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KNOWLEDGE-BASED SYSTEM FOR CATEGORIZATION AND SELECTION OF CREATIVITY SUPPORT TECHNIQUES IN DESIGN

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Esta Dissertação foi julgada adequada para obtenção do Título de "Mestre em Engenharia Mecânica", e aprovada em sua forma final pelo Programa de Pós-Graduação em Engenharia Mecânica.

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To my partner for believing in me even when I did not believe, encouraging me to follow my own path, and teaching me to be a better person. To my family for the unconditional love and support. To my friends for walking with me for so many years.

To my advisor Prof Dr. Eng. Jonny Carlos da Silva for his knowledge and patience. To the members of NeDIP for laughs and turning work into a light experience. To CNPq for financial support.

Sit on the floor, knees under your chin.
Wrap your arms around yourself,
squeeze as small as you can.
Now explode!
To the fullest of you.

(Tilda Swinton)

RESUMO

Para manter a parcela de mercado no cenário competitivo atual, toda organização deve melhorar suas habilidades criativas, que são a base para inovação e desenvolvimento de soluções adequadas para consumidores com necessidades em constante mudança. Uma grande expertise é necessária para alcançar tais níveis de criatividade, uma capacidade ainda dependente da capacidade humana. Sendo este conhecimento ainda sujeito à disponibilidade, o desenvolvimento de um sistema computacional com a capacidade de selecionar técnicas de criatividade se torna relevante, emulando a habilidade humana de tomada de decisão. Este trabalho visa elucidar os ciclos de desenvolvimento e as métricas de implementação de um sistema baseado em conhecimento para selecionar técnicas de criatividade de diversas áreas de conhecimento, convergindo conhecimentos de Engenharia Mecânica, Metodologia de Projeto, Design Centrado no Usuário, Inteligência Artificial e Engenharia do Conhecimento. O protótipo apresentado é relatado cronologicamente em três ciclos incrementais de desenvolvimento. Primeiro ciclo expõe a estrutura e implementação inicial, bem como a lógica de inferência principal. O segundo aborda melhorias e expansões do sistema em desenvolvimento. O terceiro foca nas recomendações de validação e melhoras de interface. Para selecionar adequadamente as técnicas de criatividade, o protótipo requer uma conexão lógica entre fatores de projeto e a seleção efetiva de uma ferramenta, i.e. as saídas do sistema. Este encadeamento foi estruturado através de um processo de dupla inferência usando categorização, o qual descreve o cenário de entrada em termos de cinco categorias e combina os valores identificados para cada categoria com as técnicas de criatividade. Na versão atual, o protótipo contém 24 ferramentas de suporte à criatividade, contando com mais de 500 combinações de cenários de projeto. As saídas incluem explicações quanto ao processo de inferência, aprendizados em como usar cada técnica, informações gerais e exemplos.

Palavras-chave: Criatividade, Projeto de Produto, Sistema Baseado em Conhecimento.

ABSTRACT

In order to maintain its market share in current competitive scenario, every design organization should enhance its creativity skills, the basis to innovate and develop adequate solutions to changing costumers' needs. A great expertise is required to reach such creativity level, a skill currently dependent on human capability. As such knowledge is subjected to availability, the development of a computational system with the capacity of selecting appropriately creativity techniques becomes relevant, emulating decision-making ability. This work aims to elucidate development cycles and implemented metrics of a knowledge-based system (KBS) for asserting creativity techniques from various study fields, converging knowledge from Mechanical Engineering, Design Methodology, User-Centered Design, Artificial Intelligence and Knowledge Engineering. The presented prototype is showcased chronologically in three incremental development cycles, each progressing on aspects previously unfulfilled. First cycle presents the structure and initial implementation, as well as the main inference logic. Second approaches enhancements and enlargement of the developing system. Third focuses on validation advices and interface improvement. To assert appropriately creativity techniques, the KBS prototype requires a logic connection between factors that lead to the choice and the actual tool selection, i.e. the system output results. Such chaining was structured in a double inference process using categorization, which describes the entry scenario in terms of five categories and matches the identified values of each category with available creativity techniques. In its current version, the prototype selects among 24 creativity support techniques in a combination of more than 500 design scenarios. The outputs include explanations on the used inference process, learnings on how to use each tool, overall information and examples.

Keywords: Creativity, Product design, Knowledge-based systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

AI	Artificial Intelligence
COOL	CLIPS Object-Oriented Language
KBS	Knowledge-Based System
PRODIP	Integrated Product Design Methodology (*projeto integrado de produtos*)
QFD	Quality Function Deployment
TRIZ	Theory of the resolution of invention-related tasks
SCAMPER	Substitute, Combine, Adapt, Modify, Put to other uses, Eliminate, Reverse/Remove

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1 INTRODUCTION

Artificial Intelligence (AI) applications are common in modern world, and are subtly employed to facilitate many human tasks. Online sales pages use of AI techniques to reach customers or offer products and services, while smartphones mimic human communication to provide a more personal experience. Such examples aim to perform activities that are inherently dependent on human intelligence (Nordlander, 2001; Kornienko *et al.*, 2015). On engineering, AI methods and principles are largely used to provide help and ease human mental or physical labor. Considering the level of expertise needed for current engineers and designers to create new products, effort has being put into automating some aspects of design or serve as supporting tools for development (Knight e Kim, 1991; Müller-Wienbergen *et al.*, 2011; Silva *et al.*, 2014).

Being common ground for any design process, creativity is a vital asset to any design team. Reaching unexplored solutions for varied markets require great creation capabilities, which generates possibilities of innovation (Brown, 2010). High demand, tight deadlines, and conflicting requirements strain design teams and organizations to create at a high pace, aiming to maintain or reach new market shares. A great level of expertise and effort is needed from team members to attend such innovation demand, responsibility that could be alleviated by using AI applications such as knowledge-based systems (KBS).

Although creativity as a whole is still hard to emulate with a computer (Jankel, 2015), AI can perform other aspects of the creation process. Developed approaches aim to provide access to relevant knowledge, perform systematic and automatable work, or even provoke users with stimuli to help chaining of ideas (Knight e Kim, 1991; Müller-Wienbergen *et al.*, 2011). However, at the best of this research, no computational approach was found to use creativity techniques to promote creation.

Creativity techniques, when correctly used, have the ability of catalyze the creation process (King e Schlicksupp, 1999). Many modern approaches, such as Design Thinking and agile methodologies, use of such techniques to ease the process, being a vast range of different tools available on literature (Ideo, 2011; Curedale, 2013; Ideo, 2015). The assertion of a technique over others requires experience from the team members, who should take into account for the decision many aspects of the organization, design situation and the team itself. Considering the amount of information available and expertise needed to select and use each technique, many useful techniques remain neglected, especially when considering different fields such as engineering, design and management. The simple exposure of several techniques, although useful as a database, may lack information on comparing them and choosing a technique to each situation. This heuristic knowledge gives way to the application of the (KBS) that aims to translate the knowledge to a computational environment and emulate human decision-making ability (Giarratano e Riley, 2005). This bridge would serve to transfer knowledge from the expert, whose expertise was used to develop the system, to the user, who requires knowledge. Such approach provides reliable, available and permanent information for users, serving as an indirect mean of contact between the design team and creativity experts.

1.1 Objectives

This work aims to develop a knowledge-based system tool to support product design with adequate creativity techniques, offering alternatives to users and instructing about structure and use of each technique. This objective can be divided into two main branches:

- Adequately assert creativity techniques regarding user inputted information;
- Provide an easy and intuitive tool for any design team to use and learn about techniques.

The development of the first item implies on the prototype structure, the correlation method used to combine information provided by users to techniques on the system database. Different scenarios should be encompassed, and the developing system should be able to identify key information to define the design and team characteristics, correlating and outputting the tools that considered adequate. The development should also be sufficiently broad to present techniques that are possibly unknown to the user.

Constructed the KBS structure, the prototype should also be friendly to any user, with or without deep knowledge on design. The user interface and language should be intuitive and the techniques presentation understandable. Users and teams should be able learn about each technique without great efforts, trusting the heuristic knowledge on the assertion of tools to the prototype. The development should also be validated by experts and non-experts, evaluating its structure, coherence and usability.

1.2 Justification

Literature points out the need of creativity and innovation on the current competitive scenario. Design teams use various approaches and methods to aid on the task of product design that many times proves to be an arduous and uncertain task. Creativity enhancement techniques are seen throughout literature (King e Schlicksupp, 1999; Back *et al.*, 2008; Brown, 2010; Baxter, 2011; Ideo, 2011; Curedale, 2013; Ideo, 2015)and can aid the process of creation, offering cognitive flexibility and alternative mind-pathways for ideas. Unfortunately, the choice of a single technique on the broad field of possibilities may be on cases difficult and demands great expertise.

The use of a KBS approach may aid in the process of filtering and choosing of creativity techniques in design. Considering some projects related to this research (Silva, 1998; Matelli, 2008; Pedroso, 2013), this work aims to develop a computational system to help design teams in need for creativity enhancement, overcoming possible creativity blocks. The assertion of creativity techniques imply on the understanding of the team scenario and design situation, aspects that help the system prototype to identify the necessities and correlate adequate outcomes to the user.

1.3 Work structure

This work is divided in seven chapters, each providing information on the structure and development of the KBS prototype. Chapter 2 introduces important aspects of creativity and innovation on personal and organizational scopes, being the main source of knowledge for the inferencing process leading to assertion of techniques. Chapter 3 encompasses the methodological background on engineering and presents the intersection between design methodology and creativity. Chapter 4 presents fundamental aspects on AI and KBS, the computational grounding of this work. Those three chapters are based on literature review and cases, the main grounding of the prototype development.

Chapter 5 presents the first development of the prototype, the system entries and exits, as well as correlation method, structured on categories that help connecting the user inputted information to the implemented techniques. Chapter 6 presents evolutions of the system as well as the validation process, followed by conclusions and future works on Chapter 7.

2 ORGANIZATIONAL CREATIVITY AND INNOVATION

As a converging study field, this work encompasses knowledge from creativity, design methodologies and knowledge-based systems, topics that will be addressed separately in the following chapters. This chapter introduces the basic concepts regarding the creative principles of individuals and organizations, as well as the innovation process, influence factors and techniques. The knowledge here described is the foundation to the knowledge construction and inferencing process of the KBS, which asserts creativity techniques based on the heuristic knowledge of creation and innovation on personal and organizational levels.

All presented information contributed to the prototype development. Creativity is not a simple concept and several study fields deal with it on many situations. Psychology, management, engineering and design are some of the areas that develop works on this theme that is relevant not only for industrial purposes, but also as means of personal development. In addition to the complexities of the organizational and market environment, creativity and innovation become complex matters that are at the same time fundamental and demanding to any company. The techniques are capable of exposing and using the concepts of creativity in everyday situations of companies, making them powerful allies of design teams and vanguard organizations.

2.1 Creativity

Different cultures of humankind have studied, theorized and defined creative thinking. From an etymological perspective, the English word creativity refers to *creare*, late 14th century's Latin word, meaning "to make, bring forth, produce", and also to *crescere* meaning "arise, grow" (Harper, 2001). Both origins indicate a novel nature, or even an amplification of an existing element by means of effort and activity.

Alongside the meaning, the interpretation of the term has varied throughout history. The first theorization of what is now called creativity is accredited to Plato on Classical Greece, attributing the ability to a deity's will or even to a madness frenzy (Souza, 2001; Sawyer, 2011). This vision was sustained by many philosophers even in recent history, such as Cesare Lombroso in 1891, which argued that creative geniuses suffered from many "degenerations", claiming that famous historical genius were short, lame, hunch-backed, club-footed, among others (Sawyer, 2011). He defined creativity as an irrational and involuntary skill, thus being a pathology (Souza, 2001). Immanuel Kant, during renaissance, in order to understand masters of Arts as Da Vinci and Michelangelo, also defined creativity as inherent, natural and unpredictable, which impedes its formal teaching. Even Charles Darwin on 19th and 20th century aimed to conceptualize creativity as a force inherent to life, dividing organic matter as capable of creation and inorganic matter as only able to copy the same entities (Souza, 2001). This concept indicated that creation is similar to the evolutionary process, facing a blind variation (mutation of genes or association of ideas), selection of the fittest and retention of adequate species or ideas (Sawyer, 2011).

Also during the 19th century, the evolution of science and psychology allowed a deeper understanding of creativity and its relation to human being. *Associationism* theorized that creation of the new began with progressive association (trial and error) of old concepts, following rules of frequency, recentness and vivacity (Souza, 2001; Dacey, 2015). This means that thoughts that are constantly accessed, involving recent and strong experiences are more likely of being associated and promote creation. This theory does not account with the idea of originality, being all creation derived from connections among existing facts and not properly creating new concepts, but recombining existing ideas in a common and predictable way (Souza, 2001). Against this theory, a group of psychologists on 20th century USA sustained the *Gestaltism*. This line claimed that some creation does not need a chaining of ideas or associations for being too sudden and fast (Sawyer, 2011). They see creativity as a conscious line of non-arbitrary thoughts, seeing a problem as an unbalance of the mind that needs a solution in order for the brain to be re-harmonized (Souza, 2001). The theory fails to explain the origin of the creation process or what triggers the unbalance, therefore excluding the capacity of generating original questions (Souza, 2001).

Psychoanalyst vision, such as from Freud, sees creativity as unconscious (id) driven and related to imagination. This impulse is result of an internal conflict ultimately solved by the ego, which intermediates id and reality. Therefore, creativity is random and unpredictable, being even associated with neurosis and disturbs (Sawyer, 2011). The philosophy separates creative thinking, providing several ideas, from the structured and rigid thinking, acting as filter to reality. Without the first, the creative process is unable to create something new, and without the second the creation is arbitrary, thus useless (Souza, 2001).

Dr. Guilford's vision as president of the American Psychologists Association had a big impact on creativity research. Until the 1950s, researchers focused on behaviorism or Freudian psychoanalysis, which gave little space to investigate creativity. In addition, most psychologists saw creativity as a byproduct of intelligent mind, being talent and human potential associated to intelligence (Sawyer, 2011). As a counterpart to the Freudian approach, humanist psychologists as Maslow, Rollo May and Carl Rogers saw creativity as a peak of healthy human personality (Sawyer, 2011). This theory is the first to attribute creative practices as healing activities, linking creativity to the environment in which the person is inserted. Only the self-realization impulse and intrinsic characteristics are not enough to trigger the creative impulse, but should be supported by social conditions, such as freedom of choice and action (Souza, 2001).

Dr. Guilford himself posteriorly published studies on creativity, classifying it as part of human mind capacities. Creativity fits into the productive category, which makes use of information absorbed by cognitive category and judged by evaluative category. His works were the first to divide convergent and divergent thinking, the first following conventional responses on a previously known system, while the second occurs in unknown problems or with undefined methods, requiring creativity (Souza, 2001). Koestler's *Bisociation* brought the idea of creativity as the capacity to simultaneously think over more than one reference system (experiences) and the ability to create new configurations based on thinking or behavioral patters (matrixes), which were not previously combined (Souza, 2001; Baxter, 2011). His vision separated routine skill, which acted on a single plane, from creative thinking, which always operates in more than one plane (Ko e Butler, 2007). Other notable definition was developed by Gardner, which assumes creativity as present in every human intelligence (Souza, 2001).

Modern approaches include cognitive psychology models, in which the human being tries to represent any situation (seen as any internal disturbance caused by external factors) in a way to reach comprehension. If the individual is unable to satisfactorily structure, he/she will recur to reasoning in order to construct a plausible representation of the situation. Such representations are made using schemes necessarily filtered by the five senses, which aim to explain reality. New patterns may:

- Be associated to old ones, confirming and strengthening existing knowledge;
- Be part of a new experience that generates knowledge;
- Contradict previous systems, occasion on which the knowledge is unable to explain the present situation and should be modified.

Creativity starts with this conflict between old and new knowledge and the necessity of searching adequate answers to the situation (Souza, 2001).

Consecutive visions confirm aspects of previous studies, presenting an evolution of creativity connotation over the centuries. Coincident with the Darwinist vision of creativity, creativity is inherent to the living nature, not being seen its practice in a rational way in other species. Creation is a skill used in day-by-day and is influenced by experience of the person, agreeing with the *Associationism*; the environment, convergent with the Humanism; and using of originally unrelated areas to generate new ideas, matching to Koestler's *Bisociation*. *Gestaltism* attests that creativity is in essence random, but necessary to solve problems of conflicts generating new knowledge, aspect posteriorly reinforced by cognitive psychology. Psychoanalysis and Dr. Guilford Mind Capacities both present the separation of irrational and rational thinking in creativity, using divergence to generate ideas and convergence to analyze and synthetize ideas.

2.1.1 Definition of creativity

Visions on creativity evolved through the centuries, based on scientific discoveries and works or many researchers. Even so, many definitions and interpretations can be found in literature, using concepts and ideas from many schools. No definition is absolute and universal, but great efforts were made in finding an adequate meaningfulness to the term, out of which some can be highlighted:

- "At its heart, creativity is simply the production of novel, appropriate ideas in *any* realm of human activity, from Science, to the arts, to education, to business, to everyday life. The ideas must be novel – different from what's been done before – but they can't be simply bizarre; they must be appropriate to the problem or opportunity presented " (Amabile, 1997);
- "(...) creativity is the capacity of people to generate new projects, products or ideas, which until the moment of generation were completely unknown to the creator." ((King e Schlicksupp, 1999), translated);
- "(...) considers creativity as an ability to generate novelty and, with that, ideas and useful solutions to solve day-by-day problems and challenges." (CAVE, 1999 apud (Souza, 2001));

- "Creativity can be considered the input of the innovation process, turning into a necessary condition to add value and high degree of novelty to the product/process/service." (Aranda, 2009).

Such definitions converge for the novel quality of creativity, which is inherent aspect of it. Three visions mention the useful characteristic, namely new ideas are not creative if not adequate or useful in fulfilling some function. Although creativity in a personal level can grasp utopic ideas, the aim of creation, especially in organizational environments, is ultimately useful ideas. Both first and third definitions mention creativity as an everyday ability, showing its necessity in a day-by-day basis and not being used punctually or "when necessary". Finally, according to the first definition, creativity is able to solve problems any knowledge domain when needed, not being restricted to formal product, process or service design.

Creativity is, therefore, the human capacity of producing new and adequate ideas to a situation derived from any knowledge domain. It is an impulse of knowledge over the known, looking into the future. It can be seen that recent studies often contradict the still perpetuated common sense of creativity as a special talent. Any person with the right environment can be creative, being a learnable and developable ability (Amabile, 1997; King e Schlicksupp, 1999; Souza, 2001). As a broader interpretation, this concept correctly addresses as creative the behavior of pre-historical humans, which developed stone tools and clothing, as new artifacts fashioned to fulfill their needs. With the increase of social complexities and human capacity, creativity became a much more profound and discussed theme. Human necessities adapted to different lifestyles, evolving from simple food or shelter needs to a much more refined demand. Even so, a similar pattern can be found on every creation process, following consciously or not a set of stages.

2.1.2 Creativity stages

Many factors can corroborate for a person or organization to be creative. To better understand its structure, creativity is commonly divided into steps (Souza, 2001; Mostert, 2007; Back *et al.*, 2008; Baxter, 2011):

- **Inspiration:** focus on a specific problem, triggering the creative process;
- **Preparation:** gather information about the problem at hand, serving as knowledge acquisition. It is considered the rational stage of creation;

- **Incubation:** distancing from the problem to ideate unconsciously. It is the irrational stage of creativity;
- **Illumination:** known as the "eureka" moment, the mind successfully creates connections that fit the problem;
- **Verification:** proofing of the solutions adequacy to the original problem, serving as a reality filter. Every idea should be evaluated;

This separation presents the dual nature of creativity, as described by psychoanalysts and Dr. Guilford. Even depending on irrational neural associations of the incubation period, the basis to create should be grounded on rational knowledge. While having inspiration and objective to create is important, an effort on gathering information and experience is essential to leave room for random mind associations to occur. Unfortunately, this irrational period can be time-consuming and is considered the bottleneck of creative thinking (Mostert, 2007). To let the mind freely diverge will eventually lead to creative and appropriate solutions, but, on current market, time is a valuable and scarce asset.

The understanding and formalization of the creative pattern allowed researchers to focus on enhancing organizational creativity by different approaches, which, when combined, potentiates the capabilities of a design team to come up with more innovative products. To diminish time consumption, organizations focus on offering better working environment, adequate amount of pressure, flexible schedules, and creativity techniques. Each approach has its advantages and, combined, potentiate creative thinking by allowing better ideas, and higher satisfaction of customers and employees. Creativity techniques present an advantage by undertaking the actual bottleneck of the process: the incubation time (King e Schlicksupp, 1999). By using adequate techniques, the mental associations are more easily triggered and teams are able to come up with more ideas in less time, or overcome creativity blocks.

The generated ideas should, then, be tried and suited to the initial inspiration. The last stage of creativity is particular and focuses on befitting the developed ideas to reality. Many ideas are internally imagined while creating and each has its importance. Even out-of-the-box ideas may leave room to chain other solutions. While pure ideation helps to diverge and come up with different ideas and unusual combinations, innovation serves as a filter, bringing the ideas to a feasible reality (Amabile, 1997). This verification step is what transforms abstract ideas into concrete solutions, transforming pure ideation into innovation.

The conceptual structure of creativity can be seen as a first signal for stablishing a computational-aid tool. Even been extremely particular and dependent on cognitive brain processes, the incubation phase, as a bottleneck, deserves special attention. The use of adequate creativity techniques may help reducing this time demand, and the assertion of a tool is feasible as an artificial intelligence approach (Botega e Silva, 2015a). The developed KBS prototype supports this line for aiding teams in reaching more and better solutions for innovative products.

2.2 Innovation

Etymology relates innovation to the 1540s Latin word *innovates*, meaning “to renew, restore, or to change”, being posteriorly referred also as “to make changes in something established” (Harper, 2001). The renovation should occur over something previously created, made or produced, which is the etymological definition of creativity. This reasoning indicates innovation as a derived stage, depending initially on creativity (Valentim, 2008).

Even deeply intertwined, creativity and innovation can be separated in two distinguished constructions: divergence and convergence. While creativity focus on diverging quantity of ideas and overlooks quality or adequacy to reality, innovation converge these conceptions into appropriate and factual solutions, priming for quality over quantity (Amabile, 1997; Levitt, 2002; Aranda, 2009), as represented in Figure 2.1. Consonant to the Freudian view, both are imperative during the creation process and cannot be isolated. Lack of creativity may converge ideas prematurely, leaving predictable concepts that neglect more appropriate solutions (Back *et al.*, 2008). Lack of innovation generates large amounts of useless information, being slow and occasionally diverging from the original requisites. Innovation complements creativity and, together, are indispensable skills for any organization to maintain its market share.

A pioneer author to address innovation in organization as a competitive factor was Schumpeter in 1911 (Kiperstok *et al.*, 2002). Innovation is a broad concept seen as introduction of a new good, production method, market, source of raw material, or economical organization. The definition, although not directly mentioning creativity, denotes a “novel” quality, or something different from what exists, aiming to permeate the market and maintain company’s profitability.

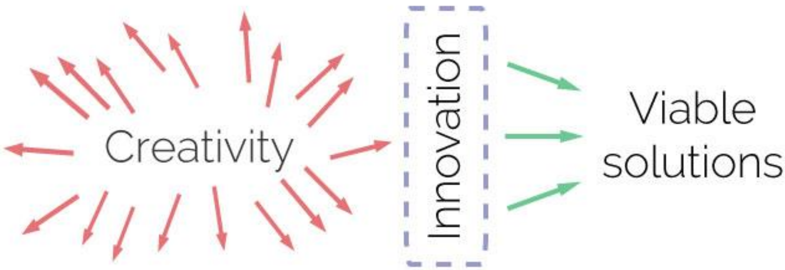

Figure 2.1 – Interaction between creativity and innovation.

Traditionally, in industry, innovation was seen as a synonym to technological progress. With appearance and dissemination of Total Quality Management (TQM) on 1980s and 1990s, new aspects of innovation gained space, reaching for a bigger contact with customers and exploring new markets (Vianna *et al.*, 2012). The perception evolved from designing a product based only on its function to studying also user's needs. This trend gave place to new approaches focusing on understanding stakeholders and customers, using such knowledge to create new products and generate a higher appeal to the market.

Innovation is dependent on many factors inside an organization, and there is no ideal or better way of developing a product, service of process. Each design, team, and market requires different designing capabilities (Brown, 2010). Three spaces can be used to explore if a development has fundamental prospective to lead to an innovation, as shown in Figure 2.2. This vision gives equal importance to three factors inherent of design, grounding the design thinking approach. In order to be innovative, any development should balance (Brown, 2010):

- **Feasibility:** encompasses aspects of engineering, infrastructure and technology, as in what is functionally possible with current technology and applicable in short-time future;
- **Viability:** is the basis of management and business, covering what can potentially become part of a sustainable business model, granting income and composing the organization's portfolio;
- **Desirability:** arises from customers, representing the desires and values of the target public that may lead to a market acceptance. It is linked to culture, social and temporal context.

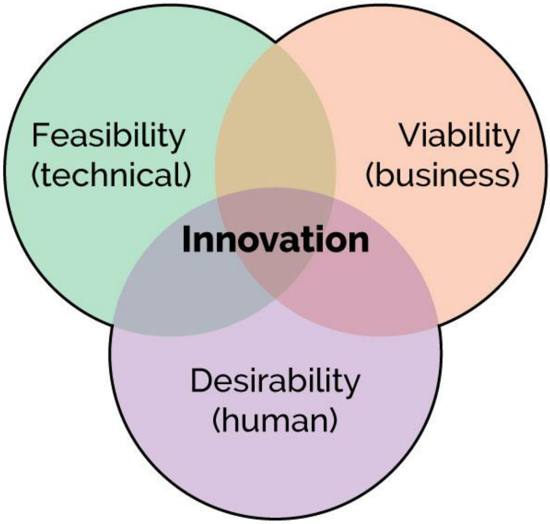

Figure 2.2 – Three spaces of innovation (Brown, 2010).

A commonly presented division includes the approach or intensity of creative and innovation use inside an organization, affecting directly its market posture and adequacy to economic scenarios. Traditionally, innovation is divided into two main categories (Schumpeter, 1934; Henderson e Clark, 1990; Back *et al.*, 2008; Brown, 2010; Souto, 2015):

- **Incremental:** tend to incur in lower costs and risks, occasioning inferior degree of novelty and profit. Presents alterations or evolutions of the product, service or process, aiming to maintain organizational portfolio and present new iterations to the market. It consists in partial improvements, exploring potentials that reinforce the dominance of a product/service/process in the market. This approach tends to be better managed by functional groups with defined hierarchy, centering tasks to experts and giving less autonomy to the design team;
- **Radical:** aims new and disruptive markets, causing great commotion and even redefining a whole industry. This type is usually based on new technology developments or identification of unsatisfied users' needs, occasioning a rupture between the non-existence and the arrival of the product/service/process. It usually incurs in high generation costs and risks, but leads to a

high degree of novelty and profit. This approach tends to be more successful when given more autonomy to the teams, which can work integrally and cohesively on the design.

This polarization between incremental and radical innovation has been studied and increased. Some authors suggest a restructuring of the two categories, adding other dimensions to the problem. This is caused by the multidimensional nature of innovation when approached from different perspectives, which add important factors to this categorization. Henderson e Clark (1990) reorganized the structure in relation to the exchange of chore concepts and the architecture of the system, as presented in Table 2.1.

Table 2.1 – Innovation classification based on core concepts and architecture (Henderson e Clark, 1990).

		Core Concepts	
		Reinforced	**Overturned**
Linkages between core concepts and components	**Unchanged**	Incremental innovation	Modular innovation
	Changed	Architectural innovation	Radical innovation

This new classification was developed in observance of products that, even with minor technological changes (characteristic of incremental innovation), occasioned a great impact in the industry (characteristic of radical innovation). This was the case of Xerox, American multinational seller of business services and document technology. Even though the company had developed the core technology for plain-paper copiers, the insertion of much smaller and more reliable competitor products in mid-1970s claimed almost half of their market. It took eight years for the company to regain stability and accompany the new trend. Even with the same core technology, the architectural alterations and the different market targeted by the competitors changed the whole conception of the product (Henderson e Clark, 1990). The separation of a product in core concepts – i.e. the choice of a component among all the ones that exercise the same function – and their connections allowed the addition of two more categories to the two previously described (Henderson e Clark, 1990):

- **Architectural:** does not incur on an alteration of the technology, but the interaction between concepts inside a product. Usually it is triggered by changes on size or form of a component, which leads to a general reorganization. Even being more subtle than radical innovation, it causes relevant changes on costumers vision of the product or even on its utility;
- **Modular:** changes internal components without altering the interaction among them, usually maintaining the same architecture, but aggregating a new technology. External alterations are smaller and cause less impact on traditional users, aiming to increase the experience based solely on function.

As an illustrative example, a portable floor fan can be addressed as current technology. Alterations on blades, rotor or aesthetic can be categorized as incremental innovation; the development of ceiling or *bladeless* fans as architectural innovation; a change on the type of blade plunger as modular innovation; and installation of air conditioning as radical innovation. Naturally, the distinction among categories may not be pronounced, but the distinction can be useful for an organization to know its market place and act according to the guidelines, adequately guiding the initiation of new projects.

Another approach, described by Brown (2010), focuses on the relationship between market and users in a Design Thinking approach. It is based on the interaction between user (the customers or main market of the product or service) and offering (if the market has a provider of such product or service). This relationship also gave way to four categories as shown in Table 2.2.

This division, which has also blurred contours in practice, presents new approaches to organizational innovation. Adding to the concepts of incremental (manage) and radical (create) innovation, evolutionary innovation can be subdivided into two groups (Brown, 2010):

Table 2.2 - Innovation classification based on offering and users (Brown, 2010).

		Users	
		Existing	**New**
Offering	**Existing**	Manage (incremental)	Adapt (evolutionary)
	New	Extend (evolutionary)	Create (revolutionary)

- **Adapt:** insertion of an existing product in a new market, even by making adaptations to better suit the new users. Reduction of costs to access a public with lower income or exploration of international markets with unsatisfied niches are some example of this innovation;
- **Extend:** generation of new offers inside the same market niche, exploring necessities that are so far unfulfilled. The addition of cameras on a cellphone could be seen as an extension of the technology in the same (or similar) market.

A difference between this model and the others is the view of radical innovation. The idea of creating something disruptively new may not be attached to the development of a completely new technology, but rather the exploration of a nonexistent or regional market, which is unsatisfied and in which the organization is not at the moment inserted (Brown, 2010). This is relevant in a globalized world, in which organizations may fail to be innovative for not focusing the right market or limiting itself on local necessities, rather than abroad users.

Different approaches on innovation reveal possibilities of asserting adequate creativity techniques. Some tools are better fit to create radically new concepts (such as Biomimetic), while others are suited to incrementing the existing knowledge (such as SCAMPER) (Botega e Silva, 2015a). This shows the possibility of creating a computational tool that, added sufficient information, divides which techniques are proper in each situation. Other aspects will be further addressed during the development of this work, such as other forms of categorization throughout the design process and how to define suitable techniques.

It can be seen that innovation is not a punctual asset that should be used in stages of conceptual development, but rather permeate all areas of an organization, from higher to lower levels, from high management to human resources. Many ideas may arise from workers in direct contact with manufacturing, maintenance or assembly, and their insight are as valuable as the ones from designers and engineers. The divisions on innovation show the complexity of the team achieved by deepening basic concepts. Different approaches are responsible for great impacts on the organization’s view of the market, as well as its future goals and guidelines. Regardless of the approach, creativity is fundamental on the process of developing new products, services and processes. However, only knowing the organization’s market position and its intentions do not guarantee that the design team will reach such goals. The path leading to innovation is intricate and, independently of the company’s strategy, creativity rises as the first stage on any innovation. By having defined goals and knowing its market, is up to the organization to explore adequately the creative potential of its members in order to reach the objectives.

2.2.1 Influence factors of creativity and innovation

Creativity is a concept more intricate than just the “eureka” moment of an inventor when creating a new product or service. Intrinsic and extrinsic factors to the designer add up to a great deal of the creation process and are fundamental to the quality and quantity of generated ideas. The person in need for creativity should not only be well rested and motivated to create, but also inserted in an adequate environment that instigates creation, which makes the process more efficient.

Creativity is an iterative process (Brown, 2010). Hardly can an idea come without trial and error, discussion, exchange of ideas and knowledge on the area. Information sharing plays a great deal on speeding the process, offering more opportunity for the members to ideate, chain ideas, discuss, and evaluate not only the ideas, but the whole design process (Brown, 2010). By having a dedicated room, the team is able to maintain the knowledge and continuously develop previous ideas, which can be displayed on walls or prototypes inside the workplace (Brown, 2010). Other influence factor is virtual connection, as many ideas can be uncovered outside work-hours. If the members are unable to communicate at the right time, aspects of the idea or the whole chaining process may be lost (Brown, 2010).

With the rise of multidisciplinary teams, which promotes direct contact between members from different expertise in order to ease the work and potentiate creation (Amabile *et al.*, 2002; Back *et al.*, 2008; Brown, 2010; Baxter, 2011), a language barrier may sometimes be created. The idea of putting together people from engineering, design, finance, marketing, and any relevant area is important to share expertise and correctly contour the problem. However, these different areas may have different languages and communication is sometimes difficult. By using of co-working, models and prototype during conception of ideas (Brown, 2010), and allowing the team to define project guidelines (Back *et al.*, 2008) may help giving more freedom and increasing efficiency and creativity. This communication may even help on chaining of ideas and avoid rework (Back *et al.*, 2008; Baxter, 2011), due to every member of the team having an idea of the whole project.

The Componential Theory of Individual Creativity developed in (Amabile, 1997) structures the influence factors on creativity in three aspects, as shown in Figure 2.3. These components focus on each team member, and the factors are responsible for aiding individual creativity, which adds up to the combined creativity of the team.

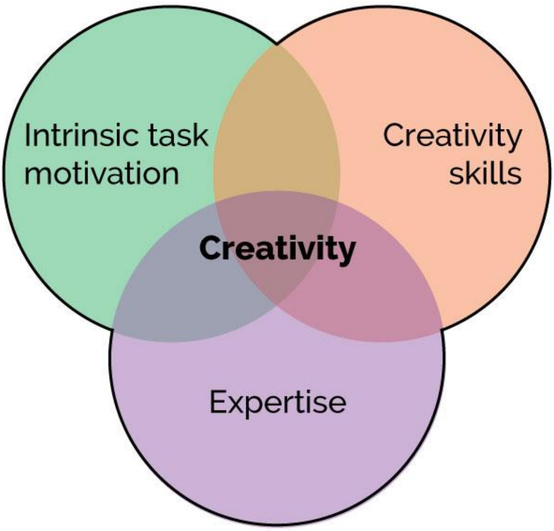

Figure 2.3 – Three-Component Model of Creativity (Amabile, 1997).

- **Intrinsic task motivation:** derives from personal interest on the task, curiosity, satisfaction, and sense of challenge, inciting the person to reach for new knowledge to solve the problem at hand. Even being intrinsic, this factor is the most influenced by extrinsic factors such as working environment, belongingness, friendships, communication and common will to reach objectives;
- **Creativity skill:** is tied to personality traits, although it can be stimulated in any person with adequate practices to improve cognitive flexibility and intellectual independence. Higher sense of independence, self-discipline, risk-orientation, tolerance to ambiguity, perseverance over frustrations, and lack of concern for social approval improve the chances for creative thinking. It is also related to a different perspective views on problems, aiming actively and persistently to reach a solution;
- **Expertise:** is the factual memory, combined to technical proficiency and special talents on the study field, which help developing the mind pathways that allow creativity to work. The more a person knows about the field, the easier it is for the mind to generate ideas and increase the "network of possible wanderings".

While expertise and creativity skill frames what a person is capable to do, intrinsic motivation sets what will actually be done, playing leading role in creation. Extrinsic or environmental factors also influence directly individual creativity, serving as support for individual stimulus (Amabile, 1997) and influencing directly the intrinsic task motivation. Solely altruistic instinct may not be sufficient in leading to better ideas (Hung *et al.*, 2011), but with the right internal motivation to achieve goals team members tend to be more willing to contribute (Amabile, 1997) and more satisfied during meetings (Hung *et al.*, 2011). Incentives such as rewards or adequate recognition, well defined objectives, and constructive feedback aid individual and team creativity, especially if designers feel that their work is relevant (Amabile, 1997).

Among extrinsic factors, the sense of recognition or reciprocity highly influence on information share (Hung *et al.*, 2011). Team members that feel that their contributions are worthy and that their presented actions will lead to future benefits tend to have more and better ideas (Hung *et al.*, 2011). Other forms of extrinsic motivation may have no influence (Hung *et al.*, 2011) or even undermine creative potential and information share (Amabile, 1997). Some extrinsic factors, when inappropriately used, may combine negatively with intrinsic motivation, frustrating a person's sense of self-determination (Amabile, 1997).

The use of milestones can also positively stimulate team members, especially if seen as a feasible challenge and not a threat or unreality of the high administration. Excessive stringency, demand, and amount of parallel works also shun creativity. If the work is often interrupted and team members are obliged to lose focus on current tasks, the potential of idea generation is diminished. Smaller groups – in which each member has well defined tasks performed individually, but with free informal interaction among members – also tend to attain better results on creativity (Amabile *et al.*, 2002).

As individual creativity is the start point of any organizational innovation, both aspects can influence one another and grow in a positive spiral. Three factors out of management levels are fundamental to generate an adequate environment for potentiating innovation and team creativity, as shown in Figure 2.4.

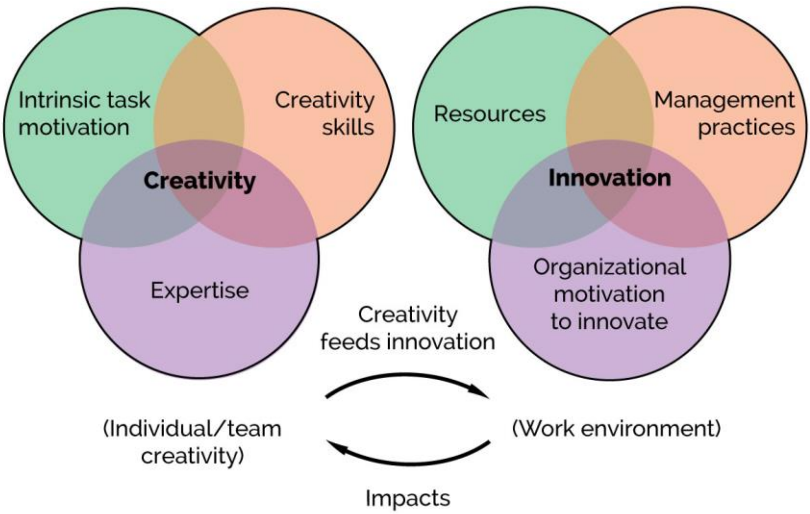

Figure 2.4 – Impact of the organizational environment on creativity (Amabile, 1997).

- **Resources:** encompasses time, funds, knowledge, information, materials, training, among others. In current market, time is an especially scarce asset that should be adequately managed. Too narrow deadlines mean excessive pressures on the design team, sometimes converging to predictable and safe solutions. Too loose chronogram may delay the release of a product and cause the organization to miss opportunities or stay behind its competitors (Amabile *et al.*, 2002; Baxter, 2011);

- **Management practices:** is the capacity of the organization and its managers to allocate members to the right tasks, making use of each individual potential. Team members should also have diverse backgrounds and expertise, which boost discussions and tend to generate better results(Mostert, 2007). It is also role of management to set adequate goals while leaving for the team to set milestones freely and work independently. Lastly, it is important to managers to serve as a communication channel between high administration and teams, reporting relevant information and giving feedback accordingly;
- **Organizational motivation to innovate:** is related to the orientation of the organization, cherishing innovation as one of its basic guidelines and allowing creativity to sprout, permeating all levels of the organization. Risk-orientation, sense of pride from members and their capacities, tolerance to failure, experiment-orientation, and general optimism are some guidelines of innovative companies (Brown, 2010).

The three factors affect directly on individual and team creativity. By being inserted in an adequate environment, members feel more motivated to create, having adequate resources and support from all parts of the organization. More than simply having an idea, team members are encouraged to explore ideas, implement, and present to higher administration other views on existing and new projects (Levitt, 2002). This vision gives voice to all parts of the organization, not limiting itself to instructions given by management. Many other factors influence the creative capacity of the organization, such as optimism, work environment individuality, freedom, cohesion, belongingness to team and organization, adequate feedback, focus on guidelines, and capacity to identify opportunities (Amabile, 1997; Levitt, 2002; Brown, 2010; Ideo, 2015). Such aspects encourage individuals to work in a common objective, and not just driven by individual desires.

