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DECISION SUPPORT SYSTEM USING MACHINE LEARNING FOR CREATIVITY AND INNOVATION

Florianópolis
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Agora, apenas deságua.

as palavras dos homens são como sombras, e as sombras
nunca saberiam explicar a luz, entre elas e a luz está e
interpõe-se o corpo opaco que as faz nascer.
[José Saramago, o Evangelho segundo Jesus Cristo]

ABSTRACT

The creation and refinement of new ideas is a strategic competence for teams and organization to innovate and be sustainable in the market. This research addresses the challenge of finding adequate creativity and innovation techniques (CITs) for improving individual or team creation efforts through the use of Artificial Intelligence (AI). The process of choosing which CIT to use is complex and demanding, especially when taking into consideration the existence of hundreds of techniques and the plurality of different design contexts. This empiric knowledge, usually retained in a design expert´s repertoire, can be acquired and implemented in a computational system, making it more available and permanent. Therefore, this work focused on developing a Decision Support System embedded in an online application with a two-stage Machine Learning inference process. The developed prototype is able to evaluate users' design scenario through a questionnaire, and infer the most appropriate CITs from the database would better fit their needs. Development was performed in two cycles, exploring knowledge acquisition and representation, implementation of models and interface, verification and validation.

Keywords: Artificial Intelligence; Creativity; Innovation; Design.

RESUMO

Criação e refino de novas ideias são competências estratégicas para equipes e organizações poderem inovar e se sustentar no mercado. Esta pesquisa visa abordar o desafio de encontrar técnicas de criatividade e inovação (CIT) adequadas para facilitar esforços criativos de pessoas e equipes através do uso de Inteligência Artificial. O processo de escolha de CITs para uso é complexo e trabalhoso, especialmente ao se levar em consideração a existência de centenas de técnicas e suas pluralidades de contextos de uso possíveis. Este conhecimento empírico, usualmente retido apenas no repertório de especialistas em projeto ou design, pode ser adquirído e implementado em um sistema computacional, tornando-o mais disponível e permanente. Desta forma, neste trabalho buscou-se desenvolver um Sistema de Suporte à Decisão, integrado a uma aplicação online, contendo um processo de inferência em dois estágios realizado por modelos de Aprendizado de Máquina. O protótipo desenvolvido é capaz de avaliar o cenário de projeto dos usuários através de um questionário e inferir quais das CITs contidas na base de dados serão mais apropriadas às necessidades. O desenvolvimento se deu em dois ciclos, explorando aquisição e representação de conhecimento, implementação dos modelos e interface, verificação e validação.

Palavras-chave: Inteligência Artificial; Criatividade; Inovação; Design.

RESUMO EXPANDIDO

Introdução

Habilidades de projeto (design) sempre estiveram presentes nos esforços humanos. Através da habilidade intrínseca de resolução de problemas, seres humanos utilizaram-se de tais habilidades em virtualmente todos os campos de conhecimento, da criação de artefatos, ferramentas, táticas de caça e métodos de plantio, até visões mais modernas de projeto de produtos, serviços, software e organizações sociais. Para serem capazes de atingir estes objetivos, os projetistas fazem uso dos impulsos criativos, os quais são cada vez mais requisitados com o aumento da complexidade da sociedade e da tecnologia atual. As soluções projetadas se tornaram mais complexas de conceber e produzir, na mesma medida em que as necessidades das pessoas se tornaram mais multifacetadas e requerendo.

Neste cenário complexo com desejos e problemas incertos, a criatividade humana se tornou um vetor para a inovação. Antes vista como um dom, a criatividade se tornou pré-requisito para organizações no mercado competitivo atual, passando a ser vista como uma habilidade não apenas estimulada mas passível de ser treinada e aprendida. O volume de informação necessária durante a criação e desenvolvimento de soluções requer formas eficientes de processar e reter conhecimento. Neste contexto, diversas técnicas de criatividade e inovação (creativity and innovation techniques – CTIs) foram desenvolvidas como uma abordagem sistemática de projeto, em geral como frameworks provenientes de práticas reais de design. As técnicas, quando adequadamente utilizadas, permitem um balanço entre razão e intuição, promovendo uma estrutura flexível para a criatividade ocorrer em consonância com os objetivos estratégicos das organizações.

Centenas de CITs foram desenvolvidas provenientes de diversas áreas, demandando, assim, novas formas de organizar tal conhecimento. Considerando o número de técnicas e a pluralidade de situações nas quais elas podem ser usadas, abordagens de inteligência artificial trazem formas eficientes de organização e disseminação deste conhecimento especializado. Neste contexto, este trabalho visa desenvolver um Sistema de Suporte à Decisão (em inglês Decision Support System – DSS) de apoio à criatividade capaz de centralizar, categorizar e recomendar CITs levando em conta diversos aspectos do cenário no qual o usuário está inserido.

Objetivos

O objetivo geral desta pesquisa é: implementar um Sistema de Suporte à Decisão capaz de potencializar a criatividade e inovação de times de projeto ou design através da seleção de técnicas de criatividade e inovação adequadas, questionando, analisando e compreendendo o cenário do time, correlacionando e exportando técnicas adequadas à este, e suportando o processo de escolha do usuário por uma técnica.

Os objetivos específicos desta pesquisa são:

- Compreender o processo criativo que ocorre durante o desenvolvimento de produtos e serviços;
- Investigar fatores que impactem na criatividade e inovação em organizações, bem como na adequação de técnicas de criatividade inovação;
- Identificar correlações dentre os fatores selecionados na categorização das técnicas de criatividade e inovação para conectá-los aos cenários de desenvolvimento de soluções;
- Definir uma arquitetura adequada para a implementação de abordagens de inteligência artificial capaz de representar o conhecimento adquirido em um Sistema de Suporte à Decisão que incorpore abordagens de Aprendizado de Máquina;
- Implementar incrementalmente o Sistema de Suporte à Decisão apoiado por abordagens de Aprendizado de Máquina;
- Verificar e validar o software tanto na academia quanto no mercado.

Metodologia

A pesquisa desenvolvida seguiu o processo de desenvolvimento de Sistemas Especialistas passando por 5 fases: estudo de viabilidade, aquisição de conhecimento, representação de conhecimento, implementação, e verificação e validação. A viabilidade foi atestada através de consulta sobre literatura em sistemas de suporte à criatividade, mais especificamente nas pesquisas com intersecção com inteligência artificial e uso de técnicas de criatividade e inovação. A aquisição de conhecimento se deu com base na coleta de informações em literatura, com especialistas humanos, estudos de caso e outras fontes de conhecimento, especialmente em metodologias de design e engenharia.

A partir do conhecimento adquirido, a representação de conhecimento se desdobrou a partir da análise e síntese de padrões de organização e categorização das CITs dentro do processo de desenvolvimento de soluções, delineando situações específicas de uso das técnicas. Isto permitiu a construção de casos específicos e mensuráveis nos quais as técnicas são recomendadas para uso, o que permitiu a modelagem de dados e implementação de abordagens de aprendizado de máquina. Com isso, a implementação se deu com base nos dados coletados em dois ciclos iterativos de entendimento e preparação de dados, treino e teste de modelos. Primeiro ciclo focou no desenvolvimento dos modelos de aprendizado de máquina que formam o núcleo do sistema, enquanto no segundo ciclo a implementação foi aprofundada, a interface gráfica desenvolvida com a adição de uma arquitetura em nuvem baseada na web.

Verificação e validação foram desempenhadas de forma semelhante em ambos os ciclos. A primeira foi realizada através do input de todos as combinações de entrada possíveis no sistema, avaliando a ocorrência de erros de execução. Por sua vez, a validação foi realizada a partir de testes com especialistas, conferindo se as respostas dadas pelo sistemas se equiparam às dadas pelos avaliadores numa mesma situação de análise.

Resultados e Discussão

Após dois ciclos de implementação, o sistema conta com 26 CITs categorizadas a partir de 13 fatores implementadas em um Sistema de Suporte à Decisão acessível pela internet. Ao todo 12 modelos de aprendizado de máquina foram testados, culminando em um modelo híbrido que utiliza: um regressor com output múltiplos que utiliza informações coletadas através de 10 perguntas feitas ao usuário para inferir quais as características de técnicas que mais beneficiaram o time; seguido de um modelo de classificação e ranqueamento que traduz essas características desejáveis em 3 CITs recomendadas. O resultado é exportado para o usuário através da interface gráfica, fornecendo informações sobre o processo de inferência realizado, bem como informações adicionais sobre cada técnica. Ao final da execução, o sistema coleta feedback sobre qual técnica foi escolhida pelo usuário para uso (caso ele/a tenha considerado alguma útil), armazenando-a junto aos dados de entrada no sistema para formar um novo caso na base de conhecimento.

Após submetido à verificação, não foram computados erros de execução do sistema. Os scores obtidos com a treino e teste dos modelos foram documentados e os modelos escolhidos foram otimizados segundo métricas específicas. Resultados de validação com especialistas apontaram para melhorias, mas também endossaram a capacidade do sistema de inferir técnicas de forma semelhante à um especialista humano. Vale mencionar que, dada a complexidade do conhecimento e as diferentes experiências profissionais dos validadores, houveram situações em que especialistas divergiram fortemente entre si durante a análise de um mesmo cenário proposto. De qualquer forma, o sistema foi capaz de indicar as mesmas CITs que os especialistas em 75% dos casos.

Considerações Finais

A complexidade de desenvolvimento desta pesquisa foi dupla: coletar e organizar dados suficientes em um ramo de conhecimento empírico; e traduzir adequadamente tais habilidades complexas em um sistema computacional de fácil usabilidade. A primeira foi abordada através de uma pesquisa ampla em literatura, internet e experiências empíricas que resultaram em categorias de base para a organização de um dataset baseado em evidências sólidas de uso adequado de cada CIT. A segunda foi resolvida através de um modelo de inteligência artificial que utiliza duas inferências para traduzir os inputs do usuário em técnicas adequadas, contando com interface gráfica e hospedado em nuvem para uso online.

Em geral, o sistema foi bem recebido por validadores e outros usuários. Os cíclo demonstraram a capacidade do sistema em crescer com pouco esforço, mostrando o potencial de se tornar um extensivo agregador e guia no uso de CITs. A taxonomia e meios de categorização empregados foram validados pelos especialistas. Dado o número de técnicas e categorias já inclusas no sistema, avaliadores indicaram a importância de testes em situações mais realistas, submetendo a aplicação a um maior número de usuários com diferentes níveis de experiência.

Palavras-chave: Inteligência Artificial; Criatividade; Inovação; Design.

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LIST OF ABBREVIATIONS AND ACRONYMS

AI - Artificial Intelligence

CBR - Case-Based Reasoning

CIT - Creativity and Innovation Technique

COOL - CLIPS Object Oriented Language

CSS - Cascading Style Sheets

DSS - Decision Support System

GBRT - Gradient Boosted Regression Trees

GUI – Graphical User Interface

HTML - HyperText Markup Language

LogReg - Logistic Regression

ML - Machine Learning

UI - User Interaction

UX - User eXperience

SUMMARY

1 INTRODUCTION

Design skills have been continuously present in human endeavors. Humans have designed throughout history, in virtually every field of knowledge: from creating artifacts, tools, hunting tactics, planting methods, and explanations to the world around us; to modern views of developing new products, services, software, social organizations, and our day-to-day life. Problem solving is an intrinsically human ability, whether by consciously using a systematized method or by unconsciously following intuition. Humans are so good designers that, in current society, every single anthropological artifact and experience we have perceived through the lens of design (LATOUR, 2008). Our products are industrialized, our services are structured, our food production is systematized, and even many of our interactions with nature happen in places designed to such ends.

To achieve results with design, humans need to somehow think differently and approach situations with new perspectives. Problems cannot be solved by thinking the same way we used to create them (VIANNA *et al.*, 2012). The creative impulse, present in any problem solving endeavor (DORST; CROSS, 2001), is thus an intrinsic ability to any human, such impulse was fundamental to achieve our current technological level. Naturally, with the raising complexity of human society and scientific developments produced after the first industrial revolution (mid-18th to beginning of 19th century), design grew gradually apart from arts and crafts (PAHL *et al.*, 2006). At the same time, craftsmen ceased to be the only responsible for every design stage, from manufacturing to sale (FORTY; SOARES, 2007). Solutions became more complex to conceive and produce, while society needs became more multifaceted and users began requesting customized solutions to satisfy increasingly niched desires.

With raising complexity came a need for investigation of design practices, and design became a science on its own attempting to create things that serve human purposes (MARCH; SMITH, 1995). From this emerging field, many fields were derived such as design engineering, industrial design, architecture and urban planning (SCHÖN, 1983), aiming to understand explicit needs or unveil latent ones in order to address them with new solutions. Technological developments and changes on users' ways of thinking resulted on the emergence of new ways of solving problems (FORTY; SOARES, 2007), in the form of new methods and methodologies for design (PAHL *et al.*, 2006). Today, human society has reached even higher levels of complexity, requiring new approaches to deal with emerging needs. The comprehensiveness of materials, market dynamics, different users, stakeholders' needs, and many other factors, make the science of design extremely wide and intrinsically contradictory, each interested part in the development having particular and many times opposing needs (BAXTER, 2011).

To address those puzzling scenarios with ill-defined problems and broad solution possibilities, the intrinsically human ability of creation became a vector for innovation (AMABILE, 2011). The previously godly or crazed notion of creativity gave place to a substantiated knowledge base on cognitive psychology and industrial creative behavior (SOUZA, 2001). Creativity is the ability of producing new ideas that are appropriate to the proposed problem, encompassing any realm of human activity (AMABILE, 2011; KIM; ZHONG, 2017), and it is fundamental to any organization thriving to innovate, a requisite to develop sustainable businesses in most current markets (STARKEY; TOH; MILLER, 2016). Based on that, innovation can be seen as a successful implementation of ideas into the social context for the users (AMABILE, 2011; HOWARD; CULLEY; DEKONINCK, 2008). Unfortunately, creativity is still popularly neglected; it is seen as an inborn ability instead of a learnable and trainable capacity (AMABILE, 2011; BERTONCELLI; MAYER; LYNASS, 2016). Many organizations still do not think about creativity as a process capable of being improved or cultivated, and abandon it to chance or simply reject creative behavior (MUELLER; MELWANI; GONCALO, 2012).

High demands, tight deadlines and an impressive amount of information bury design teams in a struggle to find right ways forward. Short time to decide makes teams grab the first found solution and adopt it like a heavenly rule, incurring in a design fixation (CRILLY; CARDOSO, 2017). The abundant and contradictory information needed and transformed during the development of solutions requires efficient means to organize the process and retain knowledge. Many creativity and innovation techniques (CITs) arose from this need for a systematic approach for design, as conceptualizations of real design practices into concise and coherent frameworks (FORSTER; BROCCO, 2008). CITs can be seen as any framework or procedure that helps design teams by guiding the creative impulse at any stage of the creative process (FORSTER; BROCCO, 2008; TEZA *et al.*, 2016). Such techniques intend to allow a needed balance between rationality and intuition along the design process (JONES, 1992), promoting a needed flexible structure for creativity to blossom and for teams to reach strategic results. Hundreds of CITs were developed to help design, from many study fields, thus requiring new ways to deal with such quantity of valuable knowledge.

After 1990s and coming through the 4th industrial revolution, dealing with high amounts of complex information is being untangled. Artificial Intelligence (AI) befits this need for organizing large sets of information, with studies since 1930s on using intelligent machines to aid solving problems (ERTEL; BLACK, 2011). AI can be defined as "the study of how to make computers do things which, at the moment, people do better" (RICH; KNIGHT; NAIR, 2009, p. 3), and current applications are able to emulate expert knowledge and even partially demonstrate human behavior, using approaches such as data mining, expert systems, neural-networks, genetic algorithms, machine learning, and deep learning (COBO *et al.*, 2015).

Used in many social and industrial applications, AI is immersed in robotics, natural language in chatterbots, decision support systems, 4.0 industry manufacturing, internet of things, driven marketing, smartphone apps, games, among many others (MAKRIDAKIS, 2017). AI in society has grown tremendously in the last decades and is behind many of current technological developments. On 1990s, it seemed unreasonable to think about self-driven cars, or computers reaching human intelligence, but both are in the brink of happening (MAKRIDAKIS, 2017). As AI impacts society, its applications also merge with design practices in the form of software and methods able to aid solution development.

Computational tools are intensely used on current design practices (BACK *et al.*, 2008). From communication means, CAD/CAE/CAM software, search engines, to project management and cloud storage spaces, the craft of design is changing with new technologies emerging every year. Computational creativity support systems are examples of technological approaches on enhancing design practices. These software systems support parts of innovation developments inside organizations, contributing for stimulating or documenting the creative process (WANG; NICKERSON, 2017). Though developing a creative machine is beyond the intention of this work, there are notorious efforts on developing computational systems that perform creative thinking themselves (from arts to engineering) (DARTNALL, 2013; DIPAOLA; GABORA; MCCAIG, 2018).

The use of creativity support systems is fundamental for current design teams, speeding up tasks and grounding the creative process. Two perspectives are prominent when thinking about future creativity support systems to aid organizations: 1) the development of an integrated software with a large library of CITs that covers the entire creative process, which includes centering information provided by different knowledge areas; 2) and the development of a modular system encompassing different tools for communication, application of techniques and concept development, all with integrated use of information (GABRIEL *et al.*, 2016). This work befits the first perspective, aiming for a Decision Support System (DSS) for creativity with potential to include a wide set of CITs from different fields able to interpret the user's scenario and offer adequate techniques to boost creativity and innovation.

This research derived from a master thesis (BOTEGA, 2016; BOTEGA; SILVA, 2020). Previous works incurred on a Knowledge-Based System using rules and object-orientation to select appropriate techniques based on 9 Boolean questions. This research deepens on creativity processes behind design methodologies, targeting a more complex, refined and scalable form of CITs categorization and users' creative context evaluation. By using Machine Learning (ML) algorithm in the development of the DSS, the research aim is to iteratively improve CITs' assertion capabilities, ultimately offering a wide computational resource to help design teams from problem definition to prototyping and testing.

1.1 RESEARCH PROBLEM

As an interdisciplinary effort, the development of new products and services requires knowledge from various fields, each with particular approaches to problem solving and all with importance in promoting innovation. Organizations are gradually focusing on innovation and encountering difficulties to understand the creation processes due to several misconceptions of the term and the belief that creativity is intrinsically chaotic. The lack of consensus and basic structure for creation efforts in such scenarios make difficult gathering such unstructured and uncentered information produced by both market and academia on this field.

