desired function without generating losses, without consumption of matter or energy and with the minimum cost.
	5	Unequal development of the parties: establishes that the more unequal development of the parties, the system tends to be more complex and less evolved. These inequalities lead to technical and physical contradictions; the elimination of contradiction is the basis for future evolution.
	6	Transition to the super system: establishes that when a system has achieved a high level of development. It can join a super system and become a part of it.
Dynamic They establish a projection of the system in the future. They are made up of two mutually exclusive laws, so a system can only follow one or the other law.	7	Transition from macro to micro level: establishes the existence of a system trend towards miniaturization of its parts, such as micro instruments, microelectronics.
	8	Increased dynamism and controllability: establishes that rigid systems should be oriented towards segmentation to increase their control, through field transitions (mechanical, electrical, magnetic, and electromagnetic).

Source: the author based on (CAVALLUCCI; WEILL, 2001)

Altshuller's eight laws of evolution of technical systems are used widely in the literature to determine possibilities of innovation. These TEs propose a general path of evolution of technical systems. To facilitate their application authors, such as (AGUILAR-ZAMBRANO et al., 2012; CASCINI, 2012), use the graphic form, called radar of the potential of evolution, as indicated in Figure C.0.1.

Table C.0.2 - Savransky's Evolution of Technical Systems Postulates

Postulate	Trends
Postulate 1	Both the quantity and quality of human needs, as well as human requirements increase over time.
	Advances in technique are occasionally stimulated by new needs that require new functions, which in turn, require new techniques. When one has sufficient scientific and engineering potential and when it is socially and economically convenient, this new need is met with the help of a new technology
Postulate 2	Every technical evolution leads to the increase of its ideality
	Numerous attempts to increase the ideality of a technique are proposed. Such an increase of Ideality occurs when it is socially and economically worthwhile and when it is allowed by the current scientific and technical level
Postulate of time evolution	Each technology and each subsystem present its own evolution in time
	This leads to non-uniform development of subsystems of a specific technology and the emergence of technical contradictions
Group I Corollaries	Multiplication: tendency for transition from a mono-system to a bi-system or to a poly-system with support economy and auxiliary functions
	Trim: downward trend in the number of subsystems with neutral and auxiliary functions
	Poli functionality: tendency to increase the amount of useful functions of a technique when adding new subsystems
	Aggregation: tendency to achieve many functions inside or outside a subsystem
Group II Corollaries	Dehumanization: a tendency to exclude people from the realization of the function through the use of mechanization, automation, and computerization
	Resource: tendency to achieve low cost of a new technique, by using multiple resources during technical improvements
	Minimization: tendency to reach the smallest or optimum dimensions (e.g. minimum size), smaller or optimum weight and/or lower power consumption of any subsystem for a given function
	New materials: tendency to replace current materials with new ones with advantageous properties, some of which may provide useful functions.
Group III Corollaries	Encapsulation: tendency to place replaceable subsystems easier to handle as cartridges.
	Modular construction: tendency to connect construction elements into suitable groups of which many variants of techniques can be assembled.
	Standardization: tendency to unify the dimensions, shapes, and other properties and values of the subsystems
	Typification: tendency to establish the best number of variants and sizes of selected characteristic properties of a given technique type
	Reutilization: tendency to use subsystems that were already designed and tested for a previous application as some of the subsystems of the new technical system or technological process
	Recycling: a tendency to use old elements as raw materials to overcome shortages of natural raw materials and reduce ecological problems.

Source: the author based on (SAVRANSKY, 2000)

Trends in Group I serve as a foundation for TRIZ techniques for the genesis of a new technique and development of existing technical systems. Trends in Group II serve as a foundation for optimization and improvement in the evolution of technical systems. Trends in Group III serve as a foundation for cost reduction. There are no strong boundaries between these groups.

Table C.0.3 - Trajectories of technical systems evolution

One Direction	**Physical states of technology**: A technology "moves" towards Ideality as its subsystems become more mobile. For example, by changing the physical state or phase of a subsystem along the Direction. **solid → liquid → gas → plasma → field → vacuum**
	Interactions in technique: A technology moves towards Ideality as the interactions between two or more subsystems or between a subsystem and a product become more precise. **Continuous → vibrating →resonant →stationary waves**
	Degree of dimensionality: A technology moves towards Ideality when its dimensionality changes from a point situation (zero-D) to a line, then to a plane, and later to a volume (3-D) **Zero-D → 1-D → 2-D → 3-D**
	Adaptability: A technology moves towards Ideality as its subsystems become more adaptable (flexible) to vary requirements, including opposite requirements. Adaptability means moving from a rigid, immobile subsystem to a subsystem that is more dynamic. Mechanization: propulsion functions are performed by the technical system ↓ - Automation: assigning control and regulation functions to the technical system ↓ - Informatics: allowing decision functions of routines and performance, by monitoring tasks to the technical system
Bi-directional	**Expansion**: the number of subsystems (elements, operations, or links) increases over time, while the main function grows (usually it grows faster than the number of subsystems).
	Convolution: the number of subsystems decreases over time while the main function grows or remains constant.
	Reduction: the number of subsystems begins to decrease, as well as the main function.
	Degradation: the main function decreases with the diminution of relations, power, and efficiency.

Source: the author based on (SAVRANSKY, 2000

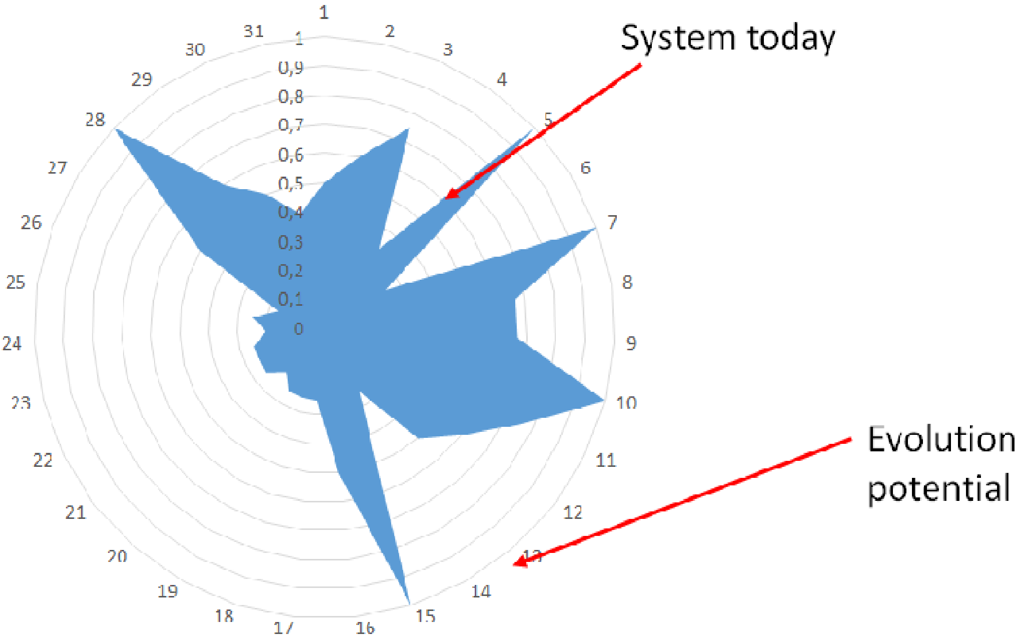
In adaptability, Transition to each next degree occurs in the depletion of natural human skills in order to improve execution with the aim of increasing productivity of technology or product quality. This transition occurs only when it is possible from the social and economic point of view, as well as if there are sufficient scientific and technical skills.

Bidirectional: Technology starts from a single element or operation intended only to perform the main function (as a rule, from the work tool). As the main function grows, there is an increase or improvement of some properties of the element. Then, an element differentiates itself. That is, it is divided into zones with different properties. Technology increases the cost and complication of its elements, which form subsystems. Besides primary functional elements and subsystems, which include these elements, the supporting subsystems, appear in the technology.

Technology becomes highly specialized, and it begins to take over functions of other "neighboring" technologies on its own, and therefore, secondary and auxiliary subsystems are added to it, and so on. Normally, these secondary functions can be considered complementary to the main function, and often they are the main functions of neighboring technology. Then, technology starts to take over the functions of other technical systems without increasing the number of their subsystems (elements and operations). At this point, technology becomes more and more versatile while the number of subsystems decreases.

Mann's 31 TEs, besides offering a possible future of the evolution of technology, show the maximum potential of evolution in each TE (ISHI; CARVALHO, 2015), which facilitates the evaluation of technology Figure C.0.1 shows how the potential of evolution can be evaluated graphically. The blue part corresponds to the current state of technology in each of the TEs, and the external part of the blue figure (white), indicates the potential of evolution. In this way, the development team has a direction.