Naturally, the KBS development does not intend to address every influence aspect in individual creativity or organizational innovation. The use of creativity techniques would hardly influence on the intrinsic task motivation or the level of expertise for individual creativity, but its use relevant for the raise of cognitive flexibility, inherent factor of creativity skill. The use of adequate techniques may encourage intellectual independence, discipline or even risk-orientation, which aid the creative process. In the innovation sphere, creativity tools are useful as resources, offering more knowledge and even reducing the work time needed to reach solutions. The implementation on an artificial intelligence environment, such as the KBS, offers adequate resources on techniques at any development stage, which propel creativity skills.

Even in the right environment, other factors can still negatively affect the design team, occasioning barriers to creativity (Back *et al.*, 2008):

- **Incorrect problem definition:** the briefing should not indicate or induce to solutions, being clear, concise and undoubtable;
- **Habits:** can aid or hamper the creative process, and should be appropriate to the reality of the problem;
- **Functional fixation:** to observe a product and its function by limited perspectives may exclude possible alternatives;
- **Overspecialization:** tends to converge quickly to a solution instead of exploring opportunities from other study fields, ultimately remaining restricted to non-multidisciplinary solutions;
- **Tendency towards advanced technologies:** the latest technologies may not be the most adequate to solve the problem or permeate the target market;
- **Practical-mindedness**: hasty definition of solutions may incur in inattention to other lines of thought;
- **Overdependence to others**: excess of authority or intimidation by others knowledge may influence members to withhold their ideas;
- **Fear of criticism**: creative mind is blocked when there is excessive concern on satisfying administration desires;
- **Denial of non-expert suggestion:** many valuable contributions may arise from non-expert members, incurring in multidisciplinary solutions;
- **Premature judgment:** disapproval or premature criticism may hamper the creative behavior of the whole team. Criticism should be restricted to evaluation phases in the form of positive alternatives;
- **Excessive motivation:** may incur in delays or overworking, occasioning unneeded stress to the team.

For being applicable in any human knowledge domain, creativity has ceased to be seen as an exclusive ability of designers or artists, and began to permeate all organizational areas. From products and services to organizational models and education, creativity serves as the first stage of essential changes, including evolution and optimization of any entrepreneurship, even the most traditional ones.

Innovation and creativity should not be seen as a punctual resource to be used in specific phases of design developments (Brown, 2010). This obsolete view hinder the real potential of generating new products or services by innovating in a restricted scenario. To effectively innovate, a culture of innovation should be cherished by the whole organization, which should commit and become creativity-oriented in all levels (Amabile, 1997; Baxter, 2011). Out of ten new product ideas generated, only three will be further developed, less than two released in the market and only one has chances of becoming a successful and profitable investment (Baxter, 2011). Some indicatives are still more severe, attesting that in 2007 only 4% of products released in the United States were a market success (Vianna *et al.*, 2012).

Individual creativity and organizational innovation mutually support one another. While creative members reach for more innovative solutions, the right environment and assistance allow each design team to reach its potential. As said, other factors can boost or block creativity and proper techniques play a key role in providing the needed capacity to develop ideas (King e Schlicksupp, 1999; Baxter, 2011). In current market, organizations that fail to be creative and motivate their employees to innovate tend to become obsolete and even go out of business, leaving space to more flexible and risk-oriented companies (Amabile, 1997; Žnidaršič e Jereb, 2011).

2.3 Case studies on obsolescence

Even more traditional design methodologies highlight a deep dependence of design and creativity. Without the ability to create, no organization or project is able to satisfy needs, leading to a stagnation of the state-of-the-art. Two cases are presented below, highlighting the necessity for innovation and vision to survive in the competitive market.

2.3.1 Motorola

On 1960s and 1970s, multinational telecommunications company Motorola was market leader in communication technology, with constant sales growth. Their researches in wireless communication foresaw the insertion of a new mobile telephone line, being the current technology of 400 MHz inefficient. Jim Mikulski, corporative researcher, observed that emerging technologies allowed the company to offer a better and more capable product, which operated at higher frequencies. He envisioned a radically new cellular technology, which could replace the existing system using high-capacity radiotelephones, but still affordable for the market (Macher e Richman, 2004).

John Mitchell, head of Communication Division, rejected the idea arguing that the current technology was sufficient to meet customer's needs. He saw the innovation as potentially harmful for the Motorola's products, for it would generate a division of the market. Mikulski, still believing on his proposal potential, reached for assistance in other parts of the company, receiving support from the Corporate Research Laboratory, a separated unit from the constituent divisions. The development and research team was kept hidden and isolated from Mitchell's division, who had real authority on which radio and mobile phones projects should be continued.

In the middle of 1970s, the 400 MHz technology's capacity proved insufficient, forcing Mitchell to reach for new technologies, imminently seeking radio communications. Despite the initial reluctance, he was forced to recognize the current system's capacity constraints and pursue cellular technology. A change on organizational guidelines opened space for Mikulski to present the new cellular system, which at the time was in advanced stages of development and ready for commercialization. In 1980, Motorola was licensed to commercialize the new 800 MHz products, reinsuring its vanguard on mobile communication with almost 60% of market share in 1990s (Macher e Richman, 2004).

The abovementioned case shows how intrinsic motivation and belief, even when initial reluctance from the organization, is fundamental to innovation and maintenance of company's market leadership. The technological inertia of Motorola's head divisions could have cost a great deal of its market for not being able to accompany emerging technologies and withholding to existing and traditional products with incremental innovation. Opposed to previous lessons, Motorola faced a similar situation with the uprising of digital cellphone technology. Unfortunately, in this occasion, no researcher had the vision, attitude and support as Mikulski. By holding to analogical models, the company lost market drastically, losing leadership to Nokia at the end of 1990s (Macher e Richman, 2004).

2.3.2 Kodak

Eastman Kodak Company is a photograph camera company founded in 1880 on the USA, being pioneer on snapshot camera in 1888. High investments and market vision put the company at the vanguard of photography market, representing 90% of the film market and 85% of camera sales in 1976 American market, reaching U$10 billion sales in 1981. Competitors' pressures propelled research and development, and the company diversified by introducing the digital image capturing technology with the first megapixel sensor, among other products. The developments and final product costs hindered sales and some products never achieved the needed market success (Lucas Jr e Goh, 2009).

The increasing pressures, especially from the Japanese Fuji, forced several restructurings between 1980s and beginning 1990s. In 1993, former Motorola CEO George Fisher took over the chairman position. He foresaw a growth in the Chinese market for film cameras and refocused the company in analogical photography area, and selling other sectors for paying the accumulated debts. This vision was proved unfruitful, and the company grew annually 3% against the 75% growth from digital cameras. In 2001, one year after Fisher stepping down as chairman, the film cameras sales started decreasing, and since 1993, Kodak reduced 80% its workforce. While digital camera competitors had growing incomes since 2001, Kodak saw its income fall from U$20 billion in 1992 to bellow U$15 billion in 1997 (Lucas Jr e Goh, 2009).

The insertion of a disruptive innovation on the photographic camera market exposed the fragility of a consolidated company in adapting to changing scenarios. Difficulties of pursuing new technologies and trusting the technological advancements may cost a great deal of company's market share, leading even to bankruptcy. Even initially detaining the most advanced technology, Kodak bet on a traditional market, which did not corresponded to the company's expectations. In current competitive scenarios, vision failures and excessive focus on tradition are becoming less rewarding, while flexible companies with future vision perpetuate. Both cases show how a disruptive innovation can change drastically a market, making leading companies that fail to adapt to its share and new organizations to rise by having the right culture and vision.

3 CREATIVIY PATTERNS ON DESIGN METHODOLOGY

Many design models are presented in literature, each representing different approaches on how to effectively develop a product, service or process. As common ground among them, creativity is no longer a punctual asset or a skill restricted to arts or embellishing things. To be creative and innovative is basic on current market, where organizations that fail to update tend to become obsolete and lose market share (Amabile, 1997; Brown, 2010; Baxter, 2011). To develop a new product is essential for a team to be creative, but also ground its work on design methodologies (Back *et al.*, 2008). A systematic approach not only reduces the project total time, but also enhances the quality of the product (Souza, 2001; Baxter, 2011), and boosts creativity. Considering the broadness and complexity required in many designs, free approaches that do not follow some sort of model or structuration become impractical. By using intensive planning and adequately specifying the development the chances of success of a product increase up to three times (Baxter, 2011).

Many models, procedures and methodologies for product development were developed focusing on maintaining knowledge, facilitating planning, improving communication, or even as a procedure of verification (Gericke e Blessing, 2011). With increasing demand and particularity of users, new requirements are constantly identified, wanting quick responses from organizations to maintain market shares. Design teams are pressed to create new products or adapt current portfolio in order to fulfill this demand before the competitors. This raise on competitiveness and complexity hampers individual and unstructured design. Although particular problems solving are entrusted to one or few people, one person can hardly do a full-scale product development in a timely fashion. The great interaction and information share between experts from different fields demands design structure and methods.

Product development can be described as every process of information development needed to identify demand, production and use of a product (Back *et al.*, 2008), and can be subdivided into prescriptive and descriptive models. The first is a set of formalizations of how a design process should be done, as a procedure of stages and activities. The last is composed of heuristics or “good practices”, which can be used for supporting design or complementing prescriptive models (Gericke e Blessing, 2011). Hardly would a development follow strictly prescriptive specifications, relying many times on experience of the team members or know-how of the organization. Such models tend not to represent accurately the dynamic behavior of different developments, presenting phases with emphasis on what is required to be done rather than how it should be done (Gericke e Blessing, 2011). Strict descriptive approaches, at the same time, may leave too much decision to the designer, hampering efficiency and knowledge transfer to newcomers.

The idea of a systematic division of the design process into a methodology allows a heuristic vision, optimizing development time especially for large sized projects. This structure does not imply on a rigidity, being that any stage of the methodology can be omitted, repeated or rearranged depending on necessity (Baxter, 2011). By using a model of the complete development process, it becomes simple for an expert to adapt and fit the methodology to its particular needs. Every organization and design team should have particular versions of a methodology, which can be suited to every project's particular nature. This chapter addresses basic concepts on product development, linking prescriptive and descriptive models aiming to identify where the creative behavior occurs and how it can be propelled by an AI approach.

3.1 Prescriptive models

Morris Asimow (Asimow, 1962) presented one of the first formalizations for prescriptive design methodology in 1962. The model displays a chaining of concepts aiming to aid design, giving form and structure to tasks so far mostly done and learned in an empirical fashion. His view, as presented in Figure 3.1, subdivided design philosophy in three parts: a general principle conjunct, which receives information about particular design and triggers the development; an operational structure leading to actions; and an evaluative feedback for measuring adequacy and indicating improvement possibilities (Asimow, 1962).

Based on this philosophy, Asimow built the operational structure into seven phases, representing fundamental stages on any design development. His vision was pioneer and evolved into many modern prescriptive models, such as Woodson (1966), Coryell's valve model (1967), the German guideline VDI 2221 (1993) and Pahl and Beitz (1996) (Back *et al.*, 2008). Those traditional methodologies were of great impact on understanding the inherent tasks of design, but lacked important factors as chaining of activities, means of information exchange, integration among specialists, and focused excessively on individual skills (Back *et al.*, 2008). Those aspects were detected and incorporated in modern approaches (Back *et al.*, 2008; Brown, 2010; Baxter, 2011), aiming for better knowledge transfer channels, as well as multidisciplinary, participative and balanced teams.

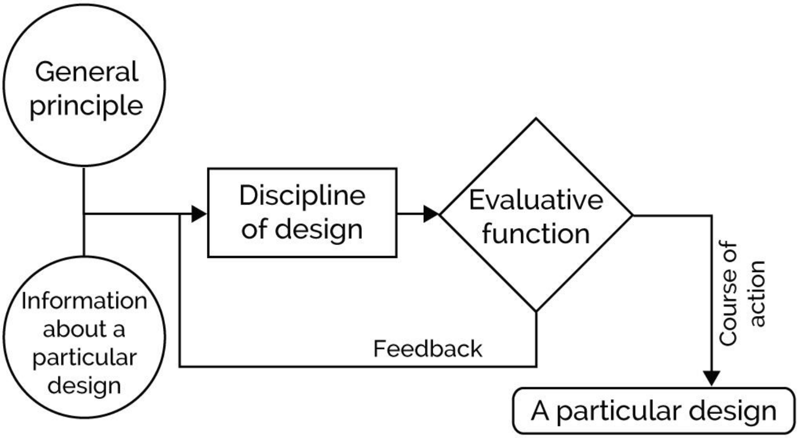

Figure 3.1 – Asimow's philosophy of design (Asimow, 1962).

The heuristic vision on design provided by prescriptive models and intensified on contemporary approaches helps reducing posterior changes on the design, anticipate or even avoid flaws, and explore the creative potential of the team and each member's individual specialties (Back *et al.*, 2008; Baxter, 2011). By encompassing phases besides the strictly technical ones, the designs are able to solve problems from the whole life cycle of a product, including feedstock, manufacturing, maintenance, use, and disposal.

A logical chaining of activities, even fundamental for product development, does not oblige the ending of a task for the beginning of others. Many activities can and should be executed in parallel, even without the ending of previous phases. Grounded on the Pahl and Beitz (1996) model, the proposition of the integrated product design methodology (*projeto integrado de produtos* - PRODIP) (Back *et al.*, 2008) adds the concept of concurrent engineering to the traditional prescriptive models. This methodology is considered as basis for this work and will be posteriorly presented on subchapter 3.4.

3.2 Descriptive models

Different design teams in different situations may require diverse approaches on design methodology in order to adequately develop solutions. Even prescriptive models being important on creating a general and detailed procedure for design, descriptive models are more particular and tend to follow adaptations on how the team actually does the design.

For being based on real scenarios and observable experience, descriptive models may be used to ground prescriptive models (Gericke e Blessing, 2011), while the combination of both allows design teams to better suit prescriptive models into their reality by developing a set of "good practices" based on descriptive models.

"Good practices" or heuristics can be seen as a set of principles that the design team follows in order to achieve desired goals. They can be seen as simplified rules that provide adequate answers for many situations (Weber e Coskunoglu, 1990), but still requiring experience and judgment from the designer in order to adequately use them. Such rules tend to arise from reoccurring patterns, which, in time, are absorbed by the team and used many times as invisible guidelines for any design. The development of descriptive models can greatly benefit from artificial intelligence techniques, such as protocol analysis (Finger e Dixon, 1989). At the same time, many artificial intelligence approaches use of descriptive models to model creative design, offering procedures by which creative behavior might occur (Cross, 1997).

Being based on experience and experimentation, engineering methodologies are less likely to give central relevance to descriptive models, while design and architecture methodologies are prone to use heuristics rather than procedures (Gericke e Blessing, 2011). This division is oftentimes unproductive, being prescriptive and descriptive models complementary. A well-defined prescriptive model can be used as basis for design, the team using its procedure to ensure the execution and control of the project. Descriptive models can then be used according to the team nature and needs, being adaptable and offering a set of guidelines, around which the development will be executed.

Descriptive models are commonly related to creativity, or ways to propel creation during design (Cross, 1997; Brown, 2010). Design Thinking (Brown, 2010), Human-Centered Design (Ideo, 2011) and agile methodologies often use of sets of principles in order to allow a better creative environment, addressing aspects around the design procedure. Common aspects of such heuristics include user-centered vision, co-working, iterative nature of the design process, holistic view, optimism, experimental or risk-oriented approach, use of creativity techniques, and experience design focusing on emotional aspects. Implications of those factors will be better discussed in posterior sections. The techniques from these models are of great value to the developing system, which can use of such knowledge as base for adding tools from other study fields. Some of the approaches already present scenarios where the techniques are useful, trait that can be augmented to an artificial intelligence system.

3.3 Design guidelines

Every design, in its inception, should be structured around guidelines, which will follow as guidance and control procedure throughout the development. To maintain goals and deadlines, techniques such as a well-structured chronogram are indispensable. The previous planning and specification, defining precisely the design and evaluation its technical and economic feasibility, can raise in three times a product's chances of success (Baxter, 2011). Responsibility matrix, milestones and goals should be assigned to each stage with techniques as Gantt Diagram or Work Breakdown Structure, aiming to ease control stages of the development. If the design excessively deviates from the set structure, the product will hardly reach the public on the desired time, which could lead to additional costs. If the guidelines in any stage of development are not adequately met, the product should be re-evaluated or even be discontinued (Baxter, 2011). The use of milestones and goals can also serve as extrinsic motivation for the teams creativity, especially when used judiciously and with attention to the team's characteristics and needs (Amabile, 1997; Amabile *et al.*, 2002; Brown, 2010).

The composition and interaction of design team also has a major role on the efficiency of developments. The use of isolated expert to each task – e.g. marketing specialist to requirements formulation, designers to conceptual development, engineering expert to manufacturing planning – is contradictory to the simultaneity principles of modern methodologies, reinforcing design principles from sequential traditional prescriptive models (Back *et al.*, 2008). Design team should act as a single entity, every member having the opportunity to influence every aspect of the design. Many insightful ideas may arise from this multidisciplinary and cooperative exchange of knowledge, and important decisions should be made in accordance to every team member's opinion (Baxter, 2011). This diversity of mind helps the conception of ideas, especially if the team is inserted in a trustworthy environment and prone to information sharing (Mostert, 2007). Even in large scale developments, when members are allocated and reallocated from the design, a multidisciplinary and integrated core of work should be preserved, which maintains the fundamental knowledge needed for any incoming team members to complete their responsibilities (Back *et al.*, 2008). This communication net is vital, being many ideas and experience lost by inadequate knowledge transfer.

The chronogram following with parallel activities entails a great involvement of the team members. For being of multidisciplinary nature, the design demands integration among different areas such as social sciences – economy, marketing, and even anthropology, which may aid in the definition of user's needs –, technical fields– such as engineering, manufacturing, and maintenance –, and applied arts – such as graphic design, architecture, aesthetics, and style. Based on this different design fields, management is a fundamental factor. For many design managers, a broad and superficial knowledge on different areas is preferred, delegating specific knowledge to experts (Baxter, 2011).

Along with the use and integration of experts from different fields (multidisciplinary vision), an interdisciplinary approach may be required in order to reach a better integration of knowledge, every team member understanding on giving opinion on other specialties. By using small teams and subdividing tasks, the development management is eased, allocating relevant personal to adequate tasks and, when needed, inserting new members in posterior phases (Brown, 2010). Gathering inadequately the team members for meetings may incur in deviations of the meeting purposes (Institute, 2013). The responsibility for failure of success of the design should also be collective, inciting every team member to contribute and, at the same time, allowing the team to distribute tasks independently (Back *et al.*, 2008).

Technical and marketing excellence, cooperation and harmony among different company areas are fundamental factors in the design development. Such measures internal to the organization can raise in two and a half times the chances of success of a product, especially when the design focuses on users and the organization has a precise planning in accordance with all pertinent areas (Baxter, 2011).

A harmonic and optimist environment is fundamental on allowing creativity to flourish. When feeling safe and content, team members tend to expose their ideas and share knowledge. This optimism is based on a feeling of safety offered by the organization, which should reward successes, but not penalize mistakes (Amabile, 1997; Brown, 2010). A culture of experimentation often incur from this optimism, where team members are able to take risks without fear. This should combine into a positive environment, where team members see the development as a communal effort instead of a chance for self-promotion (Brown, 2010; Baxter, 2011). It is also important to learn from and report risks that led to mistakes, for they serve as source of information for posterior activities. Organizations that fail to provide this trust environment and do not encourage risk-taking tend to fall on obvious solutions (Brown, 2010), being restricted to incremental innovations.

A product development goes beyond sequential and schematic stages. Other support tools, models and process should integrate the methodology in order to guarantee the satisfactory observance of design guidelines. Four main knowledge fields are demonstrated in Figure 3.2, characterized as (Back *et al.*, 2008):

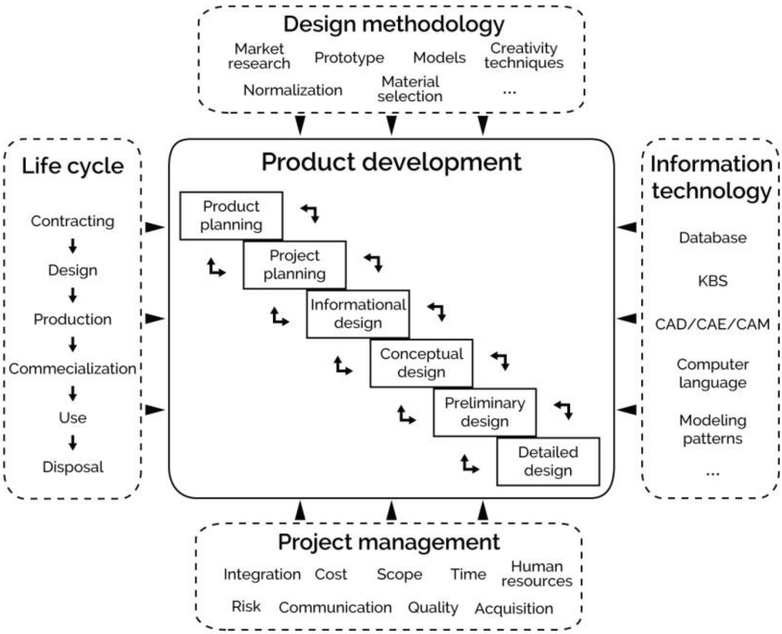

Figure 3.2 – Integrated model for product design (Back *et al.*, 2008).

- **Design methodology:** offers a base of methods and tools that help the product development in every stage, as well as information sharing. This field encompasses creativity support techniques;
- **Project management:** focuses on scope, time, costs, quality, among others, aiming to control and manage them;
- **Life cycle:** attempts to anticipate possible blocks on the development, working with reliability and guiding decisions and solutions;
- **Information technology**: offers computational support for activities conduction, methodology application and management. Artificial intelligence approaches such as knowledge-based systems fit in this field.

3.4 Product development

This subchapter introduces the main phases and aspects of product development based on the PRODIP methodology, alongside other relevant heuristics and structures from other models and descriptive methodologies. Although the complete design process being broader, the phases concerning creativity and innovation occur during design planning and design process, which will both be addressed on the following sections.

3.4.1 Need identification

Every design starts with a problem or a need to be fulfilled. This need may derive from two main sources: the market – which brings the "customer's voice" – or technological progress – generating new market niches currently inconspicuous to customers. In either cases, the intention of a design is to satisfy one or more stakeholders, including (Baxter, 2011):

- **Customer (market):** search for innovative products in any aspects, placing great importance on price and quality according to the market;
- **Sellers (market):** aim to use new products to lure customers, valuing differentiation or features that lead to competitive advantages;
- **Production engineers (technology):** focus in manufacturing and assembly design;
- **Industrial designers (technology):** have a more creative nature and focus on experimentation of materials, processes and alternative solutions;
- **Businessperson (market and technology):** aim for profit, quick and high return of capital.

Considering all involved parts, the design eventually leads to a trade-off, with many conflicting interests. For instance while some customers search for low prices, the businessperson may require quick and high return of capital, or while production engineers prime for easy manufacturing, designers may find compelling using free-shape geometries with many parts. The design team should be able to discuss and pinpoint arguments from every stakeholders when deciding which aspects are more relevant for the design. Both market and technology propel, in an isolated or combined way, the beginning of a development as seen in Figure 3.3.

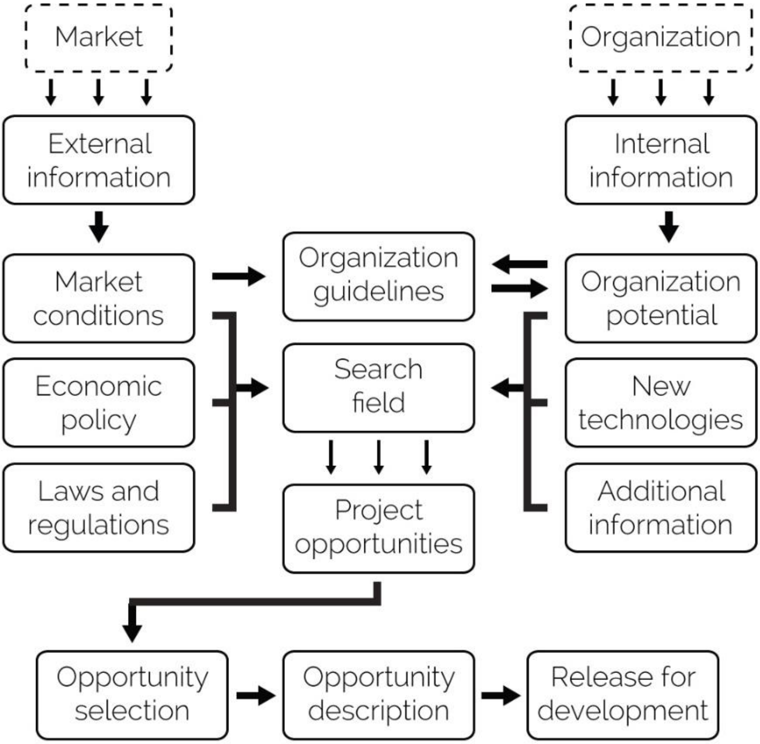

Figure 3.3 – Product planning activities (Back *et al.*, 2008).

Innovation from technological perspective commonly arises from the organization and internal information resulted from research and development efforts, or even from the design teams themselves. It is usually grounded on obsolescence of a product line or technological progresses, allowing a better attendance of market's needs, but limited to the organization's potential. Second innovation source is due to commercial perspectives, i.e. market pressures or current situation. This font is based on researches on customer's needs and the market monitoring in order to identify design entry requirements, when in accordance with the economic policy and standing laws and regulations. This external information acquisition of innovative potential may derive from customers, suppliers, distributors, competitor analysis or any other stakeholders (Back *et al.*, 2008).

Both sources demand creativity and sensibility from the organization, implying on taking risks. On initial phases, the design usually does not have a solid outline and, therefore, no guarantee of success. To define the search field based on the organization's guidelines helps filtering design opportunities. Due to the broadness and difficult differentiation of design opportunities, every project will imply on a systematic decision for a need to be addressed, preferably keeping other requirements on hold to future exploits. It is important to mention that not always a specific internal or external demand is needed to trigger a project, being many opportunities uncovered during development. Regardless the source, product developments should be seen as a constant on any organization in order to maintain its competitiveness (Back *et al.*, 2008).

A well-balanced basis of development should aim for a balance between individual, society and technology, matching human need to technological resources, and assuming the *technocentrism* – an excessive focus solely on technology progress – as an unsustainable vision on current market and environment (Brown, 2010). Organizations that are limited to technological sources tend not to be flexible to market changes. Innovation occurs at all times and has the power to eliminate or reduce the life of previous products, transforming previous innovators into conservatives. The correlation between desirability, feasibility and viability (presented in subsection 2.1.3) aids the balance of innovative ideas (Brown, 2010). A higher market orientation, offering significant benefits to customers, differentiation from competitors, higher quality or launching speed raises in up to five times the chances of product success (Baxter, 2011).

User's requirements, the biggest source of information for design (Back *et al.*, 2008; Brown, 2010), are not always of simple identification, since consumers oftentimes are not aware of their needs. Empathy becomes indispensable while exploring customer needs, being occasioned by techniques such as Observation, Interviews and first-person experiences. This constant interaction between customers and design team has a great potential for ideas generation and helps guiding the project to a realistic need. Understanding individuals, their interaction dynamics and the way they execute certain activities precedes and follows the conceptual design. Thereafter, it is essential the insertion of users on the design space. This contact helps on the initial phases of opportunity identification, conception and selection of ideas, and in the validation through models and prototypes (Brown, 2010). Many User-Centered Design techniques are focused on this aspect and may potentiate interaction.

The launching of the project should only be made after intensive research of all sources of opportunity that fit the organization, aiming to cover a large number of possibilities before converging to the design itself. Even technical and economic viability studies are superficial at this stage and do not guarantee that the chosen opportunity is adequate. In order to reduce risks, once identified an opportunity, it is vital to specify it in the most clear and direct manner based on information from technological and market perspectives. The design problem presentation should include the scope declaration, risks estimative, resources, chronogram, restrictions, priorities, production volume and historical information available for the team (Back *et al.*, 2008).

3.4.2 Phases of product development

Design consists in a series of choices and compromises, which present gradually less risks and uncertainties throughout the product development (Baxter, 2011). The decision-making process can be structured in a decision funnel, presented in Figure 3.4.

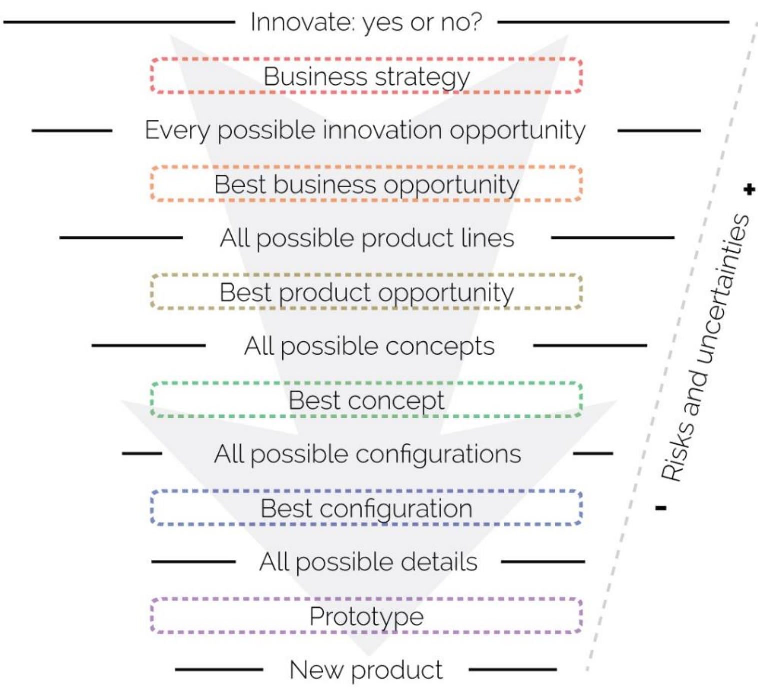

Figure 3.4 – Decision funnel (Baxter, 2011).

The first decision presents the most risk to the organization, being that choosing to innovate implies on various costs and failure possibilities. Naturally, opting to not innovate may lead to a portfolio obsolescence, which can cause more market damage than unsuccessful projects (Baxter, 2011). Based on all opportunities drawn, the organization or design team defines which direction should be explored taking into account project deadlines, capital return and innovation focus.

Based on the chosen opportunity, different product lines are able to meet the same basic need, giving way to the decision of which is the most adequate direction to the current situation. Conceptions inside the product line are then explored and, when selected the most adequate, its configuration is made explicit. After intensive detailing, a prototype is obtained, serving as basis for the new product (Baxter, 2011).

The progressive diminishment of risks and uncertainties is due to the project becoming gradually more tangible and the knowledge more concrete. Failure on starting phases implies on lower costs of redesign or shutdown, while the lessons learned embody the know-how of the organization (Back *et al.*, 2008). The decision funnel should be seen as a continuous and iterative process, being applicable in several phases during development and aiming for a constant recycling based on previous decisions. Every stage implies on a divergence of ideas or opportunities, followed by a selection of the most adequate, intrinsic characteristic of creativity and innovation (Amabile, 1997; Brown, 2010).

The decision-making process can be arranged and extended into systematic phases as presented in prescriptive methodologies such as PRODIP, which structure is shown in Figure 3.5. Although this methodology encompasses phases others than the ones here detailed, this particular frame was adopted in order to elucidate the relevant aspects for this work. Product development starts with product planning, which consists on the identification of user's needs and innovation opportunities that are plausible according to organization's strategies, its market situation, possible demand for a specific product, and resources availability (Back *et al.*, 2008). This analysis depends on creativity, empathy and research to discover good opportunities as well as an innovational focus to select appropriately which need should be addressed at the time. The best business opportunity, encompassing market and technologic sources, is thereafter stablished and specified in a product plan.

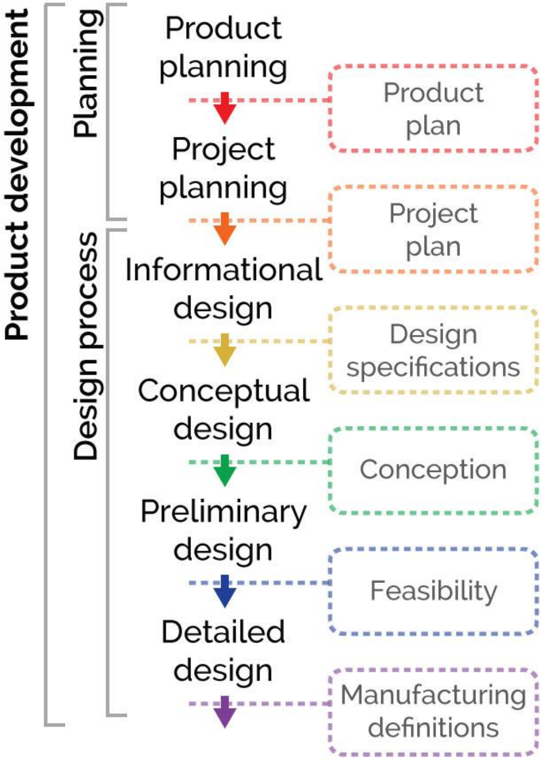

Figure 3.5 – PRODIP methodology (Back *et al.*, 2008).

With basis on the product plan, project planning focuses on stablishing guidelines, milestones, and framing the development. Management should realistically frame the work taking into account the design team and request achievable results, but delegate internal decisions to the team and allow members to specify the work more freely (Baxter, 2011). As previously said, excessive pressures tend to drop creative behavior and reach more predictable solutions (Amabile *et al.*, 2002). Both product and project plan can be seen as an inspiration stage for creation, where the design is centered on as specific problem to be addressed.

Defined chronogram, responsibility matrix, and drafted the opportunity that the product will address, the design process initiates with informational design. This phase consists in the exploration of all information needed to posterior ideation, taking into account all the knowledge available in the product and project plan. This undertaking can be correlated to the inspiration stage for creativity, where data is acquired forming a grounding for mind associations to flow. Every information – from literature, experience, observation, interviews or questionnaires – is important and may lead to plausible solutions, especially when empathically exploring user's needs and expectations as source of innovation (Back *et al.*, 2008; Brown, 2010). User's requirements can then be translated into design specifications, which should be concise, clear, and detailed topics to aid the design team in further phases (Back *et al.*, 2008).

Based on this research and gathered knowledge, the design specifications trigger conceptual design, which is the generation and preliminary filtering of ideas to solve the problem defined during planning (Back *et al.*, 2008). The team, likewise the incubation phase of creativity, deliberates over ideas, conceptions, positive and negative aspects, utilizing any available and adequate technique within the teams' capability. This is the phase most associated to creativity, although restricting it to this stage hampers the process. As said, creativity and innovation culture should permeate the whole design process, many ideas arising during previous or posterior phases of development (Brown, 2010). Even developments that do not intend to create radically new products should use creativity as support to produce small changes (Baxter, 2011). Those primary conceptions should then be combined, compared and extrapolated, converging to conceptions that fulfill adequately the organization's interests and user's needs. By using creativity techniques, the process of idea generation is eased and accelerated, not grating success but raising chances of developing better solutions in less time (King e Schlicksupp, 1999; Baxter, 2011).

The conceptual design encompasses both conception generation and initial solution selection, working as iterative incubation, illumination and preliminary verification. Many ideas can be assembled to generate more adequate conceptions or even be eliminated without thorough verification (Back *et al.*, 2008; Baxter, 2011). This primary filter reduces the number of conceptions that will be evaluated during preliminary design (Back *et al.*, 2008). At this stage, one or few conceptions are modeled and carefully studied to optimize and combine ideas, creating viable, feasible and desirable solutions, akin the verification stage of creativity. It is important to use physical, mental and computational models and prototypes to better understand their implications and functionalities (Buchenau e Suri, 2000), even in previous stages of development (Buchenau e Suri, 2000; Brown, 2010). Models, as partial abstraction of the real object, help visualizing and creating a combined language of the ideas that are being discussed, aiding chaining of ideas or associations (Brown, 2010). They should begin in conceptual phases with simple and cheap constructions, and follow the design process until complete, complex and expensive prototypes are achieved during preliminary design (Brown, 2010). Defined the solution, detailed design focus on formalization of technical drawings, preparing for manufacturing, maintenance, assembly, and distribution (Back *et al.*, 2008). Each phase encompasses a set of techniques, and this division is fundamental for the developing prototype. Although some techniques may fit more than one stage, it should be encouraged the use of techniques focused on ideation during conceptual design, as well as evaluation on preliminary design (Botega e Silva, 2015a). Each technique has a better situation of use that can be delineated and implemented on a computational environment.

During any product development, creativity and cognitive flexibility are essential aspects to ideate and select adequate solutions. In a methodological analysis, two main phases in need for creativity can be identified: a search for a design opportunity during planning, and conceptualization over solutions to identified needs during design process. Incorporating Design Thinking aspects, the Double Diamond methodology (Council, 2015), created by the British company Design Council, can be used to summarize and better understand the creative process during development and its techniques, as shown in Figure 3.6.

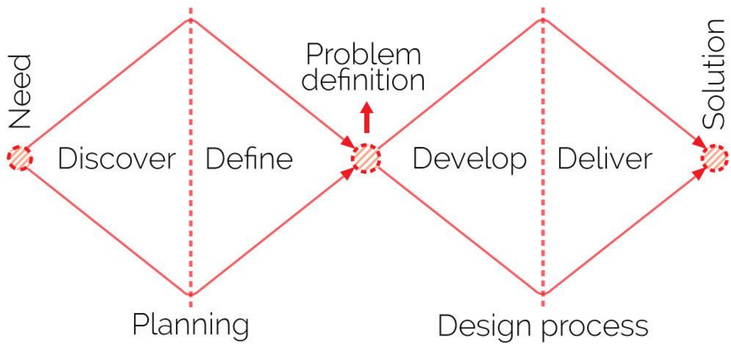

Figure 3.6 – Double Diamond model (Council, 2015).

Analogous to PRODIP and creativity models, based on the discovery of a user’s need a first stage of *discover* begins to create the design space, based mainly on observation, empathy, qualitative and quantitative research (Council, 2015). This stage, befitting the product planning, the team diverges ideas in the search for possible approaches to deal with the original need and define the problem to be solved. A focus on empathy with users starting on this phase helps keeping the project centered in the need and exploring unidentified possibilities (Brown, 2010). The second phase, *define*, consists in a convergence of ideas acquired on the previous divergence, focalizing on a viable problem that fulfills the initial need and aligns with the organizational strategy. A process of analysis and synthesis of obtained data is needed to define adequately the problem. In some cases, a single project is insufficient to meet adequately the original need, due to a single requirement deriving into many design problems. In this stage, the team consolidates the briefing of the design, evaluating what is feasible, what is priority, as specifying the design guidelines (Council, 2015). Altogether, the first diamond is analogous as the planning macro phase from PRODIP.

Problem definition, central point of the scheme, consists on the specification of the product opportunity, preferably written in a clear and detailed manner, but without inducing solutions (Back *et al.*, 2008). This closes the first diamond of the methodology, which focuses on the definition of the problem, allowing the beginning of the next phase. Second diamond starts with the *develop* phase, aiming to create conceptions that may solve total or partially the stated problem (Council, 2015). Both informational and conceptual design befit this stage, being the research for relevant information and knowledge fundamental for the beginning of concepts generation. In this second divergence phase, free ideation, discussion and preliminary modeling should be encouraged (Brown, 2010). Attained a sufficient number of ideas, factor that depends on time and resources available for the team, begins the *deliver* phase. Once again, a convergence stage is initiated, analyzing negative and positive aspects and critically synthesizing conceptions based on models, prototypes and field tests. As in preliminary and detailed design, the final concept of the project is defined, including materials, technical drawings and manufacturing specifications (Council, 2015). The presented second diamond is similar to the design process macro phase described in PRODIP.

Naturally, real life designs tend not follow strictly a methodology. The actual scenario requires much more iteration between phases and it becomes hard to acknowledge which phase of design is occurring at each time. The methodologies serve as basis for development, but design teams should not feel restricted to a step-by-step. It is highly recommended for teams to prototype simple ideas quickly and evaluate their potential (Brown, 2010), even if the design phase does not instruct for prototyping. Such nuances are hard to systematize and translate to a computational environment, being the chore of heuristic thinking on creativity techniques. For this work, the Double Diamond methodology better encompasses the aspects of creativity on design, as main structure for the development of the KBS prototype. PRODIP definitions and phases add essential concepts on structuring the knowledge for posterior implementation, using techniques from several study fields.

3.4.3 Context for creativity techniques

There is a vast number of creativity techniques through literature (Ideo, 2011; Mycoted, 2011; Vieira *et al.*, 2012; Ideo, 2015). Some books are specialized in compiling large amounts of different tools and present them to the reader, for times even categorizing them into situations of use. Unfortunately, this huge amount of information is often scattered and design teams may have difficulty on finding adequate techniques to serve their specific needs. Different bibliographies employ different languages and approaches to describe the techniques, limiting the understanding of non-experts and demanding and dedication of the reader to understand and select an adequate tool.