Practices generate procedures that become methods, techniques and tools to aid creativity and innovation in organizations. Marketing, engineering, industrial design, accounting, management, and anthropology have particular and overlapping practices that help delivering a higher innovation potential. With several nomenclatures and coinciding approaches, many CITs are created and disseminated in isolation inside each knowledge field. Many organizations use inappropriate CITs despite of the existence of better suited ones (KOWALTOWSKI; BIANCHI; DE PAIVA, 2010). This occurs mainly due to a lack of expertise on creativity and its techniques, a lack of knowledge on how to integrate such techniques to the development process, or even a lack of acceptance of the approaches because they seem too theoretical and deviate from reality (ALBERS *et al.*, 2014). Every CIT has inherent characteristics derived from the situation that originated them, such as use of physical models, verbal discussion or templates; difficulty level of execution; appropriateness to divergent or convergent creation phases, adequacy for group or individual execution; among others.

When crossing such individual, collective and organizational factors to the nature of each CIT, and adding the great number of techniques developed so far, the amount of information generated demands an AI approach to be solved. Previous works (BOTEGA; SILVA, 2020) provided information on viability and importance of a system to integrate such extensive knowledge, but it was unable to provide a higher refinement and include higher numbers of techniques. The used representation model and inference process would not allow a manageable and verifiable system, because an increase in the number of CITs on the database would incur in a proportional raise in the number of techniques exported to the user per use. Nevertheless, it is important to mention that most of CITs available at the master level prototype were not known by system evaluators, showing the need for more robust approaches to consolidate and disseminate such knowledge (BOTEGA, L. F., 2016).

To organize the knowledge on CITs and better ground the implementation in this new approach, a creative process model was developed based on the identification of key events addressed by the use of CITs. Considering the iterative nature of the solutions development, the model was used to pinpoint main contexts of use for CITs that are common to most design efforts, creating a simplified ontology for organizing knowledge. It is unreasonable to use a Traditional Brainstorming, for instance, to define final concepts, as well as using Dot Voting technique to generate ideas. Matching CIT to the design situation requires a complex architecture able to ground the implementation of the Decision Support System (DSS). This problem derives into this research question: *how to provide new AI approaches to structure the creative process in organizations and enhance creativity and innovation, using an automated learning platform able to deal with the wide number of possible design scenarios and different CITs applications?*

1.2 OBJECTIVES

1.2.1 General objective

General objective of this research is the implementation of a Decision Support System to enhance creativity and innovation potential of design teams by selecting appropriate Creativity and Innovation Techniques, while inquiring and understanding the team's scenario, correlating and exposing adequate techniques, and supporting the choosing process of the user.

1.2.2 Specific objectives

- Understand the creative process that occurs within the development of products and services;
- Investigate factors that impact creativity and innovation, as well as the appropriateness of a Creativity and Innovation Technique;
- Identify sufficient relationships (correlations) among selected impact factors on Creativity and Innovation Techniques to match them to development scenarios;
- Define adequate Artificial Intelligence implementation architecture for representing the acquired knowledge in the Decision Support System, incorporating Machine Learning approaches;
- Incrementally implement the Decision Support System supported by Machine Learning approaches;
- Verify and validate the software in both academy and market.

1.3 JUSTIFICATION

The use of CITs is fundamental for innovation development in organizations, with studies presenting the correlation of use and diversity of CITs to higher success rate on development, identification of problems and new market strategies, and sales force support (GRANER; MIßLER-BEHR, 2013; THIA *et al.*, 2005). To create means of making this knowledge available, AI systems come as a powerful approach for centering and helping to filter CITs based on different organizational scenarios. If the scenario is correctly characterized, an AI approach is able to identify which CITs are adequate, and help users selecting them. As an underlying structure, the creative design scenario should also be described and understood by the prototype, making possible the correlation of inputs to adequate CIT.

Such centered and available computational knowledge might offer aid in different contexts: helping design teams to achieve higher creativity and innovation potential by matching adequate CIT to scenario; aiding with the training of less experienced team members, due to the underlying structure and the system acting as an expert and facilitator for the creation process; and even on educational circumstances to help professors to teach creativity and its techniques on academic projects without overburdening the educational process. Though reasons are explicit to use CITs, many organizations still lack knowledge in creativity and many scenarios remain limited by the use of inadequate techniques (HIDALGO; ALBORS, 2008; REISS *et al.*, 2017; YEH; PAI; YANG, 2010).

This obliviousness to creative process mediation might derive from lack of systematized information, with knowledge about CITs scattered among many interdisciplinary fields, or lack of awareness of companies about this topic. Both issues are addressed by the implementation of wide CITs selection software based on AI. Areas of management and communication already dispose of support software, but creativity enhancement is still performed superficially or indirectly on computational efforts. Other aggravating factor is the number of CITs encountered in literature. A survey based on only 14 works presents already over 600 CITs, with one work reporting 164 different techniques (ALVES; NUNES, 2013; BACK *et al.*, 2008; BEVAN, 2006; BROWN, 2009; CLEGG; BIRCH, 2007; COUNCIL, 2018a; HAVERGAL; EDMONSTONE, 2017; IDEO, 2011; 2015; SILVERSTEIN; SAMUEL; DECARLO, 2013; TASSI, 2009; THAYER-HART, 2007; ULRICH; EPPINGER, 2012; VIANNA *et al.*, 2012).

At the best of our efforts, no work was found using AI approach to help the selection of CITs based on the design scenario interpretation and usable by both experts (for decision support and consulting) and non-expert users (for learning and guidance), presenting the originality of this research. As mentioned, the objective is based on one of the pointed and unexplored future perspectives of creativity support systems, as an integrative software able to congregate a large library on CITs, covering the entire creation process (GABRIEL *et al.*, 2016).

1.4 RESEARCH FRAMEWORK

The structure of this work started with a proposed research problem and primeval objectives that based the whole literature review. Parallel development of problem and objectives occurred along the deepening in the area through papers, books, and other sources of information such as web research, contact with experts (market and academic) and personal experiences, condensing the first half of the framework. Such knowledge acquisition stage was preceded and sided by a viability study that guided the feasibility of the work and helped defining problem and objectives. Knowledge acquisition encompassed two specific objectives of the work:

- To understand the creative process that occurs within the development of products and services;
- To investigate factors that impact creativity and innovation, as well as the appropriateness of a CIT;

With sufficient knowledge acquired, its representation became necessary to achieve remaining specific objectives. The lack of established creative design processes in literature and their relationship with CITs demanded a deepening on design methodologies, searching for how creative activities are represented in different paradigms. This centering of information resulted in an aggregative categorization for CITs employment, separating their use in defined stages, present in most creative facilitation endeavors. Other impact factors on the selection of CITs were connected to create the main body of knowledge behind the DSS:

- Identify sufficient relationships (correlations) among selected impact factors on CITs to match them to development scenarios;

Thereafter, research followed with further analysis of AI literature to evaluate best computational approaches. The selected ones should support the required complexity of both knowledge representation and computational efficiency, giving that it was foresaw an increasing the number of impact factors and CITs. These requirements pointed to the use of Case-Based Reasoning (CBR) supported by Machine Learning (ML) algorithms for iterative refinement of the system, considering the increasingly number of cases in the database as an aggravating factor computational-wise:

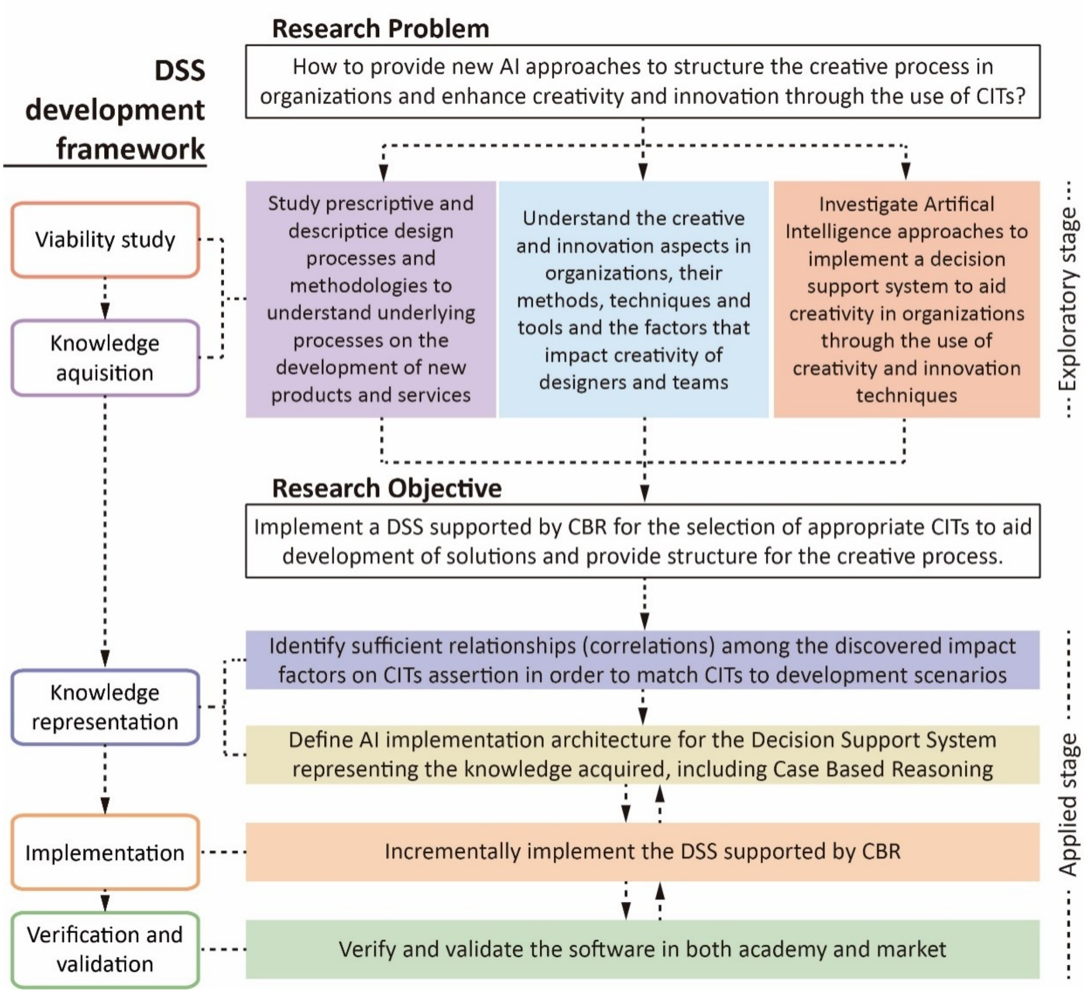
- Define AI implementation architecture for the Decision Support System representing the knowledge acquired, incorporating Machine Learning approaches;

Lastly, to achieve the general objective, the proposed architecture was executed, going through incremental implementation cycles able to embrace gradually more impact factors, more CITs, and better information treatment approaches. Naturally verification and validation of the implemented software accompanied each of the cycles:

- Incrementally implement the DSS supported by Machine Learning approaches;
- Verify and validate the software in both academy (for knowledge validation) and market (for usability and adequacy validation).

The methodology of this research is depicted in Figure 1.1, based on the structure of DSS implementation (WATERMAN, 1986) and research development framework (FETTERMANN, 2013).

Figure 1.1 – Parallel comparison between this thesis and DSS research framework.



Fonte: author, based on WATERMAN (1986) and FETTERMANN (2013)

This thesis is divided in 5 Chapters. Chapter 2 introduces the literature review on design philosophy and methodologies, as well as the adopted theory for design, creativity and innovation, including aspects of CITs. Chapter 3 presents a literature review on AI, DSS architecture and Machine Learning methods. Chapter 4 deepens in the research for knowledge acquisition and representation used in both implementation cycles, including the used architecture. Chapter 5 demonstrates the implementation, verification and validation of the models used to compose the prototype, including needed improvements promoted in the second cycle. At last, Chapter 6 closes the body of text with conclusions and future works.

2 CREATIVITY AND THE DESIGN PROCESS

AI approaches can be used to represent several different bodies of knowledge. In this research, the aimed knowledge was creativity aspects related to the design process, which offers information to understand how the CITs befit the development of solutions and which factors play key-roles on the creative design process. This Chapter presents relevant aspects of knowledge areas important to the DSS development. The design process is presented through history and foundations on design theory in Section 2.1, as well as the intersections of prescriptive and descriptive design methodologies with focus on creativity in Section 2.2. Understanding the creative process underlying design methodologies, as portrayed in Section 2.3, gives context to how creativity and innovation are faced in modern organizations, as presented in Section 2.4. As supports for these creations, the CITs and theory that supports them are reported in Section 2.5.

Most things human interact with in modern society are designed, from products, artifacts, and food production, to services, traveling ways, cities, and even interactions with nature (LATOUR, 2008). Design has transcended the act of *building* or *constructing* to a wider notion involving the articulation of signs and their dialectic interaction with humans (BECCARI, 2015). For design in corporate or business contexts, this approach brings a much more integrative perspective to the development of solutions (here perceived as synonym to *designing*).

Designing in organizations is the capacity to actively solve purposeful and constrained problems through decision making, exploration and learning (GERO, 2013), combining procedural and structured methods to heuristic and empirical experiences. Designers plan artifacts, interfaces and interactions to provide required experiences (meanings) to users, using previous knowledge to continuously design better and more refined solutions (LATOUR, 2008). This objective can be achieved through the advent of new products or software (engineering, user experience (UX), user interaction (UI), industrial design), reconfiguration of processes and practices (service and process design), or even by changing strategic perspectives (business, service and strategic design).

In order to deal with such wide variety of contexts, design became nowadays a multidisciplinary effort encompassing many areas such as engineering, industrial design, marketing, psychology, among others (BAXTER, 2011). It is important to mention that in no way designers are neutral or unbiased mediators of the process. Though based on research, empathy and techniques, there is at all points a bias on the perspective and solutions designers develop. This arises from the designers' repertoire, experience and from the culture of the society in which they live, aspects that cannot be suppressed to a point of neutrality (HEASTER-EKHOLM, 2020).

Throughout history, humans have created and adapted knowledge to develop technology and provide better conditions for life. Technology, as practical implementations of intelligence (WOODHEAD; BERAWI, 2021), has become gradually more sophisticated, and the development of new solutions in current society requires dealing with great amount of information (MARCH; SMITH, 1995). Such information arises from either natural or artificial phenomena, both studied by researchers.

In a broad definition, natural science – which includes physics, biology, and any other form of understanding the reality – is concerned with studying natural and artificial phenomena in order to theorize and justify their occurrence (MARCH; SMITH, 1995). It uses inductive reasoning to discover plausible theories (hypothesis) for such events, and deductive reasoning to justify such hypothesis by performing critical experiments attempting to falsify it (DORST, 2011).

On the other hand, design science – architecture, engineering, and any other applied science – is focused on building and evaluating artificial phenomena for serving human purposes (MARCH; SMITH, 1995). Problem-solving efforts often use abductive reasoning (making conclusions based on assumed consequences) to incorporate value and sufficiently validate the proposed solutions. Such efforts are intrinsically unfinished and are unable to provide a perfect and final answer to the needs, but are attempts to solve them given current social and technological constraints (DORST, 2011).

The exercise of developing new alternatives to aid humanity can be understood as a procedural way of making design science. From perceiving needs and finding ways of addressing them to develop groundbreaking technologies, humankind has performed design processes iteratively throughout history, which allowed us to achieve current social and technological sophistication. Though many life forms in nature use tools, humans are the only ones that design on rational ways and develop increasingly complex solutions (GABORA; KAUFMAN, 2010).

2.1 CREATIVITY AND INNOVATION AS CONCEPTS

The notion and meaning of creative thinking evolved during the centuries. First theories attributed the creative impulse to gods (mainly to the muses in Greek mythology), and humans were just vessels for their favor (GLĂVEANU, 2010). This idea evolved gradually during the centuries, but until late XIX century creativity was still related to pathological madness or uncontrollable frenzies (SOUZA, 2001). Only on modern approaches, based on cognitive psychology, creativity has been described as a learnable and trainable skill (AMABILE, 2011; BERTONCELLI; MAYER; LYNASS, 2016), in which the human brain attempts to understand and represent a situation interpreted by the senses, considered filters for disturbances caused by external factors. Creativity is acknowledged to occur in conflicts between previous and new knowledge, and the necessity to find adequate coherence to the situation (SOUZA, 2001). Furthermore, creativity is an ever-evolving concept and can no longer be seen as an individual characteristic, but as a social skill (GLĂVEANU, 2010). Interaction and information exchange are central for creativity to be developed, requiring a prominent “creative culture” in which individuals communicate with others to enhance creation capabilities (GLĂVEANU, 2010).

Creativity is an inherent human ability (NIJSTAD *et al.*, 2010) related to imagining, exploring, and ultimately pondering of possibilities based on information, knowledge, emotions, and experiences (TRAN *et al.*, 2017). This includes aspects of creation ranging from liberal arts to organizational scenarios, both requiring creativity at different perspectives and under different constraints. While creative artists as writers and composers are not necessarily bound to time and resources and are free to delay the completion of the work until satisfied, in organizational scenarios the competitive and fast pace required by the market creates a much more restricted environment for creation to occur (MOSTERT, 2007).

Novelty, as perceived by the market, is related to alternatives that were not available or did not fully address a need before launching new solutions. The idea cannot be simply fantastic, but appropriate to the original opportunity pursued (AMABILE, 2011). The same idea can be considered creative inside particular constraints (e.g. local, regional, global), but outdated in another. Not having constraints would extinguish the capacity for creative thinking (DARTNALL, 2013). Therefore, an original idea can only be considered creative in this situation if accompanied by an effective manner to achieve a goal in a particular scenario.

Such effectiveness might be perceived as an usefulness to solve a need (either social or economic) (RUNCO; JAEGER, 2012). Creative developments inside organizations are bound to constraints of time, resources, technology, among others. Such factors impose several limitations to reach a solution as soon as possible in order to maximize revenue, aiming to reach and/or satisfy markets before competitors. Creativity does not guarantee the success of an organization, but lacking it might incur in long-term failure (HOWARD; CULLEY; DEKONINCK, 2008).

Beyond individual level, creativity is related to collective and organizational perspectives (GABRIEL *et al.*, 2016). In organizational scenarios creativity might be described as “the process of sensing difficulties, problems, gaps in information, missing elements, something askew; making guesses and formulating hypothesis; possibly revising and retesting them; and finally communicating the results” (SPUZIC *et al.*, 2016, p. 5, p. 5). This notion puts in evidence a duality inherent to creativity: an ideation (divergence) and an evaluation (convergence) phase.