Figure C.0.1 - Evolution potential radar



Source: (ISHI; CARVALHO, 2015)

Table C.0.4 - Mann's 31 TEs

Evolution trend		Evolution potential
1	Smart materials	1) Passive material, 2) One-way adaptive material, 3) Two-way adaptive material, 4) Fully adaptive material
2	Space segmentation	1) Monolithic solid, 2) Hollow structure, 3) Structure with multiple hollows, 4) Capillary/porous structure, 5) Porous structure with active elements
3	Surface segmentation	1) Smooth surface, 2) Surface with rib protrusions, 3) 3D roughened surface, 4) Roughened surface with active pores
4	Object segmentation	1) Monolithic solid, 2) Segmented solid, 3) Particulate solid, 4) Fluid, 5) Segmented fluid, 6) Gas, 7) Plasma, 8) Field, 9) Vacuum
5	Macro-nano evolution	Continuous, smaller each time (1...10)
6	Webs and fibers	1) Homogeneous sheet structure, 2) 2D regular mesh structure, 3) 3D fiber, alignment according to load conditions, 4) Addition of active elements
7	Decreasing density	Continuous, smaller each time (1...10)
8	Increasing asymmetry	1)Symmetrical system, 2) Partial asymmetry, 3) Matched asymmetry
9	Boundary breakdown	1) Many boundaries, 2) Few boundaries, 3) No boundaries
10	Geometric evolution (linear)	1) Point, 2) 1D line, 3) 2D plane, 4) 3D surface
11	Geometric evolution (volumetric)	1) Planar structure, 2) 2D structure, 3) Axisymmetric structure, 4) Fully 3D structure
12	Dynamization	1) Immobile system, 2) Jointed system, 3) Fully flexible system, 4) Fluid or pneumatic system, 5) Field-based system
13	Action coordination	1) Non coordinated action, 2) Partially coordinated action, 3) Fully coordinated action, 4) Different actions during intervals
14	Rhythm coordination	1) Continuous action, 2) Periodic action, 3) Use of resonance, 4) Travelling wave
15	Matching to external non-linearities	1) Linear consideration of system, 2) Partial accounting of non-linearities, 3) Full accommodation of non-linearities
16	Mono-bi-poly (similar)	1) Mono-system, 2) Bi-system, 3) Tri-system, 4) Poly-system.
17	Mono-bi-poly (various)	1) Mono-system, 2) Bi-system, 3) Tri-system, 4) Poly-system.
18	Mono-bi-poly (increasing differences)	1) Similar components, 2) Components with biased characteristics, 3) Component plus negative component, 4) Different components
19	Reduced damping	1) Heavy damping, 2) Critical damping, 3) Light damping, 4) Un-damped
20	Increasing use of senses	1) 1 sense, 2) 2 senses, 3) 3 senses, 4) 4 senses, 5) 5 senses
21	Increasing use of color	1) No use of color, 2) Binary use of color, 3) Use of visible spectrum, 4) Full spectrum use of color
22	Increasing transparency	1) Opaque construction, 2) Partially transparent, 3) Transparent, 4) Active transparent elements
23	Customer purchase focus	1) Performance, 2) Reliability, 3) Convenience, 4) Price
24	Market evolution	1) Commodity, 2) Product, 3) Service, 4) Experience, 5) Transformation
25	Design point	Design optimized: 1) For single operating point, 2) At two operating points, 3) At several discrete operating points, 4) Continuously
26	Degrees of freedom	1) 1 Degree of Freedom (DOF), 2) 2 DOF, 3) 3 DOF, 4) 4 DOF, 5) 5 DOF, 6) 6 DOF
27	Trimming	1) Complex system, 2) Elimination of non-key components, 3) Elimination of non-key sub-systems, 4) Trimmed system
28	Controllability	1) Direct control, 2) Action through intermediary, 3) Addition of feedback, 4) Intelligent feedback
29	Reducing human involvement	1) Human, 2) Human and tool, 3) Human and powered tool, 4) Human and semi-automated tool, 5) Human and automated tool, 6) Automated tool
30	Design methodology	1) Cut & try, 2) Steady state design, 3) Transient effects included, 4) Slow degradation effects included, 5) Cross-coupling effects, 6) Design by Murphy
31	Reducing number of energy conversions	1) 3 conversions, 2) 2 conversions, 3) 1 conversion, 4) No conversions

Source: (ISHI; CARVALHO, 2015)

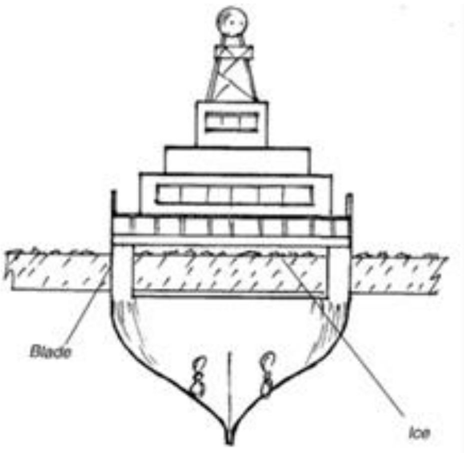
Appendix D EXAMPLES

This appendix shows three examples of PD in which issues of use, usability, and meaning carry different weight.

Example 1. The bicycle accessory company, Shimano, which usually directed its innovations in the technological domain, needed to increase its sales. With the support of IDEIO enterprise, DT methodology was used. The team, by understanding the restrictions of the design, wondered why 90% of Americans do not use bicycles. As the team studied further, they found that most people used bicycles when they were children and had good memories. Then, why did they not ride their bikes as adults anymore? With this in mind, the team discovered that many people just wanted to ride their bikes, not to compete. Additionally, they felt intimidated by the technology of new models, and the marketing strategy addressed to those who know about technology. The conclusion led to a new line of accessories, and in turn, some bicycle manufacturers adopted it, which was to produce bicycles to simply ride, this situation led to an increase in sales (BROWN, 2008).

Example 2. An icebreaker ship in order to cross ice, requires a lot of power, resulting in the engine and transmission system, by taking up most of the ship and leaving little space for cargo. It is required to increase the speed of travel. If the power were increased, the size and weight of the ship would increase. This would make the increase of speed be more difficult. Thus, the parameters of speed and power are in contradiction. TRIZ contradiction matrix suggests using the extraction principle. This way, by following this direction, a very innovative ship was proposed, with two large blocks, top (above ice) and bottom (below ice), connected by two thin side walls, which cut through ice. Which decrease the power requirements, by reaching, consequently, a higher speed, with less power, which turns out to be in more space for load (ALTSHULLER, 2007).

Figure D.0.1 - Icebreaker solution of TRIZ



Source: (ALTSHULLER, 2007)

Example 3. In the early 1970s, Sony launched BetaMax, which was surpassed a few years later by JVC's VHS. Although BetaMax was introduced first, being of better video quality and smaller size, the VHS had an ability to record twice as much as BetaMax did. This case illustrates hundreds of superior technology products, which have failed in the market, by concluding that superior technology products do not always prevail in the marketplace (PELT E HEY, 2011).

Appendix E 40 INVENTIVE PRINCIPLES

Table E 0.1 - Inventive principles

40 Inventive principles			
1	Segmentation	21	Rushing Through
2	Taking out	22	Convert harm Into benefit blessing in disguise
3	Local quality	23	Feedback
4	Asymmetry	24	Intermediary
5	Merging	25	Self-service
6	Universality	26	Copying
7	Nested doll	27	Cheap short-living objects
8	Anti-Weight	28	Replacement mechanical system.
9	Prior counteraction	29	Pneumatic and hydraulic
10	Prior action	30	Flexible membranes or thin films.
11	Cushion in advance	31	Porous material
12	Equipotentiality	32	Color change
13	The other way round	33	Homogeneity
14	Spheroidicity Curvature	34	Discarding and recovering
15	Dynamics	35	Parameter change
16	Partial or excessive action	36	Phase transition
17	Another dimension	37	Thermal expansion
18	Mechanical vibration	38	Accelerated oxidation
19	Periodic action	39	Inert environment
20	Continuity of useful action	40	Composite materials

Table E 0.2 - Inventive principles explication

	Principle	Illustrative examples
1	Segmentation. Divide an object into independent parts. Make an object sectional (for easy assembly or disassembly). Increase the degree of an object's segmentation.	i) Multiple pistons in combustion engine Cold storage air curtain in vertical sections Paper cutter blades in sections ii) Modular furniture iii) Rapid fluid or electrical connectors Folding bikes iv) Use fog-shaped water instead of droplets to put out fires
2	Extraction (Extracting, Retrieving, Removing). Extract the "disturbing" part or property from an object. Extract only the necessary part or property from an object.	i) Place noisy equipment, such as compressors outside the work area. In fiber optic light for lighting, the energy source that causes heat and electrical hazards, is removed and placed where it is most convenient. ii) Use the sound of birds of prey at airports to scare away birds, rather than the bird of prey. Use of vegetable essential oils in the kitchen instead of vegetable oils.

	Principle	Illustrative examples
3	Local quality. Transition from homogeneous to heterogeneous structure of an object or outside environment (action). Different parts of an object should carry out different functions. Each part of an object should be placed under conditions that are most favorable for its operation.	i) Sawing blades, hard and fragile material tooth and softer, more docile material body. ii) Pencil and eraser in one unit. Nail hammer to pull out nails. iii) Lunchbox with space compartments for hot and cold solids and for liquid.
4	Asymmetry. Change a symmetrical form or property of an object with an asymmetrical form. Change an external environment or external influence from uniform to non-uniform.	i) Oval-shaped O ring to improve seal. Rectangular tubes instead of squares to increase strength in one direction. Use gradients of temperature, pressure, density, expansion Refrigerators with compartments at different temperatures Multifocal lenses. ii) Special electrical plugs to avoid connection errors.
5	Consolidation. Consolidate in space homogeneous or similar objects, or objects destined for contiguous operations. Consolidate in time homogeneous or contiguous or parallel operations.	i) Electronic circuit boards in several layers. Laptop, which joins screen and processor. ii) Lawn mower that picks up the lawn. Dust-suction hammer drill. Formula 1 pits, all trades are done at the same time.
6	Universality. An object can perform several different functions so that other elements can be removed.	i) Swiss knife. Home Entertainment Center. Smartphone. Compressor transmission pulleys that are at the same time fans for cooling.
7	Nesting. One object is placed inside another and that object is placed inside a third one. And so on . . . An object passes through a cavity in another object.	i) Telescopic antenna. Telescope cylinders. Set of pots that are stored in the largest one. ii) Cables that pass through tubes of furniture structures. Retractable belt for vehicles. Multiple microscope lenses.