Every technique has an adequate situation of use, but not every situation has an adequate creativity technique. Even though techniques can and should be bended to adapt the design reality, it requires experience and sensitivity for a team member to choose the most suitable technique and use it accordingly. This expertise is often encountered on a facilitator or a person with wide experience regarding creativity on design, which will guide the session and promote creativity (King e Schlicksupp, 1999; Thompson e Lordan, 1999; Mostert, 2007; Wisconsin, 2007). In the absence of an expert, design teams rely on literature or in short hand experiences, many times overlooking more adequate techniques (King e Schlicksupp, 1999).

Engineering teams, especially those with a highly technical background, tend to focus on systematic methods (Thompson e Lordan, 1999). It is uncommon to incite a culture of creativity on engineering learning and literature, even if its methodologies present examples and discuss creativity usefulness (Back *et al.*, 2008; Baxter, 2011). Many developments under management and psychology still undergo reluctance when permeating the most technical areas of engineering (Thompson e Lordan, 1999), suffering from a study field bias. Such progresses could be fundamental on enhancing creativity and lateral thinking, offering new approaches that may lead to more innovative products, services and processes.

A great advantage of prescriptive methodologies, like the ones typically used by engineering, is its easiness to incorporate other approaches. Heuristics and techniques out of Design Thinking or Human-Centered Design approaches can be integrated on the procedural process, inciting more experimentation, empathy, iterative development, multidisciplinary teams, and an overall innovative culture. By balancing traditional and design techniques, the developed prototype offers a wide range of approaches, leaving to the team the decision of which method of combination of techniques to use.

Methods and techniques can be applied in every stage of development, and can be divided in two groups. Divergence techniques aim for a large number of techniques and tend to be less formalized, matching stages of discover and develop from Double Diamond methodology. Secondly, convergence techniques, which tend to be more structured, are suited to combine conceptions using stablished guidelines, aiding in stages as define and deliver. Those filtering techniques can also be used in order to diminish the number of conceptions to be tested with models, prototypes and field tests, which tend to be more costly.

As said, techniques may vary from team to team, situation to situation. Every team has preferable approaches and can mold the technique to its current need. Even with creativity tools not granting success, they surely enhance the chances (Baxter, 2011). A wider base of creativity techniques using expertise to select the most appropriate ones may raise even further the creation potential. Implementing it into a computational environment makes the knowledge permanent, being more available and reliable for use. By mixing design and engineering languages, the prototype may reach different spectra of design, creating a bridge for different approaches to support one another.

4 KNOWLEDGE-BASED SYSTEM STRUCTURE AND DEVELOPMENT METHOD

Artificial intelligence can be defined as "the study of how to make computers do things which, ate the moment, people do better" ((Rich *et al.*, 2009), p. 3). Current technology is able to add features to computers to be more useful to humans, or even try and mimic the human thinking process (Nordlander, 2001), even though complex human abilities are still difficult to represent. Computational approaches rely on aspects that human intelligence lacks, such as precision, speed, availability, reliability, and replicability (Martin, 2001). Still humans exceed in complex fields regarding originality, associative memory, independent reasoning, and even common sense (Martin, 2001), fundamental abilities on any profession.

Such positive aspects give way to new approaches to try helping humans to better develop and use their expertise. This knowledge, especially in business and organizations, are valuable assets to maintain competitiveness and remain in market. Depending solely on human availability is an uncertain choice, being that humans can have mood swings, retire, quit, or even dye, making knowledge less available and reliable (Giarratano e Riley, 2005). A combination of AI approaches and human expertise appears to be the most reasonable solution, using by times AI as an advisor, but having someone in charge of verifying results.

AI techniques may have various approaches to exploit human knowledge, representing it in a way that captures generalizations, is understandable, can be easily modified and corrected to represent constantly changing scenarios, can be used in various situations, and is able to assist human expertise (Rich *et al.*, 2009). Every implementation has its limits, but it is important to AI methods to explore such boundaries even if accuracy is lost, leaving better judgment to the users (Rich *et al.*, 2009). Some methods branched out of AI concepts include knowledge-based systems (KBS), neural networks, *chatterbots*, robotics, and evolutionary algorithms. Used in this prototype development, the KBS will be discussed in the following sections, introducing the main structure and development procedure, as well as important concepts to aid on the system presentation.

4.1 Knowledge-based systems

Knowledge-based system is an AI approach that focuses on emulating empirical human knowledge into a computational environment, translating experts' decision-making ability based on inferences (Nordlander, 2001). Any problem requiring significant human expertise can be performed by a well designed KBS, which inferences (computational reasoning) are able to point to solutions based on the knowledge acquired during implementation (Giarratano e Riley, 2005). Above a simulation, the idea of emulation implies on acting in all aspects as a human expert, being much stronger and intricate.

Among important advantages of KBS approaches are, along with the mentioned AI benefits (Silva, 1998; Nordlander, 2001; Giarratano e Riley, 2005):

- Store rare skills;
- Preserve knowledge of retiring or quitting personnel;
- Combine knowledge from several experts in a required domain;
- Make the knowledge available in hostile or difficult access environments
- Allow the use of such knowledge in multiple places;
- Train new personnel;
- Reduce automatable or monotonous work;
- Offer counseling or second opinion on pertinent matters, especially in situations when there are disagreements among experts.

Not all fields are adequate for a KBS implementation. Being a system based on knowledge, applications that do not demand empirical expertise or that can be solved with a conventional programming are not adequate. The task under implementation should require (Silva, 1998):

- Cognitive skill, not being easily automatable or solvable through pure mathematic manipulation;
- Be sufficiently difficult to require expertise, usually demanding years of experience;
- Be teachable to a beginner – meaning that excessively difficult reasoning that require intensive cognitive process may be hard to implement;
- Be precisely understood – avoiding especially intensive manipulation of commonsense knowledge.
- A well-bounded domain, the problem being sufficiently restricted to be manageable and sufficiently broad to attract interest.

Besides an adequate task, KBS development also depends on external factors, which can help or hamper the process, such as reliable experts on the domain, capable of explaining methods applied to derive solutions; cooperative experts, interested on the development and proactive to information share; and support from other parts involved on the development (Silva, 1998; Giarratano e Riley, 2005). The system should not be restrained to bibliographical knowledge, but also include intuition and reasoning, helping in the selection of the best options at any scenario (Nordlander, 2001).

4.1.1 KBS structure and development

A KBS is a computational tool that aims to mirror the cognitive reasoning of a human. This approach grounds itself on aspects computational implementations such as long-term and short-term memory. A cognitive processor, mimicking the brain, is responsible for identifying different sensorial stimuli and outputting adequate responses, matching information from the short-term memory to the rules stored on the long-term memory. For computational means, rules are composed of conditional patterns that, when satisfied, perform actions, as presented in Figure 4.1. Only rules that match the original stimuli are activated. The chaining of actions inside multiple rules is responsible for the inferencing process and presenting adequate responses (Giarratano e Riley, 2005).

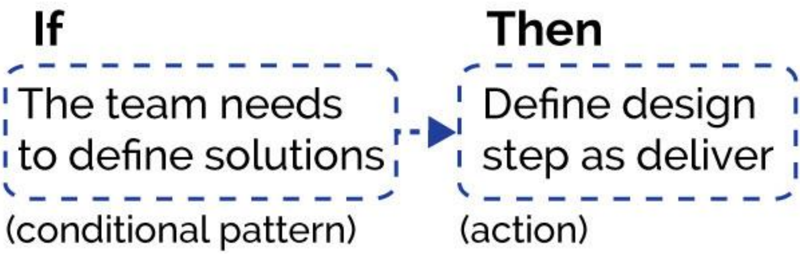

Figure 4.1 – Rule structure.

The idea of short and long-term memory bounded by cognitive processor created the basis of current KBS, as shown in Figure 4.2. The long-term memory is represented by the rules, which are a translation of pertinent knowledge. Such rules are triggered by fulfilling adequate facts on the operational memory. This short-term memory combines stimuli from the input user interface and, when sufficient arguments are satisfied, the corresponding rule is activated. Inference engine acts as a mediator, deciding which rules are satisfied by which facts, prioritizes the sequencing of rules, and executes them adequately.

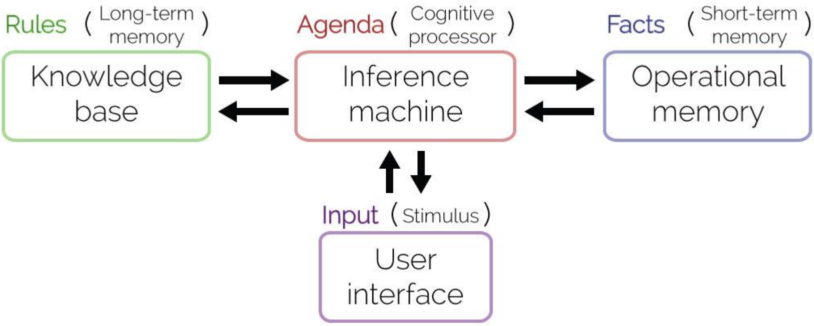

Figure 4.2 – Schematic representation of the architecture of a KBS (Adapted from (Giarratano e Riley, 2005)).

The problem solving strategy is an important factor regarding the use of rules. Two methods are commonly presented: forward chaining, which reach conclusions in a direct form, facts leading to conclusions; and backward chaining, using of potential conclusions hypothesis to be supported by facts. The hypothesis can be seen as a doubtful fact in need to further information to be confirmed, or a goal to be proved (Giarratano e Riley, 2005). Some guidelines aid the identification of the system chaining (Rich *et al.*, 2009):

- The size of start and goal states is relevant, preferring to begin the reasoning with smaller and move to larger set of states;
- The branching factor (or the number of children in each node on a tree data structure) is also significant, and reasoning should proceed in the direction with the lower branching factor;
- It is important to consider the way the user think and follow a similar direction, which can help the systems to justify its reasoning process;
- If the arrival of a new fact trigger the problem-solving, forward chaining is more adequate. If it is a hypostasis requiring a response, backward chaining is more natural.

A fundamental aspect of any KBS is the explanation ability (Silva, 1998). The chaining of information behind the “decisions” of the system should be clearly presented and explained for the user. This demand as explanation skill of the system, resulting on not only valid responses, but also making explicit the reasoning behind each of them. The knowledge engineer, responsible for developing the system, should mind the explanation factor during the whole development, from dialogues with the human expert to the way in which this knowledge will be presented for the system's users. The flux of information should be capable of directing the knowledge from expert to user with minimum interference. The parts involved on the development of a KBS are presented in Figure 4.3.

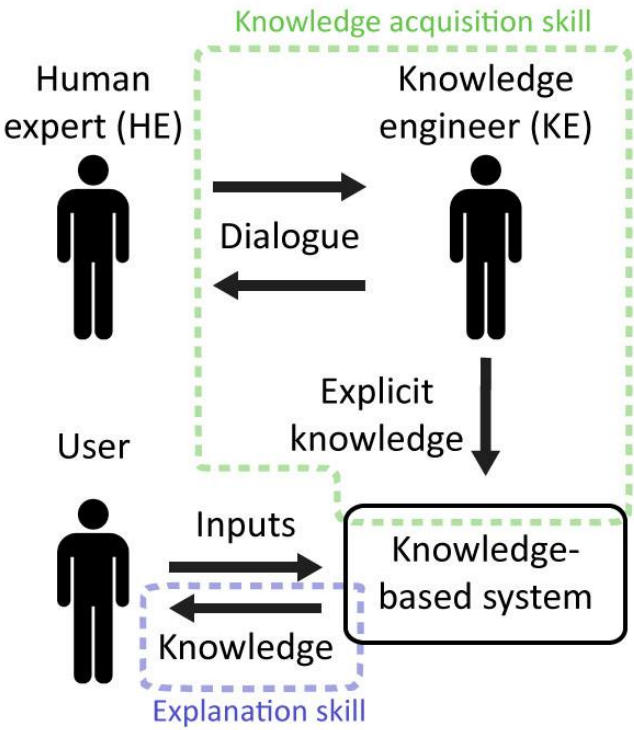

Figure 4.3 – Schematic representation of the knowledge transfer in a KBS.

The knowledge engineer is the responsible for implementing the knowledge into the knowledge base. It is required from the KE, besides the ability of adequately representing acquired information and coding it in adequate language, non-technical skill as friendliness and interpersonal communication (Gonzalez e Dankel, 1993). This knowledge acquisition skill is important on contacting and extracting knowledge from human experts, which may sometimes be unwilling to share information or be constantly unavailable (Giarratano e Riley, 2005). Acquired sufficient information, it is also essential that the KE filters adequate knowledge and makes it explicit in the KBS, using approachable language to reach potential users. This aspect reflects on the explanation skill of the system, which may be designed in an excessively technical fashion and be incomprehensible to users. Not only the presented information should be of easy understanding, but also the interface can benefit from adequate design, being user-friendly and intuitive.

KBS development traditionally follows five phases (Waterman, 1986; Silva, 1998), according to Figure 4.4. As previously said, not every problem is adequate to a KBS method, and a viability study is imminent to determine the relevance of the approach. This study will present the requirements that should be followed, encompassing scope of the problem, choice of experts, necessary resources and system objective (Silva, 1998). The grounding structured, the second phase of knowledge acquisition begin to collect information, deciding models, strategies, subtasks and constraints to solve the previously set problem. Such concepts and information are then transformed into organized knowledge for the development, expressing key factors and relations according to the global structure of the used implementation tool. Fourth step implements the previous progresses into the system coding, integrating different knowledge sources than can create conflicts and contradictions among rules or the data structure.

Verification is an internal intrinsic task in any implementation for debugging and correction of errors, corrected by the knowledge engineer usually with the help of the implementation platform. Validation is here considered an external stage, using experts and non-experts that were not consulted in any phase of the internal development process. It is responsible for testing performance, usefulness and accuracy of the system, being the last stage, usually performed by non-experts and experts other than the used in the development. This last phase is vital for revealing knowledge representation mistakes, which originate iterations for refine, redesign, reformulate or even replan (Silva, 1998), and other important refinements for the system.

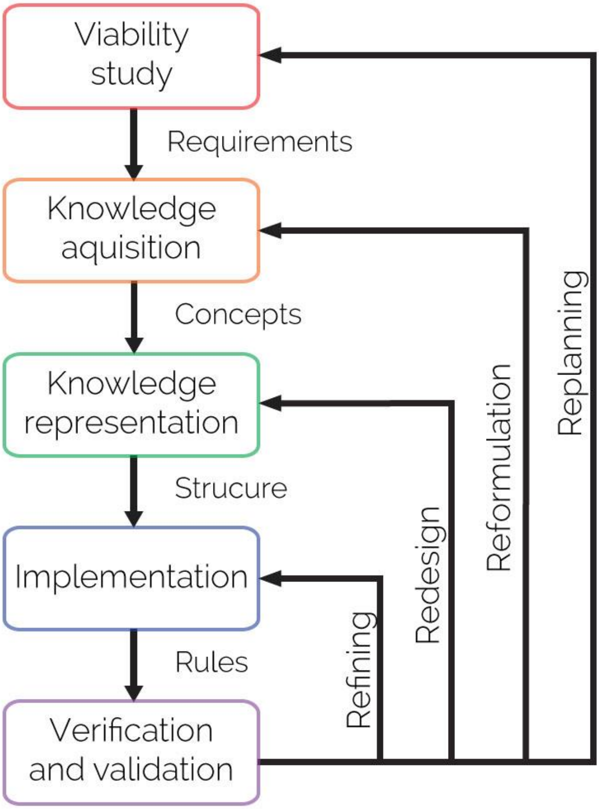

Figure 4.4 – Phases of a KBS development (Adapted from (Waterman, 1986; Silva, 1998)).

The importance of verification and validation lies on identifying mistakes such as (Giarratano e Riley, 2005):

- **Syntax error:** incorrect definition of implementation constructions, being usually identifiable by the system software;
- **Semantic error:** inadequate transference of knowledge from expert to the developing system, derived from misunderstandings of the knowledge by the KE;
- **Expert knowledge error:** derive from failures on the HE knowledge, which is also susceptible to inaccuracies;
- **Inference machine error:** may come from a combination of other errors or an incorrect specification of constructions' chaining

- **Ignorance limits error:** every KBS development is framed to be useful in a range of situations, becoming susceptible to loss of accuracy on the knowledge boundaries. When identified by HE and/or KE, this boundaries should be designed to foresee and acknowledge such uncertainties;
- **Rules errors:** several errors can be arise from rule constructions and chaining, such as redundant rules (identical rules leading to identical outcomes), conflicting rules (identical rules leading to different outcomes), included rules (more restricting rules can overlap less restricting ones), no-exit rules (the conclusions of such rules are never used by the inference process), and “lost” rules (rules that can never be used during the inference process).

Validation should encompass different aspects of correction and alignment of the developing system. Other experts are useful in identifying knowledge and semantic errors, but non-experts also provide great insights for being closer to the final user of the system. This information is valid on improving interface, usability and understanding of any computational system.

Although conceptualized in a linear structure, the implementation of a KBS usually follows more iterative patters. The incremental approach used in this development helps segmenting the work and turning the development into a constantly evolving implementation. The first cycle of implementation is responsible for the main architecture, grounding the approach and encompassing sufficient information to formulate a first prototype. This restricted but simplified system is of easier validation, focusing both on the implemented knowledge and the coherence of the system structure. Further cycles are responsible for improvements and expanding the prototype limits, adding more knowledge using same or similar structure as the first validated implementation.

Other non-linear aspect of the implementation includes the parallelism of activities, following similar structure as the concurrent engineering (Silva, 1998). While previous phases are being validated, new cycles can feed from new information and be in stages of deeper knowledge acquisition of ever implementation. This approach compresses the time of development, especially for beginning prototypes as the on presented this work. The dynamic and flexible implementation hones the prototype to further industrial applications, acquiring knowledge from multiple experts in a constant feeding process.

To surpass the limitations of the Rule-Based representation methods, Object-Oriented modeling permits a higher complexity of the knowledge, allowing entities with several characteristics, grouping, generalization and specification, pertinence relationships, among others (Silva, 1998). Having great similarity to the Frame representation (Silva, 1998), this approach gives a new dimension to its objects, allowing the addition of attributes (slots) and values to each instances in each class (Giarratano e Riley, 2005). Values are placed inside slots, which are placeholders of information inside an instance. An object can have a single slot, receiving only one value, or multislot, being able to hold multiple values. Classes can be seen as a set of entities with similar properties, while instances or objects of a class are the representation or specific elements of a class with defined attributes.

This approach is more adequate to represent stereotypical knowledge or even commonsense, as similar to creativity techniques selection, using of default value for attributes, which allows a better representation of commonsense knowledge (Giarratano e Riley, 2005). Other important facet is the ability of this technique to create a hierarchic net of nodes and inherit attributes from one object to its heirs, gradually becoming more concrete on lower levels of the hierarchy. For engineering design activities purposes, the Object-Oriented models are advantageous for supporting complex relationships and evolutionary processes (Silva, 1998).

The decision of using Object-Oriented modeling gives way to the application of fundamental properties useful to represent complex systems, such as (Gonzalez e Dankel, 1993; Silva, 1998; Armstrong, 2006):

- **Abstraction:** allows the representation of complex reality in a simplified model, suppressing irrelevant details and focusing on enhancing understanding;
- **Encapsulation:** the most common conceptualization states that this property is used to package data alongside its correlated functions. Other accepted connotation states that encapsulation is a form of hiding unnecessary details of the object’s implementation, allowing user’s access only via its defined external interface;
- **Inheritance:** is the capacity of using characteristics of one class can as basis to other classes, both sharing those characteristics.

Lower levels on the hierarchy are more specific, while top ones contain concepts that are more abstract;

- **Polymorphism:** is the ability of different objects responding to the same message with their own behavior.

The properties concedes to an Object-Oriented technique a great flexibility in implementing a KBS, a powerful knowledge representation technique (Silva, 1998).

4.1.2 KBS on creativity

Other approaches were used to represent or boost creativity on design. The CODA system (Concurrent Design Advisor), published in 1991, shows the usage of a knowledge-based system in product design, aiming to enhance the efficiency and quality of design. The automation of many routine tasks allowed the achievement of the goals. The system also contains a creativity support system (CSS), helping the users to come up with creative solutions to complex problems (Knight e Kim, 1991). The system does not present different tools or applicability for the team to create, but focus on the exhibition of a variety of random stimuli, trying to deviate the team from obvious answers. The CODA system focus on design with a limited and chained set of creativity tools (quality function deployment), which are traditionally used as part of the design process in engineering.

Hewlett Packard (HP) developed an online advice system (CAST/BW), a KBS that provides quick and accurate hardware sizing, network configuration, and usage recommendations (Nordlander, 2001). Other notable implementations include expert system prototype for hydraulic system design (Silva, 1998), knowledge-based system for design of natural gas cogeneration plants (Matelli, 2008), and expert system development to support the diagnosis of low performance problems in hermetic compressors (Pedroso, 2013).

5 PROTOTYPE DEVELOPMENT

The acquired knowledge on creativity, design methodology and artificial intelligence was the basis for the prototype development. This chapter presents the body of knowledge constructed to implement the system, encompassing the main prototype structure, information input, knowledge output and the correlation method (input-output-means model). An emphasis is given to the categories created as correlation method between the users' inputs and the available techniques, as well as the correlation process leading to this assertion. The last part presents the implementation of the first cycle, depicting the previously discussed structure.

5.1 Prototype structuring

In order to be implemented into a computational environment, the knowledge should first be adequately structured and described based on the required language. For a knowledge-based system (KBS), this knowledge should be assessed using inferences, which is the computational equivalent representation of human reasoning (Giarratano e Riley, 2005). All the data and information acquired by the knowledge engineer from experts, literature, and experience should be filtered and sorted to create a coherent and implementable scenario, considering possible uncertainties and errors that may hamper comprehension.

As knowledge source for this developing system, a set of literature foundations was chosen to identify creativity techniques, the important factors on opting for the use of a technique, and when is it relevant to use each, regarding aspects of design and team. Although the experience of human experts add great value for any KBS implementation, the vast examples of case studies, books and websites available were sufficient to consolidate the project (King e Schlicksupp, 1999; Diegm, 2005; Back *et al.*, 2008; Tassi, 2009; Baxter, 2011; Ideo, 2011; Mycoted, 2011; Ideo, 2015; Toh e Miller, 2015). The use of human experts as source of information for this work would possibly hinder development for unavailability, time restrictions, and for the fact that the use of creativity techniques are extremely particular on design, usually teams deciding for safe and known tools instead of searching for new alternatives.

For creativity enhancement purposes, a KBS is a valid computational method because it is able to represent empirical and heuristic knowledge. Here, it is not the intention to offer ready creative solutions, but rather instigate creativity by presenting adequate techniques depending on the design team's scenarios, aiming to widen the range of possible ideas and help converging them into feasible solutions. The prototype system should act as a consultant on creativity techniques, not only informing suitable ones, but also presenting enough information for the team to execute and facilitate them. This selection is often a heuristic ability for depending on a wide range of aspects of the design (including team, environmental and organizational factors), being sometimes conditioned to team's preference. Even so, a filtering of techniques is feasible, informing the most adequate ones but leaving for the team the option to use.

The target audience for this KBS development was defined as engineers, designers, or any person involved on product development, having or not previous knowledge on creativity and its techniques, but in a situation that requires such expertise in order to overcome creativity blocks, learn about new techniques, deepen the knowledge on known techniques, or that desires counsel for exploring other ideation possibilities. The abilities to represent heuristic knowledge and explain the reasoning are relevant factors for the choice of KBS as implementation method. This approach also facilitates the process of expansion by incremental developments (Silva, 1998), allowing the implementation of a core system that can receive as input new creativity techniques. The friendly learning process and available advisor on KBS also contributed to the approach, aiming to mitigate possible implementation problems.

The software used for development was CLIPS v6.3 (C Language Integrated Production System), a shell tool developed by NASA. Inputs and outputs are given in standard text-oriented input interface provided by the software. The complexity of the domain also impelled the modeling of the system with CLIPS Object Oriented Language (COOL), instead of a strictly Rule-Based approach as previously presented.

As earlier mentioned, two inference methods commonly describe human reasoning: forward and backward chaining (Silva, 1998). While the first bases its conclusions and results on facts, the second formulates hypothesis or potential conclusions to be confirmed by evidences (Giarratano e Riley, 2005). For creativity techniques selection, the availability of facts (user's needs) as input of the system allows the identification of a design scenario-that can be computed as the described categories. The system then correlates such attributes and compares them to a properly structured creativity techniques database, selecting which are appropriate and outputting them. This double inference process (needs – categories – techniques) is closer to a forward chaining approach, mimicking the reasoning used by experts of matching specific needs to adequate techniques using categories.

Following the organization used to structure the prototype, this work will approach knowledge representation in an output-input-means order, starting with the last part of the structure or the chosen techniques and their aspects, then analyzing characteristics for the user's input of information, and for last adequately connecting the starting to the end point. This traditional approach allows a better understanding of the system and eases the correlation and implementation process.

5.2 Creativity techniques (outputs)

A great advantage of creativity techniques is their ability of reducing the incubation time for creation, which is intrinsically random according to *Gestaltism* (Souza, 2001; Sawyer, 2011). While creation on a purely artistic level (as for writers, composers or painters) may be blocked for years, design teams do not have such benefit and should innovate readily and intensively. As seen throughout creativity theory, an aspect of high importance is the ability of sharing information and ideating together that boosts the potential of chaining ideas and quicken the creation process. Many influence factors may hamper communication – such as introverted members, language barriers, overconfidence, and study field bias – and creativity techniques are great allies on surpassing these limitations. Also physical and virtual communication characteristics influence on the creation process. While strictly debating ideas using Brainstorming may be sufficient or necessary for some teams, a greater visualization with a Mock-up Model of ideas can be beneficial in the global ideation process. Naturally, the intensive use of creativity techniques based on schemes and models is more time consuming and requires a greater integration of the team, aspects that are oftentimes scarce.

Some techniques, especially for validation such as Live Prototyping, may require a great learning curve, implying on time and even costs. For some organizations, this trade-off is advantageous, being that, once learned, the technique is incorporated on teams' creativity portfolio. Other organizations may need easier techniques of quick use for projects of short duration, being sufficient techniques as 5Whys. Some techniques are geared toward small alterations on existing artifacts (SCAMPER), while others focus on creating radically new concepts

(Biomimetic). The choice in this case can be based on the project objective, aiming to create a new product or evolving an existing one. In addition, the current design scenario, considering the different phases of a product development is essential on choosing a technique. A technique focused on selecting a solution may be inadequate for ideation phases, converging too early to predictable conceptions. Tools that focus on ideation may also be unsuitable to preliminary design, where is important to define and test conceptions. Other factors influence on the choice of a technique over others. Many aspects were not considered in this work given the broadness of the subject. The elements used were considered sufficient in limiting the number of techniques and presenting a sufficient scenario for the team to choose one over others.

Throughout literature and study cases, a high amount of creativity techniques were encountered, reaching over 100 different methods or variations (Diegm, 2005; Back *et al.*, 2008; Tassi, 2009; Baxter, 2011; Ideo, 2011; Mycoted, 2011; Ideo, 2015). A restricting method was necessary for dealing initially with a small number of techniques and allowing the first implementation cycle. Well-known techniques with ample information on the sources were chosen, regarding also familiarity and easiness of understanding. As other used constraining factor, the first development cycle included only techniques from the design process macro-phase of development. This emphasis on conceptualization and solution selection was given based familiarity to the area, making the techniques easier for representation and implementation.

As a first separation method, techniques were classified on their objective, meaning separating tools that are better suited to ideating in a high quantity and use lateral thinking (diverge) from the ones appropriated for selecting or combining ideas and use vertical thinking (converge) (Aranda, 2009). An emphasis on divergent techniques was given because convergent techniques are considered more universal. For a second separation, techniques were divided on their approaches, trying to balance tools from structured and intuitive sources. Structured techniques usually follow defined steps for creating or selecting conceptions, while intuitive tend to be based on basic notions that lead the reasoning. This approach gave way to the selection of 12 techniques presented on Table 5.1, and better described on Appendix A. Although having multiple interpretation on literature, each technique was analyzed and described gathering positive aspects of each version, aiming to encompass multiple approaches.

Table 5.1 – Techniques used on first cycle with initial categorization method.

Technique name	**Objective**	**Approach**
Analogies and Associations	Diverge	Intuitive
Biomimetic	Diverge	Intuitive
Brainstorming	Diverge	Intuitive
Brainwriting	Diverge	Structured
Functional Tree	Diverge	Structured
Mind Map	Diverge	Structured
Mock-up Modeling	Converge	Intuitive
Morphological Analysis	Diverge/Converge	Structured
Pugh Matrix	Converge	Structured
SCAMPER	Diverge	Intuitive
TRIZ (Contradictions)	Diverge	Structured
Voting	Converge	Intuitive

5.3 Questionnaire (input)

As presented in the schematic representation of knowledge transfer of a KBS (Figure 4.3), in order to output knowledge the KBS requires a form of inputting information, used as inference source to define adequate responses. This work was structured around questions with simple answers to be defined by any design team, aiming to use information common to most design team scenarios regardless the background of the user. The prototype was implemented in English as universal language, granting higher visibility, and the most commonly language used in creativity literature for theory and techniques description.

To correctly select creativity technique, the KBS prototype should first deduce the scenario where the design team is currently inserted. Considering the influence factors on the choice of a creativity technique, three broad aspects were considered sufficient in identifying and filtering tools, aiming to identify nature and significance of the problem, situational variables, creativity thought development plans, and quality of envisioned solution (King e Schlicksupp, 1999):

- Design scenario: focuses on the current methodological phase;
- Organizational guidelines: aim to define the project and organization intention;
- Team characteristics: influenced by team composition, physical and virtual structure, and overall communication means during design.

A great difficulty on creating the input questionnaire was to encompass all the aspects of the team in simple and few questions. Any user should be able to understand the questions and transpose the real scenario of the team to extract the needed information. The used language should be brief but precise, without being excessively technical, which would hamper universal understanding. The number of questions was also an aggravating factor, since verification should address each entry scenario. Even with simple questions of yes/no, an excessive number of question would create an explosive combination of scenarios, for example ten questions leading to two to the tenth power or 1024 scenarios. This combination would progressively create an expressive number for inputs validation, leading to a counterproductive amount of work.

Nine questions were developed to encompass general factors of design development, as presented in Table 5.2. They gather information with the intention of determining the design scenario in order to select the most adequate creativity techniques. The above mentioned three aspects were considered to formulate the entry questionnaire, using simple and direct questions that can be easily answered by design teams.

During use, it is required answering at least eight questions to frame appropriately the entry scenario. Q1.1 is triggered depending on the answer of the first, being considered an auxiliary but necessary question. Those two inputs encompass aspects of the design guidelines or the intention of the organization towards innovation. Q2 and Q3 address the design situation, while Q4 to Q8 comprehend the design team behavior and environment. Q8 is a singular question, which information may be required depending on previous answers combinations. The nine questions account to 336 scenarios, considering the particularities of Q1.1 and Q8.

Using the output-input-means model of development, the “means” phase was developed to link the created inputs, or the presented questionnaire, to the outputs, or adequate creativity techniques. Considering the three basic aspects in this work – design situation, organizational guidelines and team characteristics – five categories were developed to identify the users’ requirements and assert adequate techniques. The categories are the core of the double inference process (needs – categories – techniques), around which this development was structured.

Table 5.2 – Questionnaire for user's information input.

	Question	Answers
Q1	Is the design based on existing products, serving as line extension or upgrading of parts?	Yes No
Q1.1	Does the design aim to fulfill different needs in relation to the base product, targeting new functionalities or new markets?	Yes No
Q2	Is the number of generated ideas and conceptions alternatives sufficient for the team?	Yes No
Q3	Is there available time for posterior tasks according to the chronogram?	Yes No
Q4	Is the team multidisciplinary, having members with different expertise in direct and continuous contact?	Yes No
Q5	Does the team have an exclusive physical environment (e.g. room)?	Yes No
Q6	Does the team have virtual communication for design purposes, sharing progress and information online?	Yes No
Q7	Does the team have periodical meetings (daily or weekly rate) among all members?	Yes No
Q8	Does the team have a good relationship among members for open information exchange and mutual helping?	Yes No

5.4 Categories

Several factors may help in the definition of adequate creativity techniques. An expert should consider nuances and particularities to correctly assert a technique, including organizational, behavioral, and situational aspects. Considering the broadness of influence aspects on creativity, the KBS prototype required a summarization of the expertise into concise and broad categories. Such categories serve as basis of comparison, linking the inputted information and the creativity techniques repertoire in order to limit the number of techniques adequate for the situation. The prototype system serves as a filter of creativity techniques, using the categories to limit the number of appropriate tools according to the given scenario. The choice of a particular technique is delegated to the user, which is informed of potentialities of each selected tool and how to adapt them into the real design situation.

Literature presents a wide range of possible categories such as problem nature (analysis or synthesis); stage of development; available time; size of the team; interaction rate; relationship among members; experience on creativity techniques; knowledge about the problem; presence of a moderator/facilitator; creativity requirement (logical/structured or lateral thinking/random stimulus); organizational environment; and required organizational innovation (incremental/architectural/radical) (King e Schlicksupp, 1999; Brown, 2010; Ideo, 2011; Council, 2015; Ideo, 2015). Five categories were structured based such developments, aiming to embrace enough information to filter techniques. They divide the selection into three aspects:

- Design situation: based on methodological structure of design stages;
- Design guideline: based on the innovation focus given to the particular development;
- Design team: based on relationship of the team, preferred execution methods, and required expertise (difficulty of use).

5.4.1 Design step

The systematization of the creativity techniques expertise for implementation has its basis on the categorization of the design process and its inherent needs. The mentioned design methodologies present a foundation for creativity inside the design process, showing where it is relevant to use enhancement techniques. The first acknowledgeable division, noticed on the Double Diamond scheme (Figure 3.6), is the division between the design planning – definition of the problem space to be addressed during the project –, and the design process –the conception of solutions aiming to fulfill the specified needs. The same methodology presents a derived subdivision. Each diamond contains a two-step structure, one for divergence of ideas, and the other for convergence, coherent with Freudian and Dr. Guildford mind characteristics approaches (Souza, 2001; Sawyer, 2011). This categorization is not so visible during design process, but aids the selection of the tool according to the situation.

Unifying design planning and process with divergent-convergent duality, the four steps of the diamond appear as the first classification of creativity tools for the KBS prototype, and dividing the techniques as presented in Table 5.3.

Table 5.3 – Correlation of design step categories and creativity techniques.

Design step	**Creativity techniques**
Discover	CSD Matrix, Canvas, SWOT Matrix
Define	Work Breakdown Structure, Personas, Journey Map
Develop	Brainstorming, SCAMPER, Morphological Analysis.
Deliver	Prototyping, Pugh Matrix, Voting.

During the development of this KBS prototype and given the broadness of creativity techniques in the whole design process, the implementation focused only on the stages of develop and deliver (design process diamond). This decision restricted the number of creativity techniques and made the problem more approachable and manageable for this initial implementation, leaving space to a posterior growth of the system including the first diamond.

5.4.2 Innovation focus

Organizations with different guidelines tend to differ also in the focus given to innovation. In correlation to a product, innovation has been categorized in several forms. Brown’s categorization (Brown, 2010), presented on Table 2.2, focuses on the relationship between user and offering, culminating in three areas of innovation: incremental (manage), evolutionary (adapt or extend) and revolutionary (create). This categorization fits best on the first diamond for dealing with user’s needs and the market offering, and techniques such as Journey Maps, Personas, CSD Matrixes, forms of Observation, Questionnaire and Interviews are fundamental on this stages. As the developing prototype did not cover planning phases, this approach on innovation focus was not implemented on the first cycle, but the knowledge acquisition foundation is established for further developments.

A second approach on innovation focus took into account conceptual aspects of the product, better fitting the second diamond of design process (Henderson e Clark, 1990). The impacts of innovation focus on the creativity techniques are observable in the form of stimulus provided, or if the technique is based on existent conceptions or reach for disruptive ideas. The division was structured around the core concepts of conceptions and the linkage between such parts, dividing into three innovation categories[1], each with correspondent techniques as presented in Table 5.4.

Table 5.4 – Correlation of innovation focus categories and creativity techniques.

Innovation focus	**Creativity techniques**
Incremental	SCAMPER, TRIZ
Architectural	Mind Map, Morphological Analysis
Radical	Analogies and Associations, Biomimetic

5.4.3 Team relationship

To improve creativity on a team, a series of variables should be addressed. As presented by (Amabile, 1997), individual creativity is a correlation of expertise, creative skill and intrinsic motivation of the task, meaning that a creative person must learn and be personally motivated in order to create. Organizational innovation, on the other hand, builds itself on resources, management practices and organizational motivation to innovate, meaning that an organization as a whole must be innovation-focused, permeating from its goals and guidelines to its designers.

The team should focus, search, discuss and correlate in order to be creative. Any team that lack, for instance, communication among the members should come with alternative ways to debate the ideas. For that, the right assertion of creativity tools come at hand. Team composition is also fundamental. Consistent to Koestler's *Bisociation* (Souza, 2001; Sawyer, 2011), different specialties are important to generate discussion, but the background and mind of each individual play a central role in innovation (Mostert, 2007). Even a multidisciplinary team with similar mentalities will be handicapped of the necessary perspectives.

A division between interactive and dissociated groups help asserting right creativity techniques. While the first uses of discussions and integrative tools to create a mentality collectively, the second needs more structured or individual techniques to overcome problems of communication. A technique that gives equal voice to different members of the team, avoid quarrels and unify the language would allow all

[1] For this development and creativity techniques assertion, modular innovation was considered a particular case assimilated by other innovations

members to share his/her thoughts and contribute to creation. Adequate techniques to each category are presented on Table 5.5.

Table 5.5 – Correlation of team relationship categories and creativity techniques.

Team relationship	Creativity techniques
Interactive	Brainstorming, Analogies and Associations
Dissociated	Brainwriting, Pugh Matrix

5.4.4 Execution method

The execution of the tool is another determinant factor. Sharing of ideas is potentiated when verbally and cohesively constructed, but teams that lack such easiness of communication may resort to other creativity techniques. Some tools have a verbal intention to debate and create the ideas together, while others have a more written or illustrative perspective. This division is challenging, even that in more verbal tools, some form of symbolism needs to be used, while the symbolic tools should also lean on discussions, which may enhance the team creative ability.

The developed separation of techniques, as presented in Table 5.6, focuses on aspects such as team availability, meetings and interaction between the members. Teams whose constant contact is impeded by distance or time have difficulties in maintaining long and recurrent discussions, which would benefit creativity. By sharing the same space (as in a dedicated room), a team can create schemes or prototypes which would better inform other members of the progress of the design. While reports can become excessively large and not communicate properly the ideas, white boards, post-its, pictures and simple models are very effective in creating a general design idea when the creation is not conjunct, maintaining knowledge.

Table 5.6 – Correlation of execution method categories and creativity techniques.

Execution method	Creativity techniques
Verbal	Biomimetic, Voting
Symbolic	Mind Map, TRIZ (Contradictions)

A virtual space may become handy in situations of limited contact. Pictures and schemes are easily uploaded, and can be shared simultaneously with the whole group, each member following the design progress. This virtual network and integrated space are essential to preserve information in teams with high turnover. It is important to notice that the concept of verbal communication is not restricted to physical contact in this scenario. Online chats available for the team can act as a type of “verbal” communication in which ideas are exchanged in an integrated fashion. In general, the design progress is more easily understandable in symbolic form and new team members become aware in less time of the whole process. Yet in the team factor, bad interaction, especially with personal quarrels, or the presence of introverted members interfere on discussions, which are primarily verbal.

5.4.5 Difficulty of use

A creativity expert will not be always available, leaving to the team the responsibility to moderate its own sessions. As a common form of categorization (Ideo, 2011; 2015), this considers the expertise required to learn and apply tools as of great influence on tool selection. A high difficulty technique not only requires a longer learning curve to understand, but also has a more intricate utilization form, needing more discussion and deepening on the design process. The positive aspect is the better quality of outcomes covering several aspects in an orderly fashion. Because of its difficulty, the tool may generate more quarrels between group members over the usage.

Low difficulty tools are easily learnable, usable and overall quicker. These tools are ready to use and require little to no expertise. This easiness also tends to create more predictable and superficial outcomes, being more adequate when there is a time shortage, a constant need to restart the chain of thought or as a quick-starter for ideas. The moderate difficulty tools are intermediate, usually requiring more attention than the easy ones, but not a deepening as the difficult ones. These tools are learnable through repeatable usage and are more versatile. Adequate techniques to each difficulty are presented in Table 5.7.

Table 5.7 – Correlation of difficulty of use categories and creativity techniques.

Difficulty of use	**Creativity techniques**
Low	SCAMPER, Mind Map
Moderate	Brainstorming, Morphologic Analysis
High	Pugh Matrix, TRIZ (Contradictions)

The difficulty of usage category is linked to the time available to create. Tools that are more difficult require more time to generate adequate outcomes. It is important for the team to have enough time to create, but never lose focus on the tasks and goals ahead. Based on the principle that a larger amount of ideas culminates in better innovative solutions, the team should focus all the spare time in the chronogram to divergent thinking. Although convergence is essential to innovate, a bigger picture to associate and filter will generate a more adequate project outcome (Baxter, 2011).