Design and creativity are social, and thus subjected to a shared condition. This includes the team state, composition and behavior aiding in the exchange of information, which is one of the bases for creativity enhancement. Though ideas appear on individual level, the process of creation in a team is boosted if team members use developments from other contributors to better base their ideas (MOSTERT, 2007). The organization has also a deep influence on creation levels, offering an adequate environment, being concerned with the team’s composition and well-being, and providing an overall innovative-centered culture (GABRIEL *et al.*, 2016). This notion points to a division among impact factors for defining the adequacy of CITs: individual factors, team or collective factors, and organizational factors.

A novel idea is the predecessor of a creation, which incorporated usefulness to the novelty. For organizational purposes, aiming revenue or not, such creations do not yet guarantee a market acceptance (BAXTER, 2011). The generation of an idea and its validation as a creation does not account to an impact on society, which would characterize an innovation. Innovation requires the implementation of such creative concepts into solutions for the users (AMABILE, 2011; HOWARD; CULLEY; DEKONINCK, 2008), meaning that every innovation is necessarily social (SHARRA; NYSSENS, 2010). Creativity can therefore be seen as a fundamental part of innovation, feeding the process with ideas that can be adequately implemented using the second (ANDERSON; POTOČNIK; ZHOU, 2014).

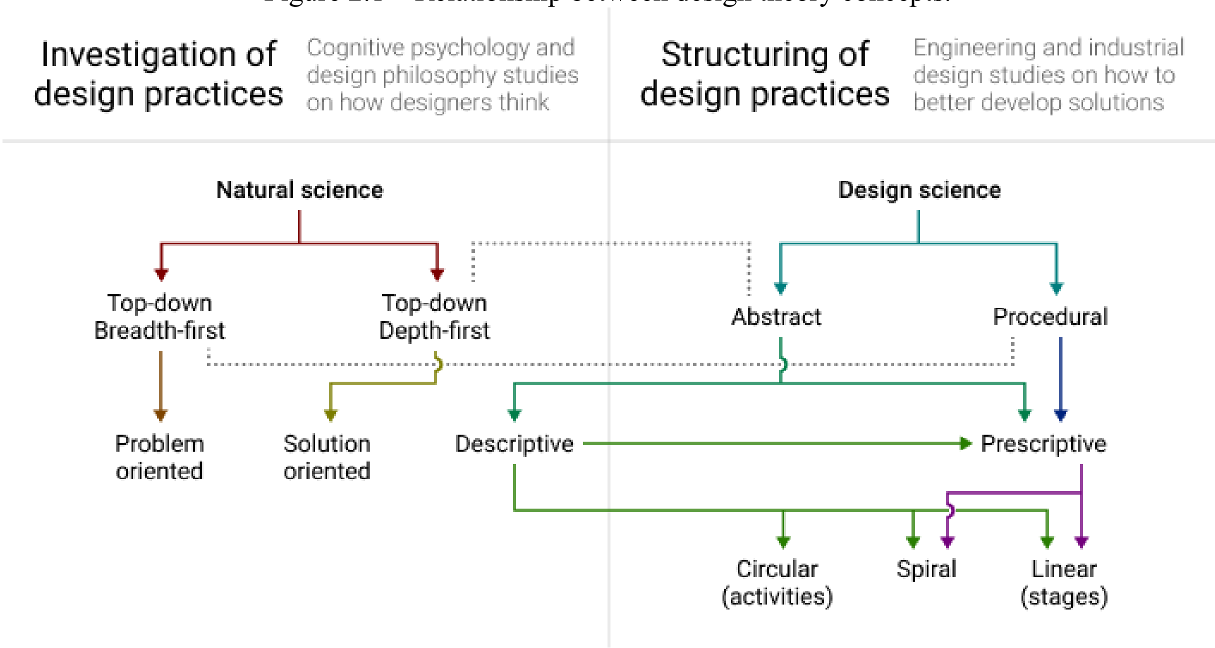
Innovation sets boundaries to the creation process. Lack of innovation would be incompatible with social and market needs, generating large amounts of useless information; on the other hand, lack of creativity would be unable to provide matured ideas, many times neglecting more appropriate solutions (BACK *et al.*, 2008). Both should be balanced on organizational scenarios to provide sufficient divergence of ideas, but converge the work to fulfill the task (AMABILE, 2011).

2.2 PERCEIVING THE DESIGN PROCESS AS A SCIENCE

Given the growing complexity of human problems, developing solutions to fulfill such innovation demands has also become a more intricate art. Systematic design processes to develop solutions emerged on the 20th century to fulfill a gap for a rational and consistent way of designing, which was previously an empirical effort (BALL; ORMEROD, 1995). The study of design philosophy gave way to two different approaches to understand solutions development. The first is based on perceiving and theorizing how "designers design" in practice, and thus a form of natural science according to MARCH and SMITH (1995). The term "natural science" is perceived by these authors as efforts that try to understand reality and explain how and why people act in a particular way. The second approach is based on proposing how design efforts should occur, and thus a form of design science also according to MARCH and SMITH (1995). In the authors understanding "design science" is perceived as efforts concerned with creating things (in this case methodologies) to serve human purposes. This separation is shown in Figure 2.1.

Pioneers investigators of the design process on early 20th century noticed reoccurring patterns on real design activities and verbal protocols (BALL; ORMEROD, 1995). Such empirically-based psychological studies began the condensation of a rather informal knowledge into consistent models in the 1950s onward, which still have great impact on current methodologies. Models are propositions of relationships between constructs (vocabulary of a domain), as a simple description of "how things are" (MARCH; SMITH, 1995), while methodologies are combinations of problem-solving philosophies (models), a set of principles, and problem-solving systematizations (methods) (LUTTERS *et al.*, 2014).

Figure 2.1 – Relationship between design theory concepts.



Source: author

Most of those initial researches with experts identified the use of top-down and breadth-first strategies, decomposing a problem in hierarchical goals and sub-goals that allowed the planning of an ordered sequence for solution-finding (BALL; ORMEROD, 1995), for then decomposing such sub-goals into a sequence of activities. This problem-oriented approach establishes that the design should start with an abstraction of the problem and thorough analysis prior to solution generation, with the designer focusing more on what he learned during current developments than using previous experiences (WYNN; CLARKSON, 2010). The solution development would then occur in a modular and integrated form, starting from such abstract instances and evolving until reaching the desired level of detail (BALL; ONARHEIM; CHRISTENSEN, 2010). This means that designers should develop all sub-stages of the problem in one level of detail (e.g. conceptual development) before advancing to the next level (e.g. modeling and prototyping).

With further studies on design during 1980s (BALL; ONARHEIM; CHRISTENSEN, 2010), researchers noticed that expert designers often violated such stepwise and breadth-first structure, employing in many situations a top-down and depth-first way of thinking (BALL; ORMEROD, 1995). When experienced designers were interposed with complex or unfamiliar goals, they attempted to explore solution ideas to foresee future problems, and usually skipped the sequential procedure and developed more concrete ideas from the beginning. After all, it is unrealistic to expect from human mind to behave linearly, as it should be free to jump from one idea to the other as intuitively as possible (JONES, 1992). This opportunistic behavior (BALL; ORMEROD, 1995) was reported in many studies and later surveys on software engineering reported up to 53% of designers deviated from pure top-down breadth-first model (GUINDON, 1990). This solution-oriented approach envisions going through the whole design process from abstract to concrete iteratively (i.e. one increment at a time) until performing all tasks and reaching the final goal. It can be seen as a more “try and see” model of proposing a possible solution and iteratively refining and restructuring it (WYNN; CLARKSON, 2010).

Both breadth and depth-first models have advantages. The first minimizes commitment to highly detailed design decision on initial stages and subdivides the work to be simultaneously developed modularly by small and independent teams (BALL; ORMEROD, 1995). The second provides information about development viability at the beginning of the process, when the design can be discontinued with minimal spent time and resource allocation (BALL; ONARHEIM; CHRISTENSEN, 2010). The early exploration of solution ideas allows experts to evaluate the viability of uncertain concepts and gain confidence in their potential relevance for the global solution (BALL; ONARHEIM; CHRISTENSEN, 2010). From 1990s onwards, research on the field reached a consensus that both models are mixed on practice and their combination is a much more precise model for thinking about solution-development (BALL; ONARHEIM; CHRISTENSEN, 2010).

2.3 REPRESENTING THE DESIGN PROCESS WITH DESIGN METHODOLOGIES

Models of thinking derive into methods and methodologies of designing, here defining methods as representations of a model into tasks and results (MARCH; SMITH, 1995). To cross the bridge from how designers think or act to how the design practice can be described, several propositions can be used to organize and understand such complex effort. Though the methodologies might differ, each has adequate situations of use and might be adapted to different scenarios.

Top-down breadth-first model of design is a cognitive classification that resulted on several propositions of how the design process logically occurs, meaning what steps designers tend to follow to achieve good solutions. Entering the design science spectrum, propositions using this logic are focused on reaching a great discretion of activities for design (breath-first) and on going through successive stages of abstraction until reaching the needed detail (problem-oriented). Such paradigm reflects on a procedural approach for solution developing (as seen on the right part of Figure 2.1), in which the design process is seen as inherently staged and should be represented as a concrete and stepwise structure (WYNN; CLARKSON, 2010).

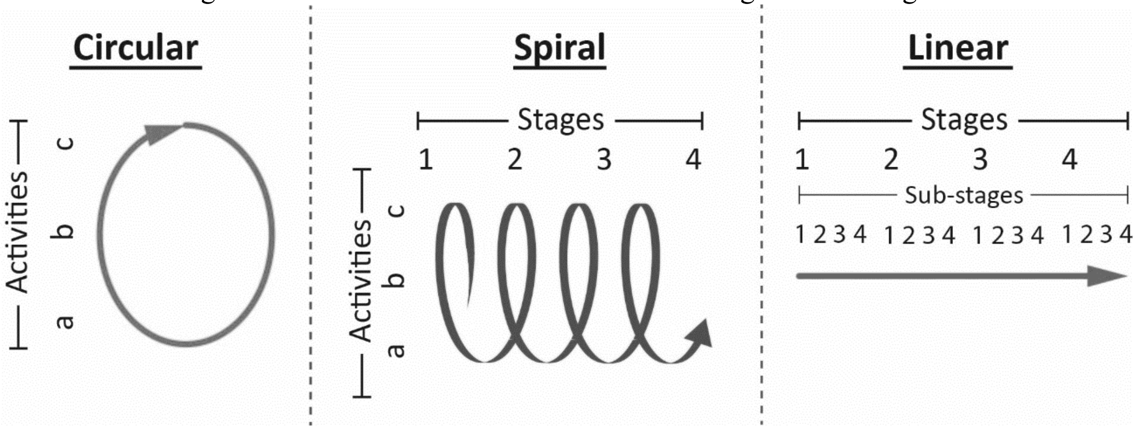
Around this procedural view of design activities, a series of prescriptive methodologies were proposed and are used in both market and learning contexts, especially in engineering (WYNN; CLARKSON, 2010). This paradigm is grounded on offering stepwise information (guide) for designers on what to do in order to develop solutions (COSTA *et al.*, 2015). Such methodologies do not intend to be an accurate representation of real design practices, but guidelines on how to better design or how design "should be done" (ECKERT; STACEY, 2010).

In contrast, top-down depth-first models incurred in a much more abstract approach for understanding design science propositions, in which the development process has a basic direction but not an organized structure of activities to happen (WYNN; CLARKSON, 2010). This paradigm considers that, when interposed with a problem to solve, designer's experiences will help him or her automatically structure a process using previously acquired knowledge and skills, thus not requiring a thorough systematization of activities.

Abstract models give way to proposition of prescriptive methodologies based on how the design process occurs in specific scenarios, but also to descriptive methodologies (WYNN; CLARKSON, 2010). These are commonly representations of one or more real development efforts, focusing on describing which practices are coherent with the goals of the design (GERICKE; BLESSING, 2011) and capturing knowledge on "how work is actually done" (COSTA *et al.*, 2015). Descriptive models tend to provide a set of heuristics based on superficial or generic macro-phases, rendering to designers the responsibility to follow personal lines of action. Descriptive models are considered a form of natural science (MARCH; SMITH, 1995), because they derive from observation of real practices, though they can be used to ground new prescriptive models (GERICKE; BLESSING, 2011), which in turn belong inherently to the spectrum of design science (MARCH; SMITH, 1995).

Most current methodologies tend to be grounded on either prescriptive or descriptive model but incorporate features from the other to better adequate their configuration to the needs from design teams. When proposing new methodologies, activities and design stages can be composed in different arranges, as seen in Figure 2.2.

Figure 2.2 – Different method natures from design methodologies.



Source: author based on WYNN and CLARKSON (2010)

Linear methods, as seen in the right part of the figure above, mostly derive from prescriptive models, and are one of the main branches of product and service development studies in engineering (e.g. ASIMOW (1962), PAHL *et al.* (2006), (BACK *et al.*, 2008), ULRICH and EPPINGER (2012)). They are overall staged and serial (procedural), in which completing a phase is partially or completely necessary to advance to the next. Some approaches in descriptive models also use linear templates to represent the design process (e.g. (IDEO, 2011) and (COUNCIL, 2015a)). Circular methods, on the left of Figure 2.2, usually represent descriptive models, since they do not intend to present a set of stages for development, but a set of activities that may be repeated constantly until the required detail is met (e.g. PDCA cycle (ISNIAH; PURBA; DEBORA, 2020), Circular Design (Ellen MacArthur FOUNDATION; IDEO, 2017), SCRUM (SUTHERLAND; SUTHERLAND, 2014)). Intermediate spiral methods, on the center of Figure 2.2, incorporate general stages, but set activities that reoccur along the design process, being a hybrid combination of both prescriptive and descriptive depending on the given focus (e.g. BAXTER (2011)).

Creativity is intensely immersed in both prescriptive and descriptive approaches, for it is fundamental for the design practice to occur. All projects inside an organization require a level of creativity, and by analyzing design approaches the creative design process can be evidenced. Procedural and linear methodologies, which are intensely used in training and engineering teaching, might not reflect the actual reasoning process behind designing for lacking the inherent iterative nature of thinking and problem-solving. Such structure can be perceived in most modern design methodologies (GOMEZ, 2005), though the procedural paradigm is not a consensus among designers (BAXTER, 2011). The linear process might guide students into believing that their natural thinking processes are inadequate (GOMEZ, 2005) and interfere with the learning of inherently non-linear phenomena like creativity due to a too rigid structure, making difficult for them to perform effectively in real scenarios (MUNARI, 2018). Searching for intersections among different methodologies may reveal important components for creativity enhancement, as well as being an important factor when defining adequate CITs.

2.3.1 Prescriptive design as a staged effort

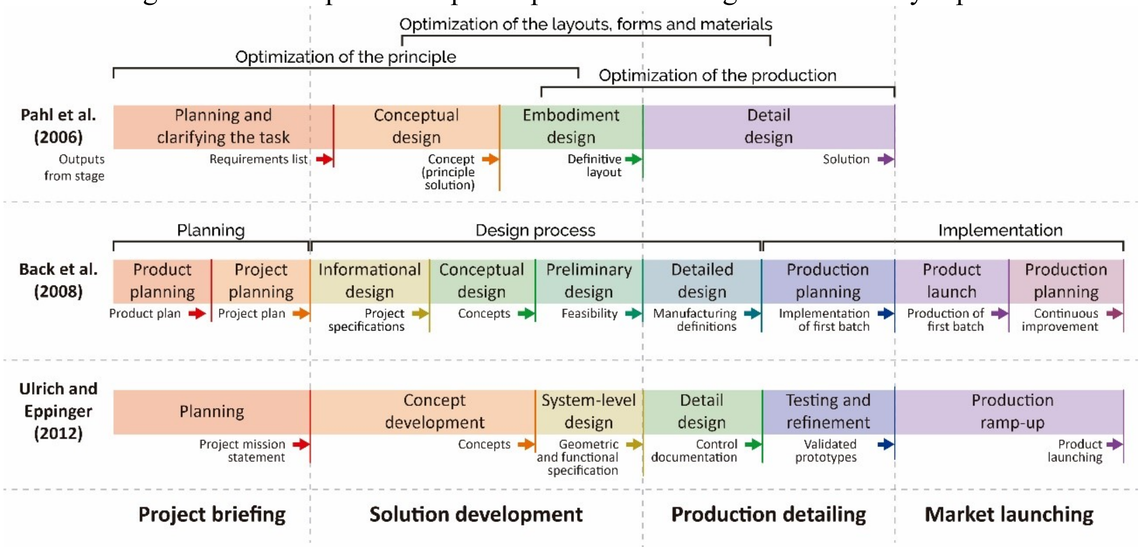
First developments on design methods date from middle of 19th century, with several propositions until early-mid 20th century (PAHL *et al.*, 2006). Developments until mid-20th century did not successfully describe the design process but gave a solid basis for both prescriptive and descriptive later developments. The systematic approach pioneered in the 1920s Germany, grounding the rudiments of what is currently called prescriptive models as stepwise, iterative and conflicted in nature, with most propositions deriving from engineering fields (PAHL *et al.*, 2006).

Prescriptive linear methodologies have a great importance for design training and refinement, organizations using them to consolidate and structure an overall process method for solution development. The prescriptive model is a tentative of generalizing the design practice to guide the design team in many situations, hence most methods leaving room for adaptation (GERICKE; BLESSING, 2011). However, most of these methodologies were developed based on complex engineering product developments, especially ones with high technical profile and larger number of components. While the idea behind is to fit a general method into many particular cases, adapting them to foreign scenarios may lead to misunderstandings.

Among the description of activities, the creative process is naturally delineated and divided in phases. It usually begins with the transformation of users' needs into a list of technical requirements, delegating the prior discovery of such needs to other areas. This is then followed by an abstract components creation phase to be then modeled and prototyped for defining architecture, materials, tolerances and manufacturing approaches.

Three traditional engineering methodologies were selected to evaluate prescriptive paradigms: PAHL *et al.* (2006) as one of the most traditional engineering methodologies employed and an important milestone that influenced several other studies; BACK *et al.* (2008) as a methodology developed at UFSC and with influence on several engineering programs in Brazil; and ULRICH and EPPINGER (2012) as a more recent methodology with good acceptance in the market. Figure 2.3 presents in parallel three of these methodologies, representing the proposed stages and main activities. Stages were divided by similitude, first focusing on project planning, second on solution development, third on manufacturing specifications, and last on market launching. Used nomenclature at the bottom of the figure will be used to draw a parallel between prescriptive and descriptive methodologies and provide a better division of the creation process inside methodologies. Some methodologies do not encompass the whole design process, focusing on specific stages.