	Principle		Illustrative examples
8	Counterweight. Compensate for the weight (or downtrend) of an object, combine it with other objects that provide a lifting force. Compensate for the weight of an object, have it interact with the environment (for example, use aerodynamics, hydrodynamics, buoyancy).	i) ii)	Counterweight lifts. Pneumatic cylinders for hood opening (rear gate) carriage. Roman scale. Racing car spoilers to increase floor pressure. Airplane wings. Rehabilitation exercises submerging in water (hydrotherapy). Helium balloons in air advertising.
9	Prior counteraction. Preload counter tension to an object to compensate for excessive and undesirable stress. Perform anti-actions to control harmful effects, when it is necessary to perform an action with harmful and useful effects.	i)	Produce a tension or deformation contrary to mechanical parts subjected to high stresses. Masking tape in parts that should not be painted. Immunize wood. Sterilize surgical instruments. Preheat plastic parts for easy assembly. Heat-generating process coolers (motor radiator).
10	Prior action. Make the necessary modification of an object in advance (in whole or in part). Pre-organize the items so that they can get into action from the most convenient place and without wasting time on their delivery.	i) ii)	Self-adhesive paper. Commercial perforated sheets. Pre-mechanizing parts. Pre-cut and pre-folded cardboard boxes. In surgeries, surgical instruments are arranged so that medical staff have these easily. Quick access memory of a CPU or cache, which maintains data to be used more easily than querying in main memory
11	Cushion in advance. Prepare emergency means in advance to compensate for the relatively low reliability of an object or system.	i)	Airplane parachutes Safety valves Magnetized merchandise to prevent theft Air bags Redundancy of equipment or systems
12	Equipotentiality. If an object has to be lifted or lowered, redesign the environment or object so that the need to lift or lower it is eliminated, made or facilitated by the environment.	i)	Transport in water channels or rails. Tunnels to avoid mountains. Elevator counterweight. Horizontal rather than vertical movement or using ramps. Bathtub with door for the elderly or sick.

	Principle	Illustrative examples
13	Do it in reverse. Instead of the direct action dictated by a problem, implement an opposite action (i.e., cooling instead of heating). Make the movable part of an object, or outside environment, stationary — and stationary part moveable. Turn an object upside-down.	i) Hyper-cool tin welding instead of heating to remove it. ii) Hospital stretchers that match the height of medical staff, instead of adjusting to the height of the stretcher. iii) Stationary Treadmill. Mobile floor with people standing. iv) Ramp access buses (slightly) to facilitate entry. Dumping hoppers.
14	Spheroidicity. Replace linear parts with curved parts, flat surfaces with spherical surfaces, and cube shapes with ball shapes. Use rollers, balls, and spirals. Replace linear motion with rotational motion; utilize centrifugal force.	i) Cylindrical or spherical tanks for high pressures. Arches on domes or bridges to increase resistance. Sheet metal folding in cars to increase endurance. ii) A ballpoint pen instead of a pen. Helical gears. iii) Crank mechanisms. Separation of components with different densities by centrifugation. Spinning clothes drying.
15	Dynamicity. Characteristics of an object or outside environment, must be altered to provide optimal performance at each stage of an operation. If an object is immobile, make it mobile. Make it interchangeable. Splitting an object into parts capable of moving with each other.	i) Adjustable car seats or steering wheel. Shape memory in polymers or alloys. Temperature, pressure, humidity controlled environments to control or improve processes. ii) Fixed to mobile bed, for medical use Laparoscopy probe. iii) Bed slats divided into several moving parts to fit the movement of people.
16	Partial or excessive action a. If it is difficult to obtain 100% of a desired effect, achieve more or less of the desired effect.	i) Liquid or powder dosing, a lower amount is applied than calculated, to measure and to adjust until the desired accuracy is achieved. Equipment testing is carried out under more unfavorable conditions when it is difficult to replicate the conditions of use Bottle filling at high speed, the excess liquid is applied and subsequently this excess is removed.
17	Transition Into a new dimension Transition one-dimensional movement, or placement, of objects into two-dimensional; two-dimensional to three-dimensional, etc. Utilize multi-level composition of objects. Incline an object, or place it on its side. Utilize the opposite side of a given surface.	i) 5-axis cutting tools. Tents with second level for children. ii) 6 CD compactor to increase capacity. Multilayer electronic circuits. iii) Swinging trolleys to lower the load. Tilted bed to reposition the patient. iv) Dual-layer electronic circuits. Double layer CD.

	Principle	Illustrative examples
18	Mechanical vibration. Utilize oscillation. If oscillation exists, increase its frequency to ultrasonic. Use the frequency of resonance. Replace mechanical vibrations with piezo vibrations. Use ultrasonic vibrations in conjunction with an electromagnetic field.	i) Powder screens. Electric knife. Vibration conveyors. ii) Ultrasonic scalpel. iii) Conventional radio Destroy kidney stones, by using ultrasound iv) Quartz clock oscillators on watches. v) Electro acoustic filterers.
19	Periodic action. Replace a continuous action with a periodic one (impulse). If the action is already periodic, change its frequency. Use pauses between impulses to provide additional action.	i) Rivet by manual hammer action. Intermittent siren. Hydro pulse washer. ii) Ultrasonic cleaner. Rotary hammer drill. Pneumatic riveter. iii) CPR cardiopulmonary resuscitation, by giving breathing after 5 compressions. Active pause, breathing exercises and stretching between activities. Pacemaker.
20	Continuity of useful action. Perform the work continuously; make all parts of an object work at full load, all the time. Remove idle and intermediate motion. Replace “back-and-forth” motion with a rotating one.	i) Moebius strip cutting saws, continuously uses both edges. Accumulation flyers on die cutting machines. Cold accumulators, which Hydraulic accumulator, which stores energy from idle time processes. ii) Kayak with double rowing on a single bar. Two-stroke engine. iii) Compressors and rotary motors rather than alternative ones.
21	Rushing Through. Perform harmful and hazardous operations or stages at a very high speed.	i) Ultra-pasteurized instead of pasteurized. Fast plastic machining Wax hair removal

	Principle	Illustrative examples
22	Convert harm Into benefit. Utilize harmful factors — especially environmental — to obtain a positive effect. Remove one harmful factor by combining it with other harmful factors. Increase the degree of harmful action to such an extent that it ceases to be harmful.	i) Reuse process waste materials. Solar heat absorption cooling system. Produce electricity with heat left over from processes. ii) Neutralize acidic solutions, by adding foundations. iii) Putting out explosion fires.
23	Feedback Introduce feedback. If feedback already exists, change it.	i) Sensor on/off control instead of manual operation, such as in household ovens. ii) Proportional control instead of on/off control. Statistical process control. Use AI to decide, which action to take.
24	Mediator Use an intermediary object to transfer or to carry out an action. Temporarily merge one object with another that can be easily removed.	i) Refrigerant liquid in cars or oil in transformers. Transfer process in fabric stamping, is printed on paper that is easy and this printing is transferred by thermal process to the fabric. ii) Ice used to temporarily fix objects. Particular abrasives submerged in water in waterjet cutting.
25	Self-service. An object or a system must service itself, by carrying out supplementary and useful operations. Make use of waste material and energy.	i) Self-adjustable flanges or seals. Self-service public bikes and skateboards. Self-cleaning clothes. Adhesives in urinals to decrease splashes. ii) Use heat from a process to generate electricity. Use differential pressure to reinforce sealing action.
26	Copying. Use simple, inexpensive copies instead of the original fragile, expensive, or unavailable object. Replace visible optical copies with infrared or ultraviolet copies. Replace an object with its optical image, which can be reduced or enlarged.	i) Scarecrows in crops. Affordable product versions. Adhesives with wood finishes, instead of wood. Fake jewels. ii) Infrared images for disease or intruders. iii) Photogrammetry to measure land of direct medicine in situ. CAD models.

	Principle	Illustrative examples
27	Dispose. Replace an expensive object with a cheap one, by compromising other properties (i.e., longevity).	i) Disposable bed linen of medical examination tables. Screwdrivers with changeable tips. Express banking. Cheap tool versions with less precision, capacity, or durability.
28	Replacement of mechanical system. Replace a mechanical system with an optical, thermal, acoustical, or olfactory system. Use an electric, magnetic or electromagnetic field to interact with an object. Replace fields that are Stationary with mobile, fixed with changing in time, random with structured. Use fields in combination with particles sensitive to this field.	i) Laser scalpel. Replacing mechanical barriers with acoustics. Voice commands instead of typing. Barcode. Magnetic bearing. ii) Magnetic locks. Electrostatic precipitation to separate particles. Electromagnetic contactors. Security tapes in stores. iii) Electrostatic paint with variable field for Faraday cage. Linear motors with scrollable fields. iv) Mixture of substances by electromagnetic field with paramagnetic particles.
29	Pneumatic or hydraulic constructions. Replace solid parts of an object with a gas or liquid.	i) Shoe gel soles. Power accumulators in hydraulic systems. Exhaust brake. Gas springs. Hydraulic rotary power transmission coupling Inflatable boats.
30	Flexible membranes or thin films. Replace tridimensional constructions with flexible membranes or thin film. Isolate an object from its outside environment with flexible membranes or thin films.	i) Inflatable mattresses. Demountable or inflatable warehouses. Inflatable boats. ii) Polyester food packaging films. Thin plastic layer for motorcyclists. Tea bag. PVC plastic curtains in cold storages.
31	Porous material. Make an object porous, or use supplementary porous elements (inserts, covers, etc.). If an object is already porous, fill pores in advance with some substance. Make use of pores, by introducing a useful substance or function if an object is already porous.	i) Tennis soles. Make holes to decrease weight of structures. Billboards with perforations to decrease wind force. ii) Porous tanks for storing acetylene. Porous bushings with lubricant. Felt markers.