5.5 Correlation (means)

The five categories were used as a bridge to connect the inputted information to the knowledge inside the KBS prototype. Table 5.8 presents an overview of all categories and possible values. The first inference process is responsible for identifying aspects on the answers given by the users and correlate their values to each category, describing a scenario of design requirements on creativity. Correlations between answers are not strictly direct and they may intertwine to generate the scenario and define the categories. The categories of “execution method” and “difficulty of use” are multislot, being possible to receive multiple values for user’s requirements – e.g. it may be relevant for the team to use both moderate or high difficulty techniques, without a loss in creativity – , while the other three must be defined by only one value (one slot) – e.g. while identifying user’s requirements, a design step cannot be both develop and deliver.

Table 5.8 – Developed categories and values.

Category	**Possible values**		
Design step	Develop	Deliver	
Innovation focus	Incremental	Architectural	Radical
Team relationship	Interactive	Dissociated	
Execution method	Verbal	Symbolic	
Difficulty of use	Low	Moderate	High

The correlations will be described in a schematic form to facilitate understanding, but the complete table and inferencing process are presented on Appendix A, relating all the scenarios that lead to the assertion of values for each category in the current cycle of development (third cycle). Figure 5.1 presents the questions that have influence on the definition of the categories values.

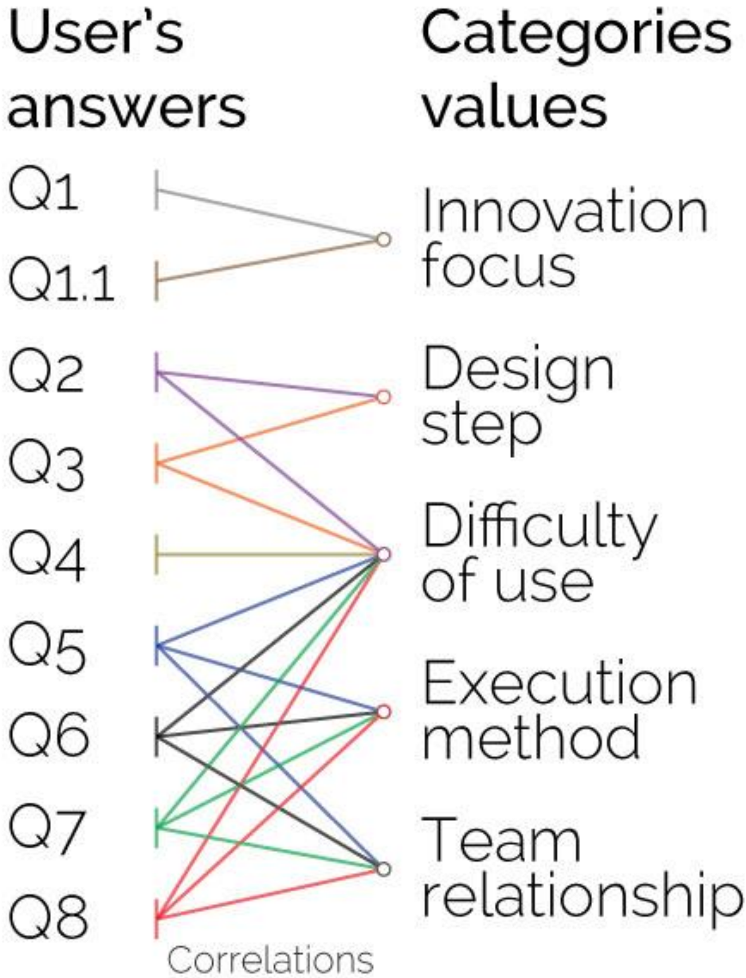

Figure 5.1 – Correlation between user's answers and categories values.

The answers of each question trigger values to each category, for instance Q1 – related to the existence of a basis product (for line extension or upgrading of parts) –, and Q1.1 – if the design aims for new functionalities and/or markets – are responsible to define the "Innovation focus", as exemplified below:

- Q1 answered “yes” / Q1.1 answered “no”: defines the value incremental innovation, the project focusing on improving an existing product to the same market.

Other combinations lead to other values, and the frame can be extended to all the categories. “Design step” is defined using Q2 – inquiring over the sufficiency of generated ideas – and Q3 – regarding the available time on the chronogram. For defining the “team relationship” and “execution method”, questions Q5 – related to the physical environment –, Q6 – related to virtual communication –, Q7 – related to meetings periodicity – and Q8 – related to team relationship – are intertwined.

Team relationship category definition is peculiar regarding Q8, which asks directly for the value of this category (answering “yes” defines the team as interactive, while answering “no” defines dissociated). Although direct questioning being fairly inappropriate – a team may have difficulty in identifying relationship problems and define itself inadequately, even to portray the image of a cohesive and well-mannered team –, other means of identifying characteristics of team relationship would demand greater amount of questions and not guarantee efficiency. In this initial approach, the direct question was considered sufficient and necessary, leaving other and more adequate approaches to future works.

The last category and the most intricate is the “difficulty of use”, depending on the answer of Q2 to Q8 and including Q4 answer – regarding the multidisciplinary composition of the team. Many aspects are important in defining if an easier or harder technique is adequate, and this inference uses up to seven questions to assert values. This is the only category that is defined in an inverse order, starting with all three possibilities asserted and removing unfitting values based on the answers.

All the above mentioned scenarios depict the user’s requirement in each execution of the prototype. The structure of the input questionnaire is able to acquire information about the team, organization and design stages, and is used as a trigger for inference. With the answers, the system prototype is able to correlate information and define values to each category, completing the first stage of a double-inference process. Those are used as comparative to assert creativity techniques during the second stage of inference, which searches through the implemented database in order to find ones that fit the inputted design scenario.

Each technique was defined as a set of values to each category based on literature and case studies, as presented in Table 5.9. Differently from the user’s requirements part of the correlation, four categories on the techniques side – “design step”, “innovation focus”, “team relationship” and “execution method” – are multislot and may contain more than one value, while the last category – difficulty of use – may hold only one, being single slot. This is due the same technique being applicable in multiple cases and, considering the still small number of implemented tools, a looseness was used to cover more scenarios and offer different options. Being extremely particular, the choice of a single technique over others is not the aim of this work. This development does not intend to replace creation or be creative, but rather offer help on adequate techniques taking into account several aspects of the design process, organization and team profile. By presenting a set of techniques as output, it is left for the team to opt for a singular tool, regarding system guidance.

As previously mentioned, this division is not absolute and does not aim to cover all aspects of design. The intention on each correlation is to surpass possible difficulties found by design teams, such as communication and integration problems, or lack of expertise. For being a first approach, the adding of new techniques may change values for techniques, better befitting them to a more adequate scenario. All the correlations and developments presented so far on this chapter were used as basis to implement the first cycle, described in the following subsection.

Even limited to 12 techniques, the entry combination scenarios are of difficult correlation, leading to 336 different combinations. The number of techniques can be easily increased by having the structure set, needing solely to define the new technique categories’ values to implement it on the prototype.

Table 5.9 – Techniques and respective categories' values.

Technique name	Design step	Innovation focus	Team relationship	Execution method	Difficulty of use
Analogies and associations	Develop	Radical	Interactive	Verbal	Moderate
Functional tree	Develop	Incremental & Architectural	Dissociated	Symbolic	Moderate
Biomimetic	Develop	Radical	Interactive & Dissociated	Verbal	High
Brainstorming	Develop & Deliver	Incremental & Architectural & Radical	Interactive	Verbal	Moderate
Brainwriting	Develop	Architectural & Radical	Dissociated	Symbolic	Low
Mind map	Develop	Incremental & Architectural & Radical	Interactive	Symbolic	Low
Pugh matrix	Deliver	Incremental & Architectural & Radical	Dissociated	Symbolic	High
Morphological analysis	Develop & Deliver	Incremental & Architectural	Dissociated	Symbolic	Moderate
Prototyping	Deliver	Architectural & Radical	Interactive	Symbolic	Moderate
SCAMPER	Develop	Incremental & Architectural	Interactive & Dissociated	Verbal & Symbolic	Low
TRIZ	Develop	Incremental & Architectural	Dissociated	Symbolic	High
Voting	Deliver	Incremental & Architectural & Radical	Interactive & Dissociated	Verbal & Symbolic	Low

5.6 Implementation

To construct the rules and object-oriented model combination, a set of classes were developed to harbor the instances and store values. Classes represent a set of entities with common attributes, being used to represent objects (known also as instances) with similar characteristics (Silva, 1998). They also aid in the inheritance of properties, child-classes receiving attributes of its mother-classes. Three classes encompass the chore of technique assertion. NEEDS class save the values of user's inputs used in triggering rules that define the attributes of the five categories, which are saved on REQUIREMENTS class. This defines the user's requirements on a manner that allows the comparison with the implemented techniques inside the TECHNIQUE class. By similarity, the system associate values of the REQUIREMENTS with each technique and outputs that match. The relationship between the three classes is better visualized in Figure 5.2. Other classes are responsible for interface and explanation facilities and are used to receive and save values for further use as output.

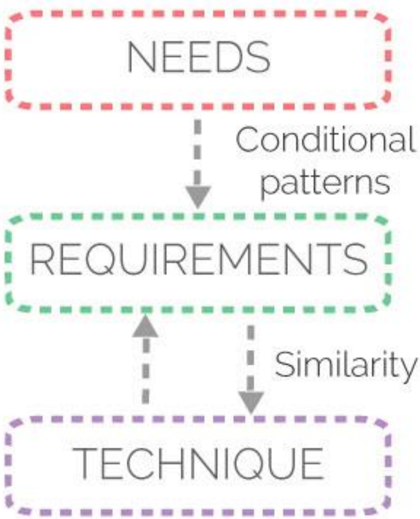

Figure 5.2 – Relationship between three main classes of correlation.

While NEEDS and REQUIREMENTS classes have instances to store identified values for singular executions of the system, TECHNIQUE class contain one object for each available technique. Such objects contain a set of attributes with corresponding values. This semantic net is often referred as object-attribute-value triple, which is better displayed in Table 5.10. Other elucidative representation of the method uses semantic net links, i.e. an object HAS-AN attribute, which IS-A value. The approach is particularly useful in stablishing comparisons (Giarratano e Riley, 2005) as in between identified user's needs (stored in REQUIREMENTS) and the values of each technique. When values for both instances match, the action of the rule is triggered and defines the technique as adequate for the inputted scenario.

Table 5.10 – Object-attribute-value triple.

Object	**Attribute**	**Value**
Mind Map	Design step	Develop
Mind Map	Difficulty of use	Low
Pugh Matrix	Design step	Deliver
Pugh Matrix	Difficulty of use	High

Techniques were modeled to have a set of six attributes, each with an adequate value. Attributes of design step, team relationship and difficulty of use have one defined value for each technique, while innovation focus and execution method may have more than one value depending on the technique characteristics. These attributes aid on asserting adequate techniques by similarity to identified user's needs. Information on each technique was identified in literature and empirical experience. The last attribute is the corresponding name, used to trigger explanation facilities, which will be further explored below.

The implementation was established for identifying the user's needs and compared them to the available database of creativity techniques. The previously described questionnaire inputs the necessary information for defining the entry scenario, which is a set of nine objects with answers' values. This are responsible for triggering rules that define the team requirements in the form of the presented categories, using conditional patterns that match adequate values to each category, as illustrated in Figure 5.3. Not necessarily in every occasion will the same questions be used to define a value, i.e. the information required on an assertion may be achieved without the information of subsequent questions. Either way every scenario requires at least eight questions to generate all the categories' values. Table 5.11 presents a resume of the influence of user's inputs in the categories values, showing which questions may influence on each category.

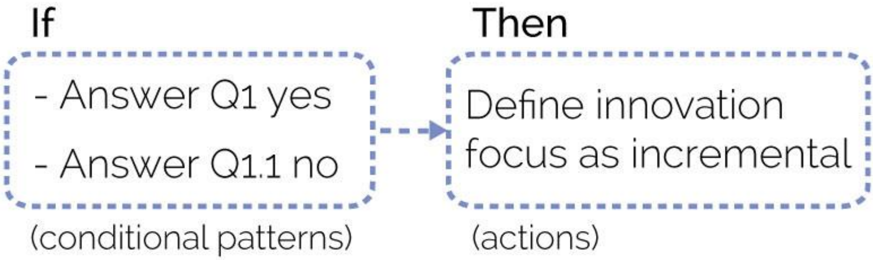

Figure 5.3 – Example of rule structure for defining categories values.

Table 5.11 – Influence of input questions on categories values assertion.

Used questions for inference	**Categories**	**Values**
2 / 3	Design step	Develop / Deliver
1 / 1.1	Innovation focus	Incremental / Architectural / Radical
5 / 6 / 7 / 8	Team relationship	Interactive / Dissociated
5 / 6 / 7 / 8	Execution method	Verbal / Symbolic
2 / 3 / 4 / 5 / 6 / 7 / 8	Difficulty of use	Low / Moderate / High

A rule is responsible to crosscheck the correlated team needs to each available creativity technique. Every technique that fits in every category with at least one value is asserted as adequate and outputted by the system. This rule creates a multislot attribute containing the name of every technique correlated that is used by other rule in order to construct the output scenario. As a fundamental characteristic of a KBS, the explanation facility is provided by a rule which receives all the values stored in the NEEDS class and matches them with corresponding explanations. Those strings are stored on an object named [Interface], creating a full text with all the system inputted information that will be later informed to the user. Another rule is used to store values of the correlated team requirements, which will be connected to the [Interface] on the output.

On this first cycle to test all aspects regarding coherence and inference capacity, the system output was restricted to the CLIPS prompt. After the execution, answering of questions and internal correlations, the system outputs three blocks of information:

- Entry scenario based on answers given by the user, which describes the interpretation of the prototype about the inputted information;
- Correlated team needs in a list of categories with corresponding values;
- Asserted techniques with explanation of the assertion regarding the identified values of the categories.

Although this primal system lacks specific information and how to use the techniques, further cycles of implementation will address this aspect and include the available knowledge. Other features of the implementation include:

- A batch (.bat) file was structured to ease execution of the system. Users can run the prototype by simply accessing the file on the CLIPS environment, which clear the environment and runs the code automatically;
- Header explaining the prototype and introducing the system on the beginning of the execution;
- Exiting at all times with the command “exit”;
- Possibility of re-execution at the end of consultation;
- In case of the prototype being unable to identify adequate techniques, the notice "Unfortunately, no techniques match the correlated needs (not implemented yet)" is presented;
- Evaluation of the user’s input answer adequacy, which should match the available values presented with the question – in case of invalid answers, the system notifies the error and presents the question again.

In order to verify this first implementation cycle, the system was run to evaluate possible syntax errors, which are invalid ways of organizing constructions of the language. Then, a verification table was structured, containing every combination of input answers. Values were manually given to the categories based on the knowledge representation, and category values of each technique were compared to each scenario, asserting matching tools. The system prototype was then executed blindly several times and checked if the theoretical and executed answers were compatible. Syntax errors were corrected and no discrepancies between verification table and prototype execution were encountered. Not every 336 scenarios have matching techniques, issue which will be addressed and revised in following implementation cycles.

5.6.1 System execution

This subsection aims to elucidate interface and other aspects of this implementation cycle of the KBS prototype. By loading the ".bat" file the prototype is automatically run presenting the interface of Figure 5.4. As previously said, the title and heading elucidate aspects of the KBS and gives the main instructions. First question is also presented with the possible values to be written by the user: "y" for yes, "n" for no, and exit for finishing the execution. After answering all presented questions, the system presents the dynamic information of scenario, correlated values to categories, and adequate techniques to the user's situation, as presented in Figure 5.5. Answers for each question were given randomly for this example.

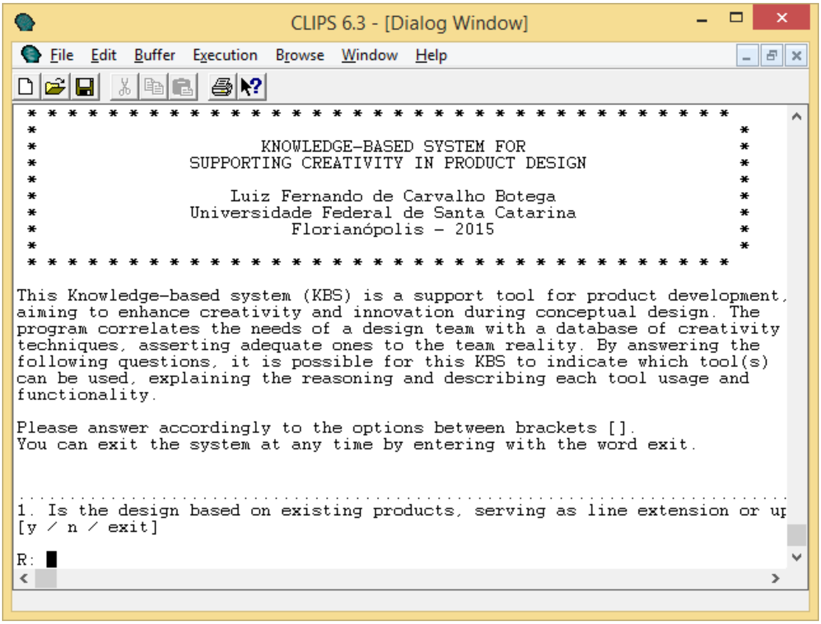

Figure 5.4 – Introduction interface of the prototype in CLIPS v 6.3.

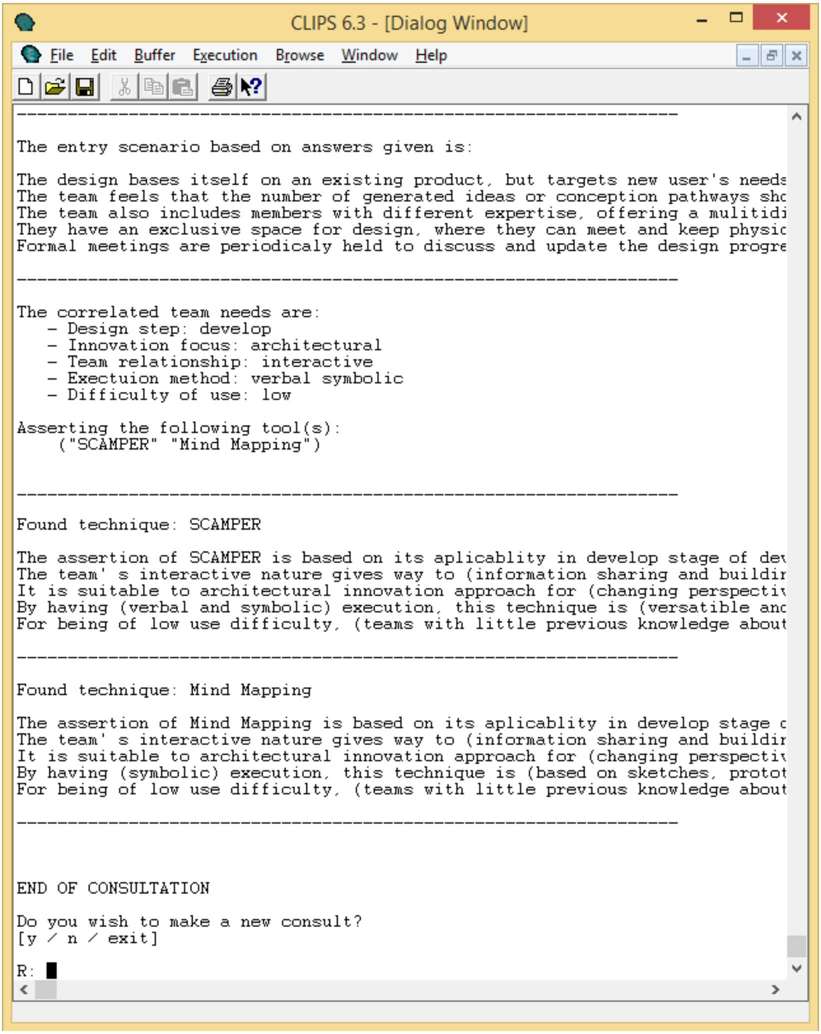

Figure 5.5 – Output interface of the prototype in CLIPS v 6.3.

As shown, this first prototype is able to identify user’s needs, correlate requirements and present adequate creativity techniques. The system chore is coherent and grounded on previous developments and literature. This first cycle was not validated by experts or non-experts, due to lack of interface and small size of the system that was further explored and increased on the second cycle of implementation.

6 IMPROVEMENTS AND VALIDATION

As the last stage on the development of a KBS, verification and validation add feedback to increase and change the prototype into a more robust and better fitting system. The implementation presented in the previous chapter highlighted the use and main structure of the system, but still has room for improvements. During the verification process, which addressed mainly coding and coherence errors, some aspects were better studied and alterations made to expand and ease the prototype use. This second cycle, presented here, was validated by experts and non-experts, leading to more changes, especially on interface and usability. The process leading to the current version of the prototype is presented in this chapter on an incremental order, starting with the second cycle, going to validation and then the third cycle.

6.1 Second cycle

The first cycle was responsible for generating the KBS prototype chore, focusing on input questionnaire and the correlation means. The second cycle aimed to evolve the developing system into a usable tool, centering in the output part of implementation, but also covering other aspects of the first implementation. Between cycle one and two, no external validation with experts or non-experts was performed, the development was restricted to further demands identified during posterior knowledge acquisition and prototype implementation.

During first cycle development, a higher focus was given on the develop phase of product development. This was due to a higher amount of techniques in the former, acting as divergent stage, and because the techniques of the deliver phase are applicable to more scenarios. Further research on creativity techniques revealed other information of this last phase, uncovering nuances that the previous questionnaire was unable to perceive. In order to cover such aspects and give a higher and deserved focus on the deliver phase, Q3 was adapted receiving an additional answer, and assuming the structure presented on Table 6.1. This change incurred also in a slight change on the question structure, in order to maintain concordance and logic.

Table 6.1 – Alteration on question 3.

Question 3	Answers
Is there time available to explore ideas and alternatives according to the timeframe?	1. Yes, the timeframe is loose and there are no imminent milestones.
	2. Yes, but there are close milestones to be met.
	3. No, the deadlines are imminent.

This decision changed slightly the inferencing method of categories definition, offering more possibility to assert the value “deliver” in the “design stage” category, as presented on Table 6.2. This nuance gave more focus to the deliver stage and its techniques, removing excessive pressures occasioned by the KBS prototype use. The new correlations are made explicit on Appendix A.

Table 6.2 – New scenarios impacts on categories values.

Q2	Q3	Design stage	Difficulty of use
No	1	Develop	Moderate & High
No	2	Develop	Low, Moderate & High
No	3	Develop	Low
Yes	1	Develop	Moderate & High
Yes	2	Deliver	Low, Moderate & High
Yes	3	Deliver	Low & Moderate

This new format allows for teams to converge ideas in a more flexible fashion, while the previous structure compelled teams to go to deliver stage only when the team had no available time. Although the focus on diverging is relevant and allows to the team more possibilities to explore ideas before defining conceptions, it is also important that the teams discuss and define solutions with a looser timeframe, avoiding rushed decisions and allowing a higher completeness of the chosen solution. The addition of an answer to Q3 also augmented the scenarios possibility from 336 answers’ combination to 504. Similar to the first cycle, all scenarios were structured in a table to posteriorly verify the implementation.

Second alteration promoted on the second cycle was the addition of 12 creativity techniques. The aim was to cover possible breaches on the outputted techniques, so that the system prototype always offered at least one technique for each answers’ combination. Chosen techniques are presented in Table 6.3 with respective categories values. The selection took into consideration availability of information and familiarity, never forcing a technique to fit in unsuited scenarios. Some of the previous techniques changed categories to better specify their use. The current values (third cycle) are presented in Appendix B along with the description of each technique. From this implementation cycle onwards, no category value was further altered.

The 24 techniques cover the 504 validated scenarios. As a measure of categories balance, Table 6.4 depicts the number of techniques with each category's values. The total number surpasses the amount of techniques due to some tools having multiple values to the same category. The KBS prototype is slightly more focused on divergent techniques with symbolic and interactive innuendo, which is coincident with techniques available in literature.

Table 6.3 – Balance of techniques in each category.

Category	Value	Number of techniques
Design step	Develop	15
	Deliver	9
Innovation focus	Incremental	17
	Architectural	23
	Radical	20
Team relationship	Interactive	17
	Dissociated	13
Execution method	Verbal	9
	Symbolic	17
Difficulty of use	Low	7
	Moderate	12
	High	5

Table 6.4 – New techniques and respective categories' values.

Technique name	Design step	Innovation focus	Team relationship	Execution method	Difficulty of use
5Whys	Develop	Incremental & Architectural & Radical	Interactive & Dissociated	Verbal	Low
Affinity diagram	Develop	Incremental & Architectural & Radical	Interactive	Symbolic	Moderate
Holistic impact assessment	Deliver	Incremental & Architectural & Radical	Interactive	Symbolic	Moderate
Live prototyping	Deliver	Incremental & Architectural & Radical	Interactive & Dissociated	Symbolic	High
Negative brainstorming	Deliver	Incremental & Architectural & Radical	Interactive	Verbal	Moderate
Potential problem analysis	Deliver	Incremental & Architectural & Radical	Dissociated	Symbolic	Moderate
Quick and dirty modeling	Develop	Architectural & Radical	Interactive	Symbolic	Moderate
Resource assessment	Deliver	Architectural & Radical	Interactive	Symbolic	Low
Reverse brainstorming	Develop	Incremental & Architectural & Radical	Interactive	Verbal	Moderate
Six thinking hats	Deliver	Incremental & Architectural & Radical	Interactive & Dissociated	Verbal	High
Storyboard	Develop	Architectural & Radical	Interactive	Symbolic	Low
TILMAG	Develop	Architectural & Radical	Dissociated	Symbolic	Moderate

The last major alteration on this implementation cycle can be considered to cause the highest impact. By resorting to the ASCII output available in the CLIPS interface, all techniques information and explanations migrated to a HTML interface. This offered more usability and understanding to the creativity techniques description, which became more intuitive for using a more familiar interface. The user input format was left unchanged, remaining on the prompt interface of CLIPS. The HTML code is subdivided and assembled using several files, each responsible for a different coding aspect.

The main HTML code is constructed during the execution of the prototype, which includes the explanations on entry scenario, correlated team needs and asserted techniques. In addition to this dynamic information, this file also includes contains static texts on each technique such as a resume, situations of use, step-by-step, examples, related techniques, and complementary readings. This file is offline and created directly on the folder containing the execution file responsible for the containing the prototype.

Examples of interface are presented in Figures 6.1 and 6.2, demonstrating the architecture of the HTML. The first showcases information already available on the first implementation cycle, but in a structured and more understandable frame. On the bottom stands the asserted techniques, and each button redirects to the position of the technique on the HTML window. The second figure is an example of technique description. Firstly, it presents the correlation that led to the choice of the technique, facet already present on the first cycle, and bellow follows the explanation on what is and how to use the technique.

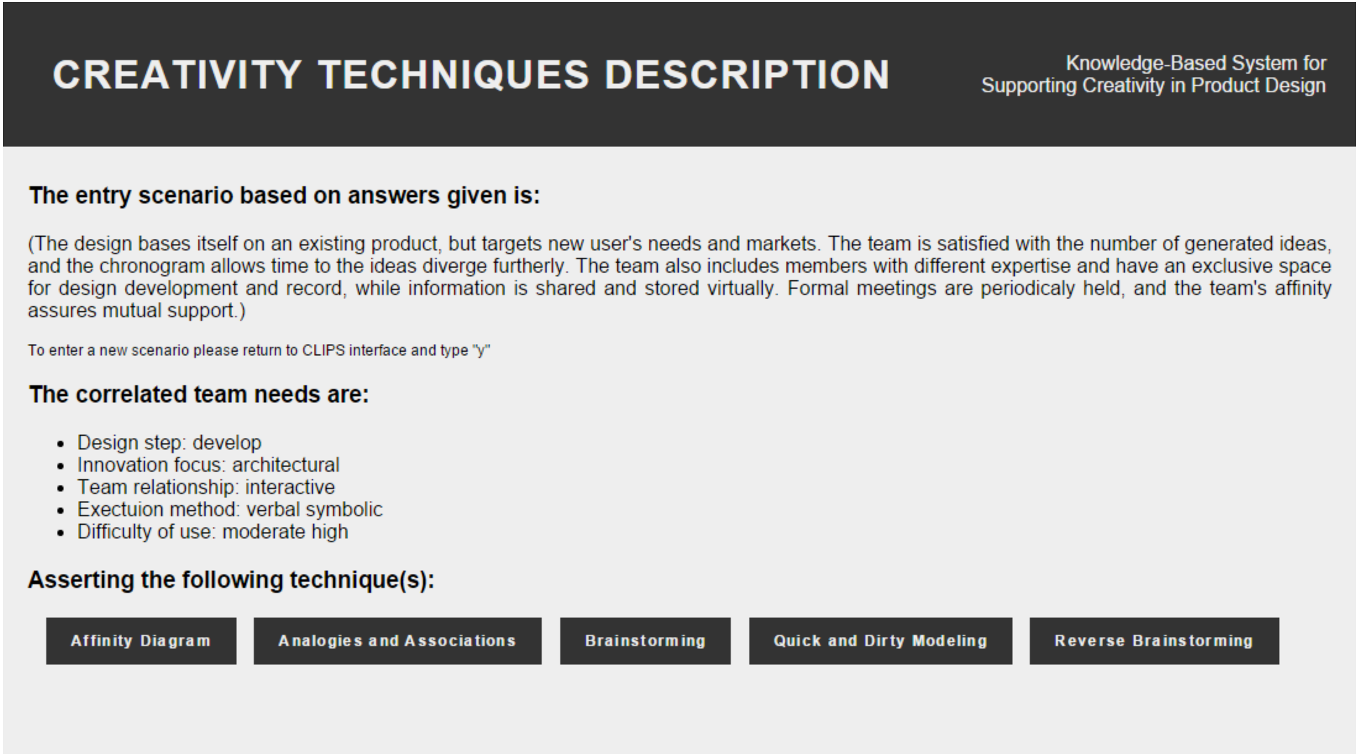

Figure 6.1 – Example of explanation on HTML interface.

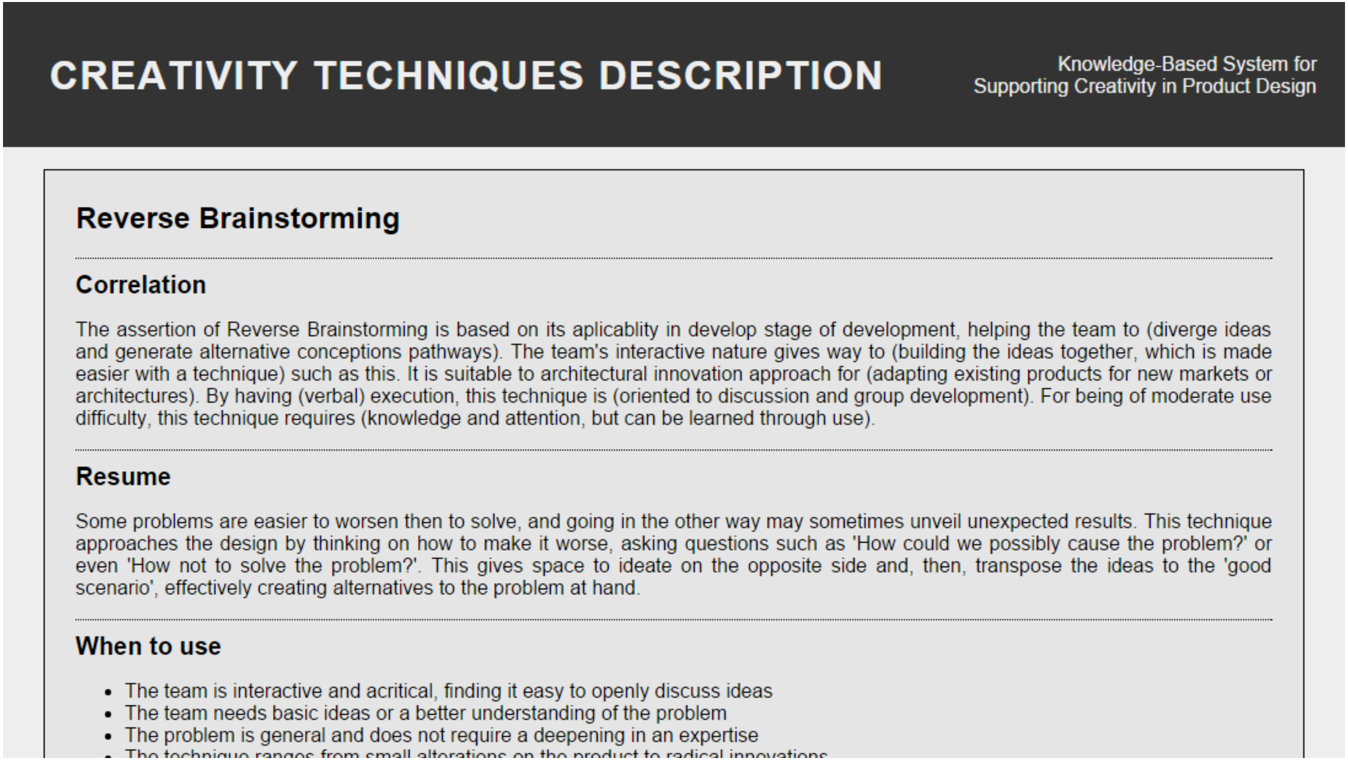

Figure 6.2 – Example of technique on HTML interface.

6.2 Validation

To verify and validate the system understanding and usefulness for any design team, a usability test with engineers and designers was formulated. Being a computational system, the interface should be suitable to the target public, making the navigation intuitive and avoiding mistakes or doubts. The importance of friendly environment goes beyond appearances. Understanding how a user thinks and how the interface will be used reveals important information to make the system more useful with less effort.

An interface that mitigates errors is fundamental to allow a good performance of the system. Even if the KBS is able to correctly assert adequate techniques to the design team situation, the system relies on the user's interpretation of the real scenario to answer the initial questionnaire, as well as their understanding of the questions. The KBS is only usable if the user can correlate their design circumstances and the questions, and understand the presented outcomes and explanations.

"Human errors" is a common label for users not used to an interface, and is usually seen as lack of practice or ignorance about the content. Many errors that are assigned to lack of knowledge from users have their real roots on a "design error", or a lack of usability (Stanton e Baber, 2002). To predict those flaws is fundamental while developing a successful product or service and directing it to their users. By imagining how users would interact with the design, the team can preview some of the flaws and prevent them. However, to address effectively errors and improve solutions a live testing prototype and usability studies are essential.

Ways of performing usability studies vary from questionnaires and interviews to prototypes, depending on the requirements of the current design phase. The aim is to understand how and why users use the system and which features can be improved to help them. It is important to notice that what users say is not necessarily what they experience, since many factors can add noise to their answers. When possible, interviews and first hand experiences are preferred and give a wider image and information. Unfortunately, the required timeframe for this work and agenda of the validators hampered those approaches, limiting to questionnaire applications.

First information required for such evaluations include by whom, why, when, and where the system will be used. As previously said, this prototype is directed to any design groups in need for creativity boosts during development, on stages that range from conceptual discovery to solution identification. Naturally, a complex usability study would require more information on psychological and organizational factors of the design team and environment. This study is limited to ease the understanding and apply the feedback in optimizing the KBS. The developed questionnaire embraces four aspects of the validation process:

- Language of input questions;
- Relevance of implemented techniques;
- Adequacy and language of outputs;
- Overall performance of the system.

A brief introduction explains justification and context of the study for the validator. The questionnaire should be answered individually after executing the prototype several times, and presents three different entry scenarios to help adding background to the simulation. It is important to notice that every input combination is satisfactory, and the questionnaire aims to evaluate the KBS, not the validators understanding of those scenarios. The validation questionnaire and its structure can be seen in Appendix C. To ease the validation process, three hypothetical design scenarios were described and sent with the validation files. The scenarios contain information that may help validators to use the developing system even without a real demand, which would hamper answering the prototype's initial questionnaire.

To execute the KBS prototype, a simple "Read-me" text file provides instructions on how to validate the system, from extracting files until the procedure for feedback. Two main profiles were attributes to validators. Experts are validators with deep knowledge on more than one of the following areas: design methodologies, computational systems (especially KBS), and creativity. Their knowledge is relevant for validating the system structure and coherence to the expertise. Non-experts were considered to have less expertise on such areas, focusing solely on one or with shallow knowledge on more than one area. The insights provided by them are fundamental in testing interface, language, easiness of use and overall understanding. The same questionnaire was used in both cases, but results confirmed the abovementioned view. Nine questionnaires (6 non-experts and 3 experts) were answered up to date and they provide sufficient base for the presented alterations of the prototype. The whole validation process requires a larger amount of data, especially to endorse the coherence of the system.

6.2.1 Results

As expected, expert validators directed their answers to the relevance of the theme and coherence of the outputs as well as overall usability, while non-expert focused on use and interface of the system. First aspect to be noted is reported on question 2 and addresses improvements in the system's questions language, aspect mentioned by 23% of the validators as shown in Figure 6.3. Other aspect addressed by the language is the easiness to correlate real scenarios and questionnaire, as 56% of validators said to have difficulties in this correspondence. By using less technical questions, the system becomes more understandable and easier to correlate. To evaluate better options of information input, the prototype should be taken to real scenarios and situations on which the information required to answer the initial questions is evident. By using imaginary scenarios, the validation questionnaire may not entirety address this aspect.

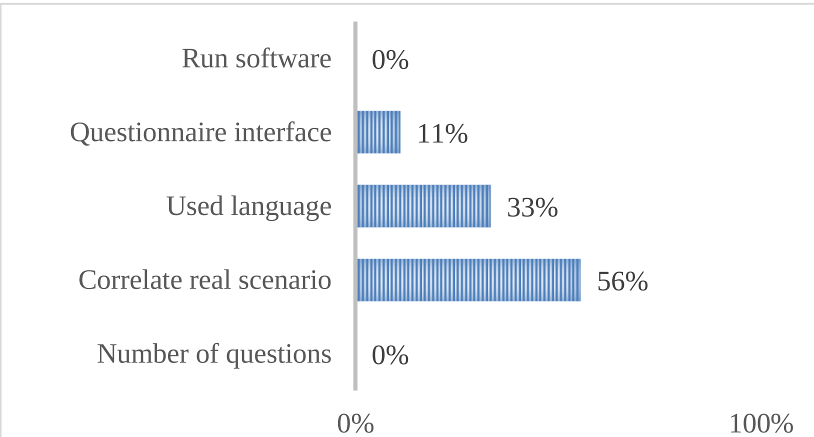

Figure 6.3 – Bar chart representing answers from question 2: "Which were the biggest difficulties while answering the questionnaire?".

The initial questionnaire interface presented some difficulties, considered an unfriendly environment. Unfortunately, interface alteration on the used software was foreclosed, leaving the simple prompt format and simple questions as only option. No validator mentioned difficulties with the number of questions or the execution of the software. All validators considered the output techniques adequate to the presented scenario, but mentioned that other techniques may also be useful. The system presents what is considered the most adequate ones, but does not limit the use of other techniques if the team considers adequate. The KBS is a consultation and advice tool, but the decision to use one technique is the team's choice. No validators said to have difficulty employing them, but mentioned that less experienced users might find it challenging with the used output format.

KBS's initial construction aimed both to describe the technique and help user effectively employ them. It counts with a set of information, explaining the correlation that led to the technique, presenting a resumed overview of them, situations in which each technique is adequate, a step-by-step, some tips regarding the use, examples, related techniques and complementary readings. Validators reported a greater focus on 'what' is the technique rather on 'how' to use them. This unbalance made the system more information oriented, lacking effective and direct usability. By relying on descriptions and tips, the system was directed to facilitators and users with experience on creativity and its dynamics, limiting comprehension of users with lesser knowledge on this area.

Based on answers to question 7, as shown in Figure 6.4, adjustments on the implementation focusing on examples and more direct information help to broad the KBS to less experienced users and align it to its original intention. 67% of validators mentioned a need for more visual and first-hand information as in more examples, mentioning specially videos of techniques application (56%). Some interface alterations (indicated by 57% of validators) and interactivity improvements (indicated by 29% of validators) will be implemented on the next cycle intending to ease consultation and give more fluidity of use. The wanted information should be readily displayed and the intensive use of texts hampers the required quickness. By using schemes, infographics, videos and visual examples, the KBS tends to be more accessible and valuable to real life usage.

From the 24 presented techniques, no single validator mentioned knowing more than 17, keeping an average of 12 known tools. This shows the broadness of the system and the relevance of this approach to present different options for teams to overcome creativity blocks. By bringing techniques from different design development backgrounds, the KBS presents knowledge for the teams to explore new mind-pathways and overcome difficulties by using adequate techniques.