Figure 2.3 – Comparison of prescriptive methodologies on creativity aspects.



Source: author

By comparing the three methodologies, a clear procedural trend can be seen which reflects on the problem-oriented practices from engineering design in organizations (WYNN; CLARKSON, 2010). All methodologies present specific stages with activities to be done before advancing to the next, with a comprehensive step-by-step structure (that will not be presented here). Even with recommendations of parallel activities from one stage to the other, the process goes from abstraction to concretization through a series of iterations involving synthesis and analysis, which is a key component of the problem-oriented approach.

Four main phases can be distinguished throughout the stages: first a concern with the problem to be addressed; followed by primary attempts to solve the problem conceptually and then with models and prototypes; then a technical production phase in which generated solution is prepared for manufacturing; and at last a market-focused stage for implementation of the solution. Second phase of Solution Development is particularly highlighted in such methodologies, coming from the design engineering background. The four phases give hint to how creativity develops alongside the methodological process, acquiring different focuses on each part: creative problem discovery, creative solution-finding, creative definition of manufacturing requirements, and creative means to implement the solution.

The prescriptive and linear models of such methodologies give freedom to the inclusion of descriptive methodologies elements. As said, most modern literature tends to apply a mix of prescriptive and descriptive models (WYNN; CLARKSON, 2010) to achieve a more realistic representation of the design process but still provide a structure for training and teaching. For example, ULRICH and EPPINGER (2012) assume modeling and prototyping as fundamental throughout the whole design process, from opportunity identification to later testing; while BACK *et al.* (2008) portray a series of design practices that might improve creative thinking, as well as conditions that might block it in specific contexts.

It is important to notice, though, that depending on the stage definition from each literature, the borders among the four creative process phases may be blurred. For instance, on PAHL *et al.* (2006) the requirements definition list occurs during the first stage of development (*Planning and clarifying the task)*, though this activity is inherently related to *Solution Development*. This can be noticed in both BACK *et al.* (2008) and ULRICH and EPPINGER (2012) bringing this activity on later stages (*Informational design* and *Concept development* respectively).

2.3.2 Descriptive design as a representation of design practice

Similar to the engineering developments in prescriptive methods, research deriving from psychology and industrial design focused on understanding and representing cognitive models of how designers design in practice, supporting their research on cases and protocol analysis (FINGER; DIXON, 1989). Dating from the second half of the 20th century, such pioneers works (CROSS, 1984; SCHÖN, 1983; SIMON, 1969) gave foundation to what was then denominated descriptive models (FINGER; DIXON, 1989).

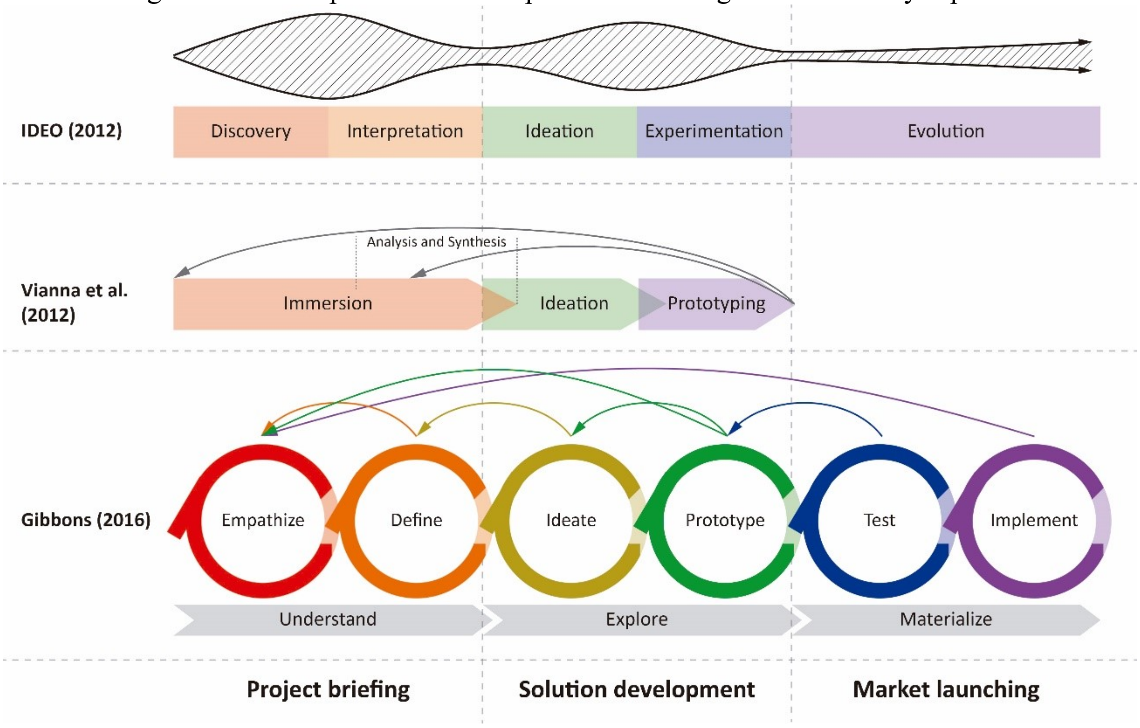
The approach intended to scope which practices were successful and describe them to aid design, but without aiming for a general stepwise method to guide every type of solution development. This approach derived on several methodologies that focused on creating heuristics or “recommended practices” that might result in better solutions. The discovered prevailing phases, though presented sequentially, are not seen as a step-by-step guide, but an overall direction immersed on several heuristics of how the project should run. Descriptive methodologies use methods, techniques, tools, mindsets, and recommend practices to allow an adequate development instead of a thorough structure of activities. The unfolding of activities and tasks is rendered to the designer or design team, based personal experiences on design (GOMEZ, 2005).

In fact, descriptive methodologies tend to see the beginning of projects as inherently fuzzy, in which several opportunities appear and should be explored. By enduring such chaotic beginning and persevering on creating value the process starts to untangle, and the best concepts begins to gain form. With solid concepts, validated with stakeholders, having potential economic viability, and technical feasibility, the process of delivering it to the market is considerably simpler and linear.

Prominent descriptive methodologies of Service Design, Human-Centered Design and Agile Methodologies gained popularity on the last decade for being applicable to open and complex problem situations (DORST, 2011). Three descriptive methodologies, two linear and one circular, are presented on Figure 2.4: the first (IDEO, 2012) as a methodology based on practices of a major consulting organizations on innovation; the second (VIANNA *et al.*, 2012) as a methodology based on practices from a Brazilian consulting organization on technology and innovation; and the third (GIBBONS, 2016) as a methodology developed by the Nielsen Norman Group for user experience research, training and consulting. The used nomenclature at the bottom of the figure is used later to draw similitude between methodologies. First line of the table shows the similarity of phases along need finding and problem definition, second focuses on ideation processes, and third on implementation and economic viability. Bottom line presents main heuristics recommended by the authors.

Other recommendations include intensive iteration throughout the process, embracing ambiguities that are inherent to the development of solutions (IDEO, 2015), constructing interdisciplinary teams, divergent and convergent iterative thinking, knowing when to give up on an idea or project, realizing every product is a service (BROWN, 2009), among others. As stated, the descriptive methodologies do not define accurately a sequence to the phases. The inherently iterative view uses the three stages merely as a general outline for design.

Figure 2.4 – Comparison of descriptive methodologies on creativity aspects.



Source: author

Descriptive methodologies, in a first analysis, present a similar structure from prescriptive ones, though only using three phases. The development starts with a creative discovery of the problem, goes through a solution-finding process, and ends with seeking ways for implementing solutions in the market. The methodologies tend to skip or dilute the technical manufacturing phase because main applications focus of such approaches is on software, services and simple products. Also, a highlight is given on the first part of Project Briefing, intensely using of methods and techniques to define and redefine constantly the briefing. Biggest difference from prescriptive approaches can be seen in the heuristics, which makes real development processes empirical and solution-oriented (WYNN; CLARKSON, 2010). As a systematic step-by-step is not present, a high abstraction can be perceived in which the designer can jump from one stage to the other freely, especially by bringing users to the development and collect feedback iteratively.

Current research in design reached a virtual consensus that the use of design methodologies improves quality and success rate of projects (BACK *et al.*, 2008; BAXTER, 2011; CLARKSON; ECKERT, 2010; GOMEZ, 2005). The structure provided by such methodologies is fundamental, though incorrect match of methodology to project may be harmful (WYNN; CLARKSON, 2010). With the abundance of available design methodologies, it is unreasonable to assume that one methodology may be efficient to every design scenario, but that designers should construct or assemble their own practices to each design effort based on previous knowledge about design (GOMEZ, 2005).

2.4 OUTLINING THE CREATIVE DESIGN PROCESS

Underlying all the presented methodologies, the creative design process becomes evident by using the separations highlighted in Figure 2.3 and Figure 2.4. Regardless the approach, the creative process is very similar inside different propositions and the stages can be delineated for both prescriptive, which are more solution-focused, and descriptive, which are more problem-focused, methodologies. The approaches are complementary and none of the presented methodologies are exclusively prescriptive or descriptive, but rather combinations of both. Currently, design research support organizations in the implementation of better strategies, methodologies, methods, techniques and tools for addressing opportunities on the complex and competitive global market (GALLEGO; MEJÍA; CALDERÓN, 2020; ROBERT *et al.*, 2020).

A parallel among methodologies can be perceived in terms of outlining a common creative process. Overall, four different creative aspects are condensed and focus on different components of the development process:

- Project Briefing: focus on creatively defining the problem brief, seeking to achieve the highest possible innovation potential. Both approaches aim to define the problem to be addressed taking into consideration economic viability, technical feasibility and market needs. Prescriptive approaches give a slightly higher focus to the first two, while descriptive approaches focus on the third. In both, a creative divergence and convergence process can be perceived, and a concise briefing is expected at the end of the phase;
- Solution development: central point is the creative development of a solution, incurring both in wide generation of possibilities and maturing of them into a concise answer to the proposed problem. In both approaches a clear creation process of divergence and convergence can be seen, but with different approaches. Prescriptive approaches tend to separate the conceptual ideas from the body of the solution, while descriptive develops parallelly ideas and models. Descriptive models put also a higher emphasis on the iterative nature of creation, while prescriptive ones are more linear. Overall, the methodologies start by defining requirements, and go to

concepts ideation, selection, modeling and prototyping to reach a sufficiently mature solution;

- Production detailing: with a proposed solution, creation focus becomes "making it real" and several manufacturing or concretization processes can be used to such ends, incurring on required machinery, blueprint detailing, final geometry and materials definition, and many other aspects. Though requiring lesser levels of creativity, this detailing process is fundamental to achieve a concise production or implementation plan. For being naturally more complex, prescriptive methodologies assume this as a separated phase from solution development, while descriptive focus directly on means of implementation that may not require an extensive manufacturing process;
- Market launching: creativity is finally used to put the solution in the market, developing business plans (if not done yet) and iteratively refine solutions. This includes in both prescriptive and descriptive the development of pilot batches, alpha and beta try-outs, feedback retrieval and market monitoring.

Similarities between the approaches are evident based on the exposed information. Creative activities behind each phase are similar and hint for a loop inside each part, although the process is permeated with particularities. Main differentiating point is the opportunistic behavior, in which an idea at the first part can be immediately discarded or remodeled by thinking on further phases, or new-found information on later stages can be used to remodel great part of the previous creative work. As previously said, this work aims to implement an AI support system for CITs assertion but focusing on the first two phases, which are more intensely attached to the creation of a solution (first defining constrains and second defining the solution itself). Therefore, last two phases will not be further explored.

Though presented in a sequential fashion, descriptive methodologies are inherently iterative and even prescriptive linear methodologies often mention the need for constantly revising and reevaluating previously defined parts. The non-sequential view derives from the idea that problem understanding and solution-finding are developed parallelly throughout the design process (DORST; CROSS, 2001). This co-evolution implies on the cyclic nature of the creative design process, some activities repeating several times before reaching a satisfactory solution. Problem-space and solution-space should evolve together, the designers constantly double-checking and trying to refit problem and solution given changes on the boundary conditions encircling the development (DORST; CROSS, 2001). Adopting an adequate CIT also includes understanding the needs for loops in the design process, breaking the linear frame when necessary.

Regardless the nature of design, creativity and innovation are improved by a good understanding of the available methods and techniques that allow a structured and flexible approach for problem-solving. While prescriptive and well-structured methods of design can benefit from new techniques to refine practices and avoid always thinking the same way, descriptive strategies can benefit from the structure provided by traditional methods and techniques, but without losing the flexible nature of such problem-solving approaches. The selection of adequate practices that allow a balance between planning the problem and finding adequate concepts, given the boundary conditions to the development, is fundamental to match problem to solution method, raising the creative potential and the possibility of reaching innovative solutions.

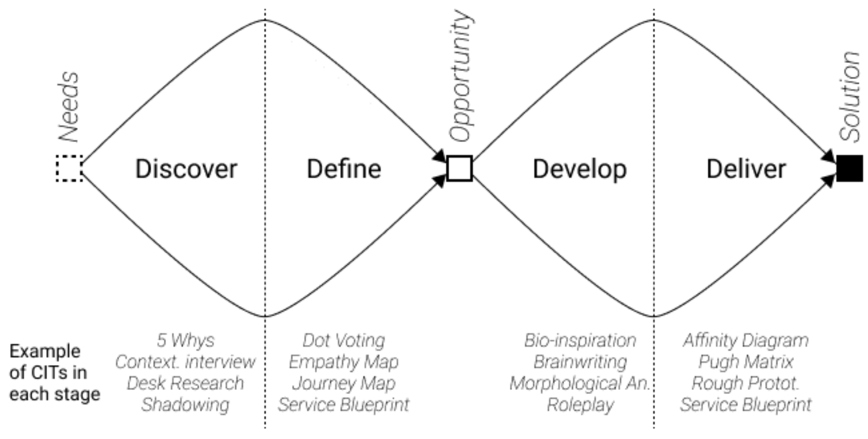
As perceived throughout the presented design methodologies, creativity plays a key role on developing adequate solutions and is fundamental to innovate. The matching of methodology to design scenario becomes a background to the use of adequate methods, techniques and tools to aid design, thus several Creativity and Innovation Tools (CITs) were proposed and are intensely used. Throughout the decades, different CITs were proposed and many are used in a daily basis in design efforts. On this context, AI systems may help in several dimensions, from aiding the selection of adequate techniques to the team scenario (as in this work), but also to help with facilitation, creative information organization, and even triggering impulses to spark designers' creativity. The emergence and use of CITs come as aids inside a creative design process, in which they can be used to enhance practice, contour blocks, or even constrain the team to follow a needed scope.

2.4.1 Fundamentals of the creative design process

Many factors influence the creativity of a team and the practice of a creative design process. On a collective level, the creative potential is positively influenced by the team diversity (multidisciplinary composition) and adequate size, a good relationship among members, the inclusion of users and other stakeholders on the development, sufficient expertise, adequate motivation to solve the task, freedom, among (AMABILE, 2011; GABRIEL *et al.*, 2016; IDEO, 2015; MOSTERT, 2007). On an organizational level, the creative design process is influenced by the innovative culture of the company, with factors positively impacting creativity such as clear problem definition, availability of resources, adequate extrinsic motivation, good managerial practices, adequate communication means, definition of work methodology and methods, available infrastructure, among others (AMABILE, 2011; BROWN, 2009; GABRIEL *et al.*, 2016; IDEO, 2015). These factors and many others can be mapped to perceive their influences on creativity, and then be used to assert adequate CITs

Two distinct creation cycles can be perceived throughout the design process. The first intends to better understand the problem (identify customers' needs and organization's capabilities) and reaches a sufficiently mature briefing (pre-established target specifications), and the second starts with such problem definition (requirements list) and ends with a tested concept solution (generate, select, and test product concepts) to be sent into production (plan downstream production). This model can be better represented by the Double Diamond methodology (COUNCIL, 2015a) presented on Figure 2.5, depicting the two cycles as successive divergences and convergences, but without deepening to how the processes occur inside each diamond.

Figure 2.5 – Double Diamond methodology of design.



Source: author, based on (COUNCIL, 2015a)

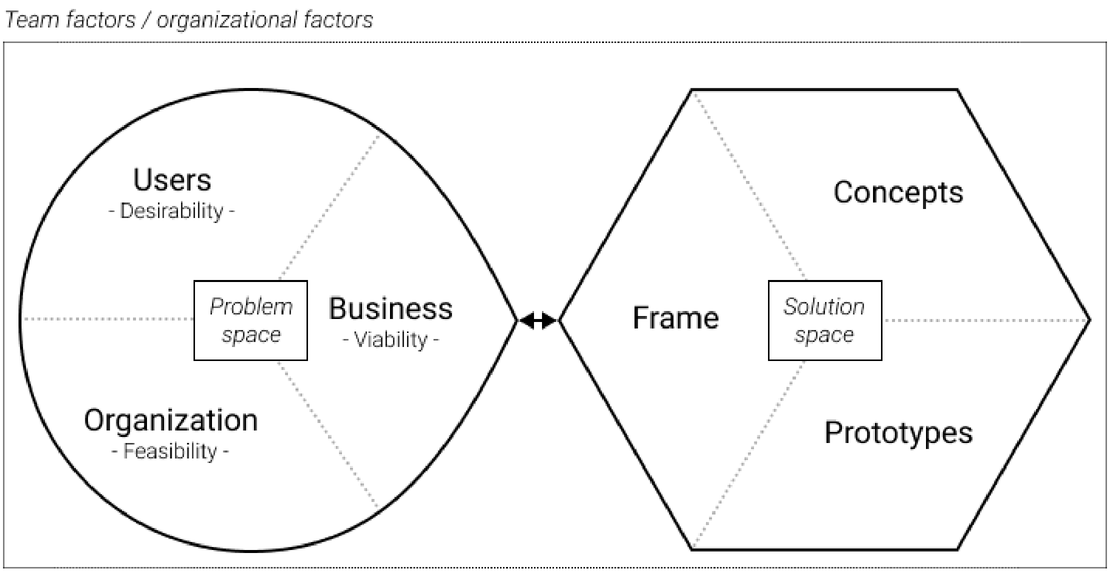
Both diamonds presume an internal cyclic nature (for instance between develop and deliver) and even external between both diamonds referring to the co-evolution of problem and solution. During the development, consecutive cycles of ideas generation and synthesis are common, until a sufficiently mature solution is established (ULRICH; EPPINGER, 2012). To help along this creative process, specific CITs where developed to creativity at each stage. Presented models and methods do not exclude creative aspects in the post-development stages of production detailing and market launching, but such phases are out of the scope of this work.