	Principle		Illustrative examples
32	Changing the color. Change the color of an object or its environment. Change the degree of translucency of an object or its environment. Use color additives to observe an object, or process which is difficult to see. Use luminescent or emissivity traces if additives are used to observe.	i) ii) iii) iv)	Yellow colors on moving equipment. Color as institutional identity. Dark environments to help sleep. Artificial night light in fattening poultry. Semi-transparent dresses instead of necklines Frosted glass lets in the light and maintains privacy. Glasses for welding masks. Color additives to determine leaks in pipes. Tracer bullets. Phosphorescence applications in cancer surgeries. Fluorescent or phosphorescent tapes.
33	Homogeneity. Objects interacting with the main object should be made out of the same material (or material with similar properties) as the main object.	i)	Friction welding Diamond cutting tool made of diamond Edible food containers (cone wafer, tortillas)
34	Rejecting and regenerating parts. After completing its function, or becoming useless, an element of an object is rejected (discarded, dissolved, evaporated, etc.) or modified during its work process. Used-up parts of an object should be restored during its work.	i) ii)	Food capsule that dissolves in the stomach. Lost wax casting or Styrofoam model, which evaporates in the process. Dry ice particles for sandblasting or jet cleaning. Self-sharpening of cutting blades during operation. Electric cars that self-charge, by using kinetic energy, downhill or braking. Gym machines that generate electrical energy in their operation. Closed water cooling circuit, which recovers water.
35	Transformation of properties. Change the physical state of the system. Change the concentration or density. Change the temperature or volume.	i) ii) iii)	Transport of gases in their liquid phase. Liquid soap instead of solid soap. Powder paint instead of liquid paint to eliminate solvent use. Foods, such as powdered eggs. Alter mixture density to separate solids. Raise the metal temperature to Curie's point to alter magnetic properties. Increased temperature of drawing dies to compensate for wear. Increase temperature to generate endothermic reactions to store heat, such as body heaters.

	Principle		Illustrative examples
36	Phase transition Use the phenomena, which take place during phase change, such as a change in volume, temperature, absorption, or liberation of heat.	i)	Use volume increase in ice water transition. Thermal cooling cycles, which use temperature increase in gas compression. Latent heat build-up Water evaporation cooling.
37	Thermal expansion Use expansion or contraction of volume, with changes of temperature. Use various materials with different coefficients of thermal expansion.	i) ii)	Mounting bearings by thermal expansion. Mercury thermometer. Increased temperature of drawing dies to compensate for wear. Bimetallic sheet thermometer or bimetallic thermal switch, which are based on the difference in thermal expansion coefficient.
38	Accelerated oxidation Transition from an oxidation level to a higher level. Pure air environment by air enriched with oxygen. Air enriched with oxygen by pure oxygen. Pure oxygen to ionized oxygen. Oxygen ionized to ozonized oxygen. Ozone ozonized (or ionized) oxygen. Ozone to simple oxygen.	i)	Pressure air in forges. Oxygen instead of air for asthmatics. Oxy-fuel welding and cutting. Ionized air to destroy bacteria. Use ozone to destroy bacteria.
39	Inert environment Replace a normal environment with an inert one. Introduce a neutral substance or additives into an object. Carry out the process in a vacuum.	i) ii) iii)	Inert gas in MIG or TIG welding. Propane gas additive to generate odor and to detect leaks. Anti-ignition additive in plastics. Vacuum cooking to decrease times or temperatures. Soft drink bottlers work at low pressures to reduce foam in packaging filling.
40	Composite materials Replace homogeneous materials with composite or multiple ones.	i)	Concrete. Polyester fiberglass. Fiber-reinforced ceramics and plastics. Parts made of layers to take advantage of different characteristics of materials, e.g. a surfboard.

Source: author based (ALTSHULER, 2007)

Appendix F 39 ENGINEERING PARAMETERS

Table F 0.1 - 39 Engineering parameters

39 Engineering parameters			
1	Weight of moving object	21	Power
2	Weight of stationary object	22	Loss of Energy
3	Length of moving object	23	Loss of substance
4	Length of stationary object	24	Loss of Information
5	Area of moving object	25	Loss of Time
6	Area of stationary object	26	Quantity of substance/the matter
7	Volume of moving object	27	Reliability
8	Volume of stationary object	28	Measurement accuracy
9	Speed	29	Manufacturing precision
10	Force	30	External harm affects the object
11	Stress or pressure	31	Object – generated harmful factors
12	Shape	32	Ease of manufacture
13	Stability of the object’s composition	33	Ease of operation
14	Strength	34	Ease of repair
15	Duration of action by a moving object	35	Adaptability or versatility
16	Duration of action by a stationary object	36	Device complexity
17	Temperature	37	Difficulty of detecting and measuring
18	Illumination intensity	38	Extent of automation
19	Use of energy by moving object	39	Productivity
20	Use of energy by stationary object		

Moving objects: They are objects, which can easily change position in space, either on their own, or as a result of external forces. Vehicles and objects designed to be portable are the basic members of this class.

Stationary objects: They are objects, which do not change position in space, either on their own, or as a result of external forces. Consider the conditions under which the object is being used.

Table F 0.2 - 39 Engineering parameters explication

	Title	Explanation
1	Weight of moving object	The mass of the object, in a gravitational fi eld. The force that the body exerts on its support or suspension.
2	Weight of stationary object	The mass of the object, in a gravitational fi eld. The force that the body exerts on its support or suspension, or on the surface on which it rests.
3	Length of moving object	Any one linear dimension, not necessarily the longest, is considered a length.
4	Length of stationary object	Any one linear dimension, not necessarily the longest, is considered a length.
5	Area of moving object	A geometrical characteristic described by the part of a plane enclosed by a line. The part of a surface occupied by the object. OR the square measure of the surface, either internal or external, of an object.
6	Area of stationary object	A geometrical characteristic described by the part of a plane enclosed by a line. The part of a surface occupied by the object. OR the square measure of the surface, either internal or external, of an object.

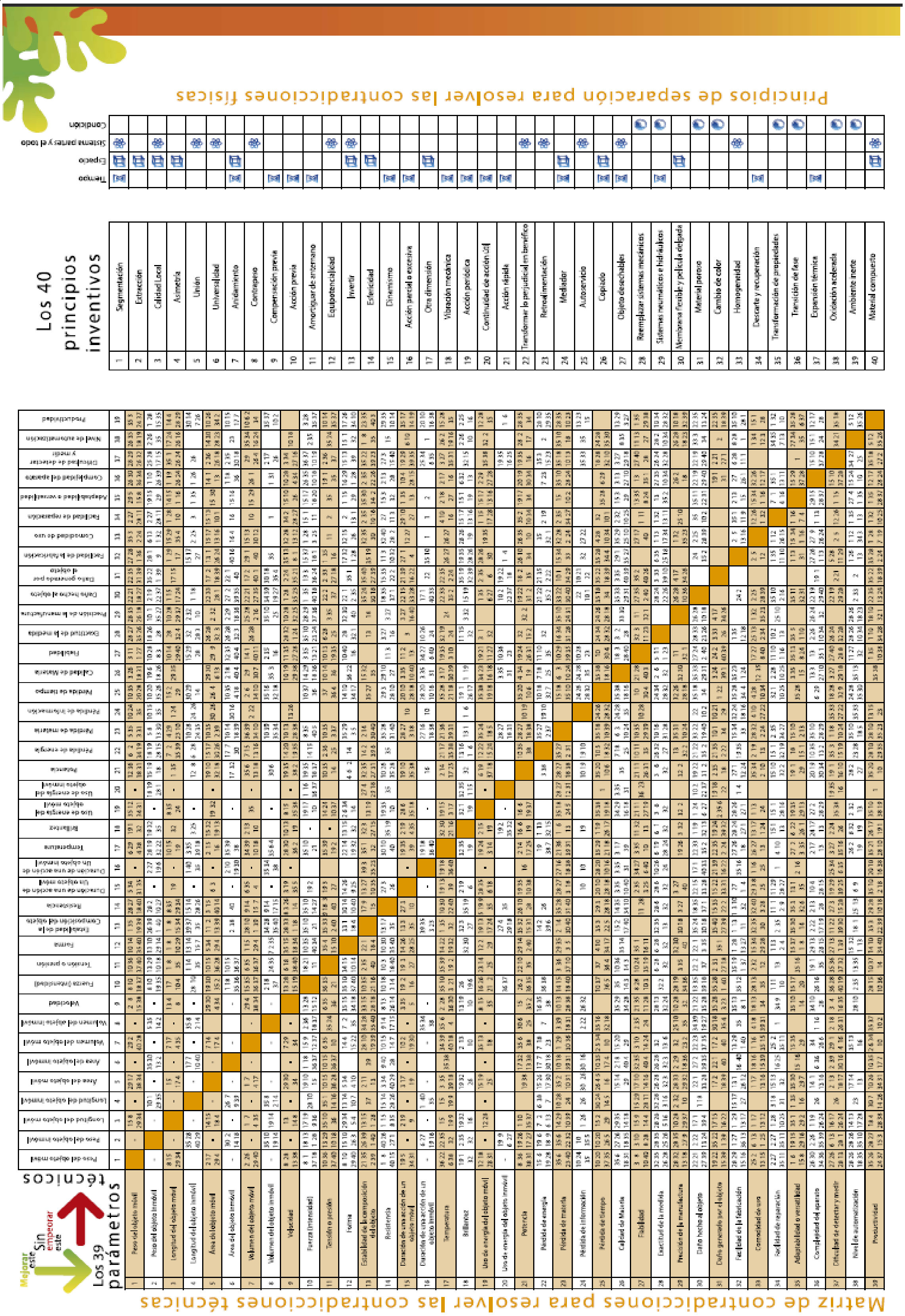
	Title	Explanation
7	Volume of moving object	The cubic measure of space occupied by the object. Length x width x height for a rectangular object, height x area for a cylinder, etc.
8	Volume of stationary object	The cubic measure of space occupied by the object. Length x width x height for a rectangular object, height x area for a cylinder, etc.
9	Speed	The velocity of an object; the rate of a process or action in time.
10	Force	Force measures the interaction between systems. In Newtonian physics, force = mass x acceleration. In TRIZ, force is any interaction that is intended to change an object ' s condition.
11	Stress or pressure	Force per unit area. Also, tension.
12	Shape	The external contours, appearance of a system.
13	Stability of the object's composition	The wholeness or integrity of the system; the relationship of the system' s constituent elements. Wear, chemical decomposition, and disassembly are all decreases in stability. Increasing entropy is decreasing stability.
14	Strength	The extent to which the object is able to resist changing in response to force. Resistance to breaking.
15	Duration of action by a moving object	The time that the object can perform the action. Service life. Mean time between failure is a measure of the duration of action. Also, durability.
16	Duration of action by a stationary object	The time that the object can perform the action. Service life. Mean time between failure is a measure of the duration of action. Also, durability.
17	Temperature	The thermal condition of the object or system. Loosely includes other thermal parameters, such as heat capacity, that affect the rate of change of temperature.
18	Illumination intensity	Light flux per unit area, also any other illumination characteristics of the system such as brightness, light quality, etc.
19	Use of energy by moving object	The measure of the object ' s capacity for doing work. In classical mechanics, Energy is the product of force x distance. This includes the use of energy provided by the super - system (such as electrical energy or heat.) Energy required to do a particular job.
20	Use of energy by stationary object	The measure of the object ' s capacity for doing work. In classical mechanics, Energy is the product of force x distance. This includes the use of energy provided by the super - system (such as electrical energy or heat.) Energy required to do a particular job
21	Power	The time rate at which work is performed. The rate of use of energy.
22	Loss of Energy	Use of energy that does not contribute to the job being done. See 19. Reducing the loss of energy sometimes requires different techniques from improving the use of energy, which is why this is a separate category.
23	Loss of substance	Partial or complete, permanent or temporary, loss of some of a system ' s materials, substances, parts or subsystems.
24	Loss of Information	Partial or complete, permanent or temporary, loss of data or access to data in or by a system. Frequently includes sensory data such as aroma, texture, etc.
25	Loss of Time	Time is the duration of an activity. Improving the loss of time means reducing the time taken for the activity. "Cycle time reduction"is a common term.