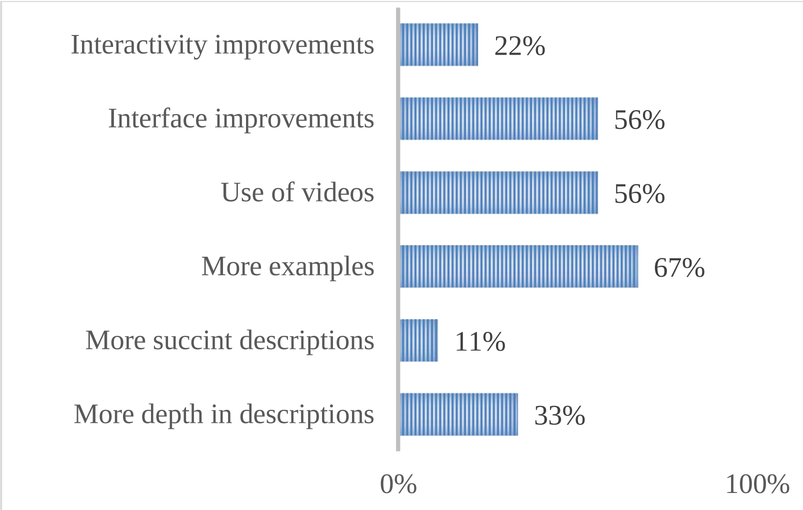

Figure 6.4 – Bar chart representing answers from question 7: “Which other factors would help understanding the Creativity Techniques Description output?”.

Answers from question 8, presented on Figure 6.5, show that most validators (89%) consider the KBS to be advantageous in group developments, and 33% to be also valuable in individual design. 78% consider its use advantageous when having creativity blocks. Respectively 67% and 33% indicate that the system is useful in initial creation phases (to create basic conceptions) and posterior developments (when the team already has conceptions at hand). Up to 33% of validators consider the system useful in situations with time constraints, and 78% of them find it valuable when the team has little knowledge about creativity techniques or no facilitator, as well as to learn about other techniques.

Validators’ knowledge and insights propelled the third cycle of the KBS prototype, addressing the failures identified and implementing improvements indicated, taking into consideration every feedback given from experts and non-experts. Other considerations brought by them included:

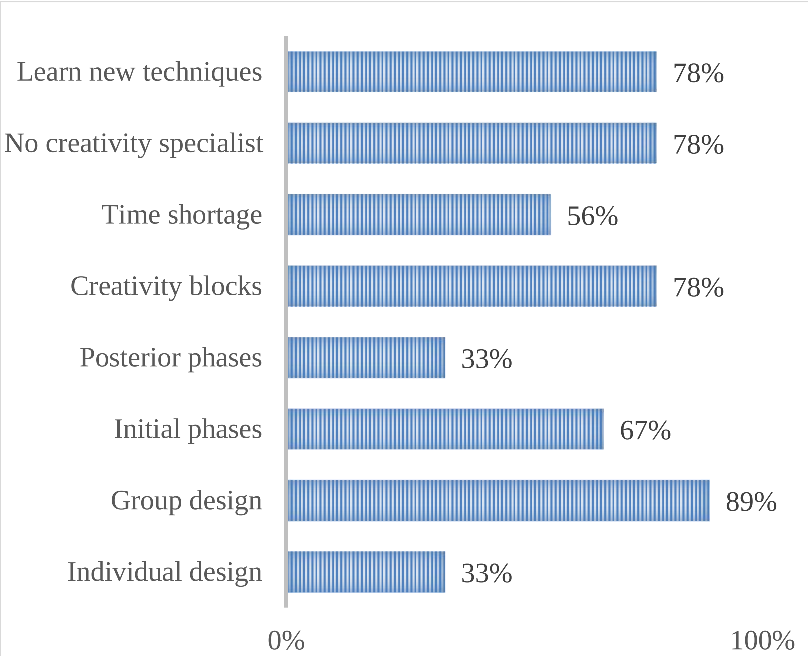

Figure 6.5 – Bar chart representing answers from question 8: “In which situations do you consider the system useful?”.

- Translating the KBS into Portuguese for the first validation process to help comprehension, not considered an impeding factor and would be time consuming. The translation could benefit the study by avoiding language barriers and mistranslation of terms;
- To use a score system to grade techniques and then output the best, which will be accomplished in future implementations of the system using fuzzy logic. This construction would allow a better understanding of the design situation, but be more demanding on verification and validation. Nevertheless, the approach is seen as advantageous for better encompassing the singular nature of each design development;
- Small typing errors regarding words or constructions were indicated and corrected;
- As a measure of overall performance, validators gave an average of 4 on a scale from 1 to 5, considering 5 as highest score.

6.3 Third cycle

Validation process fed valuable information for the establishment of the third implementation cycle. Two main issues elapsed from validators' insights: the difficulty of correlating real scenario and the questionnaire, and the necessity of changes on the HTML interface to better present the creativity techniques, including more information that could help teams choosing one technique over others and execute them adequately. To address the first issue, changes on initial questionnaire language were developed, using more commonplace vocabulary and aiming for a more universal understanding. The used technical repertoire limited the comprehension and hampered users from different background to overlap the real scenario to the questions. By using a more accessible language, the system is directed to a wider variety of users including non-experts in design. The new questions lexicon is presented on Table 6.5.

Second issue of improving interface and techniques exposition provoked greater changes on the prototype. Instead of readily presenting to users all data on the asserted techniques, the developing system was altered to display firstly the dynamic part of the previously described HTML, containing information on the entry scenario, correlated team requirements and explanation on the asserted techniques. Instead of information each tool, the file created during the system execution – which was renamed as "Creativity_Techniques_Report.html" – explains the process leading to the definition of categories values and presents highlights of the techniques. The correlation process is showcased using the entry scenario and team requirements in interconnected lists, as presented on Figure 6.6.

Table 6.5 – Restructured initial questionnaire for the KBS.

	Previous questions	**Restructured questions**
1	Is the design based on existing products, serving as line extension or upgrading of parts?	Is the design based on existing products, focusing on improving or keeping them in the market?
1.1	Does the design aim to fulfill different needs in relation to the base product, targeting new functionalities or new markets?	Does the design focus on coming up with new functions or reaching different users with the current product?
2	Is the number of generated ideas and conceptions alternatives sufficient for the team?	Are the number of generated ideas and alternatives satisfactory for the team?
3	Is there available time for posterior tasks according to the chronogram? 1. Yes, the timeframe is loose and there are no imminent milestones. 2. Yes, but there are close milestones to be met. 3. No, the deadlines are imminent.	Is there time available to explore ideas and alternatives? 1. Yes, the team has loose time and there are no deadlines near. 2. Yes, but there is some pressure and close milestones to be met. 3. No, the deadlines are at the doorstep or already passed.
4	Is the team multidisciplinary, having members with different expertise in direct and continuous contact?	Does the team have members with different backgrounds and expertise (multidisciplinary) in close and constant interaction?
5	Does the team have an exclusive physical environment (e.g. room)?	Is there a dedicated room or an exclusive physical environment for the team?
6	Does the team have virtual communication for design purposes, sharing progress and information online?	Does the team have online communication to help sharing progress and information about the design?
7	Does the team have periodical meetings (daily or weekly rate) among all members?	Does the team have periodical meetings (daily or weekly) among all members?
8	Does the team have a good relationship among members for open information exchange and mutual helping?	Does everyone on the team have good relationship to help each other and exchange information?

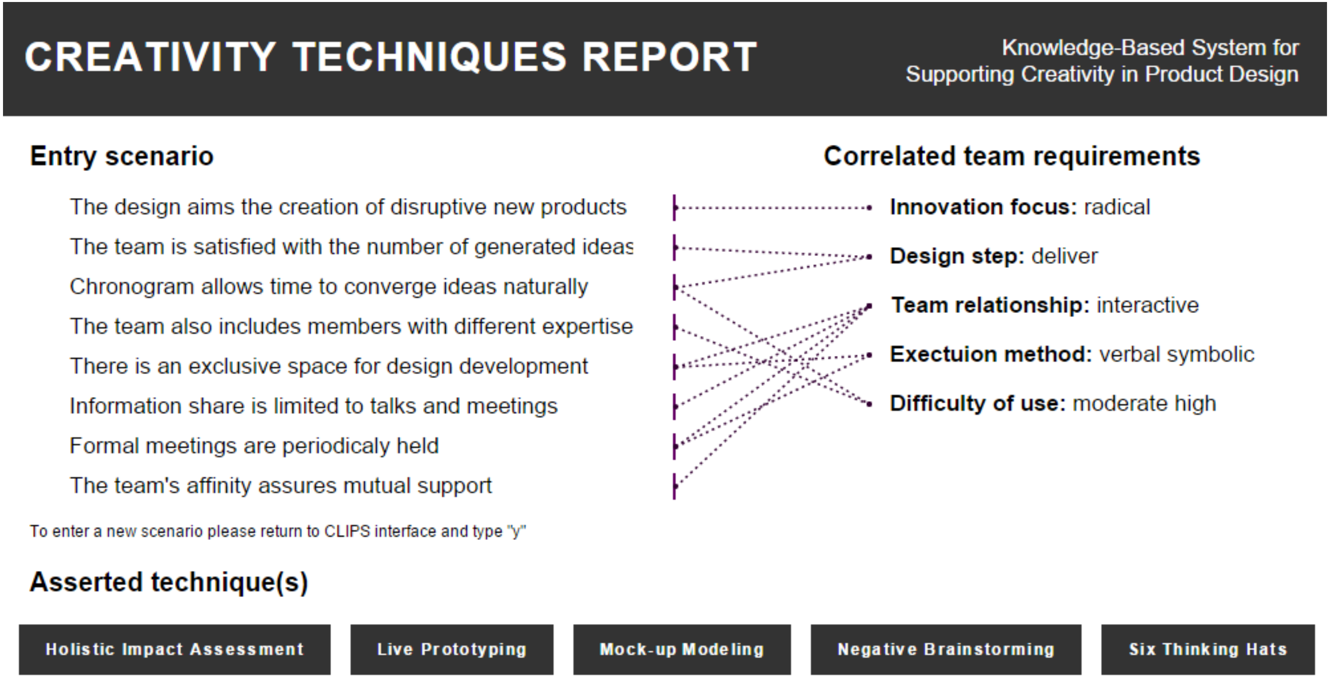

Figure 6.6 – Heading interface for third implementation cycle.

The left column is constructed with the information inputted by the user, while the right column consists on the values correlated to each category. The connection indicates the conditional patters that lead to the assertion of each category, and was made possible using jQuery (Foundation, 2015) and jsPlumb (Jsplumb, 2015) facilities, which are responsible for creating the dashed line pattern. On the bottom are presented the asserted techniques, which redirect to each technique correlation description.

Techniques information on this file includes the explanation on the inference process that led to the assertion, as presented on the left side of Figure 6.7, as well as important aspects that help paralleling and choosing a technique. To inform the user of each technique's highlights, three scales and a series of badges were developed containing essential information to compare techniques. Each tool received a grade on each scale and three badges, as shown on the right side of Figure 6.7. They were structured to help the user choosing a technique over others, considering nuances still overlooked by the system inference machine, but perceived by the design team. Each badge was designed to be of easy understanding and can be used to identify the main features of the technique. In further implementation cycles a help icon can be used to better explain each by simply hovering the cursor over the badge. The scales represent important tendencies to compare and indicate if a technique is:

- Auxiliary or systematic, being is more or less structured in a step-by-step approach;
- Used individually or in group, if the technique is adequate to individual use or if its execution requires group interaction;
- Geared to ideate or evaluate, priming for quantity of ideas or analyzing and synthetizing conceptions.

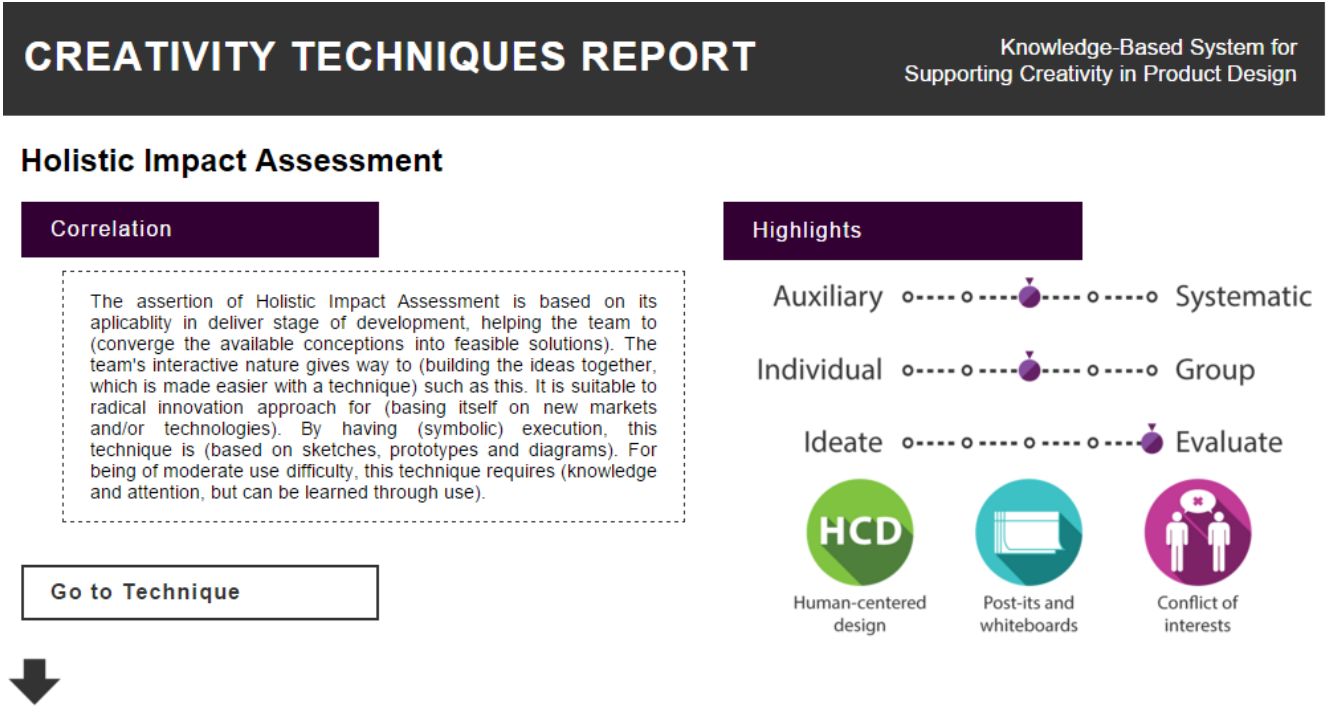

Figure 6.7 – Techniques correlation and highlights interface.

After presenting information to help on the choosing of a technique, the user is able to click on the link "Go to Technique", being redirected to a different website called "Creativity and Innovation Booster for design" or "CRIB for design". This contains all information on each technique as presented on previous implementation cycles. To address interface and technique exposition issues, information on each technique were divided in two main groups: "how to use" and "what is", as presented on Figure 6.8. The first included technique resume, step-by-step, example and tips, while the second is composed of when to use, related techniques and complementary readings. This separation helped focusing the output on usability, presenting the first directly and leaving the second as additional information. Users can easily and readily navigate through examples and learn to use the technique, but still access more detailed information, descriptions and references if necessary. To ease consultation, the information and descriptions were reorganized presenting only retracted titles, which can be expanded to reveal its content. This approach leaves a cleaner and more intuitive interface for users, but still grants access if a bigger detailing is required.

The changes incurred in a great simplification of the KBS prototype code, being the information on each technique not directly accessed by the KBS. The files containing information on the implemented tools were replaced by the "CRIB.html", separating dynamic and static data in two separate but intertwined websites. This last developed implementation cycle counts with 6 classes, 5 message-handlers, 27 rules, and 41 instances. Other added features include:

- Auto-execution of the "Creativity_Techniques_Report.html" file after prototype run;
- Stocking of former scenarios in an old entries directory, maintaining previous execution reports;
- A "next" downward arrow button that presents the following asserted technique (seen in Figure 6.7).

The last development cycle was submitted to initial validation with two experts and two non-experts. Validators that took part in previous cycle reevaluated the growth of the developing system, indicating if the alterations corrected or mitigated highlighted errors. The validation results are presented in Appendix D. Further validation shall lead to future changes and improvements to the next system cycle.

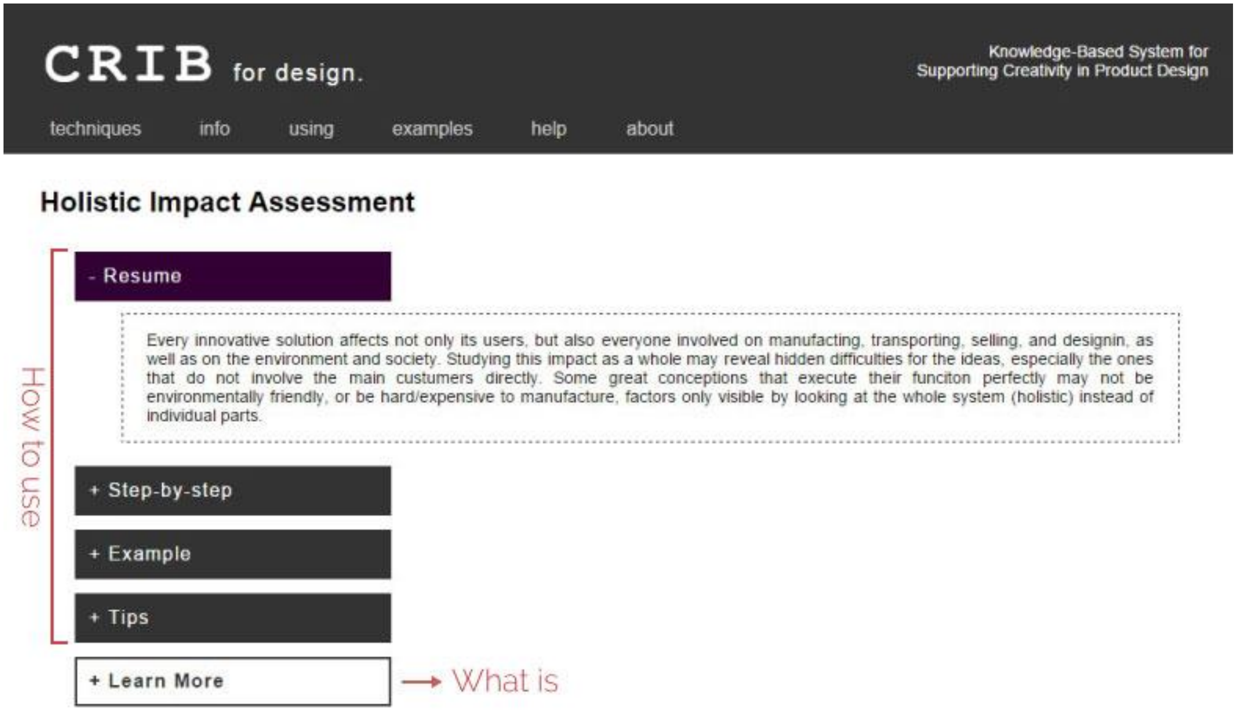

Figure 6.8 – “CRIB for design” website interface.

7 CONCLUSIONS

Creativity is an inherent ability of any human being and can be found on the most common tasks in everyday life. Considering the current competitive market, creativity has surpassed the involuntary and special talent field to become an ordinary ability in any organization. To maintain market share, any organization is compelled to innovate and come up with new products to better satisfy or reach new requirements from increasingly demanding users (Žnidaršič e Jereb, 2011). This market demand puts high pressure on design teams to reach new products and services with new and better functionalities (Amabile *et al.*, 2002).

Many auxiliary methods have arisen during the years to help with this responsibility. Creative thinking, although imperative throughout the whole design process, could be highlighted and studied along with the emergence of design methodologies, identifying which parts demand higher creative behavior. Many aspects were found to influence creativity, and several methods and techniques were designed to suit different situations.

The choice of a technique cannot be restricted only to methodological aspects. The guidelines of the organization can assume the form of an innovation focus that directs the design towards a more offensive and radical line, or to a more defensive and incremental approach. Other aspects should be considered when defining the innovation focus of a design, such as the market, target customers and core concepts of the product, but this approach can also be used to define adequate techniques for the design scenario.

Alongside design situation and organizational guidelines, the third aspect that can be considered when choosing a creativity technique is the team environment. To adequately innovate, a team should be able to share information and think together, an ability that can be hampered by several factors. Personal quarrels, introverted members, meeting impossibility, and lack of contact are some factors that may mitigate the knowledge transfer inside a team. The presence of such aspects can influence the choice of a technique, some of which are based on discussion for interactive members, or on systematic constructions to dissociated teams. The execution method and difficulty of a technique also influences on the choice, all affected by the team environment and relationship.

Although many aspects can be added to assert a creativity technique, the five categories presented on this work are considered sufficient on identifying the user's requirements and selecting adequate techniques:

- Design step
- Innovation focus
- Team relationship
- Execution method
- Difficulty of use

They address three main sides of techniques assertion and help refining the spectra of possible tools. The categories have been shown to serve as a mean between user's needs and creativity techniques, passing through a double inference process. They are used to define the user requirements scenario as values for the categories, as well as comparing such values to the attributes of each technique. This is the core of the presented prototype, which can be seen as the consolidation of expertise into an available, reliable and permanent system (Giarratano e Riley, 2005) to be used by any user in need for creativity support

The prototype was exposed on an incremental order, each stage adding knowledge and usability to the system. On the last phase, the KBS prototype has 504 different combination scenarios of user's input and 24 available techniques from different fields. The system is able to identify the user's scenario using nine questions, assert values to each category and correlate techniques to fit each cases. No scenario was left without at least one possible outcome. This was partially due to the incremental approach that revealed on the first cycle the zones lacked techniques that were found through literature and easily implemented.

The used combination of Rules and Object-Orientation also proved to be adequate. This approach was able to represent the knowledge on a coherent and precise fashion, allowing the incremental approach that helped assimilating knowledge in consecutive stages. During verification and validation, every found bug and incongruity was addressed and corrected. Validators' insights were of particular benefit, pointing new directions and improvement possibilities in structure, usability and coherence of the developing system.

Clearly, the system is not complete and many other aspects and knowledge should be taken into consideration. It can be said that no KBS is ever finished, but is in a constant recycling to become more and more useful to its purpose. Nevertheless, the main objectives for this stage of development were accomplished. The system is able to combine knowledge from several study fields in a concise and reliable tool to aid design. It reduces the necessity of over research on hundreds of creativity techniques throughout literature (Diegm, 2005; Baxter, 2011; Ideo, 2011; Curedale, 2013; Ideo, 2015), reducing time and offering ready knowledge to design teams. The prototype was verified and validated by specialists and non-specialists in fields of engineering, knowledge management and design, receiving an overall good response.

This work development promoted publications on the "IV International Conference on Design, Engineering, Management for innovation (IDEMI)" with the paper entitled "Knowledge-Based System for Supporting Creativity in Product Design – Issues on Knowledge Acquisition" (Botega e Silva, 2015c) and on the "23rd ABCM International Congress of Mechanical Engineering (COBEM)" with the paper "Knowledge-Based System for Supporting Creativity in Product Design – Foundation" (Botega e Silva, 2015b). The first was awarded as the best work on the theme "Sustainability, Knowledge Management and Organizational Learning", and selected to be published in the "International Journal of Knowledge Engineering and Management (IJKEM)" with the title "Knowledge-Based System for Categorization and Selection of Creativity Support Techniques" (Botega e Silva, 2015a).

7.1 Future works

The here described implementation process can be seen as a first step in the construction of a computational system to support design team in creating better products and fulfill demand. However, many aspects, including the ones mentioned during the description of the development, are still lacking to a real and commercial application. Following steps include:

- Further validation of third cycle;
- Implementation of other design phases, including the first diamond from the Double Diamond methodology;
- Evaluation of new categories befitting the new design phases;
- Change on user questionnaire interface, keeping the CLIPS interface hidden from the user;
- Use of fuzzy approach for information input evaluation, which would allow identifying more aspects of the design scenario;
- Inclusion of new techniques from any area connected to the design process;
- Implementation of an easy input method for new techniques in organizational scenarios;
- Implementation of new methods for differentiating techniques considering the expanding number tools;

- Tryouts in commercial scenarios, offering feedback for evolving the system's interface, usability, language, and coherence;
- Implementation of a method that considers the historic of the organization when selecting techniques;

A great insight presented by a reviewer advised the change of the words "creativity technique" to a more broad term, for instance "design activities". Although the system does not intend to address many management or manufacturing activities, the use of "design activities" gives a broader meaning to the system, including methods that are supportive in the creative process and knowledge transformation, such as Quality Function Deployment (QFD). The term is more accurate and may be used in further works in parallel to creativity techniques.

The developed prototype shows potential to become a unification method on creativity techniques for several areas of design, helping teams and organizations to become more innovative. The inclusion of other design aspects will surely bring techniques that may require different forms of categorization to be asserted. As previously said, the defined categories are sufficient but not complete, and other factors should be addressed when increasing the number of techniques, especially when including ones from other study fields. Besides the capacity of the system to match team needs to techniques, it is also fundamental to address issues on interface, language and usability. This will help turning this KBS into a powerful and useful tool for design, acting as a counselor and knowledge base for design teams to create and innovate.

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APPENDIX A – CORRELATIONS

This appendix explains the correlations leading to the assertion of the values of each category. The following four tables were structured to help understanding the impacts of each user answer in the values, aspects that are better explained on the bullets bellow. Table A.1 correlates Q1 and Q1.1 into defining the *Innovation focus*. TableA.2 uses Q2 and Q3 to establish values for *Design step* and *Difficulty of use*. TableA.3 uses Q5, Q6, Q7 and Q8 to correlate *Execution method*, *Team relationship* and *Difficulty of use*. TableA.4 combines Q4 to other factors in further asserting the *Difficulty of use* values. It can be noticed that the *Difficulty of use* category permeates several questions, and was not encompassed in a separate table due to the broadness of possibilities. This approach was found to be easier to understand the complex correlations behind each category.

Table A.1 – Correlations for the definition of *Innovation focus*.

Q1. Is the design based on existing products, focusing on improving or keeping them in the market?	**Q1.1. Does the design focus on coming up with new functions or reaching different users with the current product?**	**Innovation focus**
Yes	Yes	Architectural
Yes	No	Incremental
No	**	Radical

** - Value is irrelevant for the assertion

Table A.2– Correlations for the definition of *Design step* and *Difficulty of use*.

Q2. Are the number of generated ideas and alternatives satisfactory for the team?	**Q3. Is there time available to explore ideas and alternatives?**	**Design step**	**Difficulty of use**
Yes	1	Develop	Moderate & High
Yes	2	Deliver	*
Yes	3	Deliver	Low & Moderate
No	1	Develop	Moderate & High
No	2	Develop	*
No	3	Develop	Low

* - Values for “Difficulty of use” category remained “Low, Moderate & High”

Table A.3 – Correlations for the definition of *Execution method*, *Team relationship* and *Difficulty of use*.

5. Is there a dedicated room or an exclusive physical environment for the team?	**6. Does the team have online communication to help sharing progress and information about the design?**	**7. Does the team have periodical meetings (daily or weekly) among all members?**	**8. Does everyone on the team have good relationship to help each other and exchange information?**	**Execution method**	**Team relationship**	**Difficulty of use**
Yes	Yes	Yes	**	Verbal & Symbolic	Interactive	Moderate & High
Yes	Yes	No	Yes	Symbolic	Interactive	*
Yes	Yes	No	No	Symbolic	Dissociated	*
Yes	No	Yes	Yes	Verbal & Symbolic	Interactive	*
Yes	No	Yes	No	Verbal & Symbolic	Dissociated	*
Yes	No	No	Yes	Symbolic	Interactive	*
Yes	No	No	No	Symbolic	Dissociated	*
No	Yes	Yes	Yes	Verbal & Symbolic	Interactive	*
No	Yes	Yes	No	Symbolic	Dissociated	*
No	Yes	No	Yes	Symbolic	Interactive	*
No	Yes	No	No	Symbolic	Dissociated	*
No	No	Yes	Yes	Verbal	Interactive	*
No	No	Yes	No	Symbolic	Dissociated	*
No	No	No	**	Symbolic	Dissociated	Low & Moderate

* - Values for "Difficulty of use" category remained "Low, Moderate & High"
** - Value is irrelevant for the assertion

Table A.4 – Correlations for the definition of *Difficulty of use*.

4. Does the team have members with different backgrounds and expertise (multidisciplinary) in close and constant interaction?	**Value of "Team relationship" category**	**Difficulty of use**
Yes	Interactive	Moderate & High
Yes	Dissociated	*
No	Interactive	Low & Moderate
No	Dissociated	Low & Moderate

* - Values for "Difficulty of use" category remained "Low, Moderate & High"

Design step:

- Q2 answered "yes" / Q3 answered "1": implies on develop due to a loose timeframe that allows more divergence of ideas;
- Q2 answered "yes" / Q3 answered "2" or "3": defines the "design step" as deliver, the first due to a sufficient number of conceptions and the upcoming milestones, the second due to no time left for divergence;
- Q2 answered "no": frames the "design stage" as develop, due to lack of conceptions.

Innovation focus:

- Q1 and Q1.1 answered "yes": defines the value architectural innovation, the project being based on an existing product but aiming for new ways of exploring the idea;
- Q1 answered "yes" / Q1.1 answered "no": defines the value incremental innovation, the project focusing on improving an existing product to the same market;
- Q1 answered "no": defines the value radical innovation, being that the design is aiming to create new product ideas.

Innovation focus:

- Q5, Q6 and Q7 answered "yes": defines team relationship as interactive, due to high interaction rates and informal communication;

- Q5, Q6 and Q7 answered “no”: defines team relationship as dissociated. With minor physical or virtual contact, the design tends to be done in isolation and be based on deadlines and deliveries;
- In other combination scenarios of Q5, Q6 and Q7, the Q8 defines the relationship of the team directly, answering “yes” defines the team as interactive, while answering “no” defines dissociated.

Execution method:

- Q5, Q6 and Q7 answered “yes”: defines execution method as both verbal and symbolic. The use of verbal techniques quickens the exchange of ideas on formal and informal meetings, while symbolic techniques can be structured online or in the dedicated room to maintain knowledge;
- Q5, Q6 and Q7 answered “no”: defines execution method as symbolic. Being the design tasks performed in more isolated scenarios, symbolic techniques are easier to explain and present in occasion of meetings and reports;
- Q5 and Q6 answered “no” / Q7 and Q8 answered “yes”: defines the method of execution as verbal. This assertion is based on low physical and virtual contact of the team, but, by having a good relationship, the team being able to simply discuss and understand one another verbally during meetings;
- Q5, Q6 and Q8 answered “no” / Q7 answered “yes”: assert symbolic to execution method, for the contact solely on meetings and the dissociated relationship hampering communication. Symbolic techniques can be structured and presented more easily, allowing a higher focus on the task and better understanding;
- Q5 answered “no” / Q6, Q7 and Q8 answered “yes”: defines both verbal and symbolic to execution method, being symbolic techniques useful for virtual communication, but verbal techniques also advantageous in meetings;
- Q5 and Q8 answered “no” / Q6 and Q7 answered “yes”: asserts symbolic techniques to help virtual or meetings’ communication.

The following correlations disregard Q8 when defining the execution method:

- Q5 and Q6 answered “yes” / Q7 answered “no”: frame execution method as symbolic, due to a lower contact of the team as a whole and absence physical or virtual space to act as a knowledge maintainer;
- Q5 and Q7 answered “yes” / Q6 answered “no”: identify both verbal and symbolic to execution method. Being the team in constant meeting and in a conjoined physical space, verbal communication is positive for being quicker and more dynamic, and symbolic developments easier to continue in posterior meetings and maintaining track of the development;
- Q5 answered “yes” / Q6 and Q7 answered “no”: symbolic techniques are adequate to maintain knowledge in the physical space and accompanying the progress of the work, especially considering the lower contact with the whole team;
- Q5 and Q7 answered “no” / Q6 answered “yes”: asserts symbolic techniques, due to virtual communication being eased through schemes and drawings, especially for words and descriptive texts online being of harder understanding.

Difficulty of use:

- Q3 answered “1”: low difficulty techniques are excluded due to a higher timeframe to develop alternatives, leaving low and moderate difficulty techniques;
- Q3 answered “2”: difficulty of use remains with its three values and the technique difficulty choice is delegated to the team;
- Q3 answered “3”: removes high difficulty techniques, due to lack of time.
- Q2 answered “no” / Q3 answered “3”: excludes moderate and high difficulty techniques based in impending deadlines requiring quick ideation.
- Q5, Q6 and Q7 answered “yes”: removes the low value. Being the team interactive and with great contact, such techniques explore more profoundly the design characteristics and access conceptions more difficult to reach;
- Q5, Q6 and Q7 answered “no”: removes the high value. For the dissociated relationship of borderline individual design, high difficulty techniques may be hazardous, requiring more discussion and interaction;

The last scenarios include Q4’s answer – regarding the multidisciplinary composition of the team:

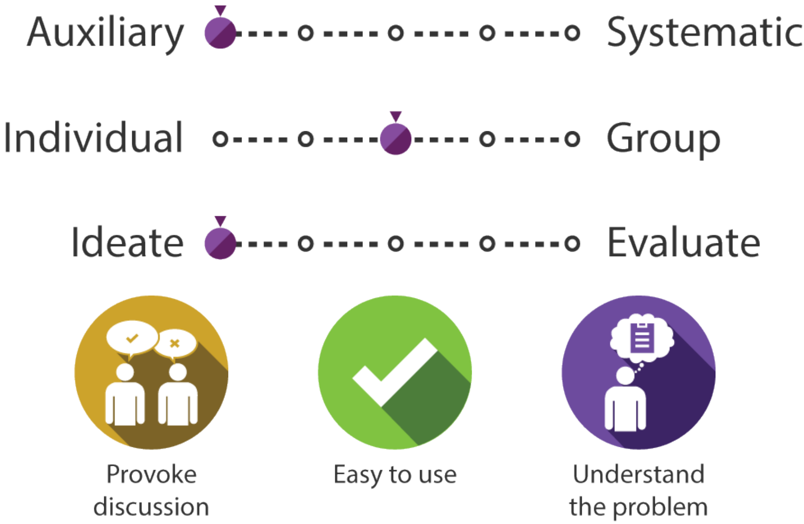
- Q4 answered “yes” / team relationship defined as interactive: removes low difficulty of use, leaving moderate and high. Interactive and multidisciplinary characteristics potentiate the creative process, the team having more knowledge to even quicken the use of a more difficult technique;
- Q4 answered “yes” / team relationship defined as dissociated: no value is removed from the category. The team can use of the multidisciplinary composition to explore mind pathways with moderate and high difficulty techniques, or be blocked by inharmonic behavior, which requires low difficulty ones;
- Q4 answered “no”: the high difficulty value is removed, due to this scenario being more challenging to have out-of-the-box ideas. Multidisciplinary teams are more prone to new and different ideas, and the lack of it hampers the achievement of new mind pathways (Amabile *et al.*, 2002; Baxter, 2011). The idea of using more than one easy or moderate technique, or even repeatedly use the same tool may also be positive in creating new lines of thought, avoiding premature convergence.

APPENDIX B – TECHNIQUES

5WHYS

Design step: develop
Innovation focus: incremental architectural radical
Team relationship: dissociated
Execution method: verbal
Difficulty of use: low

Highlights and badges



Resume
This simple objective checklist helps the team to picture the problem and set up ground for creation. Answering the questions give an overview idea of the work, reaching a starting detailing that server as basis to ideate or use another technique. The provocation of repeating the question can also stimulate the team to understand the reasons behind the problem and its requisites, increasing the number of mind-pathways.

Step-by-step

1. Gather the team
2. State the problem clearly, defining the problem to be addressed
3. Ask “Why” five times
4. Collect, structure and analyze acquired information

Example

[DIEGM, 2005]

1. Why has the machine stopped? A fuse blew because of an overload
2. Why was there an overload? There wasn't enough lubrication for the bearings
3. Why wasn't there enough lubrication? The pump wasn't pumping enough
4. Why wasn't lubricant being pumped? The pump shaft was vibrating as a result of abrasion
5. Why was there abrasion? There was no filter, allowing chips of material into the pump

Tips

- This technique is associated with 5W2H and its variants
- This technique can be used to provoke discussion or boost other techniques
- The number of questions can be altered to reach the needed deepening
- Other questions such as “Who”, “What”, “Where”, “When”, “How”, and “How much” can be added to branch the information (5W2H)
- The answers can be structured in a Mind Map to ease visualization

When to use

- The team needs basic ideas or a better understanding of the problem
- The design demands quick decisions
- The team has little knowledge on creativity techniques
- The conception generation is in initial stages and does not require a deepening at the moment

Related techniques

- Brainstorming
- Mind Mapping
- Negative Brainstorming
- Reverse Brainstorming
- SCAMPER

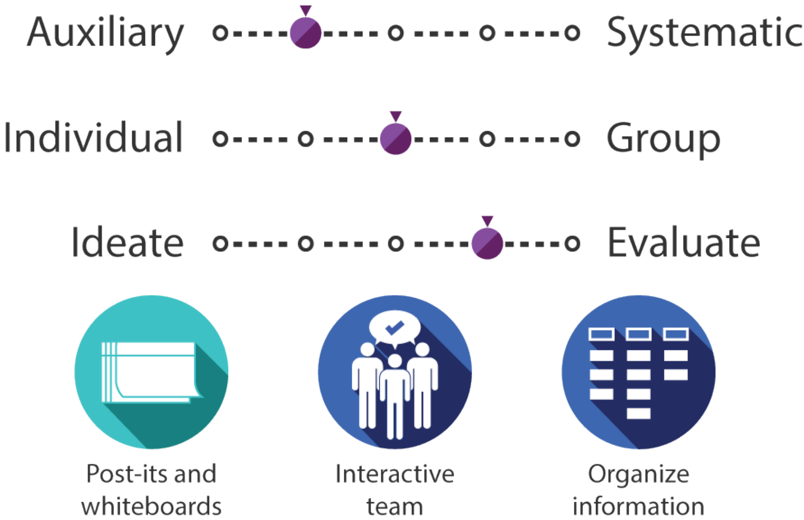
Complementary readings

- DIEGM, 2005. CREATE project
- Mycoted, 2006.

AFFINITY DIAGRAM

Design step: develop
Innovation focus: incremental architectural radical
Team relationship: interactive
Execution method: symbolic
Difficulty of use: moderate

Highlights and badges



Resume

The amount of information and ideas gathered during free ideation can be sometimes overwhelming. Kawakita Jiro developed the Affinity Diagram (also known as KJ Method) as a way to sort this amount of ideas into meaningful themes. The themes reveal which requirements should be discussed first and in which way a theme interact and benefit others, serving a step of organization and combination of ideas in search of the best solution.

Step-by-step

1. Gather the team
2. Create cards or post-its with the generated ideas
3. Sort the cards grouping conceptions that are similar to each other in themes
4. Name the themes according to the characteristic that is common to the ideas
5. Sort the groupings in a visible way (charts, walls with post-it) to allow visualization
6. Evaluate the outcomes and explain the groupings and why each group fulfill the original need
7. Rank the most relevant groups to the design

Example

[Ulrich, 2003]

A bicycle advocacy group wished to increase the number of people who commute to work by bicycle in the United States. The group assembled a team to discover some of the underlying factors that limit the use of bicycles in commuting. The team comprised two people from the advocacy group, two bike commuters and two people who do not commute by bicycle. The cycle of Affinity Diagram can be seen on the following figures. On Figure A.1 left diagram, the team generated ideas randomly and wrote them on post-its. On the right diagram, the team linked ideas that were associated to one another. On Figure A.2 left, they named themes that encompassed each grouping. On the right, the team regrouped the themes and voted for the most relevant ideas, ranking them and correlating with one another.