The understanding of how creativity unfolds during design may reveal other impact factors, besides collective and organizational. Information about the design situation is also vital to perceive adequate CITs, with different techniques adequate for each of the four stages on the Double Diamond methodology. Other project-dependent factors may also influence adequacy, such as formalization, available resources, and even the expected solutions (i.e. product, service, software).

2.4.2 Creative components

The outlining of the creative process used in the Double Diamond serves as ontology behind the implementation, as this is a core factor for CIT selection and presents itself in different fashion for different developments. A framework of creative components on design processes is presented in Figure 2.6 and was based on the studied methodologies, as well as other aspects inherent to creativity and innovation.

Figure 2.6 - Creative components on design process for categorization of CITs.



Source: author

The framework pursues which events occur inside each diamond and those encircling factors with impact on creativity, showcasing thus the fundamental and iterative creative phases behind the development of solutions. The six components can be used also as one of the impact factors when selecting adequate CITs, providing a more adequate structure than the presented design methodologies due to the specific focus on the creative process. Naturally, the creative level is deeply influenced by the environment, including team and organizational factors, and these should be considered when defining which CITs are more adequate and how the creative process will occur. Such factors, including team composition, relationship, managerial practices and overall organizational culture, might hamper the use of specific techniques, or influence how the creative design process will take place.

Composing the left part of Figure 2.6, the first set of components is related to understanding and defining the problem, and the second focuses on proposing solutions. Left part of the figure is grounded on the three impact factors on innovation, aiming to produce a better matured and structured briefing. The right part is related to actually solving the previously defined problem, focusing on understanding the briefing, proposing ideas and testing them to reach mature solutions. On creativity terms and its techniques, these six components can be used to indicate specific CITs such as:

- **Users´ desirability** (what people want) uses varied forms of Interviews, Immersion, and Observation, as well as Focus Group, Extremes and Mainstreams, and Journey Map;
- **Organization feasibility** (what the organization is able to achieve) incorporates Technology Mapping, Stakeholder Management, and SWOT Analysis;
- **Business viability** (what can become a sustainable business model) include Resource Optimization, Innovation Financial Management, and Business Model Canvas.
- **Frame** (which are the metrics of success) uses Project Charter, Quality Function Deployment (QFD), and Obstacle Map;
- **Concepts** (how we plan to solve the problem) includes a vast array of CITs such as Brainstorming, HIT Matrix, Biomimetic, SCAMPER, and Dot Voting. It is important to notice that the Concepts event includes both generation and analysis of ideas (divergence and convergence);
- **Prototypes** (what have we made tangible) includes Rough Modeling, Wizard of Oz, and Bodystorming.

There are CITs that permeate more than one component, such as Six Thinking Hats that is useful for both Requisites and Concepts. Each CIT has minor or major impact in each of the six values, due to adaptations of techniques to different problems. The six components should be balanced throughout the development, serving as one base to assert adequate and necessary CITs to the teams' current situation.

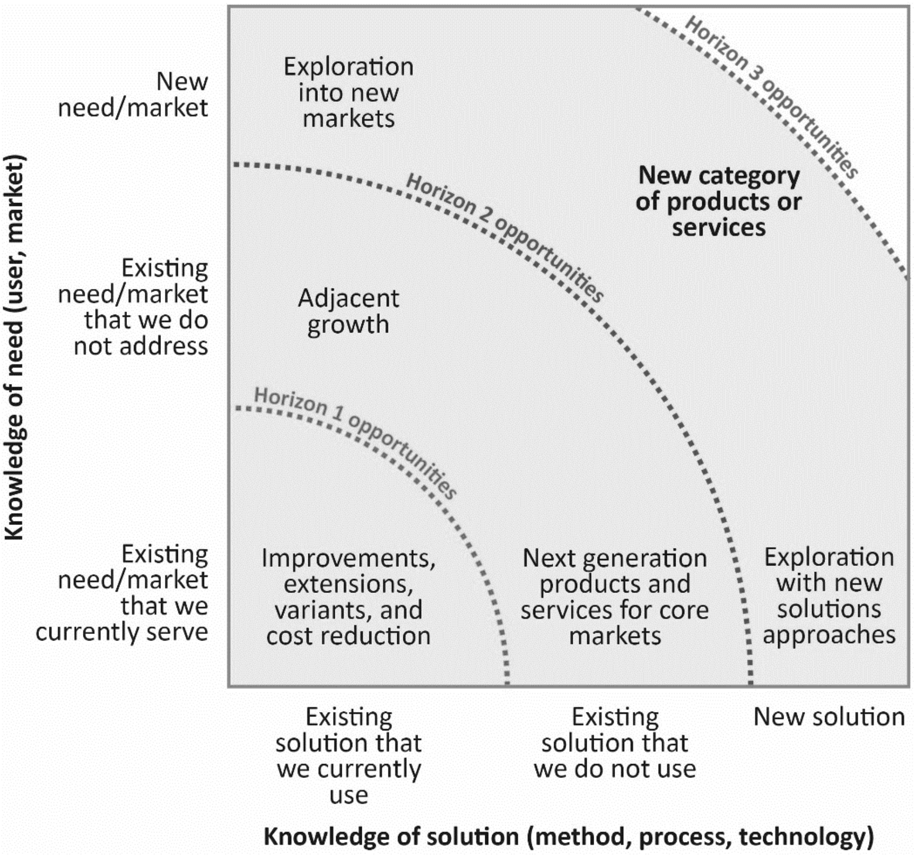
2.4.3 Opportunities and their impact on innovation

An innovation is characterized by a successful implementation of a solution in social environment (AMABILE, 2011; ANDERSON; POTOČNIK; ZHOU, 2014). Three constraints are imperative to determine success and should be balanced throughout the innovation process: technical feasibility; business viability; and human desirability (BROWN, 2009). First restriction is based on the capabilities of the organization, and/or technical maturity available at the time. Second constrains the innovation to a business perspective, meaning that the organization should be able to maintain its sustainability in order to develop solutions, as well as seek stakeholders' support and partnership. The third is firmly grounding the innovation on real needs of people, which should be one of the bases of the whole development process.

The establishment of a creation process balancing market, users and organization is vital for finding solutions that befit both social and economic aspects. Clearly the organization should have a strategy for maintaining and developing its portfolio (GARNEAU; NADADUR; PARKINSON, 2014), with each new development requiring progressive degrees of sophistication. In the space between start and end of a development several new needs from customers might arise (ARNETT; SANDVIK; SANDVIK, 2018), as is a role of the organization to perceive them and adapt the developments in a co-evolutionary effort.

Naturally, different innovation processes require different creative capacities and structures. Portfolio maintenance innovations compose most of an organizations' initiatives, and tend to have an adaptive approach for creation (BROWN, 2009). On the other hand, expanding to new markets and/or technologies is more occasional but also necessary, and might require an unbound creation process. The innovation process is more uncertain and riskier in such cases (BAKER *et al.*, 2014), especially when developing entirely new technologies. Three opportunities horizons can be depicted to better understand different focuses that a design process might try to achieve, as shown in Figure 2.7.

Figure 2.7 – Horizons of innovation based on explored user/market needs and method/process/technology employed by the organization.



Source: ULRICH and EPPINGER (2012)

Incremental innovation usually incurs in improving or extending an existing product inside the same market conditions, while radical innovation attempts might arise from both searching for new technological products or attempting to reach new markets (GUI; LEI; LE, 2021). An intermediate horizon encompasses cases of change on the organizational strategy aiming for new generation of products or market growth to adjacent areas. Such cases are often called evolutive (BROWN, 2009) or architectural (HENDERSON; CLARK, 1990) innovations. This division points to an important factor when selecting adequate CITs. Incremental innovations may require from a team more systematic approach with techniques such as Morphological Analysis or Pugh Matrix, while radical efforts may demand a more intuitive approach using Biomimicry or Six Hats. This influence cannot be perceived separately from other factors but may be decisive when defining adequacy.

2.5 TECHNIQUES FOR CREATIVITY AND INNOVATION

As a core aspect in design processes, techniques to enhance creativity and innovation are largely used to aid developments, especially in descriptive methods. As a matter of differentiation, methods are representation of a model into tasks and results (MARCH; SMITH, 1995); techniques can be described as a set of precisely described procedures for achieving a task-goal, being thus also methods; while tools are tangible or intangible instruments to aid performing a task, as in a template or framework (LUTTERS *et al.*, 2014). Though the terms technique, tool and method have different meanings, in design practice they are often interchangeable as synonyms. In this work, the term technique is adopted in a loose definition that encompasses several tools and methods for creativity and innovation in design.

Creativity and innovation techniques (CITs) are therefore documents, frameworks, procedures, systems or methods that aid any stage related to creation along the development process, enabling the organization to achieve or clarify a goal (TEZA *et al.*, 2016). They consist of guides to the creative impulse, offering alternative pathways to generate solutions (divergence), presenting means to evaluate, discard and select ideas (convergence) or any other process that support creative thinking such as defining specifications or better understanding the design environment (FORSTER; BROCCO, 2008).

Every creativity technique can be considered an innovation technique itself, since creativity can be characterized as a fundamental component of the innovation process. Literature presents an extremely wide variety of CITs, coming from engineering, industrial design, management, business, architecture, among others, with books specializing on presenting sets of such techniques as a toolbox for design (ALVES; NUNES, 2013; BACK *et al.*, 2008; BAXTER, 2011; BROWN, 2009; CLEGG; BIRCH, 2007; Ellen MacArthur FOUNDATION; IDEO, 2017; GIBBONS, 2016; IDEO, 2011; 2012; 2015; SILVERSTEIN; SAMUEL; DECARLO, 2009; STICKDORN; SCHNEIDER, 2012; TASSI, 2009; ULRICH; EPPINGER, 2012; VIANNA *et al.*, 2012).

The appearance of a large number of CITs in literature demonstrates the empiric nature of such techniques and the lack of consensus in the field, which can benefit from both systematic reviews to condense knowledge and AI approaches to deal with abundant information. CITs are often formalizations of organizational practices that were proved effective for creativity enhancement in a context (FORSTER; BROCCO, 2008). Many similar CITs arise in different fields with different nomenclature but are fundamentally similar. Notoriously, many CITs that are intensely used in practice are not described in literature or may arise from adaptations of consolidated techniques. Every technique has an adequate scenario for use, involving team, organization, environment and many other factors, but not every possible design scenario has an adequate CIT developed to its need, so adaptations may be needed.

Some design teams contain a facilitator (creativity expert) who guides the team and hints adequate techniques based on experience (KING; SCHLICKSUPP, 1998; MOSTERT, 2007). Unfortunately, many organizations lack an expert on creation, leaving development teams with no creative structure or with a limited set of techniques (ALVES; NUNES, 2013) that often are inadequate to aid the current design situation (KOWALTOWSKI; BIANCHI; DE PAIVA, 2010).

Adequate methods, techniques and tools for creativity aid by giving isles of structure in a naturally iterative and turbulent environment. They are widely recommended in literature and used in real design practices to achieve better results (BELSKI; ADUNKA; MAYER, 2016), help design teams to come up with better ideas more easily (BERTONCELLI; MAYER; LYNASS, 2016; KING; SCHLICKSUPP, 1998) and enhance the chances of success of a development (BAXTER, 2011). Despite the benefits of continuously using different CITs, studies show that in average number of techniques used by companies to develop solutions are between three (NIJSSEN; FRAMBACH, 2000) and four (CHAI; XIN, 2006).

CITs are relevant in virtually any creative effort along the design process, from adequately identifying the organizations capacity (e.g. SWOT Matrix, Business Model Canvas), market assessment (e.g. Technology map, BCG matrix), user survey (e.g. Interview, Immersion), going through concepts ideation (e.g. Traditional Brainstorming, Biomimetic), concept filtering (e.g. Affinity Diagram, Morphological Analysis), and even for modeling and prototyping (e.g. Mock-up, Wireframe). Naturally, CITs do not guarantee success of a development, but surely enhance the chances (BAXTER, 2011).

Misuses of CITs are common (ALBERS *et al.*, 2014), with designers developing Brainstorming sessions individually, or bending a Morphological Matrix to be used in service development. Either way, each CIT was developed in a specific scenario and is adequate to specific uses in which they promote an optimal enhancement of creativity (FORSTER; BROCCO, 2008). Unfortunately, many teams remain oblivious to many techniques and tend to remain using the ones in their limited toolboxes (YEH; PAI; YANG, 2010).

Many factors influence the appropriateness of a CIT to a specific design scenario, as well as many factors influence creativity in design. Techniques have varied difficulty levels, learning curves, required team size, creative design phase (e.g. convergence or divergence), use of resources, basic structure (e.g. auxiliary or systematic). Such technique categories are sometimes depicted with values in literature (CLEGG; BIRCH, 2007; IDEO, 2011; 2015) and can be used as a bridge to define adequate CITs, grounding a basic organization to allow the implementation of AI models using supervised Machine Learning. A knowledge-based approach to deal with information on CITs would not only allow the development of a system to predict adequate CITs, but also shed light on the reasoning underlying the empiric effort of techniques-to-context matching.

3 ARTIFICAL INTELLIGENCE ON CREATIVITY

Artificial intelligence (AI) is a rapidly growing field of studies with a wide number of possible researches. With the advent of computers and sophisticated programming, AI became a reality far above what former computer scientist could expect (MAKRIDAKIS, 2017). While first efforts of what is now called AI could only interpret handwritten symbols or process little amount of data, modern implementations are able to self-drive cars, win chess and go games against worldwide champions (MAKRIDAKIS, 2017), paint pictures, compose melodies, write tales (DARTNALL, 2013), and do things that humans are still unable to understand, for example predict diseases and develop own forms of language (KNIGHT, 2017).

As this work forges new connection relating AI to creativity, Section 3.1 presents a brief historical analysis of AI, its approaches, and development architectures. Section 3.2 showcases different validation approaches that can be used to evaluate computational systems, while Section 3.3 dives into Case-Based Reasoning (CBR) concepts and Section 3.4 into Machine Learning (ML). Along the sections, main reasons for considering using AI to aid in CITs selection a viable approach are also reported, demonstrating that the knowledge is complex enough to require a computationally-intensive solution, and that the development was adherent to current studies in AI. Though the implementation paradigms may differ from the previous works (BOTEGA; SILVA, 2020) to this doctoral work due to the inclusion of ML, some knowledge representation and architecture used there was adapted to befit this new approach.

3.1 METHODOLOGY AND ARCHITECTURE FOR ARTIFICIAL INTELLIGENCE

The term “Artificial Intelligence” was introduced in a conference in Dartmouth College in 1956, though previous studies on philosophy, mathematics, economics, neuroscience, psychology, computer engineering, and linguistics contributed to the birth of this science (ERTEL; BLACK, 2011; RUSSELL; NORVIG, 2016). In a burst of enthusiasm, researchers introduced approaches such as the General Problem Solver, LISP programming language, and first algorithms as SAINT, ANALOGY and STUDENT in less than 10 years (RUSSELL; NORVIG, 2016). With such and other developments, AI gradually became more sophisticated than the computational capabilities of the time, which imposed a great barrier and a shock of reality for researchers on the field. When scaling to real complex applications, such systems were unable to produce compelling responses, which derived in the discontinuity of many AI research programs (RUSSELL; NORVIG, 2016).

In the 1970s, domain specific AI systems derived in useful programs to real contexts, against the generalist paradigm employed in the decade before that aimed for a single system able to solve any problem. First expert system research projects began in late 1960s and early 1970s, such as DENDRAL – in chemistry –, MACSYMA – in math –, and MYCIN – for medical diagnosis (GIARRATANO; RILEY, 2005). From 1980s onwards, AI became an industry itself (RUSSELL; NORVIG, 2016), with modern approaches unfolding into an extensive variety of approaches as decision-support systems, neural networks, genetic algorithms, hybrid-systems, multi-agent systems, fuzzy reasoning, case-based reasoning, machine learning, data mining, Bayesian nets, among many others (COBO *et al.*, 2015; ERTEL; BLACK, 2011).

Currently, AI systems are intensely used behind digital interfaces, and intelligent robots are even seen in internet videos and talk-shows with human-like behavior (Hanson ROBOTICS, 2017). As a rising research field, many of the terms and paradigms adopted are under construction, with a vivid academic and market community building it simultaneously around the globe. AI can be defined as “the study of how to make computers do things which, at the moment, people do better” (RICH; KNIGHT; NAIR, 2009, p. 3). This simple statement captures the essence of AI approaches that aim in general to alleviate intellectual burdens, quicken or automate procedural works (ERTEL; BLACK, 2011).

To achieve such results, AI can be based on “thinking” or “acting” in a rational fashion (as humans), with various other definitions permeating different areas (RUSSELL; NORVIG, 2016). Important distinction to be marked is the terminology of weak AI and strong AI. The first, in a philosophical sense, are programs or machines that act as if they were intelligent based on restricted knowledge implemented, while the second targets systems that actually mimic broader human thinking (RUSSELL; NORVIG, 2016). Some futurism authors claim that a *Singularity* moment will occur in the 2040s, when the technological sophistication brought by AI will largely surpass human capabilities (KURZWEIL, 2005). Well, it may not take that long considering Hua Zhibing, Beijing Academy of Artificial Intelligence newest deep learning model release. Developed by researches on Tsinghua University, China, this system is considered to be first virtual student, interacting with humans through social media. The underlying model synthesizes face and voice of the young student and is able to process 1.75 trillion parameters. Hua Zhibing is currently enrolled on Tsinghua University as an experiment to accompany its learning development (TIMES, 2021). After such point, humans will transcend biological limitations and fuse with non-biological systems to reach unparalleled intelligence, and the frontier between real and virtual will become obsolete.

Sceptic or not, it is undeniable that AI is gradually becoming more integrated with human life, raising several complex issues on ethics and impacts on society (VESNIC-ALUJEVIC; NASCIMENTO; POLVORA, 2020). As a science fiction recurring theme, many books, films and series give glimpses of possible futures for AI, including some consequences of its use. In the words of Stephen Hawking: “The rise of powerful AI will be either the best or the worst thing ever to happen to humanity. We do not yet know which” (MAKRIDAKIS, 2017). While AI gradually sophisticates wealth-production and automate basic labor, productivity also increases, and human workforce could be directed to other uses.