	Title	Explanation
26	Quantity of substance/the matter	The number or amount of a system ' s materials, substances, parts or subsystems which might be changed fully or partially, permanently or temporarily.
27	Reliability	A system ' s ability to perform its intended functions in predictable ways and conditions.
28	Measurement accuracy	The closeness of the measured value to the actual value of a property of a system. Reducing the error in a measurement increases the accuracy of the measurement.
29	Manufacturing precision	The extent to which the actual characteristics of the system or object match the specified or required characteristics.
30	External harm affects the object	Susceptibility of a system to externally generated (harmful) effects.
31	Object – generated harmful factors	A harmful effect is one that reduces the efficiency or quality of the functioning of the object or system. These harmful effects are generated by the object or system, as part of its operation.
32	Ease of manufacture	The degree of facility, comfort or effortlessness in manufacturing or fabricating the object/system.
33	Ease of operation	Simplicity: The process is not easy if it requires a large number of people, large number of steps in the operation, needs special tools, etc. ' Hard ' processes have low yield and ' easy ' processes have high yield; they are easy to do right.
34	Ease of repair	Quality characteristics such as convenience, comfort, simplicity, and time to repair faults, failures or defects in a system.
35	Adaptability or versatility	The extent to which a system/object positively responds to external changes. Also, a system that can be used in multiple ways under a variety of circumstances.
36	Device complexity	The number and diversity of elements and element interrelationships within a system. The user may be an element of the system that increases the complexity. The difficulty of mastering the system is a measure of its complexity.
37	Difficulty of detecting and measuring	Measuring or monitoring systems that are complex, costly, require much time and labour to set up and use, or that have complex relationships between components or components that interfere with each other all demonstrate "difficulty of detecting and measuring" Increasing cost of measuring to a satisfactory error is also a sign of increased difficulty of measuring.
38	Extent of automation	The extent to which a system or object performs its functions without human interface. The lowest level of automation is the use of a manually operated tool. For intermediate levels, humans program the tool, observe its operation, and interrupt or re - program as needed. For the highest level, the machine senses the operation needed, programs itself and monitors its own operations.
39	Productivity	The number of functions or operations performed by a system per unit time. The time for a unit function or operation. The output per unit time, or the cost per unit output.

Source: Gadd (2011)

Appendix G EXPLANATION OF THE CONTRADICTION MATRIX

Figure G 0.1 - Contradiction Matrix



Source: the author base (GADD, 2011)

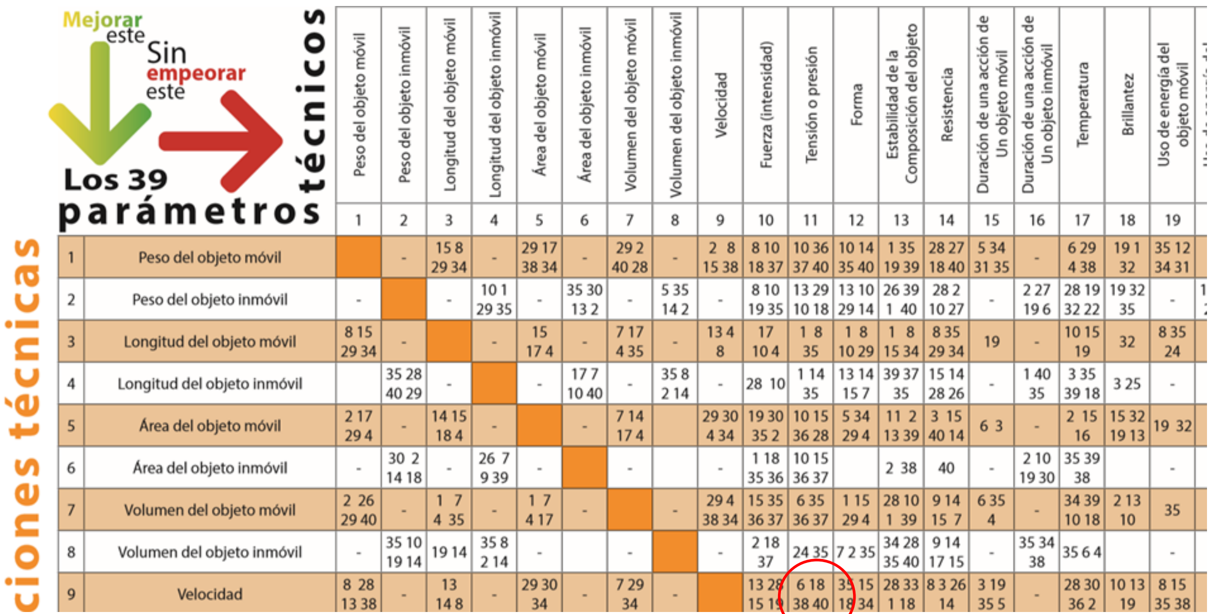
Definition
It is a matrix of 39 x 39, which relates the parameters in contradiction with the inventive principles that can serve to overcome this contradiction.

Objective
To direct the search for solutions, by overcoming Technical Contradictions.

How to proceed

- It is based on the identification of technical contradictions by the analysis of contradictions or other methods.
- By relating conflicting parameters of the problem situation to the 39 Engineering Parameters.
- By entering the matrix with the parameter to be improved and the one that opposes.
- At the intersection, we find some numbers, which correspond to the suggested IPs to address the solution, are in order of their use in the past by inventors.
- By exploring solutions based on IPs identified with brainstorming or any other supportive technique.