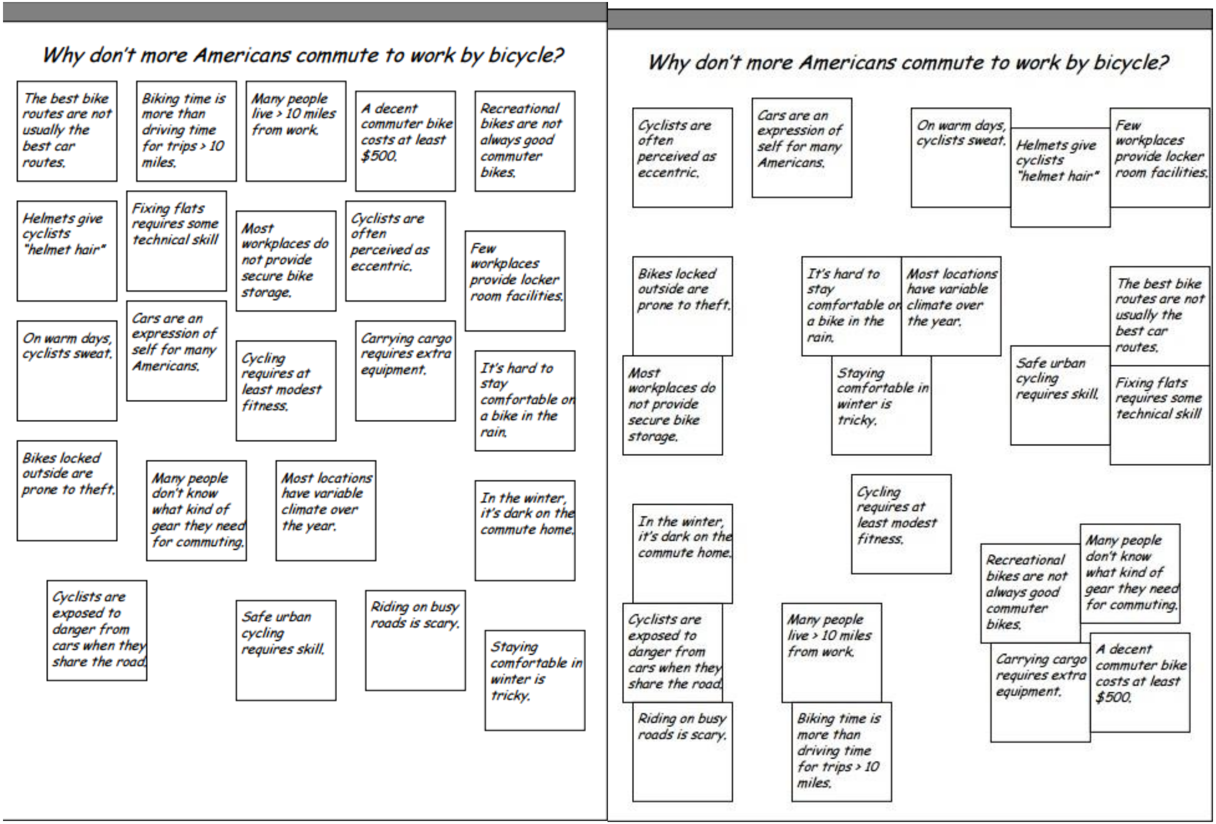


Figure B.1 – Affinity diagram example 1 (Ulrich, 2003).

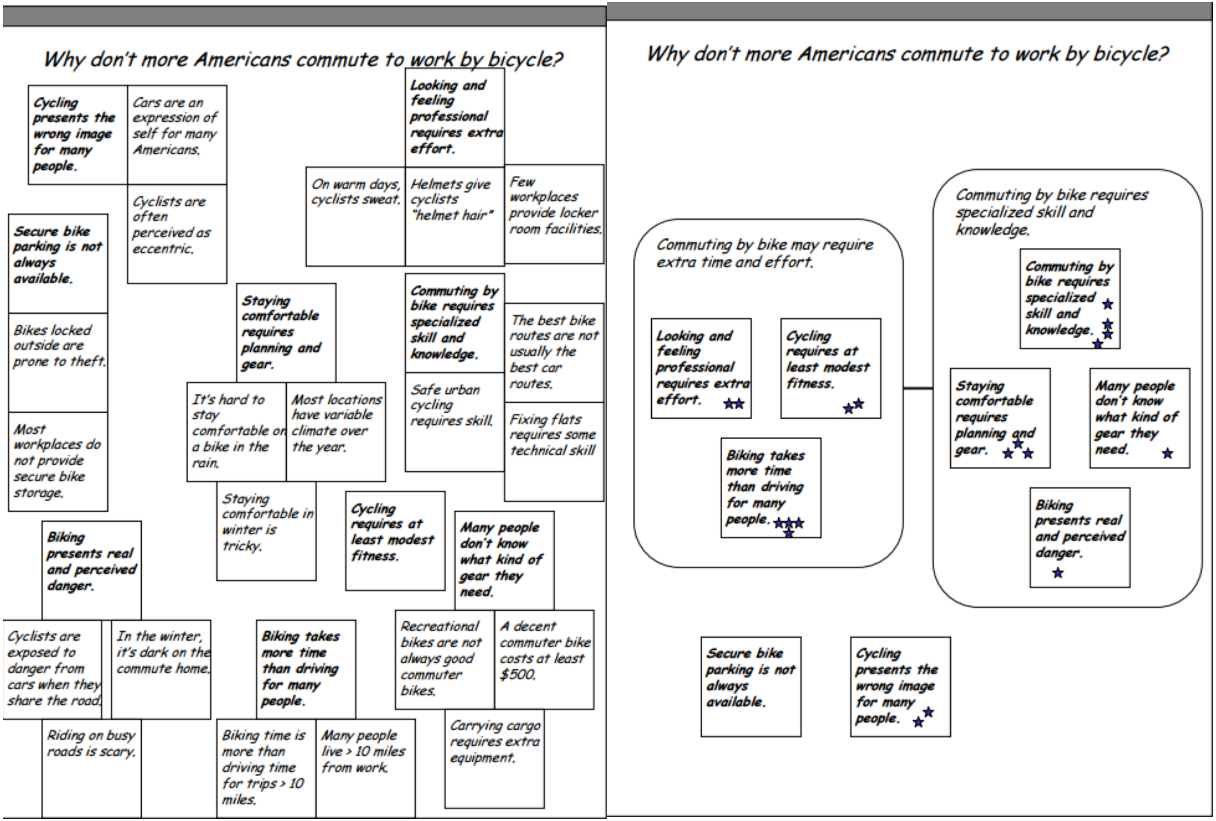


Figure B.2 – Affinity diagram example 2 (Ulrich, 2003).

Tips

- If too many groups (i.e. more than 10) are created, the team should sub-group them to reduce the number
- The technique can be adapted to conception combination in latter phases of conceptual design
- The team should feel free to expose their ideas and explain associations that they developed
- The process can be reiterated avoiding the same themes to explore further ideas

When to use

- The team has a great amount of information to deal
- The team needs basic ideas or a better understanding of the problem
- The team is interactive and acritical, finding it easy to openly discuss ideas
- The team requires an structured basis for the design

Related techniques

- Brainstorming
- Holistic Impact Assessment
- Mind Mapping
- Resource Assessment
- TILMAG
- Voting

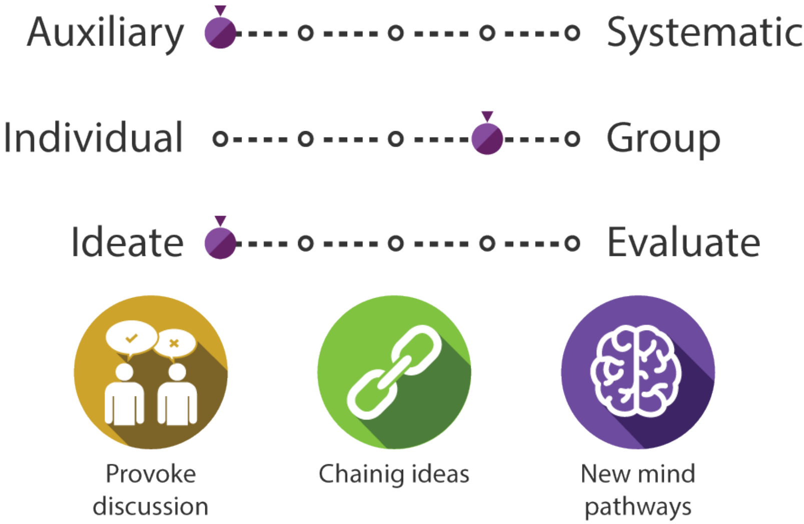
Complementary readings

- DIEGM, 2005. CREATE project
- DUX, 2014. “Designing the User Experience at Autodesk”
- Mycoted, 2006.
- Ulrich, K., 2003. KJ Diagrams.

ANALOGIES AND ASSOCIATIONS

Design step: develop
Innovation focus: incremental architectural
Team relationship: interactive
Execution method: verbal
Difficulty of use: moderate

Highlights and badges



Resume
Creative thinking often uses analogies or associations of ideas to come up with new concepts. This technique can be used to overcome creativity blocks and allow other lines of thought, generating new mind pathways. Mixing previously disconnected ideas helps to think laterally [de Bono, 1995], have more ideas, and explore connections that are hard to see. The use of random stimuli as worlds or pictures can encourage ideas generation, revealing new conceptions from unusual combinations.

Step-by-step

1. Delineate the problem of need to be solved
2. Choose the form of stimulus, such as words or pictures
3. Ideate over concepts and ideas associates to the stimuli
4. Apply the generated concepts making analogies with the original problem
5. If not sufficient, chose new stimuli and reiterate the process

Example

A problem is proposed to a design team to enhance communication on work environment. To generate such ideas, the team resort in the technique Analogies and Associations, choosing words as stimulus. The facilitator quickly searches on magazines and books for potential words and find the phrase “poker game”, considering it adequate to the problem at hand. The table below shows the associations made over the stimulus and analogies to the real scenario generated by the team.

Table B.1 – Example of Analogies and Associations use.

POKER GAME	ANALOGY TO THE REAL PROBLEM
CARDS	- Create employee presentation cards
BET	- Use games to stimulate interaction between employees - Gamification
FRIENDS	- Bring friends from outside work - Happy-hours
TABLE	- Allow interaction zones (coffees, dinners, living rooms) - Use interphones between tables.

Tips

- In case of a stimuli not sufficing, the technique should be reiterated
- The discussion environment should be acritical and the participants can use others ideas to develop further concepts
- Can be used as auxiliary technique to other tools
- The bigger the discussion over the stimulus, the bigger the association field to the original problem
- Choosing a word stimulus may require expertise of the facilitator or team. Words too far from the problem reality can be of difficult connection, while words too close may not surpass creativity blocks

- The selected picture should not be too complex as to confuse the participants, and it should also not be too simple as to lack associations
- Using positive and clear words or pictures is recommended, for stimuli of violence, death or sadness may inhibit the participants
- Selection of stimuli can be done randomly in books, magazines, newspapers, internet or any other mean

When to use

- The design aims non-conventional ideas or perspective changes
- The design is already structured and the goals are clear
- The team reached creativity blocks and needs new mind pathways
- The team is interactive and acritical, finding it easy to openly discuss ideas

Related techniques

- Biomimetic
- Brainstorming
- Mind Mapping
- Reverse Brainstorming
- SCAMPER
- TILMAG

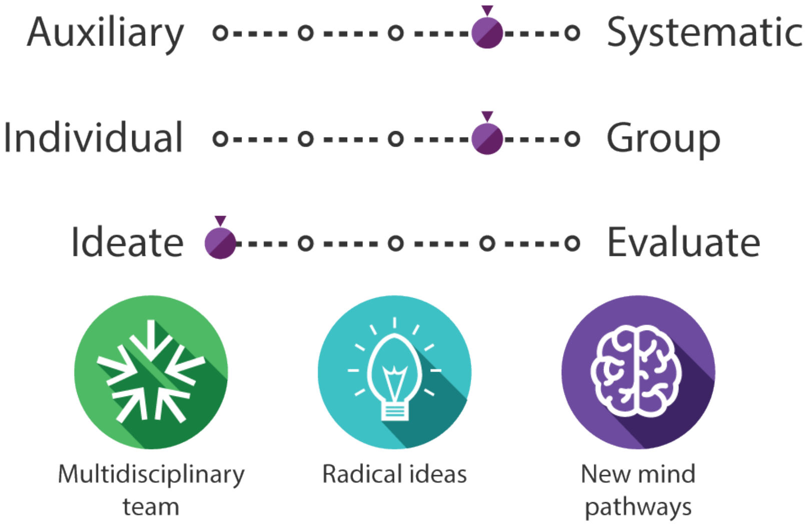
Complementary readings

- de Bono, E., 1995, O Pensamento Lateral na Administração, Saraiva, São Paulo, 252 p.
- King, B. and Schlicksupp, H., 1999. Criatividade: uma Vantagem Competitiva, Qualitymark, Rio de Janeiro, 329 p.
- Mycoted, 2006.

BIOMIMETIC

Design step: develop
Innovation focus: radical
Team relationship: interactive dissociated
Execution method: verbal
Difficulty of use: high

Highlights and badges



Resume
Nature is a great inspiration source for product development. Assuming that natural selection perpetuates the most adequate species to each environment, biomimetic aims to learn with nature and how those natural solutions work, using them on design. To ease this technique, a good knowledge of biological systems is needed, what is achievable by having a specialist in biology or correlated areas in the design team.

Step-by-step

1. Delineate the problem or need to be addressed
2. Search biological systems that adapted to overcome similar difficulties
3. Choose among the systems the best fit to the problem at hand
4. Transpose the solution to design reality, developing solutions in a non-biological environment

Example 1

A great development triggered by biomimetic is the Velcro, developed by Georges de Mestral in 1948. By analyzing in a microscope how burdocks attached to his clothes and his dogs fur during their walks, he perceived the intertwining of little hooks from the plant with the clothes' fabric or the animal's fur and, with this inspiration, developed a new fastener with high griping.

Figure B.3 – Velcro inspired by biomimetic.

Example 2

[Yang et al, 2006]

A modern example of biomimetic is the development of a heavy objects manipulation system based on an elephant trunk. By analyzing the animal's movements, the team observed a high maneuvering capacity and great flexibility of the system. By transposing it to the design reality, the use of cables and springs in separated segments mimicked the trunk functionality, generating a highly efficient robotic arm.

Figure B-4 – Mechanical manipulation system inspired by Biomimetic (Yang *et al.*, 2006).

Tips

- This technique can be used in similar fashion as to Analogies and Associations, only using nature principles instead of words or pictures
- Interactive teams with easy communication for discussions helps the development of the technique, especially during the transposition to the real scenario
- By relying on biological concepts, the technique presents ready concepts to be transposed to the design reality, lowering ideas clashes between team members
- It can be developed unconsciously in leisure time (walks, travels, among others) when the team member has contact with nature and its concepts
- Can be used as a stimulus method to tools as Brainstorming and Brainwriting

When to use

- The design aims non-conventional ideas or perspective changes
- There is a clear idea of the problem or need to be addressed
- The team has knowledge of biological system with similar principles to be used
- There is little to no restrictions to conceptual form or components

Related techniques

- Analogies and Associations
- Brainstorming
- Brainwriting
- Quick and Dirty Modeling

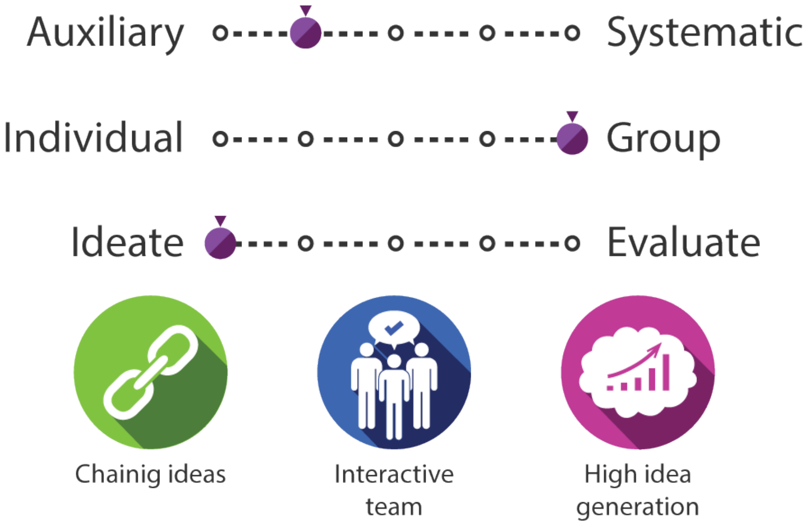
Complementary readings

- Detanico, F.B., Teixeira, F.G. and Silva, T.K., 2010. "A Biomimética como Método Criativo para o Projeto de Produto". Design & Tecnologia, Porto Alegre, v. 2, p. 13.
- King, B. and Schlicksupp, H., 1999. Criatividade: uma Vantagem Competitiva, Qualitymark, Rio de Janeiro, 329 p.
- Yang, J. et al, 2006. "Synthesis and analysis of a flexible elephant trunk robot". Advanced Robotics, Japan, v. 20, n. 6, pp. 631-659.

BRAINSTORMING

Design step: develop
Innovation focus: incremental architectural radical
Team relationship: interactive
Execution method: verbal
Difficulty of use: moderate

Highlights and badges



Resume
Developed by Alex Osborn in 1939, Brainstorming is one of the most commonly used creativity techniques. Even sometimes seen as a simple discussion for sharing information, this technique requires some rules to ease creation and allow the team to interact freely. Avoiding criticism is fundamental to develop ideas, giving space for everyone to formulate, discuss and understand them.

Step-by-step

1. Define the team
2. Gather the team and explain the problem and the technique rules
3. Generate, discus and clarify ideas in an acritical environment
4. If the fluency of ideas drops or the team reaches a block, pause the session
5. Restart the session to generate new ideas
6. Filter the generated ideas and specify accordingly

Example

[King and Schlicksupp, 1999]
A team of four people and a facilitator were gathered to a Brainstorming session on how to prevent children from opening medication bottles. Initial ideas included pressing the lid downwards before turning, pressing the bottle lateral while turning the lid, turning several times the lid before being able to open, pressing a button on the bottom of the bottle, and using higher strength to be able to open. The latter idea raised the question of how elderly with less strength would open such bottle. This provocation gave place to an alternative idea to use a special key to generate the needed strength, subdividing the function in two parts. For being too easy to lose such object, the idea of fixing somehow the key to the bottle arose. A parallel idea of using an artifact commonly used by adults (as coins or keys) was brought, and ideation continued to occur following the discussion.

Tips

- This technique serves as auxiliary method to virtually any other technique
- The acritical environment is fundamental to ideas exposition and information sharing
- The team should first expose the ideas, and then evaluate them
- The aim is quantity over quality of ideas
- Every idea is valid, even abstract and unreal ones
- The team should use other people ideas as basis to further creation
- The team should be composed of 5 to 10 people
- The results accomplished by the group and responsibility is shared
- Quality of ideas is proportional to the preparation of the group over the problem

- The team should avoid premature convergence to a single line of thought

When to use

- The team is interactive and acritical, finding it easy to openly discuss ideas
- The team needs basic ideas or a better understanding of the problem
- The problem is general and does not require a deepening in an expertise
- The technique ranges from small alterations on the product to radical innovations

Related techniques

- 5Whys
- Affinity Diagram
- Analogies and Associations
- Brainwriting
- Mind Mapping
- Negative Brainstorming
- Quick and Dirty Modeling
- Reverse Brainstorming
- Storyboard
- Voting

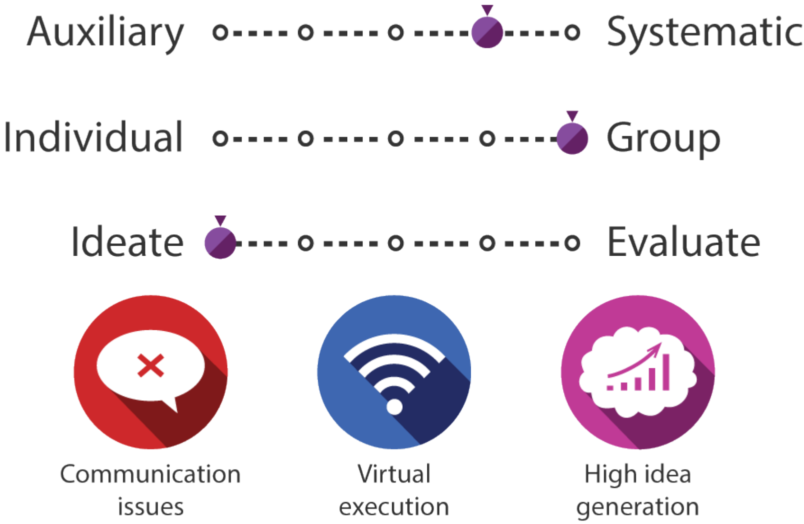
Complementary readings

- Brown, T., 2010, Design Thinking, translated by Cristina Yamagami, Elsevier, Rio de Janeiro, 249 p.
- Baxter, M., 2011, Projeto de Produto: Guia Prático para o Design de Novos Produtos, translated by Itiro Iida, 3. ed, Blucher, São Paulo, 344 p.
- Back, N., Ogliari, A., Dias, A., Silva, J. C. da, 2008, Projeto Integrado de Produtos: Planejamento, Concepção e Modelagem, Manole, São Paulo, 628 p.
- DIEGM, 2005. CREATE project
- King, B. and Schlicksupp, H., 1999. Criatividade: uma Vantagem Competitiva, Qualitymark, Rio de Janeiro, 329 p.
- Mycoted, 2006.

BRAINWRITING

Design step: develop
Innovation focus: architectural and radical
Team relationship: dissociated
Execution method: symbolic
Difficulty of use: low

Highlights and badges



Resume
To ease communication to design teams, Brainwriting was developed as a silent version of Brainstorming. By using this technique, introverted members, newly formed groups or members with personal issues can generate and share ideas freely, giving equal voice to people with difficulty to discuss. By not using verbal communication, there is less criticism and the team may feel more comfortable to share ideas. Even being less spontaneous, to see the ideas on paper helps creating a common image of the development, allowing chaining of thought even without verbal discussion.

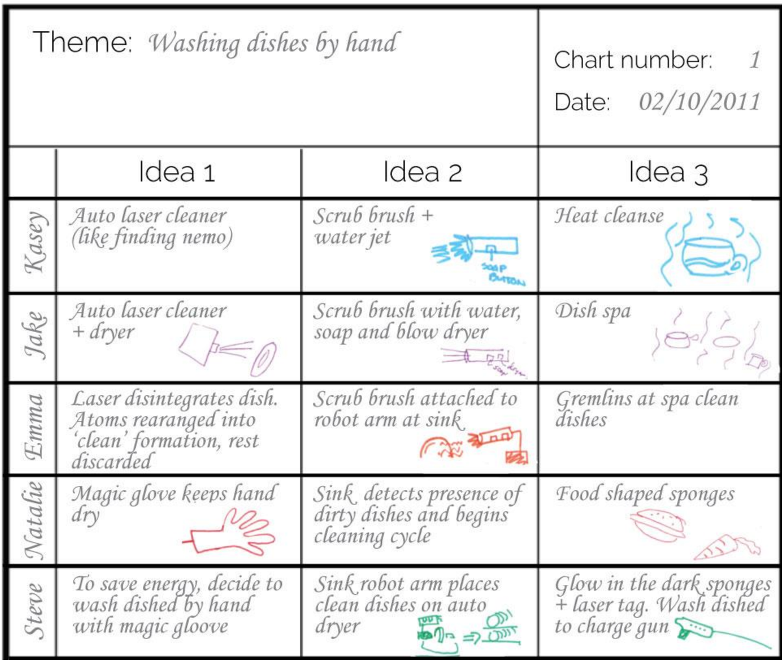
Step-by-step

1. Define the team
2. Distribute Brainwriting charts (one per member)
3. Instruct the team about the technique and the problem to be addressed
4. Each member should fill the first line of their chart with three ideas
5. The charts are exchanged and fill the next line with three ideas
6. Repeat until the chart is full
7. Analyze the ideas generated

Example

[Grim Absurdity, 2011]

A Brainwriting session group was gathered to help developing ideas for the theme "washing dishes by hand". The facilitator, after using other creativity methodologies for the problem, acclimatized the four participants with the theme and technique, and instructed them to develop 3 ideas in cycles of 3 minutes. The final chart of ideas is presented below.



Theme: *Washing dishes by hand*

Chart number: *1*

Date: *02/10/2011*

	Idea 1	Idea 2	Idea 3
Kasey	Auto laser cleaner (like finding nemo)	Scrub brush + water jet	Heat cleanse
Jake	Auto laser cleaner + dryer	Scrub brush with water, soap and blow dryer	Dish spa
Emma	Laser disintegrates dish. Atoms rearanged into 'clean' formation, rest discarded	Scrub brush attached to robot arm at sink	Gremlins at spa clean dishes
Natalie	Magic glove keeps hand dry	Sink detects presence of dirty dishes and begins cleaning cycle	Food shaped sponges
Steve	To save energy, decide to wash dished by hand with magic gloove	Sink robot arm places clean dishes on auto dryer	Glow in the dark sponges + laser tag. Wash dished to charge gun

Figure B.5 – Example of Brainwriting sheet.

Tips

- Any form of communication among team members should be avoided
- The ideas should be exposed in as clearly as possible, using preferably drawings and sketches with words to clarify
- Traditionally, the method is executed in a 6-3-5 form, where 6 people generate 3 ideas with 5 minutes per round, what generates 108 ideas by the end of the session
- Can be developed virtually with the right environment
- Every idea is valid, and using previously presented ideas of the chart is encouraged

When to use

- The team needs basic ideas or a better understanding of the problem
- The team is newly formed or with problems to openly discuss
- The technique ranges from small alterations on the product to radical innovations
- The problem is general and does not require a deepening in an expertise

Related techniques

- Brainstorming
- Morphological Analysis
- SCAMPER
- TILMAG

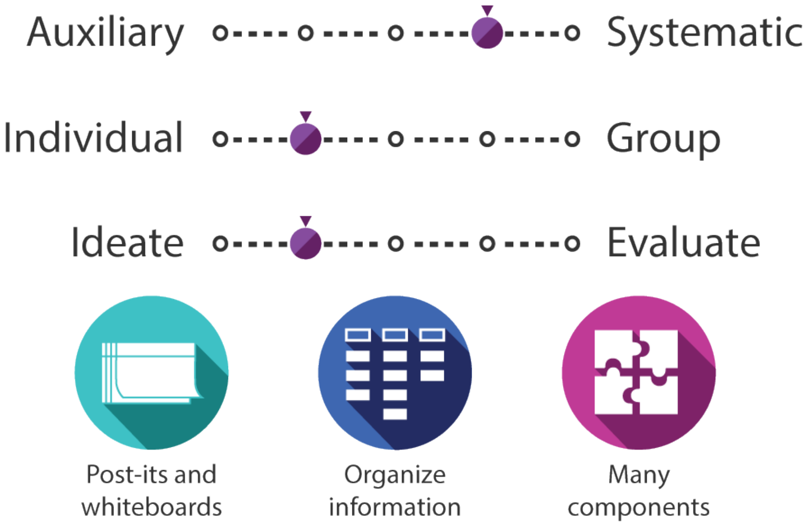
Complementary readings

- Back, N., Ogliari, A., Dias, A., Silva, J. C. da, 2008, Projeto Integrado de Produtos: Planejamento, Concepção e Modelagem, Manole, São Paulo, 628 p.
- Baxter, M., 2011, Projeto de Produto: Guia Prático para o Design de Novos Produtos, translated by Itiro Iida, 3. ed, Blucher, São Paulo, 344 p.
- DIEGM, 2005. CREATE project
- Grim Absurdity, 2011.
- King, B. and Schlicksupp, H., 1999. Criatividade: uma Vantagem Competitiva, Qualitymark, Rio de Janeiro, 329 p.
- Mycoted, 2006.

FUNCTIONAL TREE

Design step: develop
Innovation focus: incremental architectural
Team relationship: dissociated
Execution method: symbolic
Difficulty of use: moderate

Highlights and badges



Resume
The Functional Tree is a technique that is part of the Product Functions Analysis. It presents the product functions in a breakdown diagram, displaying its main function, basic functions, secondary functions, reaching up to component level. By understanding how the customers use and feel about the product and building it in a chart, this technique reveals ways to improve or insights on how to change the design and better meet the user’s needs.

Step-by-step

1. Define the problem scope and clarify it to the team
2. List the product functions based on users
3. Define the main function of the product (reason of existence of the product)
4. Breakdown into basic functions (essential to the main function, and/or are direct causes of the main function
5. Breakdown into secondary functions (how each function is performed)
6. Continue until component functions (inferior level functions)
7. Check the tree for "hows" (going up) and "whys" (going down)

Example 1

(Baxter, 2011)

Vacuum cleaner simplified functional tree:

- Main function – remove dust
- Basic function – suck air
- Secondary function – rotate the fan
- Inferior level function – supply energy

Example 2

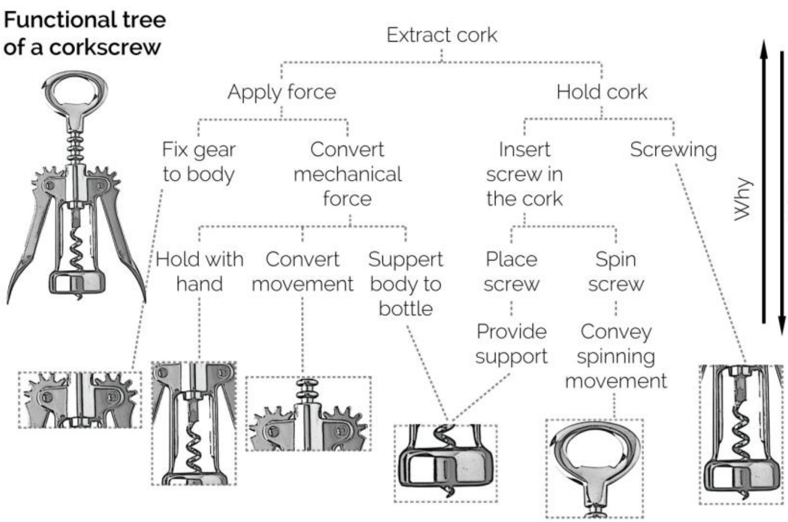


Figure B.6 – Example of Functional Tree (adapted from (Baxter, 2011)).

Tips

- Generate the product functions list using costumers point-of-views, which can reveal hidden functions or different use modes
- Describe each function with “verb + substantive” as clear and indubitable as possible
- Ask “how” in each level to go down on the tree, and “why” to go up
- Focusing on basic concepts of the tree will cause bigger design changes
- Focusing on inferior levels will cause smaller design changes

When to use

- The design explores existing products or developments in advanced stage, aiming improvements
- There is a clear idea of the problem or need to be addressed
- The design aims to change specific parts of the product, but maintain some of the state of the art
- For its visual and logic construction, the technique should be used by teams with limited or virtual contact
- There is a need for visualizing the problem in a branched form, revealing its elements and functions
- The team has a more systematic approach to the development

Related techniques

- Mind Mapping
- Morphological Analysis
- SCAMPER

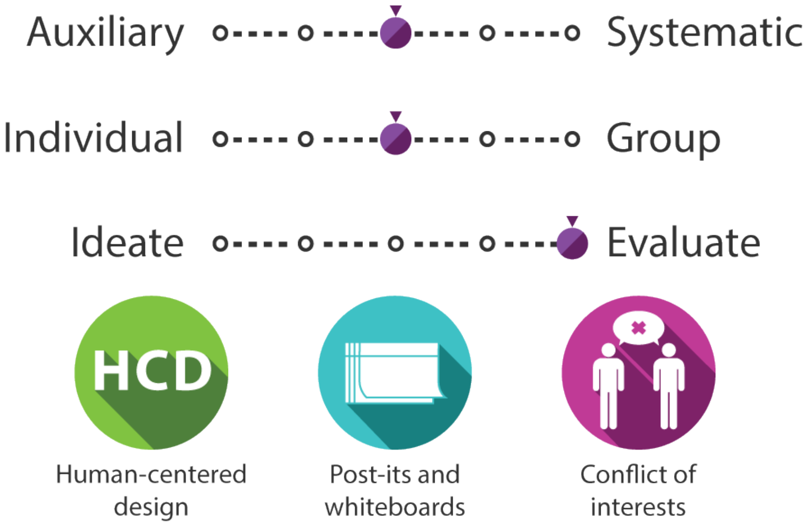
Complementary readings

- Baxter, M., 2011. Projeto de Produto: Guia Prático para o Design de Novos Produtos. Translated by Itiro Iida. 3. ed, Blucher, São Paulo.
- Burge Highes Walsh, 2015. The Systems Engineering Tool Box.
- DIEGM, 2005. CREATE project

HOLISTIC IMPACT ASSESSMENT

Design step: deliver
Innovation focus: incremental architectural radical
Team relationship: interactive
Execution method: symbolic
Difficulty of use: moderate

Highlights and badges



Resume
Every innovative solution affects not only its users, but also everyone involved on manufacturing, transporting, selling, and design, as well as on the environment and society. Studying this impact as a whole may reveal hidden difficulties for the ideas, especially the ones that do not involve the main customers directly. Some great conceptions that execute their function perfectly may not be environmentally friendly, or be hard/expensive to manufacture, factors only visible by looking at the whole system (holistic) instead of individual parts.

Step-by-step

1. Choose the solutions which will be addressed by the technique
2. Map or list all the stakeholders or actors that your solution might touch
3. Track the effects of the solution and which stakeholders are influenced by it
4. Use the development as basis to improve good impacts and lower bad ones

Example

(adapted from [IDEO, 2011])

An NGO aims to improve nutrition of children in poor countries by helping communities to produce their own food. The Holistic Impact Assessment below shows some of the impacted stakeholders and actor of the system, differentiating in green the positive impacts and in red the bad ones. Further evaluation should analyze which impacts are more relevant and in which way each actor is affected by the solution.

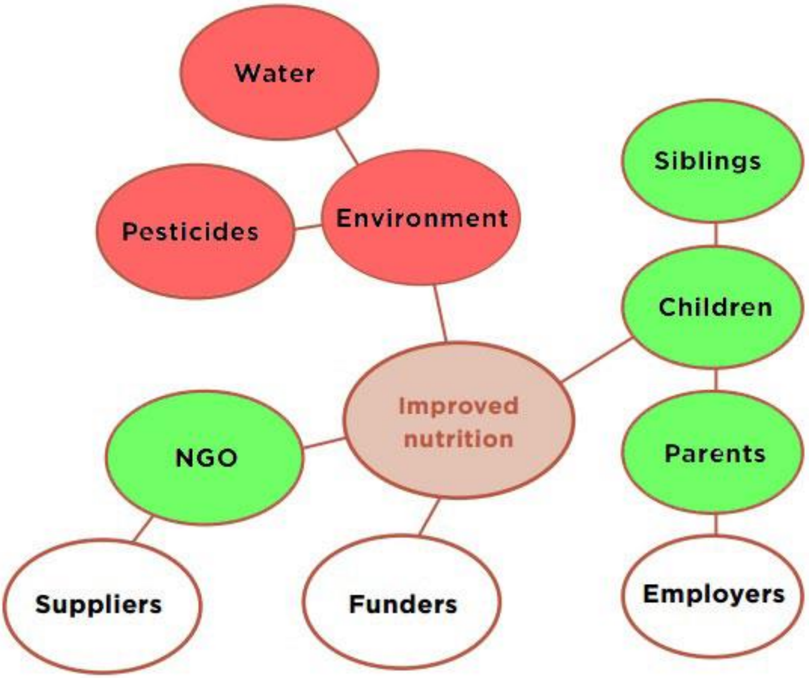


Figure B.7 – Example of Holistic Impact Assessment.

Tips

- A mind map form may help the development and connection of parts
- The actors should be differentiated if the impact is positive or negative
- It is important to map secondary impacts of the solution on humans and non-humans, e.g. if the solution is directed to a father, how does it affect his children or wife
- The stakeholders map should be branched out, e.g. environmental impacts can be translated in air, water, soil pollution
- Numeric values are beneficial, or a way to measure which stakeholders suffer more positive or negative impacts

When to use

- The team needs to select solutions from already structured conceptions
- The impacts of the concepts are hard to identify
- There are too many stakeholders interests to consider
- There are conflicts of interests or conflicting requirements

Related techniques

- Affinity Diagram
- Mind Mapping
- Potential Problem Analysis
- Resource Assessment
- Storyboard

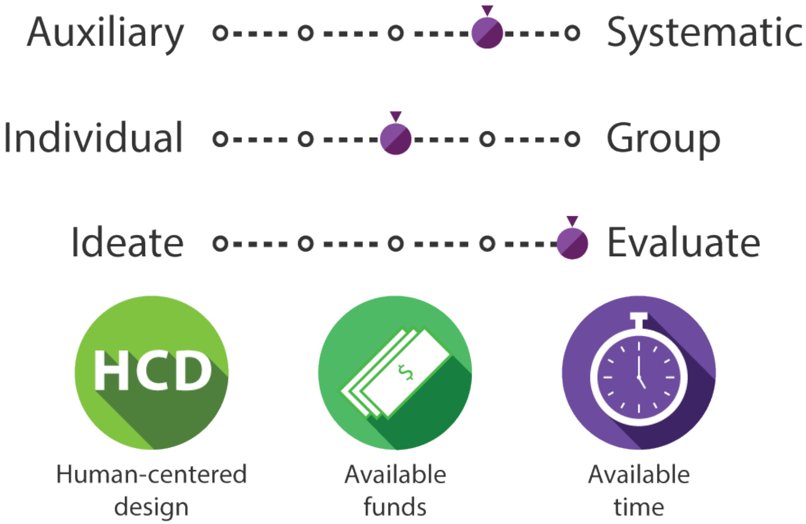
Complementary readings

- IDEO, 2011, Human Centered Design Toolkit, Atlas Books, California, 192 p.

LIVE PROTOTYPING

Design step: deliver
Innovation focus: incremental architectural radical
Team relationship: dissociated
Execution method: symbolic
Difficulty of use: high

Highlights and badges



Resume
Even the design team aiming for solutions that are feasible, viable and desirable, the team can only confirm if the product is ready by putting it in a real scenario. A Live Prototyping is a short-timed pilot test in the market for days or weeks, aiming for feedback on what can be improved. The information on how the design performs in a real scenario is important for spotting flaws or getting a firsthand contact of the product with its market.

Step-by-step

1. Define the solution that will be tested
2. Map the logistics of the prototyping, including physical space, time, users, and form of evaluation
3. Manufacture the solution according to technical specification
4. Hand over the prototypes to the users and allow them time to use (few days or weeks)
5. Capture feedback

Example

[Buchenau and Suri, 2000]

In an early project on digital photography the goal was to help a client envision what digital photography might be and how to design both the camera and the user experience as a complete system (including picture storage, retrieval, manipulation, etc.). In the initial phases of the project the team used traditional communication techniques such as scenarios, still and dynamic visualizations, and interactive on-screen simulations. After going through a series of presentations, the design team realized that the client did not completely understand the intended user experience and camera behavior. The breakthrough came when the designers built a hardware and software integrated "look and feel" prototype based on the design specifications as they stood at that time. The prototype bore little resemblance to a desirable product in shape, form, size or weight. For example, there was a sizeable cable running from the camera to a desktop computer where all the processing occurred.

This Experience Prototype contained a small video camera attached to a small LCD panel, encased in a box. The size of the LCD panel was determined by the desired resolution, rather than by the desired physical size, in order to maintain the key aspects of the proposed user experience. The working prototype was accompanied by an appearance model to communicate the appropriate size and detailed formal aspects of the design solution.

The prototype had a live video feed and captured still photos with audio annotations in real time, as response time was a critical component of the user experience. Since the processing was done by the desktop computer running regular software with a simple programming environment, it was easy to fine-tune the response time of the camera to enable the design team and the client to feel the impact on the user experience. It was the clients' developers who asked for multiple copies of the prototype which were then used as a "living specification" throughout the clients' internal design process to maintain a perspective and verify new design concepts.

The client reported that there were many pressures to change the resolution, or the speed of response, but that the prototype enabled them to see, feel and resist the negative impact of such changes.

Figure B.8 – Prototype example developed for digital photography device (Buchenau e Suri, 2000).

Tips

- If possible, few live prototypes should be run at once, testing a variety of solutions
- Encountered problems should be readily addressed and put into practice on the next prototype iteration
- Feedback can be collected by questionnaires, interviews or even observation of the team
- This technique can be expensive and time consuming, being its application only recommended in last phases of design
- The team has to be sensitive to every evidence that the user can express
- The feedback information is of great value to optimize the solution

When to use

- The design is on final stages of prototyping or pilot testing
- The conceptions need to be presented or validated by users or stakeholders
- The design requires a firsthand contact of product and market
- The team has time and resources to explore the design

Related techniques

- Mock-up Modeling
- Potential Problem Analysis
- Quick and Dirty Modeling
- Storyboard

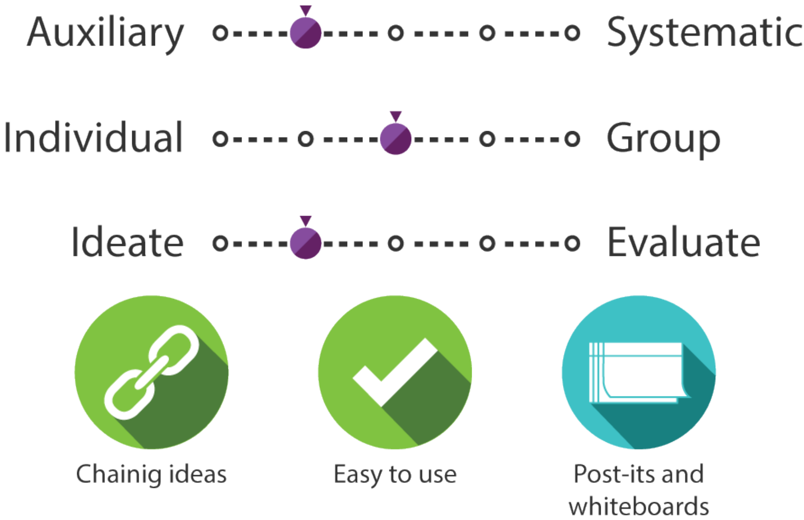
Complementary readings

- Buchenau, M., Suri, J. N., 2000. “Experience prototyping”. Designing interactive systems, New York, pp. 424-433.
- IDEO, 2011, Human Centered Design Toolkit, Atlas Books, California, 192 p.
- IDEO, 2015, The Field Guide to Human-Centered Design, California, 195 p.