Unfortunately, this positive utopia is not supported by current socio-economic data: employees are working over 40 hours a week, competing and being monitored with machines, with high levels of stress and mental illnesses, and are suffering progressive decline in real wages and welfare, even with AI systems supporting many tasks (BRYNJOLFSSON; ROCK; SYVERSON, 2017; ERTEL; BLACK, 2011). If not used ethically, AI approaches may stress society’s discrepancies, such as reinforcing social bias during criminal investigations, job application assessment, social media feeds customization, or credit scores calculation, with developed systems showing signs of social, ethnic and racial bias (VESNIC-ALUJEVIC; NASCIMENTO; POLVORA, 2020). As a matter of fact, impacts of “wicked” AI uses can already be seen in society on electoral processes and dissemination of fake news and deep fake (PENNYCOOK; RAND, 2021).

The raise of competitiveness is creating side-effects of unemployment and health issues. Although paradoxical, the raise in productivity has been accompanied by a diminishment of wages for workers, while profits are more and more concentrated in the hands of the few that lobby against such wealth distribution (ERTEL; BLACK, 2011; HAWKING, 2015). It is the responsibility of current and future AI researchers to mind the impacts of AI in society, using it to provide a better society for people to live, in opposition to current trends in which technology is continually increasing inequality (HAWKING, 2015). In this context, possible gains in productivity achieved through AI approaches such as the one developed in this research should be translated into better conditions of work for designers and be used to positive impact projects that improve social and environmental aspects of our society.

3.1.1 AI approaches evolution and consolidation

Research in AI and its approaches have grown along the decades, though many terms changed with the development of new paradigms. Rising computational capabilities allowed AI to deal with large amount of complex data, with great impact of analysis and synthesis of information. Big Data, Machine Learning and Deep Learning algorithms grew in this trend, building hybrid approaches to develop intelligent agents (RUSSELL; NORVIG, 2016) able to act as Optimization algorithms, Fuzzy Systems and Decision Support Systems (COBO *et al.*, 2015), which have multiple applications in current society from robotic vehicles, to speech recognition, autonomous planning, game playing, logistic planning, among others (RUSSELL; NORVIG, 2016).

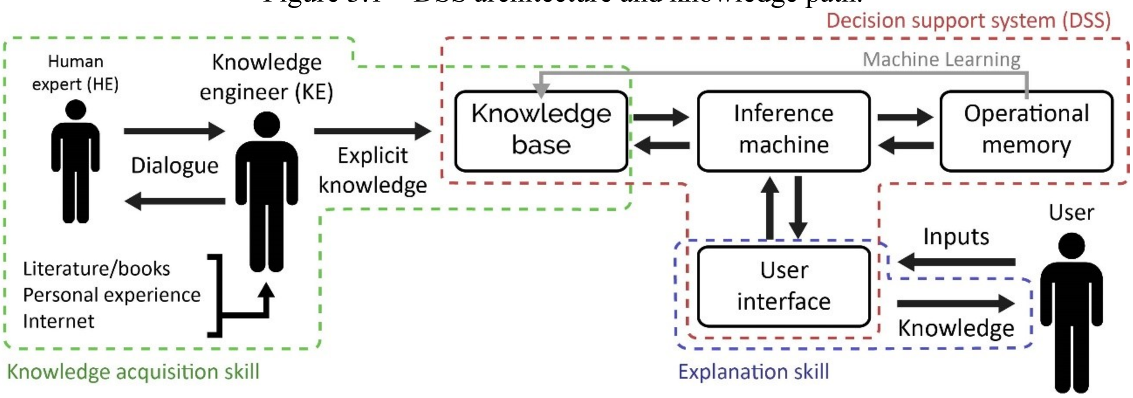
In a pure bibliometric analysis over 25 years of publications on the Journal Knowledge-Based Systems (COBO *et al.*, 2015), publications from 1991 to 2008 were focused on the themes: Expert Systems, Data Mining, Intelligent Agents, Case-Based Reasoning, Neural Networks and Classification. From 2009 to 2014, same analysis resulted in other major themes: Neural Networks, Decision Support Systems, Group Decision Making, and Rough Sets. Though nomenclature changed, many of the second subset publications are refinements or combinations of the previous terms (COBO *et al.*, 2015).

Central to this work, the theme “Expert Systems”, intensely used in the 90s, incorporated aspects of “Case Based Reasoning” and derived in the theme “Decision Support Systems” (DSS), as an approach able to aid decision-making through an integrative and interactive computer-based system. This approach is particularly relevant for situations in which the amount of information required to make adequate decisions is incompatible with human capabilities, allowing organizations to deal with unstructured or semi-structured decision problems that would demand extensive experience without a computational aid (VALENCIA-GARCÍA *et al.*, 2018). Surpassing human cognitive and memory boundaries, DSSs provide intelligent access to abundant information, complementing intuition-based decisions for situations that require precision and/or optimality. DSSs are currently used on various domains as business, engineering, military, and medicine, resulting in increased productivity, efficiency, and effectiveness (VALENCIA-GARCÍA *et al.*, 2018).

3.1.2 Development and architecture of DSSs

The implementation of a DSS, as an approach derived from Expert Systems, is made by a knowledge engineer with the capacity of collecting required information and representing it as knowledge in a program form (GIARRATANO; RILEY, 2005), as shown in Figure 3.1. To acquire knowledge, the engineer usually dialogues with one or more human experts to retrieve appropriate expertise for the knowledge representation. On the absence of such person or to complement the research, information can also be acquired by personal experience, literature, or any other means that provide data that may help substantiate the knowledge.

Figure 3.1 – DSS architecture and knowledge path.



Source: author based on GIARRATANO and RILEY (2005)

After processing such initial research, it is the knowledge engineer's responsibility to represent knowledge into a feasible structure, which acts as a long-term memory repository for the DSS. This knowledge base is a condensation of the expert's knowledge into a computational form, composing a great part of the implementation process. A user can access such information by providing necessary inputs through the user interface, which are stored in the operational memory, or short-term memory of the DSS. The Inference machine is responsible for the correlation between long and short-term memory (knowledge base and operational memory respectively), outputting the filtered solutions to the user. From the Machine Learning (ML) perspective, the system uses such inputs and internal correlations to adapt or reinforce the knowledge base.

The DSS and knowledge engineer act as a bridge for knowledge to pass from human experts to users in need for such knowledge but being a much more robust and flexible platform. By implementing such empirical experience in a computational program, the knowledge becomes more available, reliable and permanent then depending on the human expert (GIARRATANO; RILEY, 2005). Such advantages derive into other benefits such as (GIARRATANO; RILEY, 2005):

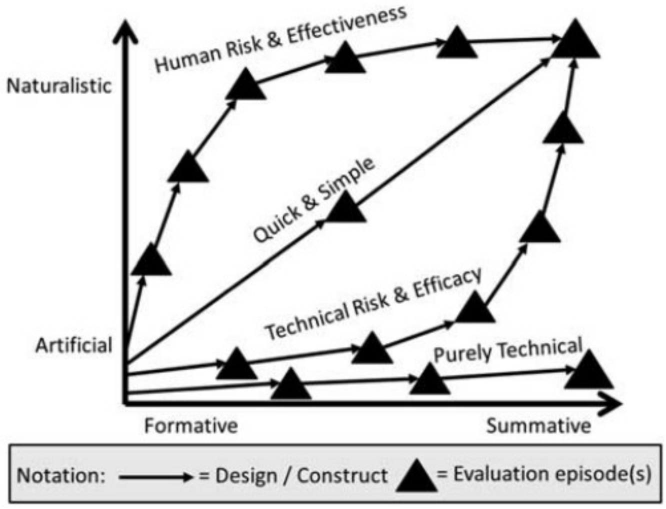
- Store rare skills;
- Preserve knowledge of retiring or quitting personnel;
- Combine knowledge from several experts in a required domain;
- Make the knowledge available in hostile or difficult access environments;
- Allow the use of such knowledge in multiple places;
- Train new personnel;
- Reduce automatable or monotonous work.

The chaining of information produced inside the DSS mimics the expert thinking, configuring it as an AI approach. The system may combine rules, object-orientation modeling, statistical inference processes or any other representation methods to achieve such behavior and the knowledge represented should not be restrained to bibliographical or technical sources. The system could also help in the selection of the best options at any scenario, transmit non-technical aspects as intuition, reasoning, user-friendliness and interpersonal communication.

3.2 VALIDATION PROCESS

The development of computational systems that incorporate AI requires a particular focus on validation. As the system is architected and implemented, loopholes may arise generating unpredictable errors in outputs. Thus, it is fundamental a solid process of validation to check if the implemented code adequately represents the knowledge, trying to perceive inconsistencies, misinterpretations, and point for the limitations of the software. Alongside this “knowledge base validation”, this process also gives basis for next cycles of implementations, collecting feedback from evaluators on which paths the prototype can grow. Other components of the process are usability and interface validation. While the architecture and represented knowledge are better evaluated by experts, non-experts may provide valuable information for new cycles based on day-to-day problems while using the system. A framework for validation of the system can be drawn to aid the evaluation process (VENABLE; PRIES-HEJE; BASKERVILLE, 2016). As presented in Figure 3.2, many approaches can be used to validate developments for design.

Figure 3.2 – Framework for evaluation in Design Science with evaluation strategies.



Source: VENABLE; PRIES-HEJE and BASKERVILLE (2016)

The beginning of the evaluation process is commonly formative, giving a higher focus on reviewing architecture and system representation to help improve outcomes, and artificial, using hypothetical cases to guide validation and theoretical arguments to discuss and improve knowledge base. Most validation approaches tend in time to become more summative, aiming to check if outcomes match expectations without deepening on internal correlations, and naturalistic, which uses of real-life scenarios that are much more complex and unpredictable than the artificial approach.

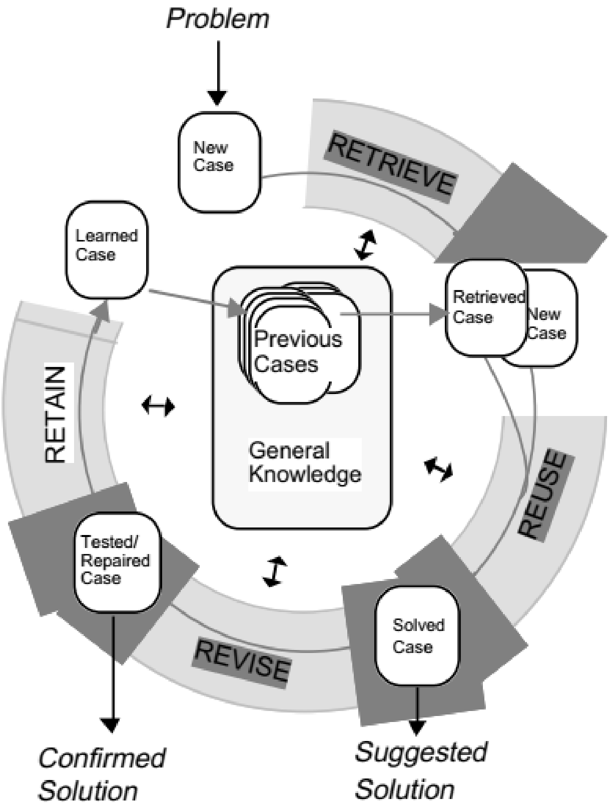
Many paths can connect these two extremes; each path is useful in different scenarios. In particular, for this research, the “Technical Risk & Efficacy” approach was primarily chosen due to the fact that study is knowledge-intensive and requires evaluation of the technical system characteristics to perform as experts. This process starts in a formative (aiming to collect feedback to improve the prototype characteristics and performance) and artificial (providing a controlled scenario for evaluators) fashion, and gradually becomes more summative (focusing on evaluating whether outcomes match expectations) for then exploring more naturalistic (submitting the system to real use cases) scenarios (VENABLE; PRIES-HEJE; BASKERVILLE, 2016).

Other strategies to validation are also valuable in other contexts. “Human Risk & Effectiveness” path goes the other way of the approach used in this work, priming for more naturalistic and real scenarios testing from the beginning. This strategy prioritizes putting the design in the hands of users as quickly as possible, even if it undermines some technical aspects. It is indicated for developments that are less knowledge intensive. This approach is also quicker but more expensive than “Technical Risk & Efficacy”, especially due to the need of reaching users. “Quick and Simple” path is a lower cost option for project with restrict timeframes, though it may incur in less extensive evaluation, such approach is a good option for smaller or simpler design efforts that require a less thorough validation. Last path is the “Purely Technical Artefact”, which should only be used in systems that have little to no interaction with users (VENABLE; PRIES-HEJE; BASKERVILLE, 2016).

3.3 CASE-BASED REASONING FOR MACHINE LEARNING

As a possible hybrid approach with DSS, Case Based Reasoning (CBR) algorithms relate user’s information to previously implemented similar cases. When the cases provide inaccurate answers, such retrieved solutions can be refitted to the problem based on comparisons and adaptations (RELICH; PAWLEWSKI, 2018). CBR approach usually imply in four activities (AAMODT; PLAZA, 1994; LEAKE; YE; CRANDALL, 2021), as shown in Figure 3.3.

Figure 3.3 – CBR activities.



Source: AAMODT e PLAZA (1994)

1. **Retrieve** uses the inputted case data to access the collection of previous cases and identify adequate combinations;
2. **Reuse** combines inputted case and retrieved case to derive a solution by similarity, resulting in a proposed solution (solved case) that may require levels of adaptation to befit the scenario;
3. **Revise** tests the adequacy of the solved case, using of internal evaluation, experts' analysis or seeking users' approval, thus resulting in a tested case or, if necessary, a repaired case;
4. **Retain** collects successful iterations that can be then integrated to the general knowledge to be used in the future as a learned case, or even to modify existing cases.

Such approach can be used to implement and retro-feed learning approaches (AAMODT; PLAZA, 1994; LEAKE; YE; CRANDALL, 2021). The reuse and revise components are deeply related to different CBR algorithms such as K-Nearest Neighbor, Logistic Regression, Decision Trees and Support Vector Machine. The approaches use of statistical computational analysis for classification, regression, clustering and/or processing large sets or complex data (PEDREGOSA *et al.*, 2011). The aim is to reach a proper model for representing the data and make predictions, perceiving trends on the data but avoiding extremes of over and underfitting (MÜLLER; C; GUIDO, 2016).

Main CBR difficulties are guaranteeing the prediction of special cases and variants; finding similarities metrics for non-numerical symbols; transforming similar cases to befit requested knowledge (ERTEL; BLACK, 2011); and exponential computational costs of some approaches (GERHANA *et al.*, 2017). The combination of CBR with Machine Learning approaches focus on relieving some of these obstacles by helping to adapt previous cases to new and unseen circumstances (LIAO; LIU; CHAO, 2018).

3.4 MACHINE LEARNING ALGORITHMS

Machine Learning algorithms are based on models for perceiving trends on data, but each with particularities that guide their application. In this research, due to the convenience of using Python libraries, different algorithms could be tested and compared, scoping for the most adequate model. Algorithms were selected considering their potential adequacy to this specific use, the amount of data available, the scalability of the system with the inclusion of new cases and CITs in successive cycles of implementation, and the requirement for transparency and explainability as to inform users about the systems inference process.

To achieve objectives of this research, a hybrid two-staged model was required: first a regression approach to translate user's scenario imputed through an entry questionnaire into CITs characteristics; and second a ranking-classification approach able to infer from such characteristics which CITs would befit the users' needs. Main reasoning behind this implementation architecture will be disclosed throughout this text, in order to limit the extent of this thesis, the text does not present each approach tested. Here, the intention is to restrict to explain in more depth the two main selected algorithms: Gradient Boosted Regression Trees (GBRT) as a regression algorithm and Logistic Regression (LogReg) as a ranking-classification algorithm.

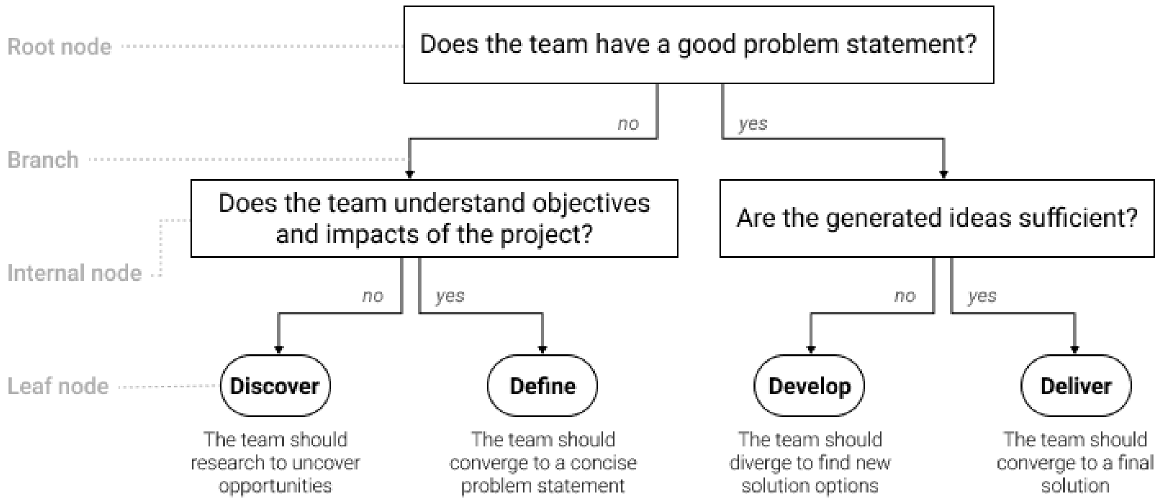
Modeling paradigm focused on supervised learning approaches, in which predictive models are constructed based on variables (or features) that are used to predict responses (or targets) (BOEHMKE; GREENWELL, 2019). In this case, learning algorithm is fed with previously known features-targets samples, over which the algorithm will try to optimize its core function in order to provide the best combination of features that can predict adequately the targets. Supervised learning algorithms are commonly divided into two groupings: classification and regression.

Classification algorithms, as the name implies, are focused on finding classes or categories. While these options can be binary (e.g. yes or no, on or off) or multinominal (e.g. rainbow colors, car names), the mathematics behind most algorithms find in fact the probability of a sample belonging to one or other class (i.e. 70% of belonging to "yes" vs 30% of belonging to "no") (BOEHMKE; GREENWELL, 2019; PROVOST; FAWCETT, 2013). Final output is normally chosen as the class with highest probability, but in a ranking approach, it is possible to define among several classes how "probable" each option would be as a correct response and select multiple ranked outputs. On the other hand, regression algorithms core mathematics focuses on finding a function that better describe the provided features' behavior (BOEHMKE; GREENWELL, 2019; PROVOST; FAWCETT, 2013), returning a function able to provide continuous values instead of categories.