Figure G 0.2 - Contradiction Matrix explication



		Peso del objeto móvil	Peso del objeto inmóvil	Longitud del objeto móvil	Longitud del objeto inmóvil	Área del objeto móvil	Área del objeto inmóvil	Volumen del objeto móvil	Volumen del objeto inmóvil	Velocidad	Fuerza (intensidad)	Tensión o presión	Forma	Estabilidad de la Composición del objeto	Resistencia	Duración de una acción de Un objeto móvil	Duración de una acción de Un objeto inmóvil	Temperatura	Brillantez	Uso de energía del objeto móvil
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Peso del objeto móvil		-	15 8 29 34	-	29 17 38 34	-	29 2 40 28	-	2 8 15 38	8 10 18 37	10 36 37 40	10 14 35 40	1 35 19 39	28 27 18 40	5 34 31 35	-	6 29 4 38	19 1 32	35 12 34 31
2	Peso del objeto inmóvil	-		-	10 1 29 35	-	35 30 13 2	-	5 35 14 2	-	8 10 19 35	13 29 10 18	13 10 29 14	26 39 1 40	28 2 10 27	-	2 27 19 6	28 19 32 22	19 32 35	-
3	Longitud del objeto móvil	8 15 29 34	-		-	15 17 4	-	7 17 4 35	-	13 4 8	17 10 4	1 8 35	1 8 10 29	1 8 15 34	8 35 29 34	19	-	10 15 19	32	8 35 24
4	Longitud del objeto inmóvil		35 28 40 29	-		-	17 7 10 40	-	35 8 2 14	-	28 10	1 14 35	13 14 15 7	39 37 35	15 14 28 26	-	1 40 35	3 35 39 18	3 25	-
5	Área del objeto móvil	2 17 29 4	-	14 15 18 4	-		-	7 14 17 4		29 30 4 34	19 30 35 2	10 15 36 28	5 34 29 4	11 2 13 39	3 15 40 14	6 3	-	2 15 16	15 32 19 13	19 32
6	Área del objeto inmóvil	-	30 2 14 18	-	26 7 9 39	-		-		-	1 18 35 36	10 15 36 37		2 38	40	-	2 10 19 30	35 39 38		-
7	Volumen del objeto móvil	2 26 29 40	-	1 7 4 35	-	1 7 4 17	-		-	29 4 38 34	15 35 36 37	6 35 36 37	1 15 29 4	28 10 1 39	9 14 15 7	6 35 4	-	34 39 10 18	2 13 10	35
8	Volumen del objeto inmóvil	-	35 10 19 14	19 14	35 8 2 14	-		-		-	2 18 37	24 35	7 2 35	34 28 35 40	9 14 17 15	-	35 34 38	35 6 4		-
9	Velocidad	8 28 13 38	-	13 14 8	-	29 30 34	-	7 29 34	-		13 28 15 19	6 18 38 40	35 15 18 34	28 33 1 18	8 3 26 14	3 19 35 5	-	28 30 36 2	10 13 19	8 15 35 38

Example: Improve **Speed** without worsening **Force**
Suggested IPs.
13: Investing.
28: Replacing mechanical systems.
15: Partial or excessive action.
19: Continuity of useful action.
Source: the author

Appendix H SEPARATION PRINCIPLES

Table H 0.1 - Separation principles

Type of Separation	Features	Direction of solution	Examples
Separation in Time	Contradiction occurs at different times. We want opposing benefits at different times.	Feature increased in a time and decreased in another time. Feature present in a time (time period) and absent in another time.	Traffic lights at vehicle crossings that alternate the track of cars and pedestrians in the same space. Aircraft wings are long on takeoff to increase lift and short in flight to improve maneuverability. Ambulance stretchers are low to get the patient into an ambulance and high to take him out of the ambulance.
Separation in Space	Contradiction occurs in different spaces. We want opposite benefits in different spaces.	Feature increased in one space (one physical part) and decreased in another space. Feature present in one space and absent in another space.	Vehicle or pedestrian bridges that separate flows. Lunch boxes with hot and cold compartments. Public places with suitable spaces for: smokers, children, the elderly etc.
Separation of system - the parts and the whole.	Contradiction occurs at the same times and spaces. When we need to separate opposing solutions at the system and parts level.	Feature has a system-level value and the opposite value at the component level. Feature exists at the system level, and it does not exist at the component level.	Blades of swords or knives must be ductile to withstand bumps without breaking and the edge very hard (which makes it fragile) so that it does not wear out. The transmission chain is a flexible system, composed of rigid parts. Bicycle handlebars should be very sturdy as a structure and soft on the handle.
Separation in Condition.	Contradiction occurs at the same times and spaces. When we need to separate opposite solutions at the same place and at the same time.	Feature is increased in one condition and diminished in another condition. Feature exists in one condition, and it does not exist in another condition.	Music that is suitable for the elderly and repulsive for the youth. Children's games differentiated by age, by their size, challenge, and aesthetics, are attractive for children of some ages and unattractive for other ages.

Source: the author based (CARVALHO, 2017; GADD, 2011)

Appendix I DT GUIDELINES

The following are the DT guidelines of the authors consulted, summarized.

Hassi and Laakso's article (2011) based on interviews with academic experts and practitioners, related to DT from different countries, and on bibliographic research, condenses DT guidelines into three categories: Practices, which are elements related to concrete activities, with tangible approaches with the use of techniques; Thinking Style, issues such as cognitive styles, thought methods, information processing; and Mindset, which refers to the individual immersed in work and enterprise culture. Mindset describes how to approach problems, and mental attitude refers to ways in which they are understood. Each category is broken down into several guidelines, as indicated in Table 6.3.

The authors emphasize that DT is not a sum of separate elements. It is more an interaction of elements. In this sense, when " thinking by doing" is indicated, it is directly related to prototypes as a practice. However, it is a manifestation of experimental and exploratory thinking, or future-oriented mentality, which is manifested in styles of abductive thinking.

Table I 0.1 - Hassi & Laakso's DT Guidelines

Practices	**Human-centered approach**: Determining need, empathy to understand users
	Thinking doing: refers to the iterative and tangible process, quick iterations, prototypes from the very first day.
	Visualization: representation of a useful idea in order to generate and to communicate concepts.
	Divergent and convergent thinking: the way of proposing many options in principle without limiting the options (divergence), by discarding some of them in order to focus on the most promising ones (convergence).
	Collaborative work style: by contrasting with the notion of solitary genius, DT emphasizes collaborative work - an aspect described by all authors. Similarly, collaboration is related to involving stakeholders from the very beginning. Concepts such as interdisciplinarity, various fields of knowledge, various perspectives.
Thinking Style	**Abductive thinking**: a designer uses abductive reasoning in order to move from what is known and to explore what could be. Designers use abduction in order to generate ideas, to challenge accepted explanations, and to infer new possible worlds.
	Reflective reformulation: it is inherent in DT to question how to represent the problem, by looking beyond the immediate boundaries of the problem in order to ensure that the right issue is being addressed.
	Holistic look: visualize the problem as a system of structures, patterns and events, rather than isolated events. The ability to connect external elements with internal functionality includes issues, such as the emotional, social, and cultural users' needs and socio-cultural factors inherent to the problem.
	Integrative thinking: DT includes a balance between the technical, the necessary in the organization and the human dimension. By searching for creative solutions when conflicting situations are presented, authors, such as (Martin, 2010), indicate the balance between exploitation and exploration.
Mindset	**Experimental and explorative**: being one of DT key features, the disposition to explore new ideas, the disposition to risk, to pull people, the team, and technology to the limit, the boundaries of the organization. Comfortable to experiment new ways of doing, despite being wrong, mistakes being a natural part of the process.
	Tolerance to ambiguity: ambiguity is a natural part of the design process. Designer Thinker presents the ability to work and to propose solutions under non-deterministic environments.
	Optimism: assume that in defiant restrictions, there will always be at least one solution to the problem. enjoy problem-solving in situations that many people give up; restrictions are viewed as challenges and with enthusiasm.
	Future orientation: ability to anticipate new scenarios; always propose the improvement of existing conditions; the logic of DT is what could be. The starting point is more often a vision than the status quo.

Source modified: (HASSI; LAAKSO, 2011)

Carlgren, Rauth, and Elmquist's research (2016) is based on a field study with six companies that use DT from different countries. It focuses on patterns and differences with three categories of analysis: Principles, Mindset, and Practices and Techniques. Five relevant guidelines were found in the practice of DT: User focus, Reformulating problem, Visualization, Experimentation, and Diversity, which are shown in Table 6.4. The concepts are approached differently by the companies according to their source of knowledge about DT, the company's own needs, and the features, which adapt DT to the company's style. The institutions that were most decisive in the companies researched were IDEO, Rotman School of Management, and ME 310 (extension course initially taught at Stanford and spread by several universities around the world).

It was noted in the interviews that some topics did not carry the same weight. For example, the focus on ideation and definition, and finding a balance between what is desirable by the user, technically feasible, and viable for the company. Regarding ideation and definition, individuals mention how they took ideas in the process or gave a sense to the collected data. However, they did not recognize these activities as distinct phases, or did not make special emphasis on them when describing their use of DT. Concerning the balance between what is desirable, feasible, and viable, while different authors refer to it as one of the benefits of DT, little is found of techniques to actually face this balance; perhaps because in organizational discourse what is feasible and viable, is important (BROWN, 2008; PLATTER, 2009), but not in the academic discourse. Therefore, the lack of Mentality, Practices, and Techniques, which address these aspects, may be linked to the acceptance and advancement of ideas developed in the process of DT. Then, more than techniques to deal with this balance, they can be a tenet (CARLGREN; RAUTH; ELMQUIST, 2016).