MIND MAP

Design step: develop
Innovation focus: incremental architectural radical
Team relationship: interactive
Execution method: symbolic
Difficulty of use: low

Highlights and badges



Resume
Using associations and lateral thinking [de Bono, 1995], Mind Mapping is a low difficulty technique that allows the design team to reach new ideas by creating new mind-pathways or new points-of-view over a problem. By branching the central problem and chaining ideas using related words, images or concepts, the team can reach new opportunities to improve the design, while still focusing on the original problem.

Step-by-step

1. Organize the team in an acritical environment
2. The facilitator explains problem context and use of technique
3. A word or image related to the problem is placed in the middle of the map
4. The team associates conceptions to the central stimulus, branching the ideas around it
5. Each correlated item can be used to branch out new conceptions, which may not necessarily be related to the central stimulus

Example

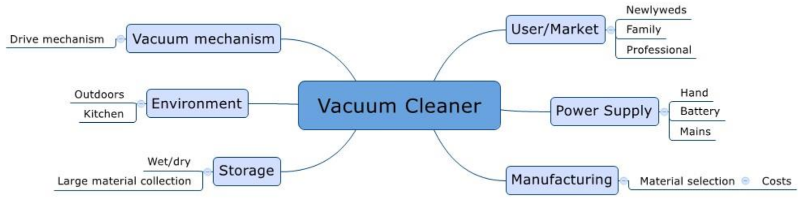


Figure B.9 – Example of Mind Map [Kokotovich, 2007].

Tips

- Use whiteboards or post-it to allow a better visualization of the outcomes
- Acritical behavior should be encouraged, and every idea is valid
- The map can be continuously developed, adding new associations even after the session
- The responsibility for constructing of the map is from the whole team
- The technique can help the conception of radical ideas by combining items that are not originally correlated and bringing them to the design reality

When to use

- The team needs basic ideas or a better understanding of the problem
- The technique ranges from small alterations on the product to radical innovations
- The team is interactive, acritical and capable of discussing freely
- The design demands quick conception generation

Related techniques

- 5Whys
- Affinity Diagram
- Analogies and Associations
- Brainstorming
- Functional Tree
- Holistic Impact Assessment
- Morphological Analysis
- SCAMPER

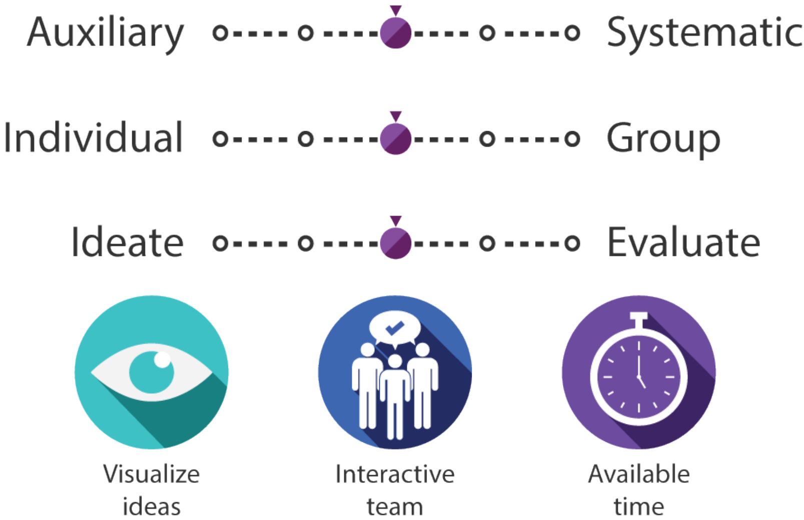
Complementary readings

- de Bono, E., 1995, O Pensamento Lateral na Administração, Saraiva, São Paulo, 252 p.
- DIEGM, 2005. CREATE project
- Kokotovich, V., 2007. “Problem analysis and thinking tools: an empirical study of non-hierarchical mind mapping”. Design Studies, Great Britain, v. 29, n. 1, pp. 49-69.
- Mycoted, 2006.

MOCK-UP MODELING

Design step: deliver
Innovation focus: architectural radical
Team relationship: interactive
Execution method: symbolic
Difficulty of use: moderate

Highlights and badges



Resume
Many design teams have difficulty in translating ideas to a language that team members, customers and stakeholders will understand. Mock-up is a form of iconic modeling that simplifies this communication turning abstract ideas into physical models with medium or high fidelity. By not focusing on the functions of the product, the model allows the team to give form to the ideas, which helps creating a unique point-of-view for discussion and allows a deeper understanding for the team.

Step-by-step

1. Gather information over concepts and ideas to be modeled
2. Delineate the objectives of the modeling
3. Acquire the needed material
4. Construct the model on adequate complexity
5. Verify and analyze the model to expose and discuss ideas

Example

[Figchair, 2013]
A chair shell Mock-up was built to assure the proportions of the design. The construction used paperboard and tape mounted on the fashion of the chair, and used a simple metallic base to support, allowing the designers to sit and experiment freely over the concept. The model also gave way to testing different forms of cushioning and how to extend the chair out, also toying with the connection between the panels.

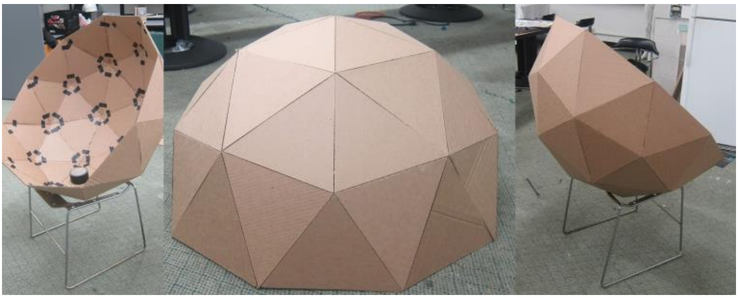


Figure B.10 – Example of Mock-Up Modeling [Figchair, 2013].

Tips

- The technique gives the team a global and single vision about the form and even functionality of the product
- The model can be easily presented and explainable to anyone interested
- The construction should allow the needed complexity, but not over spend time and resources on simple models.
- The model is only useful until its goal is accomplished
- The group should construct together the conceptual and physical model
- Using paper, paperboard or any simple resource is recommended for this modeling
- More complex models or prototypes that aims to analyze the products function can use better techniques to be materialized

When to use

- The team needs to study and evaluate early stages of structured conceptions
- The team can construct ideas together using each other's ideas to improve conceptions
- The conceptions generated are dubious or of hard visualization, which hampers only verbal communication
- The conceptions need to be presented or validated by users or stakeholders
- The design demands quick prototype generation

Related techniques

- Brainstorming
- Live Prototyping
- Morphological Analysis

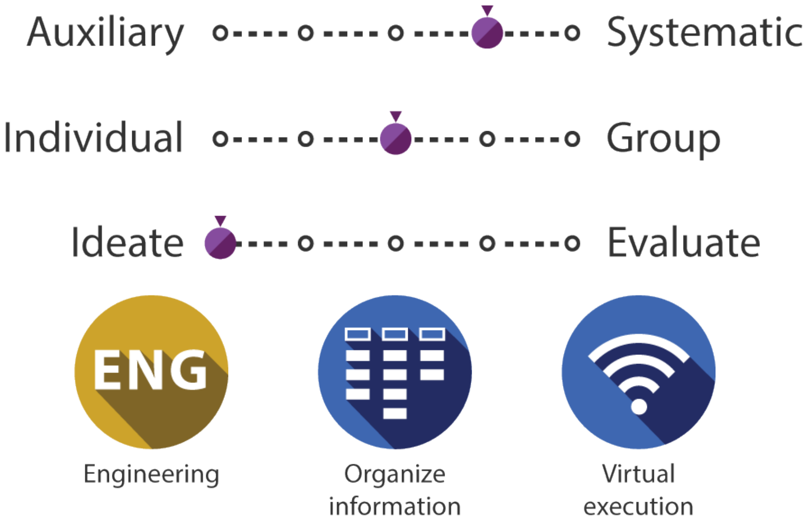
Complementary readings

- Buchenau, M. and Suri, J.N., 2000. "Experience prototyping". Designing interactive systems, New York, pp. 424-433.
- Figchair, 2013.

MORPHOLOGICAL ANALYSIS

Design step: develop
Innovation focus: incremental architectural
Team relationship: dissociated
Execution method: symbolic
Difficulty of use: moderate

Highlights and badges



Resume
Creative solutions are not only out-of-the-box or brilliant ideas. Many designs rely on upgrading parts or changing configuration of a product to innovate, mixing conceptions or aiming for smaller alterations. Morphological Analysis explores this opportunities by presenting in a table different conceptions for each element of the design, helping to focus on solving the problem in parts and then linking the ideas into solutions.

Step-by-step

1. Identify the functions and elements of the design
2. Fill the first column of the matrix with the functions, branching into sub-functions and tasks if needed
3. Fill the rows with conceptions that serve to each function/task
4. Combine conceptions of each function/task to generate alternative solutions for the global problem
5. Evaluate and select global conceptions
6. Stablish layout (architecture of the product) and describe conceptions

Example

[MAE, 2011]

The images bellow shows the construction, and posterior conception generation of a morphological chart for a vegetable collection system.

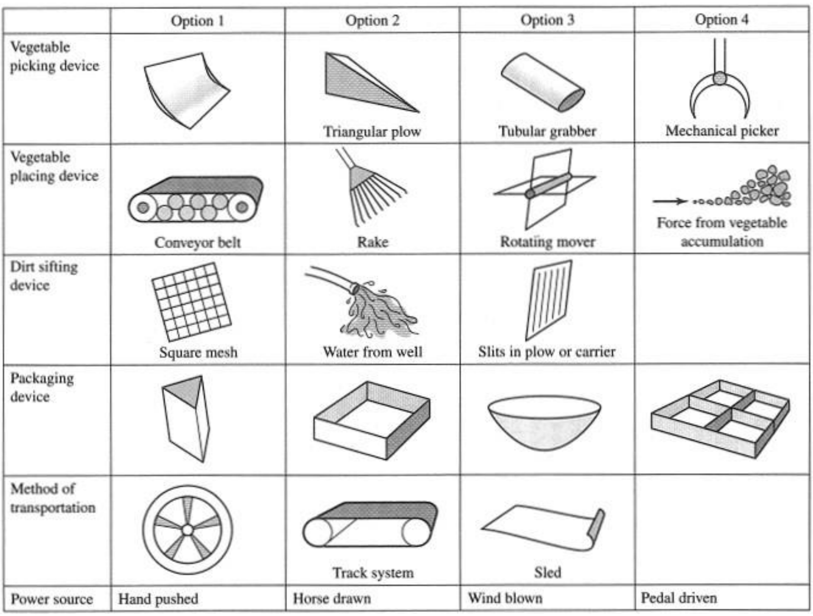


Figure B.11 – Example of Morphological Analysis chart (MAE, 2011).

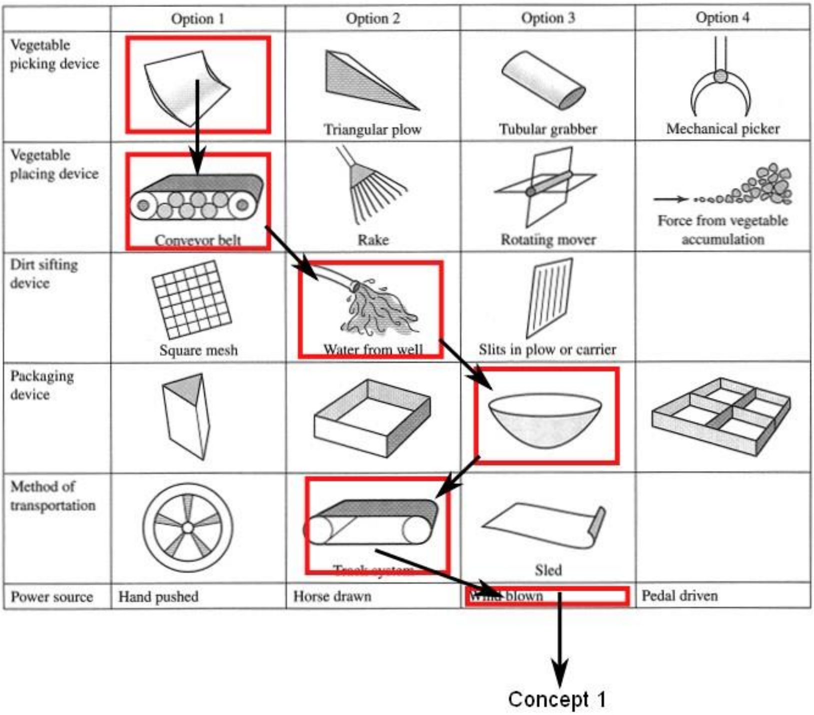


Figure B.12 – Example of Morphological Analysis conception selection (MAE, 2011).

Tips

- Not every combination of the matrix generates a viable solution. The team should have sensibility to link conceptions accordingly
- Using images to describe each conception aids the development of the technique
- Previously using structured techniques as Functional Tree or QFD helps the construction of functions and sub-functions
- Every conception of each task can lead to better global solutions
- For being a systematic approach, the team can reach results more directly, but they tend to be less radical

When to use

- There is a need for visualizing the problem in a branched form, revealing its elements and functions
- The product has many components and combination possibilities
- The design aims to change specific parts of the product

- For its visual and logic construction, the technique should be used by teams with limited or virtual contact
- The team already has knowledge of the product elements and aims to reach conceptions using stablished components for each part
- The team has a more systematic approach to the development

Related techniques

- Brainwriting
- Functional Tree
- Mind Mapping
- Mock-up Modeling
- Pugh Matrix
- TILMAG

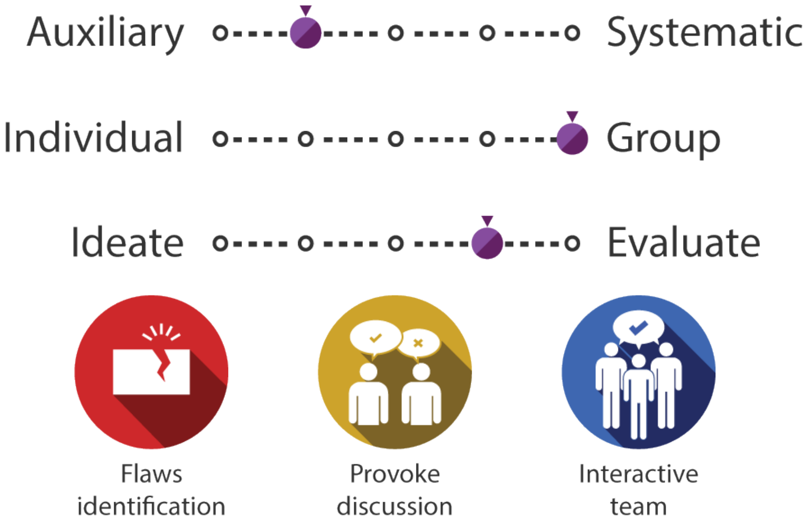
Complementary readings

- Back, N., Ogliari, A., Dias, A., Silva, J. C. da, 2008, Projeto Integrado de Produtos: Planejamento, Concepção e Modelagem, Manole, São Paulo, 628 p.
- Baxter, M., 2011, Projeto de Produto: Guia Prático para o Design de Novos Produtos, translated by Itiro Iida, 3. ed, Blucher, São Paulo, 344 p.
- DIEGM, 2005. CREATE project.
- MAE, 2011. MAE Design Model.

NEGATIVE BRAINSTORMING

Design step: deliver
Innovation focus: incremental architectural
Team relationship: interactive
Execution method: verbal
Difficulty of use: moderate

Highlights and badges



Resume
At the same time that a Brainstorming session aims to create many ideas focusing on quantity over quality, the Negative Brainstorming goes for the opposite: critique ideas, aim for quality and identify flaws on the conceptions. Questions such as “How not to solve the problem” and “What could go wrong” are the basis of the technique, trying to find difficulties and weaknesses for every solution.

Step-by-step

1. Define the team
2. Explain the solution(s) which are relevant and the technique rules
3. Generate, discus and clarify ideas, criticizing each conception

4. If the fluency of ideas drops or the team reaches a block, pause the session
5. Restart the session to generate new ideas
6. Evaluate the best ideas

Tips

- This technique serves as auxiliary method to virtually any convergence technique
- Every problem identified is valid
- The aim is quantity over quality of ideas
- The team should use other people ideas as basis to further creation
- The team should be composed of 5 to 10 people
- The results accomplished by the group and responsibility is shared
- Quality of ideas is proportional to the preparation of the group over the problem

When to use

- The team is interactive, finding it easy to openly discuss ideas
- The team already reached sufficient solution concepts to start evaluating the results
- The problem is general and does not require a deepening in an expertise
- The technique ranges from small alterations on the product to radical innovations

Related techniques

- Brainstorming
- Potential Problem Analysis
- Reverse Brainstorming
- Six Thinking Hats

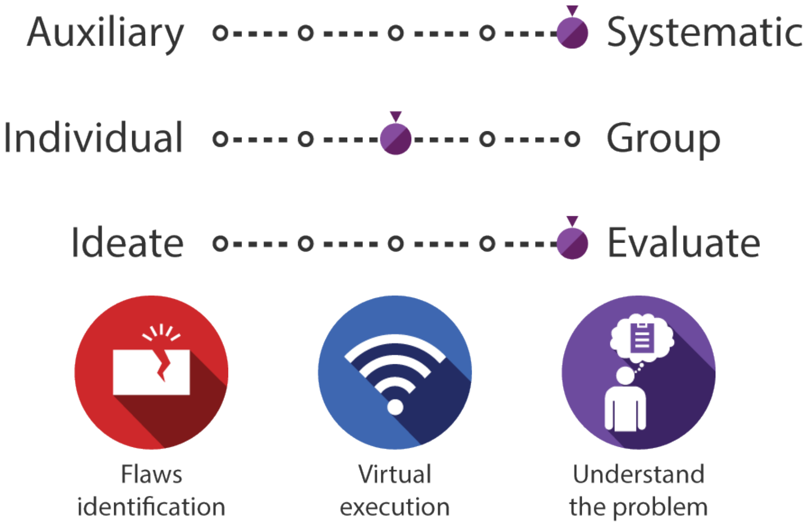
Complementary readings

- DIEGM, 2005. CREATE project
- Geniuses, 2012. “Creativity techniques”.
- Mycoted, 2006.

POTENTIAL PROBLEM ANALYSIS

Design step: deliver
Innovation focus: incremental architectural radical
Team relationship: dissociated
Execution method: symbolic
Difficulty of use: moderate

Highlights and badges



Resume
A rational and structured approach is sometimes necessary to analyze the ideas reached by the development and evaluate which are practical. To select a solution, the team should identify possible flaws and correct them, or use ideas of other conceptions as triggers to come up with a better result. Potential Problems Analysis approaches creativity by asking what could go wrong and how can the team prevent it from happening, creating opportunities to improve the solutions.

Step-by-step

1. Select the solution(s) which will be evaluated
2. Define key requirements (actions or events that 'must' happen for the design to be successful)
3. Evaluate all potential problems related to each key requirement
4. List the consequences of each potential problem
5. List possible causes for each potential problem and how likely is the event to occur
6. For each possible cause, develop ways to limit the risk and evaluate if this prevention will leave residual risk
7. Elaborate contingency plans, especially for high residual risk problems

Example

[UDEL, 1998]

To design a water balloon catapult system, a design team developed several conceptions and, after throughout evaluations, came with a final conception that needed to be evaluated. Using a Potential Problem Analysis chart, they listed the problems and acted in order to minimize chances of occurrence and impacts of failures. The chart is presented on the table below.

Table B.2 – Example of Potential Problem Analysis chart (UDEL, 1998).

	Potential Problem Analysis			
Potential Problems	**Consequences**	**Possible Causes**	**Preventive Actions**	**Contingency Plan**
A. Desired materials unavailable	launcher design requires modification	1. Supplier does not have materials 2. Materials too expensive 3. Materials obsolete	1. Preliminary research for adequate supplier 2. Adjust budget within reason 3. Research substitutes	1. Multiple suppliers 2. Multiple material choices 3. Multiple material choices
B. Parts improperly scaled	unable to be built correctly	1. Improper measurements 2. Insufficient materials	1. Obtain adequate measuring devices 2. Buy reasonable surplus of materials	1. Double-check measurements 2. Buy more material
C. Arm not strong enough	Launcher breaks during use	1. Poor material choice 2. Poor material preparation 3. Spring too strong, arm under too much stress	1. Research material before implementation 2. Waterproofing before use 3. Reinforce material, test springs	1. Alternative material choice 2. Alternative material choice 3. Alternative spring choice
D. Inadequate Spring Strength	Spring overstretches, broken Launcher has short range Spring rusts through and breaks	1. Weak spring material 2. Insufficient research 3. Arm is too heavy 4. Spring rusts in presence of water	1. Test springs of different materials 2. More in-depth research 3. Make a lighter arm 4. Research corrosion properties of spring materials	1. Have comparable spring of different material 2. Check adequacy of research 3. Alternative arm material or design 4. Waterproof coating for spring

Tips

- Techniques as Negative Brainstorming or 5Whys can be helpful to identify the potential problems
- Low risk problems can become relevant if the occurrence is frequent or if it cannot be prevented
- The team can construct the table in a more visual fashion (whiteboard, wall with post-its) for the whole team to visualize and deliberate
- The technique can be made virtually with shared online development

When to use

- The team already reached one or few solution concepts
- There are uncertainties about manufacturing, distribution or use of the design
- The team has a more systematic approach to the development
- The design is on final stages of prototyping or pilot testing

Related techniques

- Holistic Impact Assessment
- Live Prototyping
- Negative Brainstorming
- Resource Assessment
- Reverse Brainstorming
- Six Thinking Hats

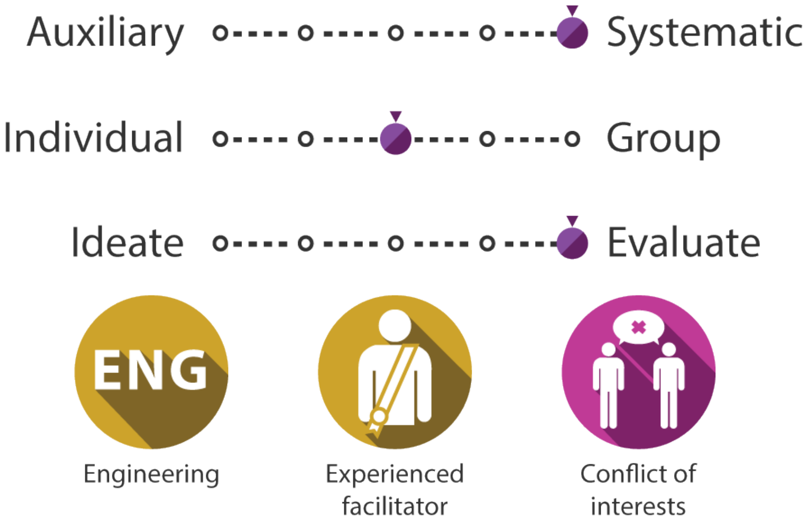
Complementary readings

- DIEGM, 2005. CREATE project
- Mycoted, 2006.
- UDEL, 1998.

PUGH MATRIX

Design step: deliver
Innovation focus: incremental architectural
Team relationship: dissociated
Execution method: symbolic
Difficulty of use: high

Highlights and badges



Resume
Pugh Matrix creates a logical and direct table to deal with conflicting requirements while selecting the best conceptions. By choosing a reference, the generated conceptions are compared using as basis the design requisites, giving higher scores to the most adequate ideas. The technique can be repeated with fewer ideas to help confirming the best solution, using combinations of positive parts of cast off conceptions to generate better solutions.

Step-by-step

1. List the design specifications or requirements
2. Assign weights to each requirements (which cause the biggest impact in the design)
3. Select a reference conception
4. Compare each conception to the reference in each requisite and grade them
5. Add the values to each conception
6. Define the best punctuations
7. Evaluate possible improvements based on conceptions with good punctuation

Example

[Burge Highes Walsh, 2015]

A user want to select the best option for toast making. Three conceptions were chosen to be evaluated: 4-slot electric toaster, electric conveyor and gas grill. The Pugh Matrix is shown below.

Table B.3 - Example of a Pugh Matrix (Burge Highes Walsh, 2015).

			Weight	Electric 4-slot	Electric conveyor	Gas grill
Selection criteria	Good toast quality	Even toasting	2	Reference	0	-
		Good taste	3		0	0
		Repeatable	3		+	-
		Quick	3		0	0
	Capacity	Large range of bread products	2		0	+
		Multiple slices/units	4		+	+
	Long life	Reliable	1		-	0
		Durable	3		0	0
		Low maintenance	3		-	0
		Affordable	2		-	+
	Physical attributes	Attractive	5		-	-
		Safe	3		-	--
		Good size	4		-	-
	Easy to use	Easy to use controls	5		0	+
		Easy to load	4		+	+
		Easy to remove toast	4		+	-
		Automated	4		0	--
		Total +		0	4	5
		Total -		0	6	9
		Total score		0	-2	-4
		Weighted total +		0	15	17
		Weighted total -		0	-18	-32
		Weighted total score		0	-3	-15

Tips

- Traditionally, the symbol + (plus) is used to define a conception that is better than the reference, - (minus) to worse and 0 (zero) to equal
- Conceptions that are considered far better than the reference can be rated ++ (double plus), and much worse -- (double minus), adding two points at the final sum
- When the technique does not exhibit a clear winner, it can be reiterated restricting the number of evaluated conceptions or changing weights
- Conceptions that presents good punctuation in some aspect should have its potentialities added or exchanged to improve the final solution
- One high difficulty of the tools is the identification of the design specifications, which should be done on beginning phases of the design
- Reference can be stablished based on competitor products, base product that should be substituted, or any conception that the team feels adequate
- If all conceptions are worse than the base or competitor product, the design should be reevaluated

When to use

- The team needs to select solutions from already structured conceptions
- The team has divergent ideas and have difficulty of reaching a consensus
- The design was structured based on specifications
- There are conflicts of interests or conflicting requirements
- The team has a more systematic approach to the development

Related techniques

- Morphological Analysis
- TRIZ (Contradictions)
- Voting

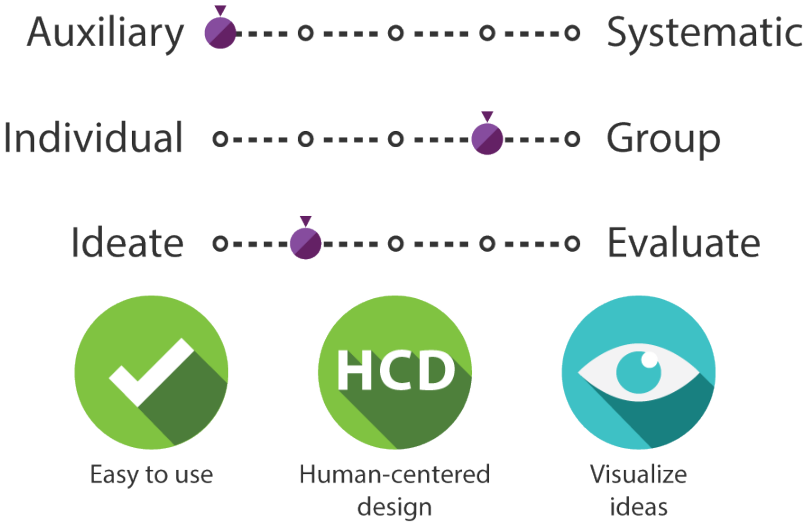
Complementary readings

- Back, N., Ogliari, A., Dias, A., Silva, J. C. da, 2008, Projeto Integrado de Produtos: Planejamento, Concepção e Modelagem, Manole, São Paulo, 628 p.
- Baxter, M., 2011, Projeto de Produto: Guia Prático para o Design de Novos Produtos, translated by Itiro Iida, 3. ed, Blucher, São Paulo, 344 p.
- Burge Highes Walsh, 2015. The Systems Engineering Tool Box.

QUICK AND DIRTY MODELING

Design step: develop
Innovation focus: architectural radical
Team relationship: interactive
Execution method: symbolic
Difficulty of use: moderate

Highlights and badges



Resume

During development and discussions, many ideas become confuse and often are cast off without further analysis for being misunderstood or complex. Quick and Dirty Modeling aims to help communication by simply making ideas tangible using everyday materials. The visualization of an idea, even being quick and with low fidelity, helps the team to discuss and lean on each other ideas. This technique should not be confused with the engineering technique Rapid Prototyping, which uses quick manufacturing techniques usually with Computer Aided Design (CAD).

Step-by-step

1. Determine what to prototype
2. Construct the idea into something tangible using any physical instrument available
3. Test the model and use it to convey better the idea
4. Upgrade the model using each other's ideas

Example

[Buchenau and Suri, 2000]

In the early stages of developing a user experience, multiple design directions need to be efficiently prototyped and compared. Ad hoc use of analogous objects as props can quickly guide decisions about which kind of experience is most appropriate. In this example, of designing a control device with six-degrees of freedom for a video game, the team identified three radically different potential directions and looked for props to help them understand the kind of experience each would afford:

- A tactile immersive experience — represented by a palm-sized pebble
- A shared experience, where the control functions could be split between two hands or two players — represented by two different-sized joysticks mounted on suction pads
- A full-body physical experience— represented by the surface of a customized skateboard

Simply 'playing' with these relatively crude props was a powerful method, enabling the designers to unveil the nuances and implications of each particular direction.

Figure B.13 – Developed models on Quick and Dirty modeling of a control device (Buchenau and Suri, 2000)

Tips

- The model is only intended to convey an idea, and not to be perfect
- Every object is usable to build the model
- The model should be iterated and used to develop ideas together
- Models can be kept and posteriorly compared

When to use

- There is a clear idea of the problem or need to be addressed
- The team can construct ideas together using each other’s ideas to improve conceptions
- The conceptions generated are dubious or of hard visualization, which hampers only verbal communication
- The team has divergent ideas and have difficulty of reaching a consensus

Related techniques

- Brainstorming
- Live Prototyping
- Mock-up Modeling
- Storyboard

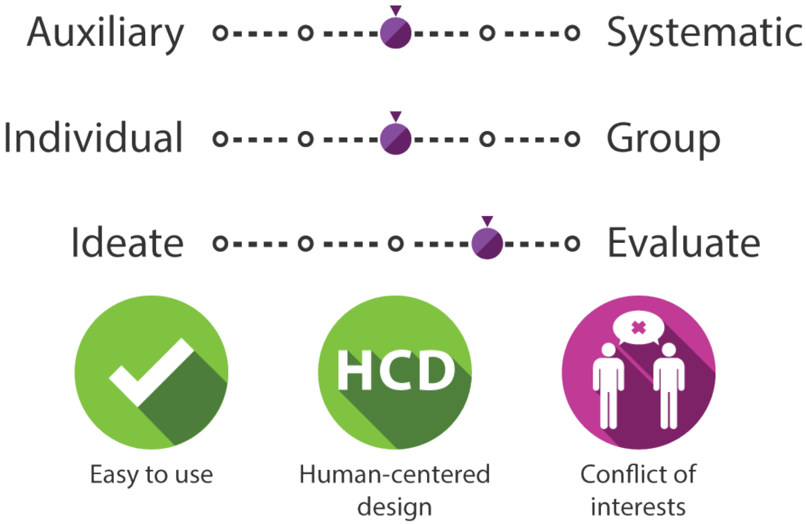
Complementary readings

- Brown, T., 2010, Design Thinking, translated by Cristina Yamagami, Elsevier, Rio de Janeiro, 249 p.
- Buchenau, M. and Suri, J. N., 2000. “Experience prototyping”. Designing interactive systems, New York, pp. 424-433.
- IDEO, 2015, The Field Guide to Human-Centered Design, California, 195 p.

RESOURCE ASSESSMENT

Design step: deliver
Innovation focus: architectural radical
Team relationship: interactive
Execution method: symbolic
Difficulty of use: low

Highlights and badges



Resume
Knowledge, resources and stakeholders are necessary to put a solution on the market. To have the idea is usually easier than to put it into practice, and a great planning is required to understand the feasibility of the solution and where the organization needs to seek help. A simple quicksheet can reveal information about distribution, necessary means and partners to execute the selected solution, leading it successfully to the market.

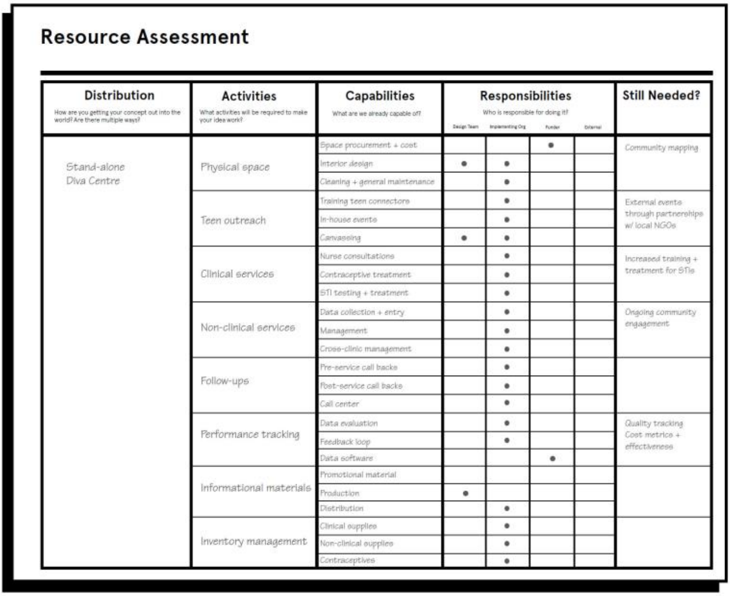
Step-by-step

1. Gather the team
2. Select the solution(s) which will be evaluated
3. Write the titles 'Distribution', 'Activities', 'Capabilities' and 'Partners'
4. Discuss what needs to happen for each category
5. Group the needs according to stakeholders or actors

Example

[IDEO, 2015]

In partnership with Marie Stopes International (MSI), IDEO.org undertook a year-long engagement to design and build out a teen-specific reproductive health program in Lusaka, Zambia. The team worked on the design of a teen-friendly model for their reproductive health services which revolved around the Divine Divas, a set of characters each representing a different contraceptive method. From the Divas, and the design principles on which they were based, sprang a redesign of the clinic itself, branding, an outreach strategy, and a communications approach. To test this out, the design team did a few Resources Assessment worksheets to better understand what it would mean to implement the original design in new spaces and forms.



Resource Assessment

Distribution How are you getting your concept out into the world? Are there multiple ways?	Activities What activities will be required to make your idea work?	Capabilities What are we already capable of?	Responsibilities Who is responsible for doing it? Design Team	Implementing Org	Funder	External	Still Needed?
Stand-alone Diva Centre	Physical space	Space procurement + cost			●		Community mapping
		Interior design	●	●			
		Cleaning + general maintenance		●			
	Teen outreach	Training teen connectors		●			External events through partnerships w/ local NGOs
		In-house events		●			
		Canvassing	●	●			
	Clinical services	Nurse consultations		●			Increased training + treatment for STIs
		Contraceptive treatment		●			
		STI testing + treatment		●			
	Non-clinical services	Data collection + entry		●			Ongoing community engagement
		Management		●			
		Cross-clinic management		●			
	Follow-ups	Pre-service call backs		●			
		Post-service call backs		●			
		Call center		●			
	Performance tracking	Data evaluation		●			Quality tracking Cost metrics + effectiveness
		Feedback loop		●			
		Data software			●		
	Informational materials	Promotional material					
		Production	●				
		Distribution		●			
	Inventory management	Clinical supplies		●			
		Non-clinical supplies		●			
		Contraceptives		●			

Figure B.14 – Resource Acessment chart (IDEO, 2015).

Tips

- Whiteboards or walls with post-its can be used to keep the whole team updated with the discussion
- The grouping of needs may reveal the need of new partners or relationships to execute the solution, especially if too many actors are identified
- The presence of stakeholders in the execution may help asserting responsibilities
- Each category has subdivisions according to the situation, e.g. distribution can be subdivided in source, storing and distribution to audience
- Previously using a Business Model Canvas may help in the execution of this technique
- The technique can be made virtually with shared online development

When to use

- The team already reached one or few solution concepts
- There are conflicts of interests or conflicting requirements
- The design aims unexplored markets or new means of manufacturing
- The design demands quick decisions

Related techniques

- Affinity Diagram
- Holistic Impact Assessment
- Potential Problem Analysis

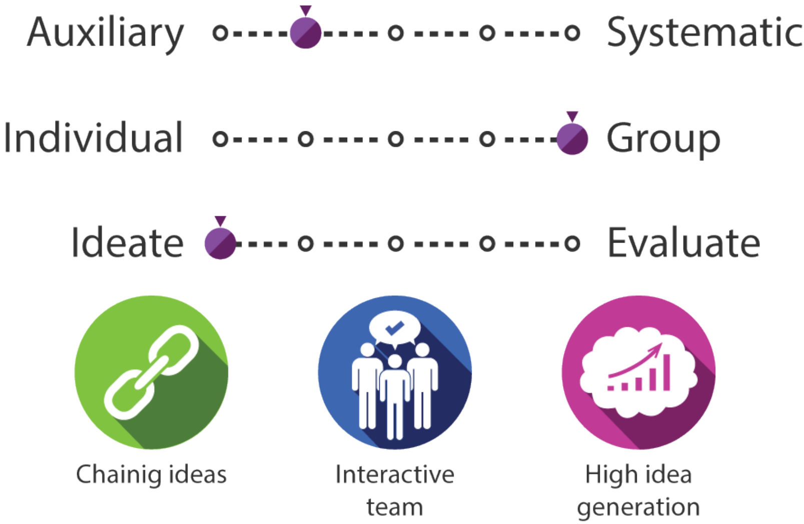
Complementary readings

- IDEO, 2015, The Field Guide to Human-Centered Design, California, 195 p.

REVERSE BRAINSTORMING

Design step: develop
Innovation focus: incremental architectural
Team relationship: interactive
Execution method: verbal
Difficulty of use: moderate

Highlights and badges



Resume
Some problems are easier to worsen than to solve, and going in the other way may sometimes reveal unexpected results. This technique approaches the design by thinking on how to make it worse, asking questions such as 'How could we possibly cause the problem?' or even 'How not to solve the problem?'. This gives space to ideate on the opposite side and, then, switch the ideas to the 'good scenario', creating alternatives to the problem at hand.

Step-by-step

1. Define the team
2. Gather the team and explain the problem and the technique rules
3. Reverse the problem by asking 'How could we possibly cause the problem?'
4. Generate, discus and clarify ideas in an acritical environment
5. If the fluency of ideas drops or the team reaches a block, pause the session
6. Restart the session to generate new ideas
7. Transpose (re-reverse) the generated ideas to the original problem
8. Filter the generated ideas and specify accordingly

Example

[Mind Tools, 2015]

Luciana is the manager of a health clinic and she has the task of improving patient satisfaction. There have been various improvement initiatives in the past and the team members have become rather skeptical about another meeting on the subject. The team is overworked, members are 'trying their best' and there is no appetite to 'waste time' talking about this. So she decides to use some creative problem solving techniques she has learned. This, she hopes, will make the team meeting more interesting and engage people in a new way. Perhaps it will reveal something more than the usual 'good ideas' that no one has time to act on. To prepare for the team meeting, Luciana thinks carefully about the problem and writes down the problem statement:

- How do we improve patient satisfaction?

Then she reverses problem statement:

- How do we make patients more dissatisfied?

Already she starts to see how the new angle could reveal some surprising results. At the team meeting, everyone gets involved in an enjoyable and productive reverse brainstorming session. They draw on both their work experience with patients and also their personal experience of being patients and customers of other organizations. Luciana helps ideas flow freely, ensuring people to not pass judgment on even the most unlikely suggestions. Here are just a few of the 'reverse' ideas:

- Double book appointments
- Remove the chairs from the waiting room
- Put patients who phone on hold (and forget about them)
- Have patients wait outside in the car park.

- Discuss patient's problems in public.

When the brainstorming session runs dry, the team has a long list of the 'reverse' solutions. Now it's time to look at each one in reverse to think about a potential solution. Well-resulting discussions are quite revealing. For example:

- 'Well of course we don't leave patients outside in the car park – we already don't do that.'
- 'But what about in the morning, there are often patients waiting outside until opening time?'
- 'Mmm, true. Pretty annoying for people on first appointments.'
- 'So why don't we open the waiting room 10 minutes earlier so it doesn't happen'
- 'Right, we'll do that from tomorrow. There are several members of staff working already, so it's no problem.'

And so it went on. The reverse brainstorming session revealed many improvement ideas that the team could implement swiftly and Luciana concluded: 'It was enlightening and fun looking at the problem in reverse. The amazing thing is it's helped us become more patient-friendly by stopping doing things rather than creating more work'.