All tested algorithms were submitted to a training-testing approach typical for Machine Learning implementations (PROVOST; FAWCETT, 2013). Full dataset with cases was divided in two, one being used to train the algorithm while the other is "hidden". Then achieved model with training is submitted to testing using the second part of the data using appropriate metrics, checking whether the model is able to reach the correct answers to these unseen cases.

Several models were tried out for both regression and classification during the development of the prototype. Here, only the two used algorithms will be presented in more depth: Gradient Boosted Regression Trees (GBRT) for regression, and Logistic Regression (LogReg) for classification. GBRT uses as base a Decision Tree algorithm powered by ensemble approaches for regression, using results from one tree to base the creation of the next (BOEHMKE; GREENWELL, 2019). This incremental-steps approach is particularly good for generalization, dealing better with variance over samples outside of training data (MAKLIN, 2019). Simply put, tree-based models use a series of splitting rules to partition the decision space and, when requested, navigate through its braches to achieve results. Figure 3.4 presents a simplified representation of Decision Trees structure based on the Double Diamond to identify in which stage team is.

Figure 3.4 – Simplified representation of a decision tree structure over the Double Diamond.



Source: author

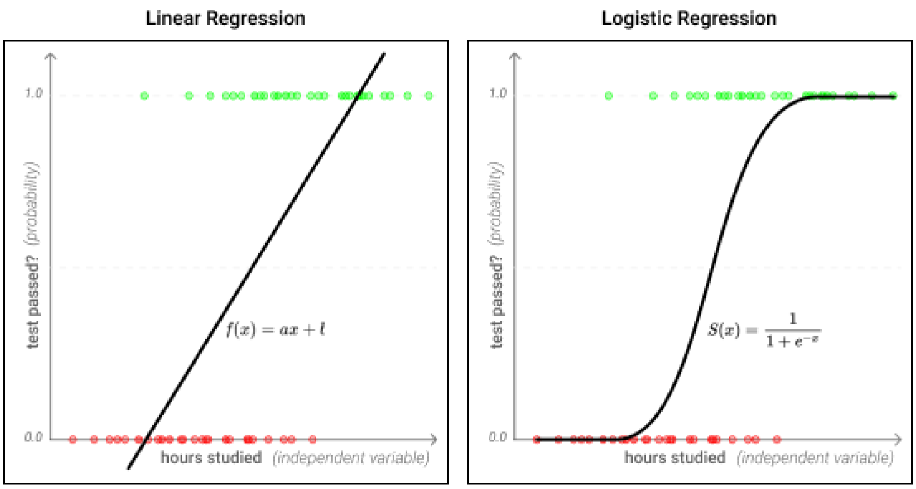
In this particular example, we can see a Tree with maximal depth 2 (root node and one level of internal nodes). As said, though at the leaf nodes are presented categories, what Decision Trees computes are probabilities of belonging to each class using multiple features (BOEHMKE; GREENWELL, 2019). The boosting approach uses residual errors from each tree to define a better starting point for subsequent trees, and does this iteratively until a preset number of trees is reached (MAKLIN, 2019). This residual error is applied using a Learning

Rate (LR), which represents how far the algorithm will go in the pointed direction in the next iteration (BOEHMKE; GREENWELL, 2019). Lower LR will take more time to converge to optimal points, while too high LR may result in instabilities. Then the algorithm retrieves all trees and combines their results to achieve final predictions. In the context of this research, this consecutive trees approach (boosting) will form a "council", in which each tree may reach different results but with consecutive trees being increasingly more accurate. The total number of trees is used to guarantee that, when individual results are averaged, the final output is correct regardless of some "less accurate" trees.

Main advantages of Decision Trees approaches are good explainability of the inference process, little pre-processing time, and a rather good robustness for outliers and missing values (BOEHMKE; GREENWELL, 2019). Combined to the boosting approach, decisions tree ensembles are more robust against overfitting (which is a concert when using single trees), meaning the model is less prone to "memorizing" results instead of making good generalization able to perform adequately even in unseen data (MAKLIN, 2019).

At the second model used for classification, Logistic Regression fits weights of a sigmoid function called logistic function weights to minimize residual sum of squares between the targets in predictions (PROVOST; FAWCETT, 2013). Though this approach has "regression" in the name, it is usually employed as a classification algorithm (PEDREGOSA *et al.*, 2011). This algorithm is a variation of the Linear Regression, which fits a straight line instead of a sigmoid. A comparison between these two functions is presented in Figure 3.5.

Figure 3.5 – Visual comparison of Linear and Logistic Regression results.



Source: author

This simplified vision of the algorithm gives insight on how the logistic function is used to calculate probabilities of classification. This approach is particularly useful when outputs are binary, but entries or exploratory variables are continuous (SCHOBER; VETTER, 2021). Considering this case, the model is able to calculate for each CIT the log-odds probability of it being adequate or not, ranking them accordingly in the end, being thus a multinomial approach. Even with a rather simple mathematical basis, with an increasing number of variables this approach is able to perform well in complex data. Through its weights, features importance can also be obtained, meaning that variables with higher weights tend to be more relevant during outcomes calculations.

Logistic Regression has traditionally one main hyperparameter for tuning: the regularization coefficient (λ). This value penalizes complexity, with large λ increasing simplicity by pushing the coefficients towards zero and allowing the occurrence of more errors and underfitting, while small λ diminishes error while risking overfitting (PROVOST; FAWCETT, 2013).

At the core of the developed prototype, the two-staged ML model uses such algorithms to translate information about the user's design scenario into adequate CITs. As a first step into building this model, knowledge on CITs and their appropriate context of use was acquired and adequately represented, allowing the construction of a dataset that served as basis for training and testing ML algorithms.

4 KNOWLEDGE ACQUISITION AND REPRESENTATION

Previous sections demonstrated the theoretical basis and relevance of AI to creativity in modern organizational contexts, with several efforts bridging creativity support and computational tools. Given the number of CITs and broadness of applications, allied to the expertise needed to apply them to different contexts, a Decision Support System (DSS) development becomes not only viable but necessary.

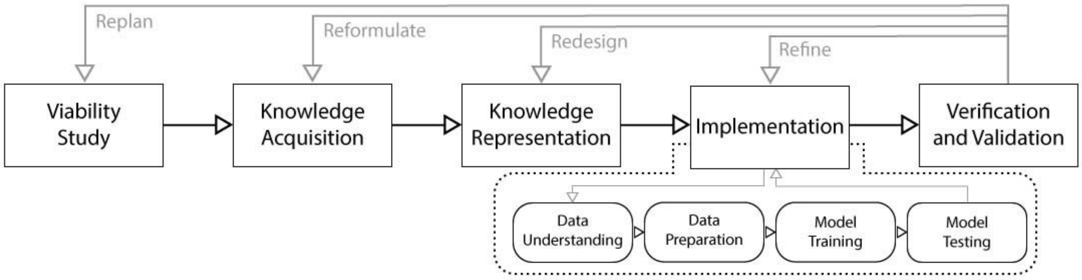
The process of translating knowledge about CITs into representative data to feed a DSS is complex and should be based on a solid methodology. The DSS prototype serves as a bridge for knowledge to pass from expert to user in an indirect path. Knowledge should be explicitly represented to construct the computational system (BLONDET; LE DUIGOU; BOUDAOUD, 2019). To fulfil its goal, the DSS should ensure not only the incorporation of experts' knowledge, but also clearly present its inference process to help users make well-informed decision (BLONDET; LE DUIGOU; BOUDAOUD, 2019).

This section focuses on presenting the methodology followed in the prototype development in Section 4.1, to then deepen in the approaches used to obtain the needed knowledge in Section 4.2 and the architectural structure used to represent it in Section 4.3. At last, Section 4.4 presents the data understanding and preparation, reaching a ready dataset to be used during Machine Learning modeling. For the AI system, such structure is important to define factors that impact the level of creativity and which CITs are relevant in each situation, promoting higher levels of creativity and innovation throughout the design process. Since both development cycles used similar knowledge acquisition processes, both will be presented simultaneously and the differences between both cycles will be highlighted when needed.

4.1 DEVELOPMENT METHODOLOGY

Every computational system has a particular architecture but tends to follow similar development frameworks. The development of expert systems, here extrapolated to DSSs, follows five phases (SILVA, 1998; WATERMAN, 1986), while modern Artificial Intelligence (AI) frameworks (PROVOST; FAWCETT, 2013) can be used to improve the methodology especially on the implementation phase, as presented in Figure 4.1. This methodology often occurs in an iterative process, constructing a prototype that is evaluated and expanded cyclically (BATARSEH; GONZALEZ, 2015).

Figure 4.1 – Decision Support Systems' development phases used in this work.



Source: author based on (PROVOST; FAWCETT, 2013; SILVA, 1998; WATERMAN, 1986)

The research presented in this work followed the DSS development methodology presented above. Viability study, which scopes whether the problem can and should be addressed using AI systems, was based upon research in similar creativity support systems literature (ALBERS *et al.*, 2015; CHEN *et al.*, 2019; DARTNALL, 2013; DEKKER; FARROW, 2013; KIM; ZHONG, 2017; LIU *et al.*, 2011), which unveiled applications of AI to creativity but also pointed to gaps in systems able to deal with a wide variety of creativity techniques and their applications (GABRIEL *et al.*, 2016; SIEMON, 2019; WANG; NICKERSON, 2017). Knowledge acquisition was then followed by gathering correlational information to ground the development, using literature, human experts, cases and other knowledge sources. This was achieved mainly through design and engineering methodologies and toolkits (ALVES; NUNES, 2013; BACK *et al.*, 2008; BAXTER, 2011; BERTONCELLI; MAYER; LYNASS, 2016; BLONDET; DUIGOU; BOUDAOUD, 2019; BROWN, 2009; BUCHELE, 2015; CLARKSON; ECKERT, 2010; CLEGG; BIRCH, 2007; COUNCIL, 2018b; Ellen MacArthur FOUNDATION; IDEO, 2017; GIBBONS, 2016; HAVERGAL; EDMONSTONE, 2017; IDEO, 2011; 2012; 2015; KNAPP; ZERATSKY; KOWITZ, 2016; LUTTERS *et al.*, 2014; MYCOTED, 2019; PAHL *et al.*, 2006; SILVERSTEIN; SAMUEL; DECARLO, 2009; STICKDORN; SCHNEIDER, 2012; TASSI, 2009; ULRICH; EPPINGER, 2012; VIANNA *et al.*, 2012), among other online sources such as blogs, white papers and videos.

During acquisition, patterns for organizing and representing knowledge emerged, especially in categorization dimensions and ways of segregating the application of CITs to specific contexts. Thus, knowledge representation followed organizing, analyzing and synthesizing data collected, establishing potential categories, and defining which could be used. This decision was based on information availability, including the use of such categories in different bodies of literature and the capacity for organizing CITs with them. Once categories were established, CITs were sourced using three main criteria:

- information availability to define values for the selected categories
- presence in at least 5 different sources
- familiarity of the author

With that, a condensed dataset was reached, containing the selected CITs and values for each of the different categories selected.

Implementation was performed in two iterative cycles, as recommended for software development (BATARSEH; GONZALEZ, 2015), aiming to translate such knowledge represented into actual system code and to structure an algorithm able to produce adequate responses to inputs. The first cycle focused on building the ML "engine" of two models, while the second cycle focused on expanding the number of categories and CITs, and implementing a web-based cloud architecture and graphical user interface (GUI). To allow the expansion of the system in the second cycle, knowledge acquisition and representation were revisited to allow gathering the needed knowledge on the new categories and CITs. All model implementations were made using Python v3.6 and supported by libraries, mainly Pandas, NumPy, SciPy, and Scikit-Learn. The second cycle used other technologies to build the cloud architecture, mainly HerokuApp, GitHub, Gunicorn, MongoDB and Python libraries as Flask and PyMongo, while the GUI was implemented using JavaScript, React, and CSS.

In data understanding, an overall computational architecture for the DSS was designed, including expected inputs and outputs for each stage. Based on that, data preparation started by translating the condensed dataset into actual data to use in training Machine Learning models. This included data cleaning, reorganization, feature tinkering, *dummification*, and normalization, reaching a final case-based dataset, in which each row represented a single use-case for a CIT. The organized data could then be used to train models, which were selected based on potential application to the given context (PEDREGOSA *et al.*, 2011). Modeling used standard train-test splits, leaving 25% of the cases to testing. Trained models were assessed based on predefined scores and promising ones chosen for further evaluation with parameter tuning. The ones that balanced better training and testing scores, as well as training times (given the possible need for constant retraining of the model) were chosen to compose the final two-staged model.

Verification was performed similarly in both cycles by building a comprehensive input case dataset containing all possible combinations of inputs. These were then automatically submitted to the model, collecting their outputs and checking for possible implementation errors. On the other hand, validation followed the "Technical Risk & Efficacy" approach presented in Figure 3.2, meaning first validation was more focused on checking whether the DSS performed as an expert would, while the second cycle aimed at evaluating if the system could be used as a reliable aid for creative design efforts. Both cycles followed an adapted Turing test approach for validation (KNAUF; GONZALEZ; ABEL, 2002), using a questionnaire to extract feedback from the 6 experts that participated in both evaluations. The questionnaires used are presented in Appendix C.

4.2 IMPORTANT FACTORS FOR CREATIVITY AND INNOVATION

As first step in the development methodology, the stage of viability study is considered covered by previous works and presented literature review, which showcased that the approach is not only feasible but also valuable to design teams. Entering knowledge acquisition and representation, focus was given on understanding how CITs can be organized based on factors that may impact their use throughout the design process.

Several variables are empirically used by facilitators to determine whether a CIT is useful to a given situation. Each technique has optimal conditions of use, in which their application will provide a maximal efficiency for creation. Idiosyncratic CITs' factors can also be mapped, and literature shows several categorization factors that hint to situations in which the technique will provide better creative level for the team.

Analysis of potential categories was based on literature review on the area, including papers on CITs selection (ALBERS *et al.*, 2015; ALVES; NUNES, 2013; BERTONCELLI; MAYER; LYNASS, 2016; DE WAAL; KNOTT, 2016; GRANER; MIßLER-BEHR, 2013; HIDALGO; ALBORS, 2008; LUTTERS *et al.*, 2014; THIA *et al.*, 2005), books and webpages with compilations about CITs (CLEGG; BIRCH, 2007; CUREDALE, 2016; SILVERSTEIN; SAMUEL; DECARLO, 2009; STICKDORN; SCHNEIDER, 2012; TASSI, 2009), and design methodology literature (BACK *et al.*, 2008; BAXTER, 2011; BROWN, 2009; IDEO, 2011; 2015; ULRICH; EPPINGER, 2012). The analysis did not intend to reveal all impact factors, as that would be extremely wide and complex to define correlations. This work aims for a sufficient analysis of factors to guide the implementation of the AI system and aid designers in choosing and employing adequate CITs.

Such literature sheds light on important factors that can be used as knowledge-base to the AI implementation. During this research, categories were scoped, and then separated into four families to ease comprehension. This division was not found in literature but help comprehending the connections among used factors:

- Project categories are related to characteristics of each project inside an organization, including methodological stage, formalization, number of stages, available resources, and the six creative components presented in last section;
- Team categories are collective aspects that impact on creativity capabilities, such as team size, expertise, cohesion, and communication mean;
- Organizational categories are more related to innovation capabilities and culture inside the organization, such as organization size, managerial support, and innovation strategy.
- Technique categories or characteristics are inherent and deeply related to the use of individual techniques, acting closer to the outputs of the proposed DSS. Among the found factors are difficulty level, purpose of the technique inside the creative process, required team size, required resources, user-friendliness and even fun of execution;

The breadth of factors that impact creative behavior and innovation capabilities reflects the complexity of both concepts. According to literature review, about 56 impact factors were found and are presented on Appendix A. To facilitate comprehension, they were divided according to the above categories, and are respectively presented on Table A.1 to Table A.4. Overall, 10 project, 12 team, 6 organization, and 28 technique related impact factors are reported, though they do not represent the totality of influence factors on CITs selection. Understanding the correlations among such factors grounds the inference process behind the DSS approach. Though many factors exist, information about some of them might not be available to design teams. It is important to filter such factors before using them to build the inference process.

The organizational categories were not used in this work due to complexity. Such factors are less available in literature and demand further deepening to be implemented in future cycles. Their definitions and values are much more abstract, and harder to correlate to other factors. Organizational categories have deep links to external contexts and influence factors outside of companies' control, such as culture, laws, limiting beliefs, and politics, and where omitted in this analysis for being excessively complex and having unclear correlations to CITs application.

Technique characteristics can be correlated to project, team and organization categories to delineate inference architecture for the DSS, allowing ML implementation to extrapolate the available information. Categories that surpass the organizational sphere, including company sector, technological dynamics, competitiveness dynamics and “market culture” were not considered in this proposal, though they may influence the assertion of CITs. Individual factors such as personal mood, level of intrinsic motivation, age, and formation, were also disregarded for being excessively complex to obtain.

It is important to mention that literature uses varied constructs to approach similar concepts. In this work, the term “Creativity and Innovation Techniques” is used as an intersection of varied terms such as “Service Design Tools and Methods” (ALVES; NUNES, 2013; TASSI, 2009), “New Product Development Methods or Tools” (CHAI; XIN, 2006; GRANER; MIßLER-BEHR, 2013; NIJSSEN; FRAMBACH, 2000; THIA *et al.*, 2005), “Techniques” (SILVERSTEIN; SAMUEL; DECARLO, 2013), “Methods” (IDEO, 2015), “Innovation Management Techniques and Tools” (D'ALVANO; HIDALGO, 2012; HIDALGO; ALBORS, 2008), “Knowledge-Management Tools” (VACCARO; PARENTE; VELOSO, 2010) among others. This merging of terms also allows the use of categories presented in different literature as a taxonomy for techniques in this work. The option for the term CITs is used to focus the development and implementation in techniques that impact directly creativity and innovation potential.

It is not the scope of this work to describe specific aspects of each impact factor, but to use them as a mean of categorization. Therefore, the categories will not be described in depth, and only the ones used during implementation will be exposed with brief explanations. The focus is given to the discovery of relevant factors and which values they can have, helping the later CITs categorization. For instance, team category of “Team Size” can be valued as a number while project category of “Design Step” can be based on the four phases of the Double Diamond.

4.2.1 Project categories

The families of categories of project and team used in this work were considered to be factors that represent the design scenario, with information that is more available to the design team and thus closer to inputs for the DSS. These are not necessarily linked to specific

CITs but are mentioned as attributes that can be used to describe the team's context. Project categories are presented in literature as a series of circumstances that have influence in the adoption of CITs through methodological or strategic aspects. For instance, a project can be limited to methods only applicable to non-virtual environments, or have from starting point guidelines to develop a product and not a service.