Table I 0.2 - Carlgren, Rauth , & Elmquist DT Guidelines

Guidelines	Mindset	Practices	Techniques
User focus: activates user participation in idea generation, prototyping, and validation. The way of addressing the user varies from direct methods, such as ethnographic, or indirect.	● - Empathy ● - Curiosity ● - Do not judge ● - Social	● - Observe, understand, and guide the process with the latent and users' pain. ● - Qualitative approach in research with users. ● - Involve users in ideation, prototyping, and testing	● - Ethnographic research ● - Informal meetings with users ● - Accumulate user stories and anecdotes ● - Extended experience, empathy map, person ● - Feedback sections with users
Reformulating problems: is focused on removing restrictions to increase problem space, and therefore, the space for solutions.	● - Unrestricted thinking ● - Comfortable with the complex and ambiguous ● - Open to the unexpected	● Reformulate the initial problem, to expand the space of the problem and the solution. ● Search insights, find patterns, different perspectives or alternatives of formulating the problem	● - How could it be? ● - Five Whys ● - Problem statement; ● - Brainstorming ● - FOG Facts, Opinions and Conjectures
Visualization: Making an idea tangible, simple representation of an idea to communicate, to understand, in order to refine the idea, where visualization is useful to reach a consensus.	● - Thinking by doing ● - Tendency to take action	● - Represent visual and tangible ideas and insights to externalize knowledge, to communicate and to create new ideas. ● - Visualize data structure ● - Make simple representations ● - Provide experiences to facilitate understanding	● - Make rustic physical prototypes, paper, Lego and available materials and artifacts ● - Sketches and storyboarding ● - Storytelling, role-playing games, videos ● - Write basic codes
Experimentation: It is referred to as iteration, doing several work cycles in a divergent and convergent way, to test many ideas. "fail too much and fail early". Experimentation is linked with curiosity, play, and optimism.	● - Curiosity and creativity ● - Playful and with humoristic. ● - Optimism and Energeticism. ● - Learning oriented ● - Anxious to share	● Working iterative, divergent and convergent. ● Converging into solutions based on a set of ideas. ● Prototype quickly and many times to learn ● Test solutions quickly and very often with users and colleagues ● Fail too much and fail too soon	● - Brainstorming technique ● - Creation of physical and flexible environments to support experimentation and visualization.
Diversity: the diversity understood from the variety of skills and team members' personality, different perspectives, get inspiration from various fields of action.	● Integrative thinking ● Open to different personalities and backgrounds ● Democratic spirit	● - Creative and diverse teams, whose all opinions are important ● - Collaboration with external entities ● - Search for diverse perspectives and inspirations, variety of fields of knowledge ● - Holistic perspective	● - Personality test ● - Conscientious Recruitment ● - Analogies ● - Study Tour ● - 360° research, analysis space, benchmarking, past failures, and successes, pattern recognition, demography

Source modified: (CARLGREN; RAUTH; ELMQUIST, 2016)

Rosa (2017) analyzed eight models of DT. She found out that only two of them did not present explicit guidelines. Table 6.5 shows the results of the author's analysis. The guidelines, which were considered, were those which were present at least in more than one DT methodological proposal. It is noticeable that the author carried out the analysis with one document per model and focused her attention on explicit guidelines.

Table I 0.3 - Rosa's Guidelines DT

Guidelines	Citations
Human focus (empathy): empathy with users, feedback with users and determining real users´ needs.	6
Experimentation: the prototype is not only a way of validating an idea, it is also a way of thinking by doing, which is an integral part of the innovation process.	4
Exploring several options: due to the difficulty of knowing expectations, the exploration of different options allows to answer the unknown	5
Show, don't say it: communicate your vision in an illustrative way, by creating meaning and experiences, by using illustrations and using text to tell good stories	2
Take into account the process: know where the process is in the design process, what the methods to be used are, and the objectives, by taking into account the planning of the innovation process.	2
Predisposition to action: from the action, gather data and quickly know the unknown, measure the immeasurable.	2
Start with the unknown: opportunities do not arise with preconceived questions and solutions.	2
Look at the details and the general: due to the difficulty of taking into account absolutely every detail, look at the general with special attention to detail, and the context where the process takes place	2
Design based on how people think: design based on what people do, not based on what they say they do or what other people say they do.	2

Source modified: (ROSA, 2017)

Fleury, Stabile and Carvalho (2016) performed a semantic analysis in order to synthesize a definition of DT. Based on their procedure, some guidelines of DT were established, which are: i) human focus, which is the most frequently treated subject; ii) prototypes, approached by seven articles, with issues such as rapid prototypes and iteration with prototypes; iii) diffuse or unstructured problem, which was approached by five references, related to problem solving; iv) mode of reasoning, divergent and convergent and abductive reasoning; v) the visual techniques in order to explore ideas; and vi) teams, which are interdisciplinary and with collaborative emphasis.

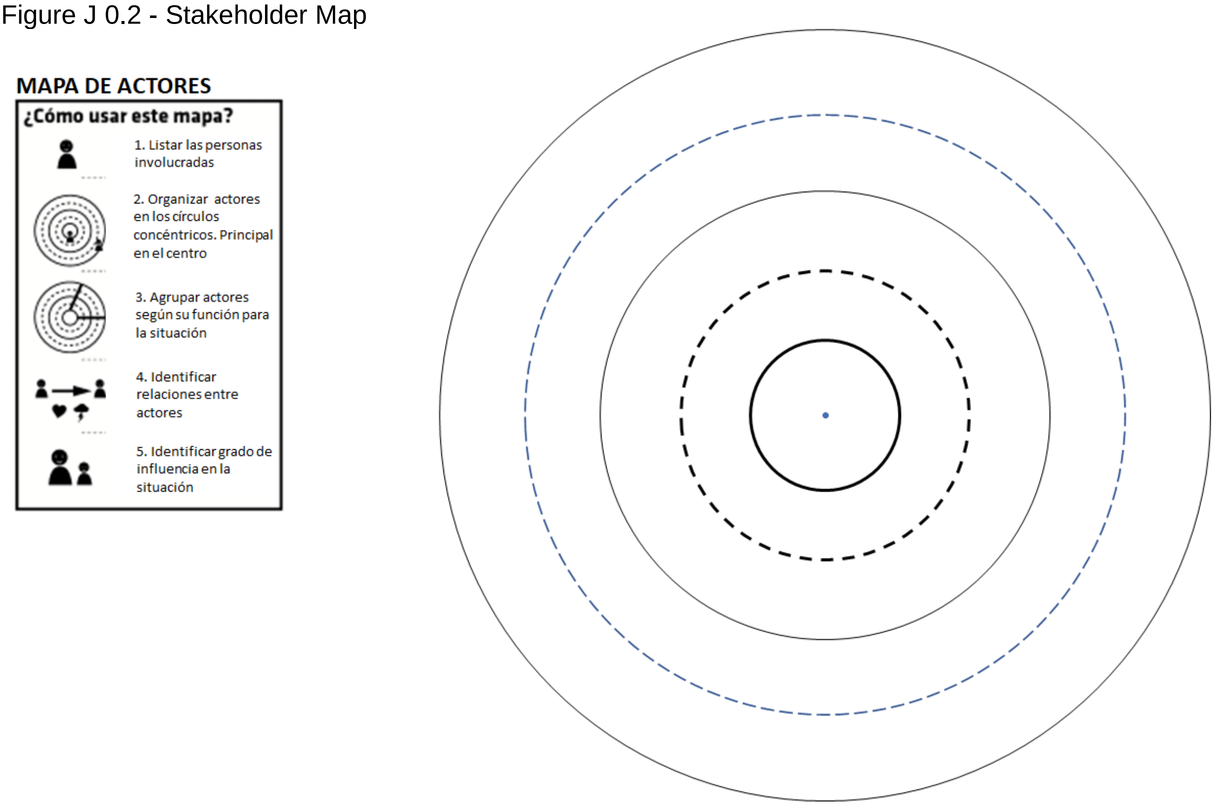
Appendix J FORMATS

Figure J 0.1 - Study of the environment

Estudio del entorno	
Demográfico: crecimiento población, natalidad/mortalidad, densidad población, distribución edad.	**Económico:** Crecimiento, perspectivas económicas.
Regulatorio: leyes y regulaciones relevantes en lo local e internacional, cambios recientes y tendencias en las regulaciones.	**Ambiental:** regulaciones ambientales, impacto de la industria, novedades.
Social: Estilo de vida, valores y deseos, distribución de ingresos, acceso a servicios.	**Tecnológico:** patentes, productos comerciales a nivel local e internacional, novedades tecnológicas relacionadas.
Conclusiones:	

Source: (AGUDELO; LLERAS, 2015)

Figure J 0.2 - Stakeholder Map



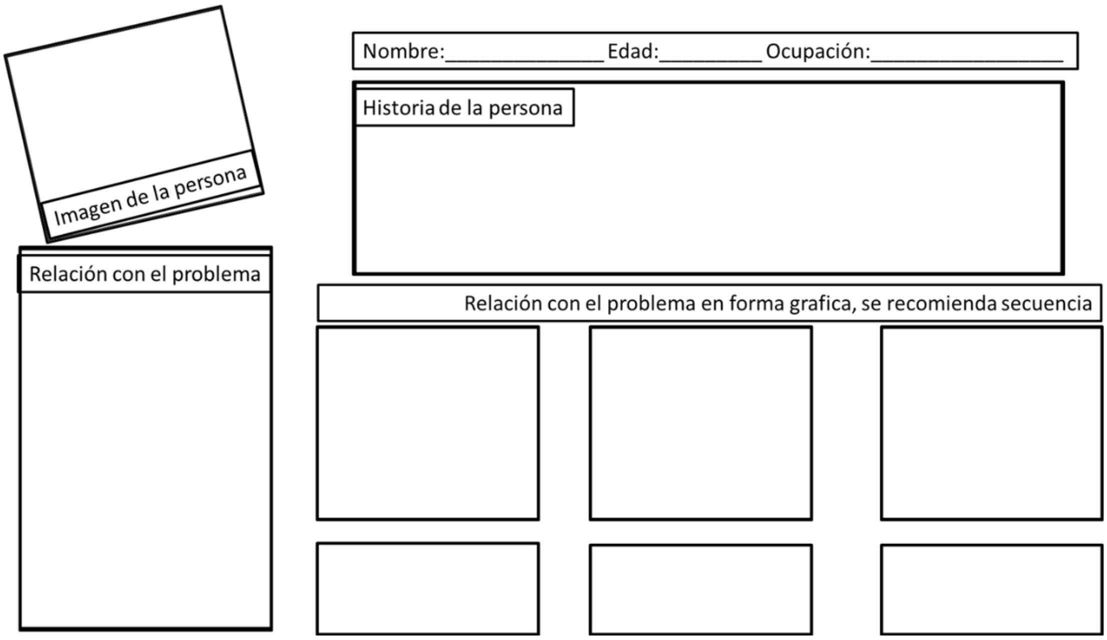
Source modified:: (AGUDELO; LLERAS, 2015)