Tips

- The acritical environment is fundamental to ideas exposition and information sharing
- The team should first expose the ideas, and then evaluate them
- The aim is quantity over quality of ideas
- Every idea is valid, even abstract and unreal ones
- The team should use other people ideas as basis to further creation
- The team should be composed of 5 to 10 people
- The results accomplished by the group and responsibility is shared
- Quality of ideas is proportional to the preparation of the group over the problem
- The team should avoid premature convergence to a single line of thought
- This technique is particularly efficient when is difficult to identify solutions to the problem directly

When to use

- The team is interactive and acritical, finding it easy to openly discuss ideas
- The team needs basic ideas or a better understanding of the problem
- The problem is general and does not require a deepening in an expertise
- The technique ranges from small alterations on the product to radical innovations

Related techniques

- 5Whys
- Brainstorming
- Negative Brainstorming
- Potential Problem Analysis

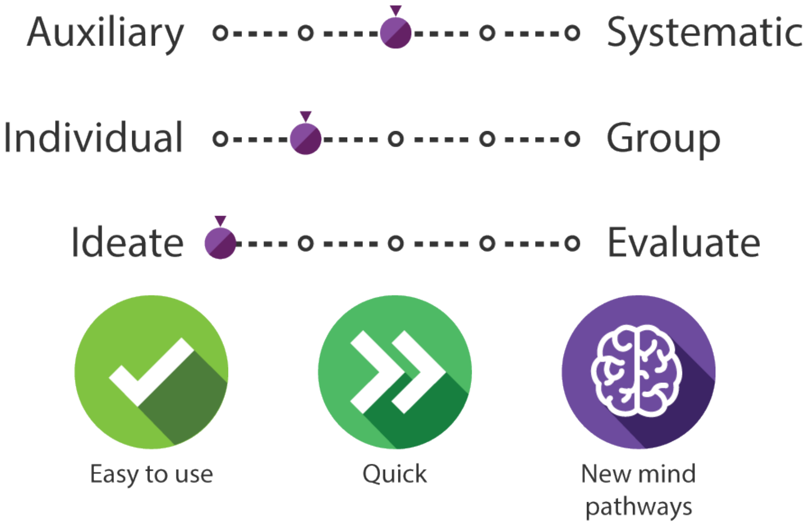
Complementary readings

- DUX, 2014. “Designing the User Experience at Autodesk”.
- Geniuses, 2012. “Creativity techniques”.
- Mind Tools, 2015.

SCAMPER

Design step: develop
Innovation focus: incremental architectural radical
Team relationship: interactive dissociated
Execution method: verbal symbolic
Difficulty of use: low

Highlights and badges



Resume
Many creative ideas can be reached by doing little alterations on the design, which can chain other ideas of conceptions. SCAMPER is a checklist that aims to create new mind-pathways and improve existing products, based on seven points:

- S - Substitute - components, materials, people
- C - Combine - mix, combine with other assemblies or services, integrate
- A - Adapt - alter, change function, use part of another element
- M - Modify - increase or reduce in scale, change shape, modify attributes (e.g. colour)
- P - Put to another use

- E - Eliminate - remove elements, simplify, reduce to core functionality
- R - Reverse - turn inside out or upside down.

Step-by-step

1. Delineate the problem or need to be addressed
2. Choose a product or conception to serve as basis to ideation
3. Use the checklist to create new conceptions pathways together or individually, filling the table with at least one idea per row
4. Evaluate and combine ideas to generate better conceptions

Example 1

[DIEGM, 2015]

A producer of computers and printers is looking for new products. An individual SCAMPER checklist would reveal design possibilities such as:

Table B.4 – Example of SCAMPER for computer and printer (DIEGM, 2015).

SUBSTITUTE	Use of high tech materials for specific markets – use high-speed components?
COMBINE	Integrate computer and printer, printer and scanner, ...
ADAPT	Put high quality ink in printer, use high quality paper.
MODIFY	Produce different shape, size and design of printer and computer.
PUT TO OTHER USES	Printers as photocopies or fax machines.
ELIMINATE	Eliminate speakers, color screens, color ink etc...
REVERSE	Make computer desks as well as computers and printers, or computer chairs, etc...

Example 2

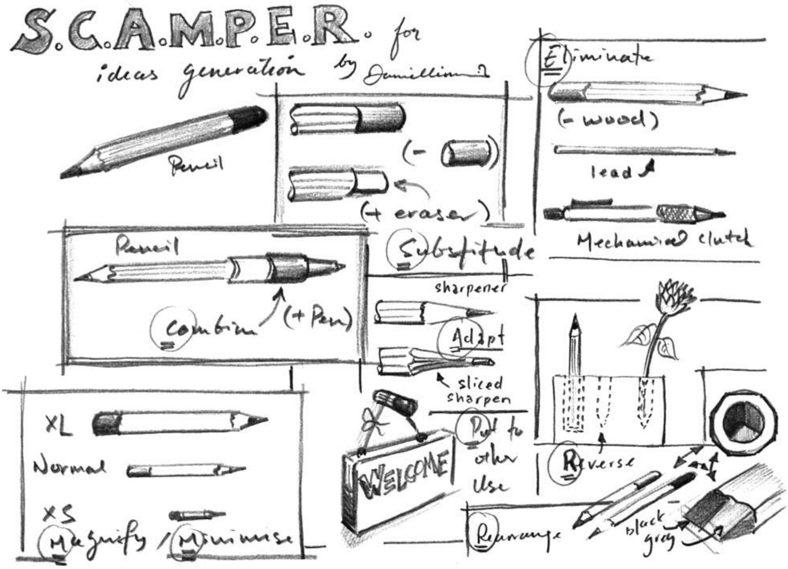


Figure B.15 – Example of SCAMPER for a pencil (Design Journal SOS, 2012)

Tips

- This can be used as an auxiliary technique to other developments
- The technique can be done verbally (in group) or in a paper individual checklist
- Every row of the SCAMPER can bring new ideas and should be ideated thoroughly
- The ideas should be restrained to each rows intention and be posteriorly combined

When to use

- The design aims to change specific parts of the product, but maintain some of the state of the art
- The team reached creativity blocks and needs new mind pathways
- The problem is general and does not require a deepening in an expertise
- The team has a more systematic approach to the development

- The team needs a versatile technique that can be used in group or individually
- The design demands quick conception generation

Related techniques

- 5Whys
- Analogies and Associations
- Brainstorming
- Mind Mapping
- TRIZ (Contradictions)

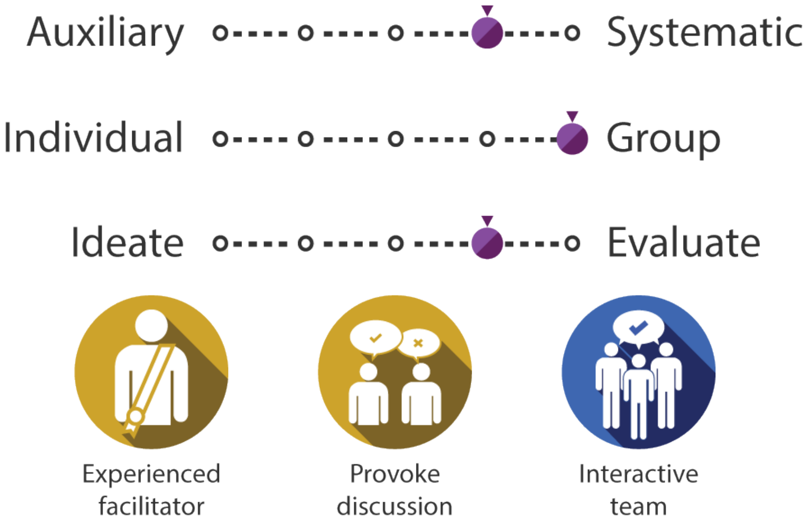
Complementary readings

- Baxter, M., 2011, Projeto de Produto: Guia Prático para o Design de Novos Produtos, translated by Itiro Iida, 3. ed, Blucher, São Paulo, 344 p.
- DIEGM, 2005. CREATE project.
- Mycoted, 2006.
- Design Journal SOS, 2012.

SIX THINKING HATS

Design step: deliver
Innovation focus: incremental architectural radical
Team relationship: interactive dissociated
Execution method: verbal
Difficulty of use: high

Highlights and badges



Resume
This technique, created by Edward de Bono in the 1980s, uses metaphorical "hats" to guide thinking and allow ideas to be discussed and evaluated. Each hat cover one design aspect in the following order:

- White hat: focuses on the available data. The wielder of this hat should analyze historical data (cases, internet, concurrents) to obtain information. No interpretation or opinions are allowed
- Red hat: uses intuition, emotion and gut reaction to evaluate an idea. Emotional and visceral reactions of users are the main point of this hat, and there is no need to explain the sensations and reactions that the idea causes

- Black hat: is the negativity hat, looking at the bad points of the ideas. The central point is to identify weaknesses and what might not work. This hat is one of the main advantages of the technique, as positive thinking alone may hide problems and flaws
- Yellow hat: opposite to the black hat, this thinks in a positive and optimistic way, searching for benefits and encouraging people and ideas to continue the evaluation. It goes for a logical approach, offering concrete and precise suggestions, based on the benefits
- Green hat: this offers a freewheeling way of thinking focusing on creativity free of critiques. Any idea from a person using this hat should be taken into consideration, offering insights on fields beyond what is well-known
- Blue hat: controls the process, usually wielded by the facilitator. This hat defines who uses each hat and controls the meeting to allow equal voice for each member and hat. It define problem, targets, questions, and, if necessary, even changes hats during sessions

Step-by-step

1. Define the team
2. Explain the solution(s) which are relevant and the technique rules
3. Assert a hat to each member
4. Deliberate about the conceptions using the instructions of each hat
5. If necessary, change hats and restart discussion
6. Evaluate the outcomes and generated ideas

Example

[Mycoted, 2006]

The directors of a property company are looking at whether they should construct a new office building. The economy is doing well, and the amount of vacant office space is reducing sharply. As part of their decision, they decide to use the Six Thinking Hats technique during a planning meeting. Looking at the problem with the White Hat, they analyze the data they have. They examine the trend in vacant office space, which shows a sharp reduction. They anticipate that by the time the office block would be completed, that there will be a severe shortage of office space. Current government projections show steady economic growth for at least the construction period. With Red Hat thinking, some of the directors think the proposed building looks quite ugly. While it would be highly cost-effective, they worry that people would not like to work in it. When they think with the Black Hat, they worry that government projections may be wrong. The economy may be about to enter a 'cyclical downturn', in which case the office building may be empty for a long time. If the building is not attractive, then companies will choose to work in another better-looking building at the same rent. With the Yellow Hat, however, if the economy holds up and their projections are correct, the company stands to make a great deal of money. If they are lucky, maybe they could sell the building before the next downturn, or rent to tenants on long-term leases that will last through any recession. With Green Hat thinking, they consider whether they should change the design to make the building more pleasant. Perhaps they could build prestige offices that people would want to rent in any economic climate. Alternatively, maybe they should invest the money in the short term to buy up property at a low cost when a recession comes. The Blue Hat has been used by the meeting's Chair to move between the different thinking styles. He or she may have needed to keep other members of the team from switching styles, or from criticizing other peoples' points.

Tips

- The choice of hats should be done proactively, although using different hats is encouraged
- Each hat has a function and should try and stay on its applicability zone
- Integrating experts or users can be beneficial to this technique
- The technique can be used in bigger groups by assigning the same hat to more than one person if all the six were already assigned once
- The technique may require an experienced facilitator and training for the team

When to use

- The team needs to study and evaluate early stages of structured conceptions
- The team has difficulty of conciliate ideas, being for lack or excess of communication and structuration
- The team has an experienced facilitator or knowledge of creativity techniques
- The team already reached sufficient solution concepts to start evaluating the results

Related techniques

- Brainstorming
- Negative Brainstorming
- Potential Problem Analysis
- Voting

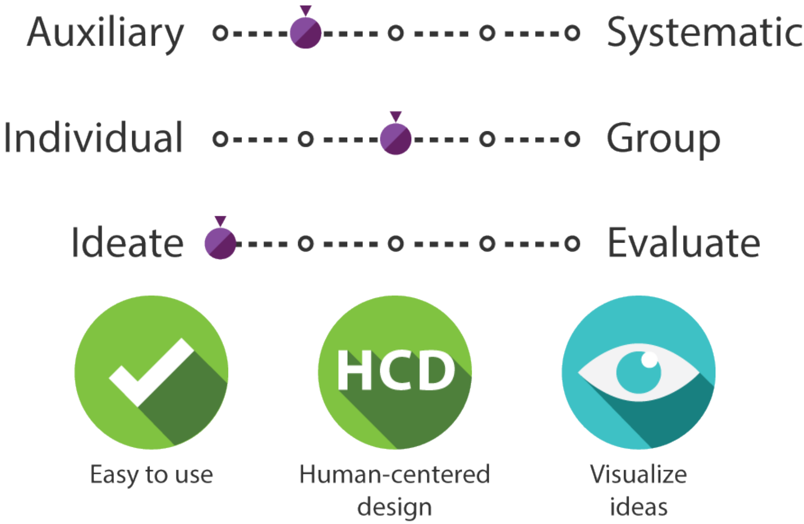
Complementary readings

- DIEGM, 2005. CREATE project.
- Mycoted, 2006.
- SIX THINKING HATS, 2005.
- de Bono, Edward, 1985. Six Thinking Hats: An Essential Approach to Business Management. Little, Brown, & Company, 192 p.

STORYBOARD

Design step: develop
Innovation focus: architectural radical
Team relationship: interactive
Execution method: symbolic
Difficulty of use: low

Highlights and badges



Resume
Some forms of modeling are simple and do not require time or resources, yet still being able to give a better comprehension of ideas. By visually plotting situations in a progressive story, the design team identify potential solutions and even feelings related to the user experience. Sketching help thinking the ideas through and give the team a universal language to discuss and improve the design. A key factor of this technique is the first person experience, or for the team to put themselves in the place of the user.

Step-by-step

1. Choose the ideas or situations which will be addressed by the technique
2. Discuss how the idea works and sketch or list the activities involved with the needed deepening
3. Draw the ideas using a series of comic book-style frames
4. Use the Storyboard to discuss the interaction between user and concept and how it can be improved

Example

[MIT, 2010]

This is a storyboard that explores the experience of discovering and interacting with products that inform the user about their state.

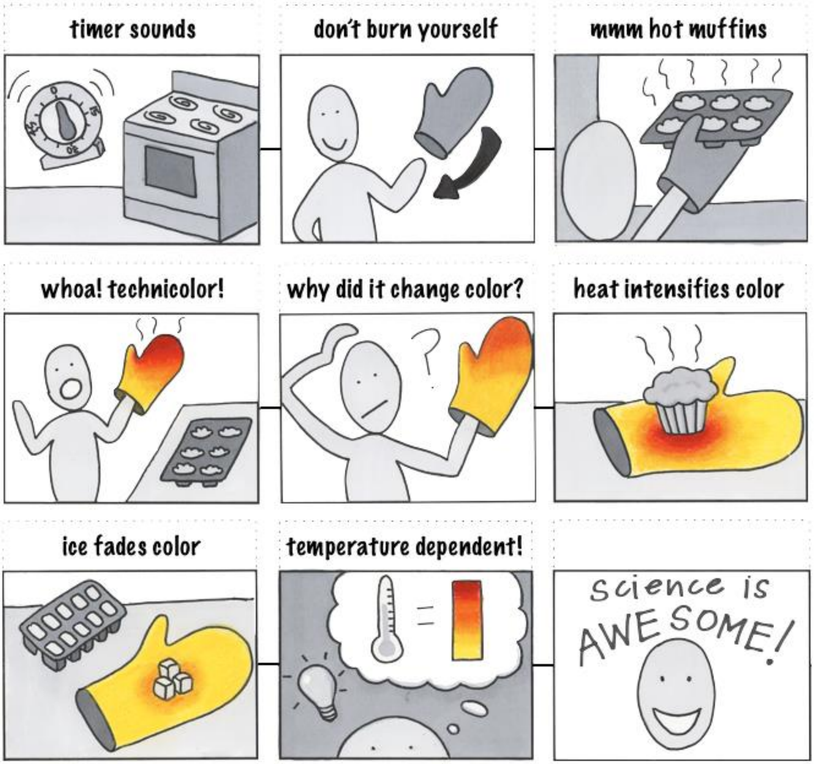


Figure B.16 Example of Storyboard for oven glove use (MIT, 2010).

Tips

- Anyone can draw
- Use rather simple draws and lines to ease communication
- The storyboard does not have to represent the entire offering. Sometimes a simple interaction or contact with the product is sufficient
- Each frame represents a key-moment of interaction between user and concept
- Each frame can be titled

When to use

- The design aims non-conventional ideas or perspective changes
- The impacts of the concepts are hard to identify
- The team is interactive and acritical, finding it easy to openly discuss ideas
- The team need to focus on the user, analyzing its experience and feelings
- The team needs a universal language to ideate

Related techniques

- Brainstorming
- Holistic Impact Assessment
- LivePrototyping
- Quick and Dirty Modeling

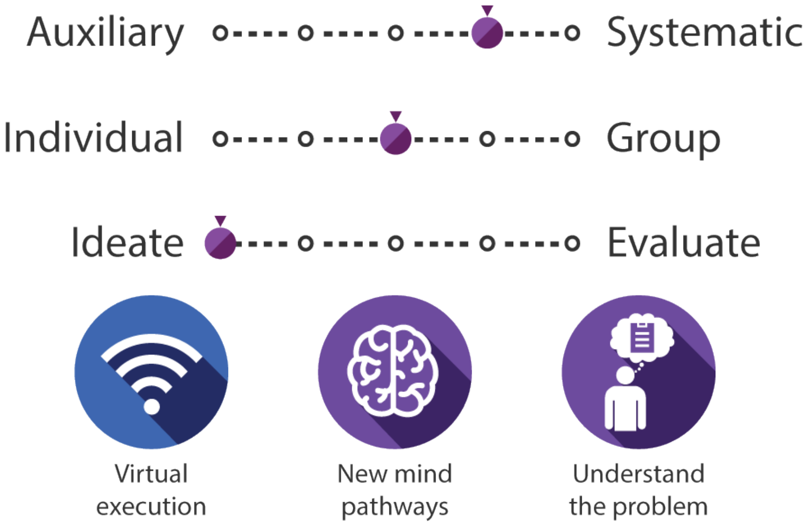
Complementary readings

- DIEGM, 2005. CREATE project
- IDEO, 2015, The Field Guide to Human-Centered Design, California, 195 p.
- MIT, 2010.
- Mycoted, 2006.
- Service Design Tools, 2009.

TILMAG

Design step: develop
Innovation focus: architectural radical
Team relationship: dissociated
Execution method: symbolic
Difficulty of use: moderate

Highlights and badges



Resume
Develop by Helmut Schlicksupp, the acronym stands for 'transformation of ideal solution elements with associations and similarities' (from the German 'Transformation idealer Lösungselemente mit Assoziationen und Gemeinsamkeiten'). The technique starts with the problem definition, identifying its Ideal Solution Elements (ISE), the basis for the matrix. Associations of two or more ISE gives way to related objects or events shared by them, which can reveal principles of solutions.

Step-by-step

1. State the problem clearly, defining the problem to be addressed
2. Identify / Define Ideal Solution Elements (ISE)
3. Construct a TILMAG matrix with the ISE in both axis
4. Associate pairs of ISE filling the matrix
5. Discuss each and every matrix cell, identifying characteristics and translating the association to the problem scenario
6. Combine potential ideas into concepts

Example

[King and Schlicksupp, 1999]

Employees from a dental clinic are dealing with a problem of "how to reduce children's fear of going to the dentist". To identify the ISE, the team brainstorms factors relevant to the stated problem, revealing five points: address fear; is fun; draws attention; is familiar; and is trustworthy. The ISE are then used to construct the matrix as presented below.

Table B.5 – Example of TILMAG for children dental clinic (King and Schlicksupp, 1999).

	ISE1 - ADDRESS FEAR	ISE2 - IS FUN	ISE3 - DRAWS ATTENTION	ISE4 - IS FAMILIAR
ISE5 - IS TRUSTWORTHY	- Therapist - Firemen	- Photography - Comics characters	- Policemen - Clock	- Money - Tooth Fairy
ISE4 - IS FAMILIAR	- Home - Comics characters	- Toys - Ice-cream	- Story books - Sunsets	-
ISE3 - DRAWS ATTENTION	- Lullabies - Traffic lights	- Amusement parks - Parade	-	-
ISE2 - IS FUN	- Toy animal farms - Outdoor adventure	-	-	-

The matrix elements are then listed and correlated in principles and associations to the real scenario. The outcome is presented on the table below, showing only a part of the developed ideas.

Table B.6 – Example of principles derived from TILMAG (King and Schlicksupp, 1999).

ASSOCIATION	PRINCIPLE	CONNECTION
Toy animal farms	- Small sizes - Safe environment	- Colored dentist chairs - Toy dentist equipment
Comics characters	- Familiar - Colorful - Attractive	- Dress up as heroes

Tips

- Avoid quick convergence to solutions
- Even being a structured technique, the associations require discussion and an acritical environment
- Some combinations of ISE can be hard to associate, but it is important to try and fill every cell with at least one idea
- Every association of each cell can lead to concept ideas

When to use

- There is a clear idea of the problem or need to be addressed
- The team reached creativity blocks and needs new mind pathways
- The team has a more systematic approach to the development
- The team needs grounding for the construction of conception alternatives
- The problem is broad with various implications or interests

Related techniques

- Affinity Diagram
- Analogies and Associations
- Brainstorming
- Brainwriting
- Morphological Analysis

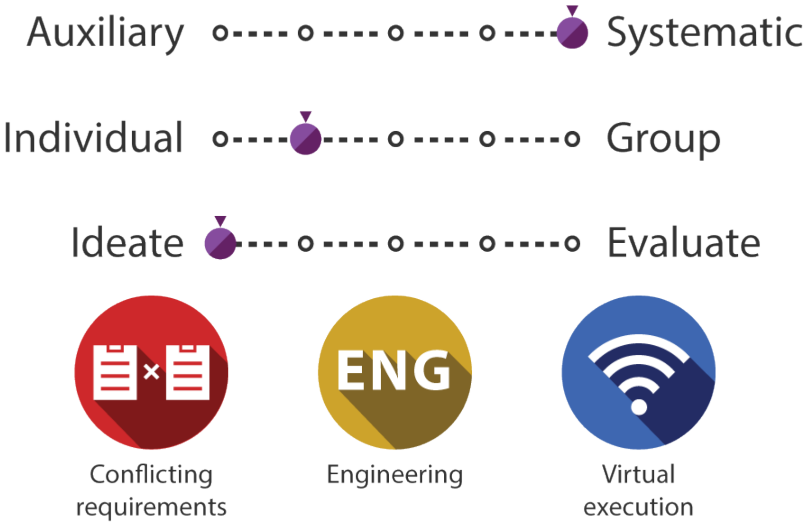
Complementary readings

- DIEGM, 2005. CREATE project.
- King, B. and Schlicksupp, H., 1999. Criatividade: uma Vantagem Competitiva, Qualitymark, Rio de Janeiro, 329 p.
- Mycoted, 2006.

TRIZ (CONTRADICTIONS)

Design step: develop
Innovation focus: incremental architectural radical
Team relationship: dissociated
Execution method: symbolic
Difficulty of use: high

Highlights and badges



Resume

Genrich S. Altshuller based the developed of this technique in the studies about contradicted demands in design. He discovered that most design must deal with conflicts, where to improve one parameter worses other parameters. TRIZ (theory of inventive problem solving) takes a specific problem to a general space, in which the method can help to solve the problem using general solutions, and afterwards adapting them to the specific problem. The Contradiction technique uses this principle with 39 engineering parameters (weight, length, area, etc…) in a matrix to correlate 40 solution principles, presenting the general solution more directly.

Step-by-step

1. Determine design specifications and list resources (physical items, processes or information)
2. Identify engineering parameters that can be improved
3. Detect relevant contradictions among the parameters
4. Chose improving features (the parameter that should be improved) and worsening features (the parameter that would suffer a worsening)
5. Check the contradiction matrix to find solution principles
6. Chose applications from the propositions of each solution principle
7. Use the principles in the design situation to find real solutions

Example

[The Triz Journal, 2015]

A project on the application of TRIZ to economy class aircraft cabin design was developed in University of Bath, United Kingdom. By using the inventive principles, the design of the aimed to increase the area for passengers without changing the whole aircraft size, which is restricted in volume. By using the contradiction matrix entering as improving feature the area of moving object and as worsening feature the volume of moving object, four solution principles were correlated:

- 7: nested doll
- 14: spherodiality – curvature
- 17: another dimension
- 4: asymmetry

As asymmetry example, the designer changed the configuration of the seats according to the first proposition (change the shape of an object from symmetrical to asymmetrical) as shown in the following figure.

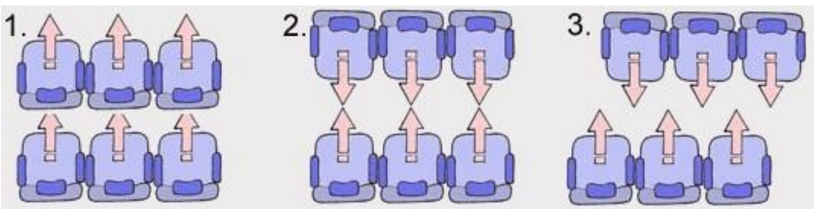


Figure B.17 – Example of TRIZ use on aircraft seat positioning (The Triz Journal, 2015)

Tips

- Free TRIZ matrixes can be found on the internet
- The technique is complex and require high-levels of pre-knowledge
- The team should focus on understanding the specifications and solution principles, adapting the language to the technique
- Some contradictions are hard to find, and not all can be translated to the matrix

When to use

- There is a clear idea of the problem or need to be addressed
- There are conflicts of interests or conflicting requirements
- The team is newly formed or with problems to openly discuss
- The design demands quick and ready conception generation
- The team has a more systematic approach to the development

Related techniques

- Morphological Analysis
- Pugh Matrix
- SCAMPER

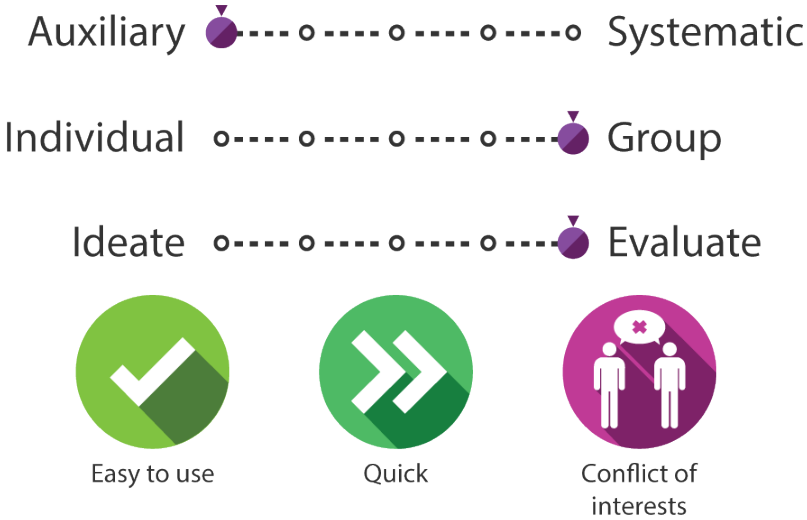
Complementary readings

- Back, N., Ogliari, A., Dias, A., Silva, J. C. da, 2008, Projeto Integrado de Produtos: Planejamento, Concepção e Modelagem, Manole, São Paulo, 628 p.
- DIEGM, 2005. CREATE project
- Mycoted, 2006.
- The Triz Journal, 2015.
- Triz40, 2014.

VOTING

Design step: deliver
Innovation focus: incremental architectural radical
Team relationship: interactive dissociated
Execution method: verbal symbolic
Difficulty of use: low

Highlights and badges



Resume
Simple techniques can be very effective when used at the right time. Direct Voting is an easy technique that obtains quick results depending on majority choice, being flexible to different teams and allowing discussion. Each member can vote one or more times in conceptions that they consider the best (or worst). The voting can be anonymous, on paper, whiteboard or even verbal, being first used to filter best ideas, then to define the best way to continue the development.

Step-by-step

1. Gather the team
2. Acclimatize the team with the design and conception
3. Discuss positive and negative aspects of each conception
4. Delineate the form of voting (verbal, written, anonymous, positive, negative)
5. Perform the voting, leaving each member to choose freely among the ideas
6. Account the votes

Example

At the end of creation phase, a team of 3 designers, engineers and manufacturing experts came up with 5 conceptions. To sort quickly the best pathways to continue the development, they decided to do a preliminary voting, aiming 2 conceptions to be further explored. They decided to allow 3 votes for each member, 2 positives and 1 negative. Each positive vote accounted for +1 point and a negative for -1. The voting occurred, resulting in:

Table B.7 – Example of Voting.

CONCEPTION	POSITIVE POINTS	NEGATIVE POINTS
A	2	1
B	2	0
C	0	0
D	1	2
E	1	0

After discussions and evaluation, the team noticed that the positive aspects of conception A could be integrated in conception E, generating a better conception to be further explored with conception B.

Tips

- If reached a tie or the team is not sure of the outcome, the technique can be reiterated using the ideas with highest votes
- Each member can vote one or more times depending on the agreement
- The voting can be evaluate positive and/or negative points
- The result is a decision from the team and every member should accept it
- Discarded ideas should be used as inspiration to improve other conceptions

- Dissociated groups should use anonymous on paper voting
- Every conception should be discussed before the voting, presenting positive and negative aspects
- This technique can be used as a primary filter of conceptions

When to use

- The team needs to select already structured conceptions
- The team has divergent ideas and have difficulty of reaching a consensus
- There are conflicts of interests or conflicting requirements
- The design demands quick decisions
- The team has little knowledge on creativity techniques

Related techniques

- Affinity Diagram
- Brainstorming
- Pugh Matrix
- Six Thinking Hats

Complementary readings

- Baxter, M., 2011, Projeto de Produto: Guia Prático para o Design de Novos Produtos, translated by Itiro Iida, 3. ed, Blucher, São Paulo, 344 p.
- DIEGM, 2005. CREATE project.
- Mycoted, 2006.

APPENDIX C – VALIDATION QUESTIONNAIRE

QUESTIONÁRIO:

Este questionário serve de validação para o Sistema Especialista desenvolvido como trabalho de mestrado e pode ser interrompido a qualquer momento caso seja de seu desejo. A intenção é avaliar o desempenho do sistema, sendo que qualquer entrada informada ao programa gerará uma saída correta para o usuário. Inicialmente o sistema deve ser rodado e respondido individualmente. As questões seguintes são relacionadas ao seu funcionamento e sua usabilidade, sendo que as informações aqui coletadas serão de grande valia para este estudo. É de importância responder a todas as questões, mesmo que de forma sucinta. Agradeço desde já o tempo disposto e quaisquer outras dúvidas fico à disposição pelo e-mail lfbotega@gmail.com.

1. Por favor, assinale se alguma das perguntas do sistema causou dúvida? O que a causou?

   ( ) 1. O projeto se baseia em produtos existentes?

   ____

   ( ) 1.1. O projeto visa novas funcionalidades ou mercado?

   ____

   ( ) 2. O número de ideias geradas é considerado suficiente?

   ____

   ( ) 3. Existe tempo suficiente para as explorar ideais e alternativas?

   ____

   ( ) 4. A equipe é multidisciplinar?

   ____

   ( ) 5. A equipe possui uma sala exclusiva?

   ____

   ( ) 6. A equipe conta com um ambiente de compartilhamento virtual?

   ____

   ( ) 7. A equipe faz reuniões periódicas?

   ____

   ( ) 8. A equipe possui boa interação entre seus membros?

   ____

2. Qual a maior dificuldade ao responder o questionário do sistema?
   ( ) Quantidade de perguntas
   ( ) Correlacionar a situação real às perguntas
   ( ) Linguagem utilizada nas perguntas
   ( ) Interface do questionário
   ( ) Executar o software CLIPS
   ( ) Outros [favor especificar abaixo]

   ____

   ____

3. Das seguintes técnicas, assinale a(s) que você conhece:

( ) 5Whys (5 Por quês)	( ) Live Prototyping (Prototipação Ao Vivo)	( ) Resource Assessment (Avaliação de Recursos)
( ) Affinity Diagram (Diagrama de afinidade)	( ) Mind Mapping (Mapa Mental)	( ) Reverse Brainstorming (Brainstoming Reverso)
( ) Analogies and Associations (Analogias e Associações)	( ) Mock-up Modeling (Maquete)	( ) SCAMPER (MESCRAI)
( ) Biomimetic (Biomimética)	( ) Morphological Analysis (Matriz Morfológica)	( ) Six Thinking Hats (Seis Chapéus do Pensamento)
( ) Brainstorming	( ) Negative Brainstorming (Brainstorming Negativo)	( ) Storyboard
( ) Brainwriting	( ) Potential Problem Analysis (Análise de Problemas Potenciais)	( ) TILMAG
( ) Functional Tree (Árvore Funcional)	( ) Pugh Matrix (Matriz de Pugh)	( ) TRIZ - Contradictions (Contradições da TRIZ)
( ) Holistic Impact Assessment (Análise de Impacto Holístico)	( ) Quick and Dirty Modeling (Modelagem Rápida)	( ) Voting (Votação)

4. Quais as técnicas de criatividade, além das citadas acima, que você mais utiliza ou considera mais importantes no desenvolvimento de produtos?

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5. Você considera as técnicas indicadas pelo sistema adequadas para a situação de projeto indicada?
( ) Sim
( ) Não, por quê?

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6. Quais outras informações em sua opinião poderiam facilitar a escolha de uma técnica de criatividade no "Relatório de Técnicas de Criatividade" (Creativity techniques report)?
( ) Mais informações introdutórias (resumidas) sobre as técnicas
( ) Mais informações sobre o uso prático das técnicas
( ) Mais informações sobre as aplicabilidades das técnicas
( ) Maior facilidade de comparação entre técnicas
( ) Outros [favor especificar abaixo]

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7. Com base nas informações disponíveis no site CRIB for design, disponível ao clicar em "Go to technique" dentro do "Relatório das Técnicas de Criatividade" (Creativity techniques report) você conseguiria executar a técnica sem maiores dificuldades?
( ) Sim
( ) Não, por quê?

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8. Quais outros fatores em sua opinião poderiam facilitar o entendimento das técnicas de criatividade no site CRIB for design?
   ( ) Mais aprofundamento nas descrições
   ( ) Descrições mais sucintas ou pontuais, com referências para um maior entendimento
   ( ) Mais exemplos
   ( ) Vídeos
   ( ) Melhorias na interface
   ( ) Maior interatividade
   ( ) Outros [favor especificar abaixo]
   ____
   ____
   ____

9. Em quais situações você considera que este sistema seria útil?
   ( ) Projetos individuais
   ( ) Projetos em grupo
   ( ) Etapas iniciais de geração de concepções
   ( ) Etapas posteriores quando o grupo já possui concepções formuladas
   ( ) Apenas ao se encontrar bloqueios criativos
   ( ) Projetos com limitação de tempo
   ( ) Projetos que não contém um especialista em criatividade
   ( ) Para conhecer outras/novas técnicas de criatividade
   ( ) Outros [favor especificar abaixo]
   ____
   ____
   ____

10. Em uma escala de 1 a 5 (sendo 5 o máximo), que nota você daria ao sistema?
    1 ( ) 2 ( ) 3 ( ) 4 ( ) 5 ( )

Obrigado pela disponibilidade e quaisquer outras sugestões podem ser indicadas abaixo ou enviadas por e-mail (lfbotega@gmail.com), pois serão de grande ajuda no desenvolvimento deste projeto.

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APPENDIX D – THIRD CYCLE VALIDATION

This last cycle of validation focused on identifying if the promoted changes in the prototype allowed a better understanding and use of the KBS, as well as searching for further improvements possibilities. The questionnaire followed a similar structure as described in Appendix C, only removing repetitive questions for the validators that already participated in the first validation cycle. In addition, the question referring to "Creativity Techniques Description" was adapted to fit the new output scenario containing "Creativity Techniques Report" and the online database "CRIB for design". Results are shown in Figures D.1, D.2 and D.3.

As expected, changes in the used language mitigated most difficulties identified in the initial questionnaire. The scales and badges method were also successful on helping users to choose a technique over others on the "Creativity Techniques Report". Lastly, the "CRIB for design" webpage still lacks improvement especially in more exemplification. An approach could be to use more schemes while presenting information for each technique, as well as demonstrative videos.

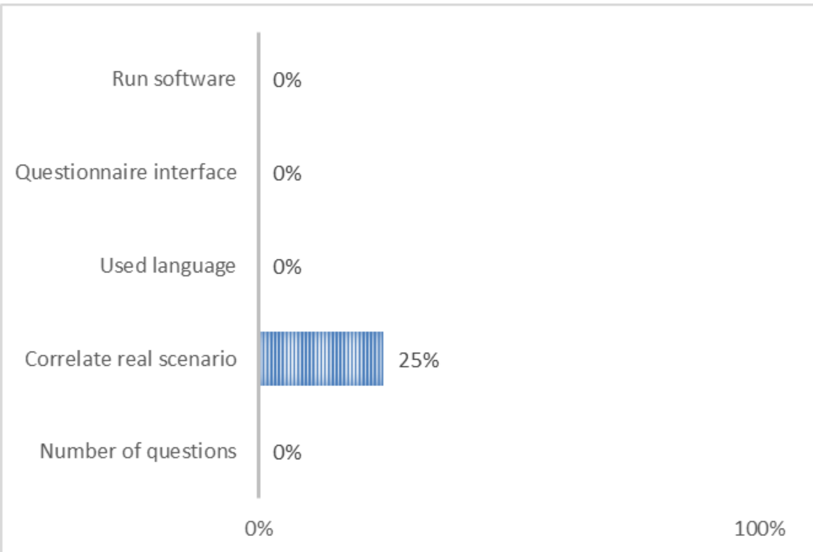

Figure D.1 – Bar chart representing answers from question 2: "Which were the biggest difficulties while answering the questionnaire?".

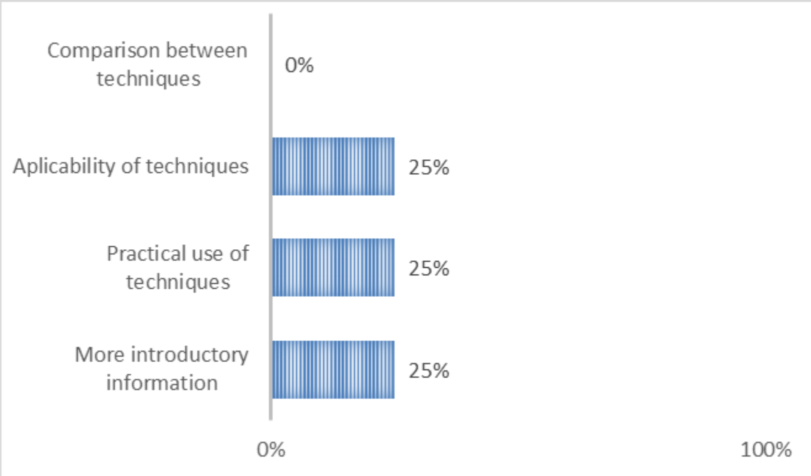

Figure D.2 – Bar chart representing answers from question 6: “Which other information could aid in choosing a creativity technique on the ‘Creativity Techniques Report’?”.

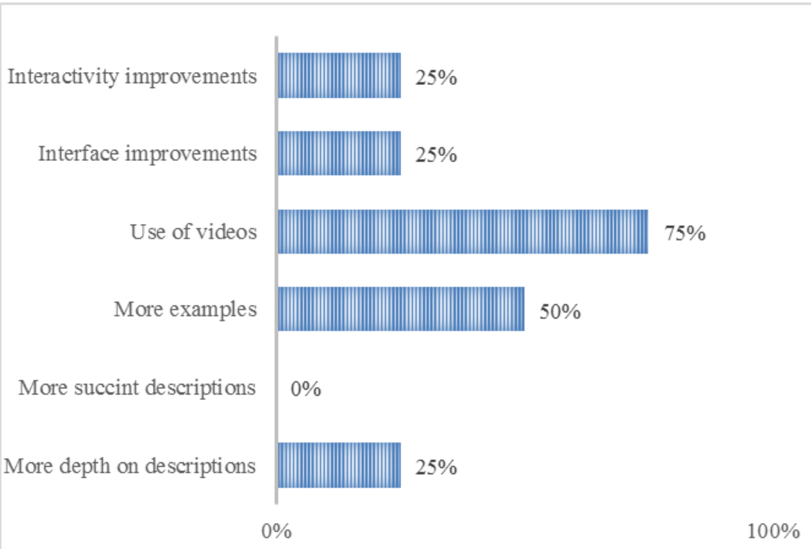

Figure D.3 – Bar chart representing answers from question 8: “Which other factors could aid in the understanding of the creativity technique on the ‘CRIB for design’?”.