Figure J 0.3 - Customer Journey

Experiencia ampliada	
1. Antes	2. Antes.
3. Durante	4. Durante
5. Después	6. Después
Conclusiones: comportamientos, emociones, expectativas, relaciones entre personas, espacio y objetos	

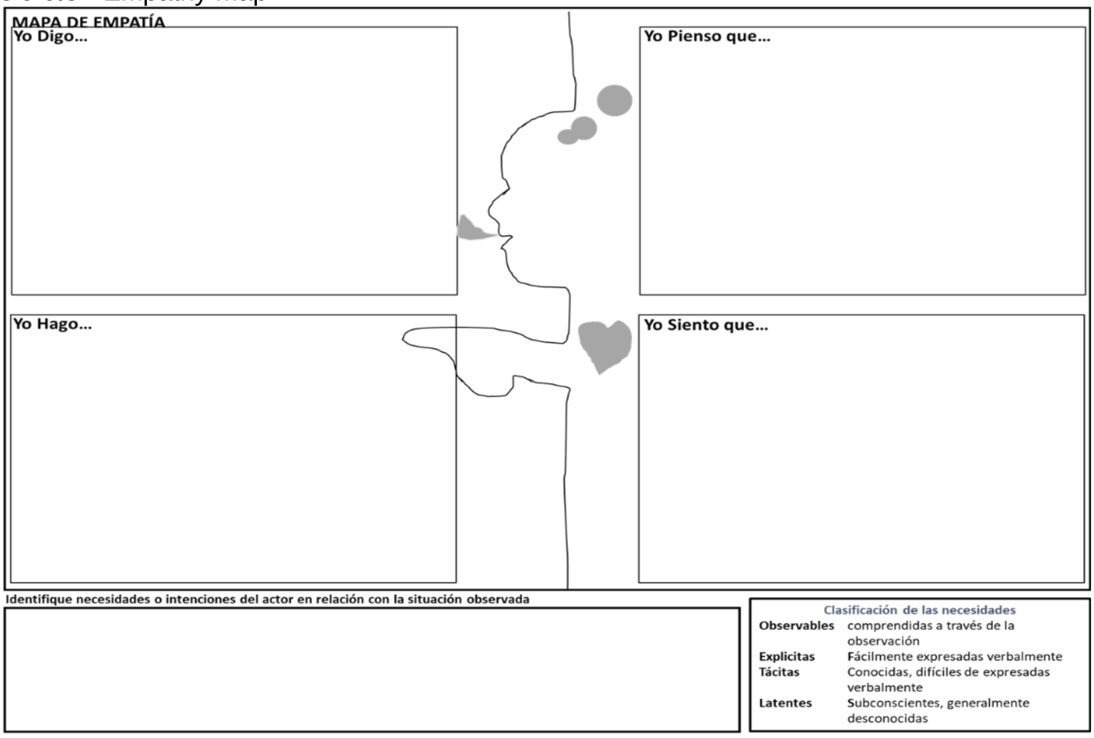
Source: the author

Figure J 0.4 - Persona



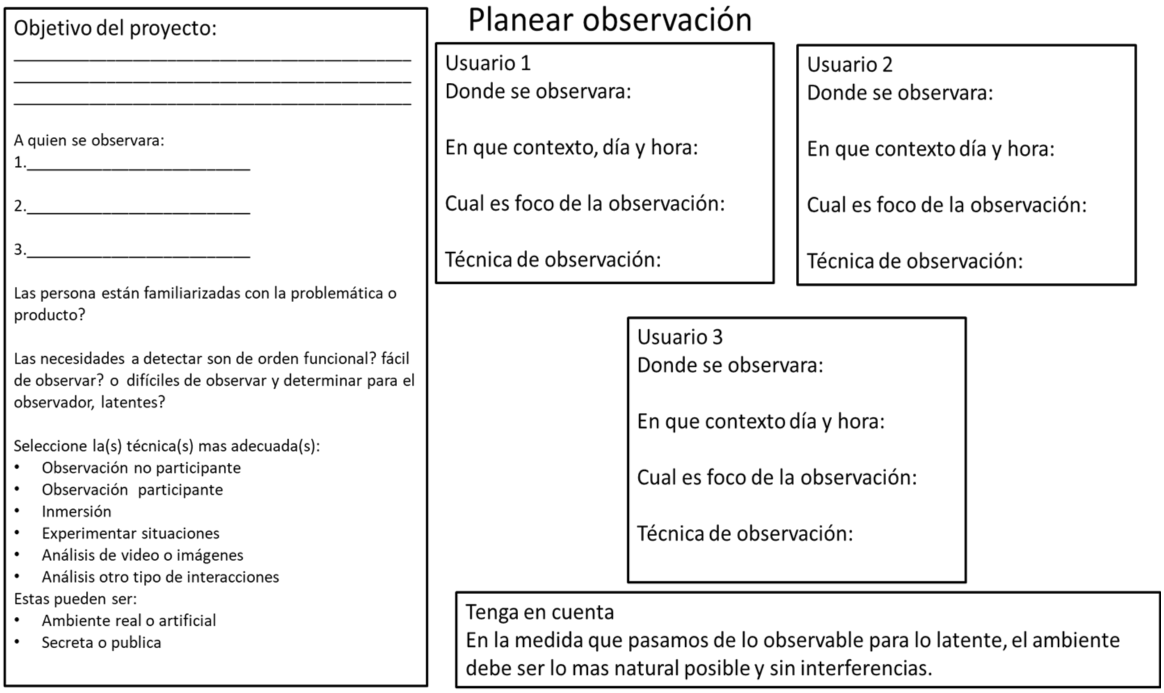
Source modified:: (AGUDELO; LLERAS, 2015)

Figure J 0.5 - Empathy map



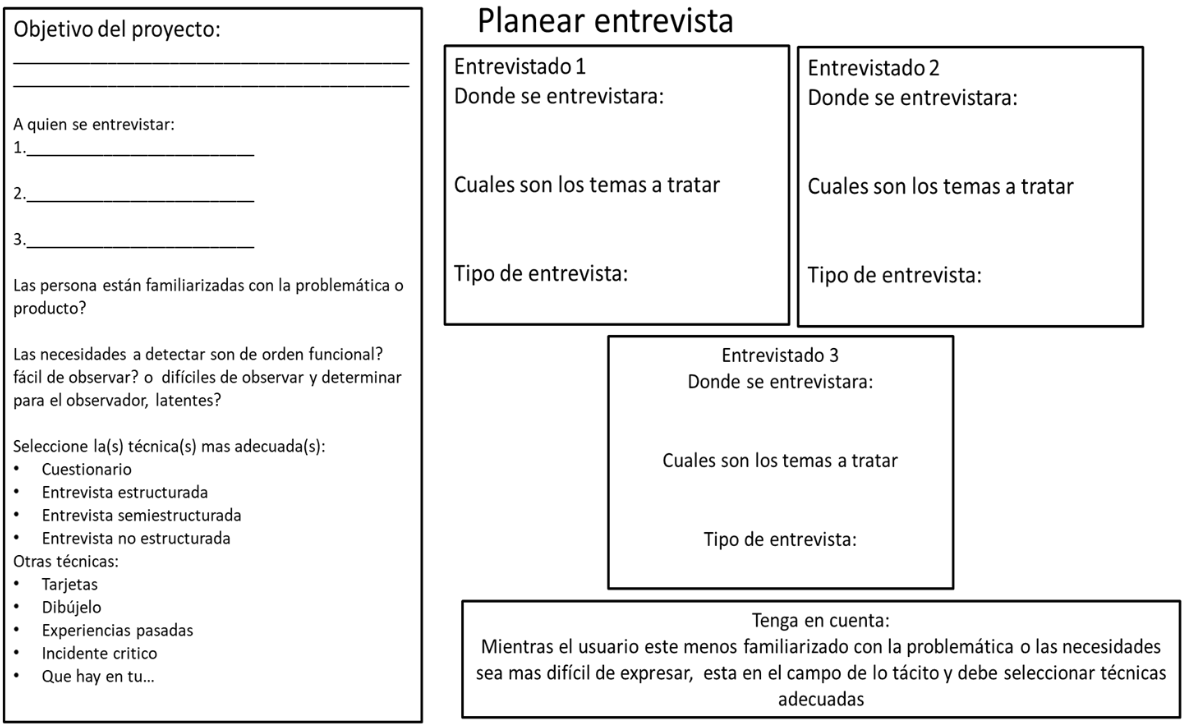
Source modified:: (IDEO, 2011)

Figure J 0.6 - Observation



Source modified:: (AGUDELO; LLERAS, 2015)

Figure J 0.7 - Interview



Source modified:: (AGUDELO; LLERAS, 2015)

Figure J 0.8 - System Operator

	Pasado	Presente	Futuro
Super sistema			
sistema			
Sub sistema			

Source: The author

Figure J 0.9 - Analysis of System Resources

Nombre del sistema:		
Tipo Recurso	Recurso identificado	Observaciones
Sustancia		
Campo		
Tiempo		
Espacio		
Recursos existentes en el sistema, exterior o el objeto, considerar residuos del proceso. Campos eléctricos, gravitacionales, magnéticos, lumínicos, centrífugos.		

Source modified:: (CARVALHO, 2017)