A total of 10 project categories were found in literature and are presented in Table A.1. The categories that integrate the developed prototype were selected by being commonly used both in literature and known by the author, as well as due to sufficient information about them in terms of CIT categorization. Project categories and their sources used during implementation were:

- Design Step (BACK *et al.*, 2008; IDEO, 2011; 2015; INSTITUTE, 2021; SILVERSTEIN; SAMUEL; DECARLO, 2013; ULRICH; EPPINGER, 2012): defines in which part of the development process the team is currently working. Different methodologies bring different values for the design step. This prototype uses as basis the Double Diamond (Figure 2.5) for being widely used in design and befitting particularly the creative process (COUNCIL, 2015b). Possible values are: discover, define, develop, and deliver. For instance, literature points out that Bio-inspiration is a CIT for having new ideas (develop), while Affinity Diagram can be adapted to both define and deliver;
- Innovation Focus (BROWN, 2009; D'ALVANO; HIDALGO, 2012; INSTITUTE, 2021): relates to the project novelty or intended innovation level. Each project is set to achieve newness but may be described as incremental (minor improvements), evolutive (expansion of an established product to new markets) or radical (disruptive solutions to the market). As examples, Reverse Brainstorming suits better more incremental innovations due to it relying on opposition of ideas, and Shadowing is often seen as a great deep-dive approach to uncover more radical opportunities or ideas;
- Expected Solution (BACK *et al.*, 2008; STICKDORN; SCHNEIDER, 2012; TIMBADIA; KHAVEKAR, 2017): relates to the required outcome of the design process. This implementation restricted this attribute to two values: products and services. As the name implies, Service Blueprint befits better service developments, while Alpha Prototyping was tailored for product testing;

- Virtual Platform (ALVES; NUNES, 2013; VACCARO; PARENTE; VELOSO, 2010): relates to the basic mean of communication to be used in the creative process, since meetings can be held physically in a shared space or virtually using online platforms. This category was added during the second implementation cycle based on evaluators´ feedback and other researches (MAFFEZZOLLI, 2019). CITs as Roleplay and Rough Prototyping are usually better adjusted to physical environments, while many others can be seamlessly adapted to virtual ones.

4.2.2 Team categories

Acting on a collective level, team categories encompass composition, behavior and available knowledge for a team to perform a project. Most of these are not directly linked to specific CITs but have deep impacts on their application and appropriateness. These categories are fundamental for information sharing, which has positive influence on raising creative potential. When lacking communication capabilities, CITs can be used to overcome such barriers.

A total of twelve different team categories were found in literature and are presented in Table A.2. The ones used during implementation along with their sources were:

- Team Cohesion (THIA *et al.*, 2005): involves personal relationships, friendship, trust, ability to share knowledge and freely discuss/critique each other. This attribute can be better represented by a scale from divided or dissociate teams (that have communication or relational barriers) to cohesive teams (that have good rapport). To illustrate that, Brainwriting structure allows ideation while avoiding communication problems, and can be very well suited for more dissociated teams;
- Team Size (IDEO, 2012; INSTITUTE, 2021): is the number of people participating in the current creative effort/session. It can be represented directly by a range of integers. For instance, it is not recommended for Contextual Interview to have sessions with more than 3 interviewers (thus having a team size range up to 3);
- Participants (IDEO, 2015; TASSI, 2009; VACCARO; PARENTE; VELOSO, 2010): is related to the presence of members other than the design team in the current creative effort. This can include users, experts, service staff or other stakeholders. Although co-creation allows teams to integrate many stakeholders in the design process, CITs such as Desk Research are better off being done only by

design teams alone, while Traditional Brainstorming can gain a lot by having other people around;

- Team Diversity (MOSTERT, 2007; WANG, 2014): expresses the level of diversity of the team in terms of, for instance, age, gender, training, and function. The creative potential is positively impacted by the team's diversity. This category was added during the second implementation cycle based on evaluators' feedback and other researches (MAFFEZZOLLI, 2019). Though not mandatory, having a diverse team can help the execution of integrative CITs as Roleplay and Journey Map to reach new perspectives

4.2.3 Technique characteristics

The above presented categories are intrinsically related to the conditions that support the creative effort and are thus considered inputs in a DSS architecture. Since the ultimate goal of the system is to provide the most applicable CITs, their inherent characteristics can act as a link between available information about the team's design scenario and which techniques are adequate. This middle-step can help bridging these two dimensions, thinking first on which particular aspects of a CIT can be useful to the context before inferring the adequate CITs themselves.

These factors are related to intrinsic characteristics of each technique, reflecting the scenario in which it was developed and consequently the situations in which its application will provide the best cost-effectiveness. Being more explicitly presented in literature than previous families, literature presents a series of characteristics that can be used to define specific values to each technique. The twenty-eight retrieved impact factors related to techniques are presented in Table A.4.

Main technique characteristics used during implementation are the ones firmly established in literature:

- Execution Time (IDEO, 2015; INSTITUTE, 2021; SILVERSTEIN; SAMUEL; DECARLO, 2013): how long it takes to adequately perform a CIT. Values can range from minutes to weeks. As an example, Brainstorming can take between 30-60 minutes, while complex prototyping processes can take up to 30 days;
- Difficulty of Use (IDEO, 2015; INSTITUTE, 2021): is related to the complexity for a person or team to master the CIT's use, or which level of expertise is necessary for

a team to perform adequately the CIT. For instance, Storyboard is a low difficulty CIT, while Service Blueprint is a high difficulty one;

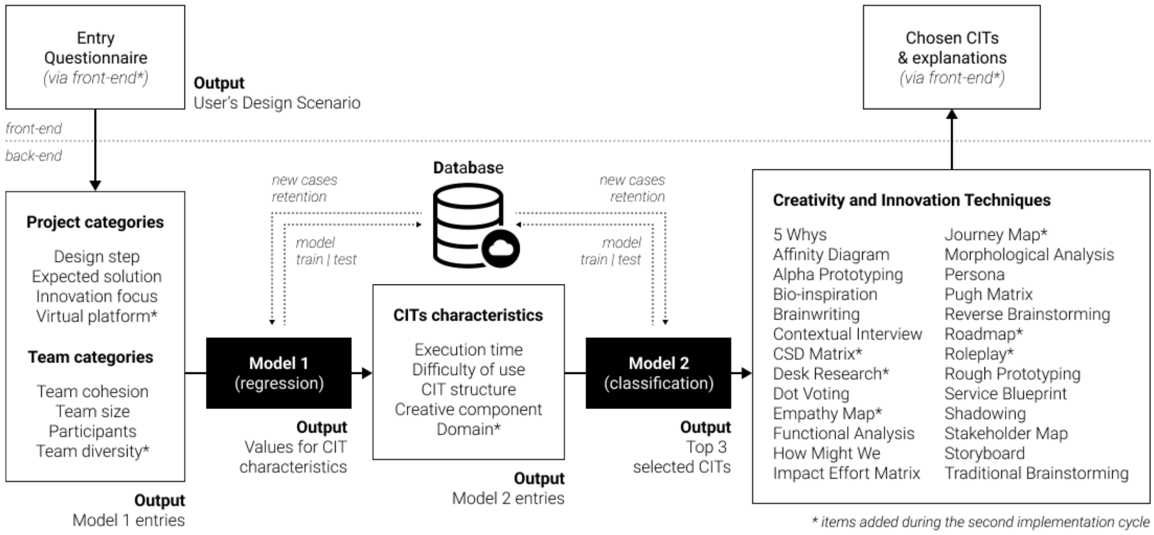
- CIT Structure (BACK *et al.*, 2008): is related to the existence or not of a strict structure to be followed for the CIT execution, depending on its nature. As examples Pugh Matrix is highly systematic, while 5 Whys is more intuitive and based on spontaneous provocations;
- Creative Components (BACK *et al.*, 2008; BROWN, 2009; ULRICH; EPPINGER, 2012): main components or parts of the creative process that are important for achieving creative and innovative solutions, as presented in Section 2.4.2. As non-sequential approach, innovative efforts tend to undergo each of these components during a full design process, and CITs can be helpful throughout them: "user desirability", "organization feasibility", "economic viability", "frame", "concepts", and "prototypes". For instance, Empathy Map is grounded on better understanding what users want, while Service Blueprint is a prototyping technique that acts as a bridge between users' needs and organizations capabilities;
- Domain (ALVES; NUNES, 2013; DORST; CROSS, 2001): based on the coevolution of the design effort as a process of iteratively understanding problems and developing solutions, as shown in the Double Diamond methodology. The domain category divides these two diamonds: one for the problem-space, where 5 Whys and Personas are great additions; and other for the solution-space, where Morphological Analysis and Rough Prototyping can shine.

CITs also have specific guidelines for some of the mentioned project and team categories. For instance, the Design Step is both a project factor, meaning in which methodological stage the team is currently in, and a technique characteristic, considering that the CIT was established to be used in a particular design stage. This means that, after inferring values for CIT characteristics (stage 1), the prototype can use some project and team categories as additional information in the search for adequate CITs (stage 2). The categories that were considered part as the design scenario and technique characteristics were Design Step, Expected Solution, Virtual Platform (added in the second cycle), Team Size and Participants.

4.3 PROTOTYPE AND DATA ARCHITECURE

The presented categories served as basis for structuring knowledge in an implementable fashion. The sources presented alongside categories provided not only information for distinguishing these dimensions, but also supplied data on CITs to pinpoint where they could be located in such variables. As shown in Figure 4.2, the development architecture was based on a two-staged process: one to infer the needed CIT characteristics, and a second to determine which CITs better befit the given circumstance.

Figure 4.2 – Prototype schematic representation.



Source: author

Overall architecture includes a starting point in which the user answers a series of questions to depict the design scenario. These answers, combining project and team categories, are organized to serve as input to the first model. The numbers presented at the right side of each title represents the total of categories used during the second implementation cycle. The first stage of inference should use these values provided by the users to identify needed values to CITs characteristics which the system deems adequate to user's needs. With these values calculated, the second stage incorporates some relevant project and team categories to feed the second model, which outputs the CITs deemed adequate. Since the ulterior intention of the system is to provide support to users' decision, a cutting number of 3 CITs was established, meaning that they would have more than one alternative, but not be overflowed with options.

In order to allow this process, information on each CIT was extracted from literature, composing a series of specific situations in which techniques use is recommended. To ensure suitableness and correspondence, CITs were only considered in this work if described in at least five different sources. References were overlapped given reasonableness of intersection, composing an initial dataset containing the CITs and situations of recommended use.

Most values provided were extracted as-is from literature, representing indications and cases in which they are deemed adequate by these sources. Four of the used categories were less obvious and difficult to analyze. For instance, Difficulty of Use is not presented in a numeric fashion, but mentioned more textually during a CIT description. As an example, during 5 Whys description in STICKDORN and SCHNEIDER (2012, p. 159-160), it is stated: "The 5 Whys are a simple, easy way to establish links between root causes and surface problems, and require very little preparation". Based on this description it can be inferred that this CIT is comparatively easy to use when contrasted to another like Bio-inspiration, whose basic inspiration is described by SILVERSTEIN; SAMUEL and DECARLO (2013, p. 153-155) as being "often non-obvious and intricate" and "is often applied by those trained to observe nature at its most fundamental level", phrases that imply a higher difficulty of use.

Following this reasoning, values for Team Cohesion, Execution Time, Difficulty of Use, and CIT Structure were comparatively measured using Analytical Hierarchy Process (AHP) applied initially following information found in literature and mediated by the author's own experience. This process can be used to translate qualitative into quantitative values based on pairwise comparison (SAATY, 2008), meaning that each CIT was contrasted to all others individually to establish a numeric relation.

Traditional scale of comparison, containing linear 9 points, indicates that evaluator has the possibility of choosing a number from 1 to 9 in each pairwise comparison to signify weight between the items under analysis (SAATY, 2008). This granularity of scaling would be unviable in this work, since there is not sufficient information on CITs to establish such fine comparisons. Hence a 3-point geometric scale was used, establishing comparison possibilities as equally difficult (1), more difficult (2), and strongly more difficult (4), with inverses of easier (1/2) and strongly easier (1/4). Table 4.1 presents a sample of one of the AHP processes used. The same line of thinking can be applied to the other categories that went through AHP. The choice for a geometric (or Lootsma) scale (LOOTSMA, 1993) instead of the original linear was based on its highest consistency and robustness to inconsistency (FRANEK; KRESTA, 2014).

Table 4.1 – Sample of the AHP performed for Difficulty of Use.

	5 Whys	Affinity Diagram	Alpha Prototyping	Bio-inspiration
5 Whys	1	1/2	1/4	1/4
Affinity Diagram	2	1	1/4	1/2
Alpha Prototyping	4	4	1	2
Bio-inspiration	4	2	1/2	1

Source: author

The pairwise comparison yields a matrix with lower triangle being the inverse of upper triangle, with main diagonal of ones. Obtained values were then post-processed using the traditional Eigenvalue method (EVM) to achieve the final rank (SAATY, 2008), which is a set of values between 0 and 1 to each CIT. For the example of Difficulty of Use, CITs with values closer to 1 are considered more difficult. It is important to mention that for the second implementation iteration, previously defined AHP values for Difficulty of Use, Execution Time, CIT Structure and Team Cohesion were rebalanced using evaluators ranking provided during the validation process, and added category of Team Diversity was also submitted to the AHP to find adequate values.

To illustrate the knowledge acquisition and representation, Affinity Diagram will be presented in more depth. Information about this particular CIT was captured in 9 different sources referred as Affinity Diagram (ALVES; NUNES, 2013; DAM; SIANG, 2020; IDEO, 2011; VIANNA *et al.*, 2012), KJ Method (SILVERSTEIN; SAMUEL; DECARLO, 2013), Find Themes (IDEO, 2012; 2015), Affinity Process (HAVERGAL; EDMONSTONE, 2017), and Synthesis Wall (TASSI, 2009). Sources point that this CIT is particularly oriented to the Define stage (HAVERGAL; EDMONSTONE, 2017; IDEO, 2011; 2012; VIANNA *et al.*, 2012), but may be used during Deliver (DAM; SIANG, 2020; SILVERSTEIN; SAMUEL; DECARLO, 2013) as a form of making sense of a too great number of generated ideas. Based on that it may fit both problem and solution domains, since the aggregation process can be used to find clusters over users' insights (IDEO, 2011; 2015; TASSI, 2009), solution concepts (DAM; SIANG, 2020; SILVERSTEIN; SAMUEL; DECARLO, 2013) or even to better frame the problem (ALVES; NUNES, 2013; IDEO, 2012; VIANNA *et al.*, 2012). It is useful for convergence after wide ideas generation, regardless of aspiring more incremental or radical innovation. Literature is unanimous that this CIT is preferably executed in groups, citing for instance 2 to 5 members (IDEO, 2012) or 6 to 8 (SILVERSTEIN; SAMUEL; DECARLO, 2013) or even higher (HAVERGAL; EDMONSTONE, 2017; IDEO, 2015), being benefited by multidisciplinary team compositions (VIANNA *et al.*, 2012) and presence of experts (ALVES; NUNES, 2013). Other mentioned factors underwent AHP to define their values in comparison to other CITs, always based on literature information such as requiring a participatory team cohesion (ALVES; NUNES, 2013; VIANNA *et al.*, 2012), a low structured execution process (ALVES; NUNES, 2013; HAVERGAL; EDMONSTONE, 2017), quicker execution (IDEO, 2011; 2012), and of intermediate difficulty of use (IDEO, 2011; 2015). Each CIT was submitted to similar scrutiny to define its values.

By grouping such analysis for each CIT, it was possible to achieve a condensed dataset representing the conditions in which the techniques are considered to be useful. This whole process was performed equally in both development cycles. First cycle included 21 CITs and 10 categories, while second cycle expanded to 26 CITs and added 3 categories, which implied in a revision of all values and AHPs performed. A sample of these condensed values is presented in Table 4.2 to illustrate the numeric representation for 5 CITs. The full set of information gathered is presented in Appendix A, Table A.5.

Table 4.2– Condensed representation of 5 CITs depicting the values obtained during knowledge representation.

CIT Name	**5 Whys**	**Affinity Diagram**	**Alpha Prototyping**	**Bio-inspiration**	**Brainwriting**
Design Step	Discover Define	Define Deliver	Deliver	Develop	Develop
Innovation Focus	Incremental Evolutive Radical	Incremental Evolutive Radical	Evolutive Radical	Evolutive Radical	Incremental Evolutive Radical
Team cohesion	0.0	1.0	0.5	0.1	0.0
Team size	1 to 8	2 to 12	3 to 10	4 to 8	4 to 8
Expected solution	Product Service	Product Service	Product	Product	Product Service
Participants	Users Experts Staff	Experts	Users Experts ServiceStaff Stakeholders	Experts	Users Experts Staff
Virtual platform	Yes	Yes	No	Yes	Yes
Team Diversity	0.3	0.5	0.3	0.3	0.0
Execution time	0.0	0.1	1.0	0.5	0.0
Difficulty of use	0.0	0.3	1.0	0.5	0.1
CIT structure	0.0	0.1	0.6	0.2	0.2
Creative components	Users Frame	Users Frame Concepts	Users Organization Prototype	Concepts	Concepts
Domain	Problem	Problem Solution	Solution	Solution	Solution

Source: author

This condensed dataset contained information on all 21 (first cycle) or 26 (second cycle) CITs, rows of the dataset, and 10 (first cycle) or 13 (second cycle) features, columns of the dataset. Information about the sources of information for each CIT can be found on Table A.6 of Appendix A. This table, containing information on each CIT with respective values to each category and based on data architecture was considered to be the outcome of Knowledge Representation, allowing to move to the next stage of Implementation on the framework.

4.4 PREPARING DATA FOR MODELING

With knowledge adequately represented, focus was given to understanding the available data and devising ways of transforming it into a case-based structure, seeking a dataset prepared for modeling. In its condensed form where each line represented one technique, the dataset contained in each row several situations for which the CITs can be used, for instance 5 Whys is recommended for the Design Stage of "Discover" for uncovering the roots of the problems, but can be adapted and used at the "Define" stage for achieving a broader view. Naturally no team can be at both stages at the same time, so these are in fact two independent cases described in a single row of the table and should be separated to achieve a case-based dataset.

To deal with this unfolding of cases, the categorical features were expanded in several columns, using an approach called *dummification* or one-hot-encoding (PEDREGOSA *et al.*, 2011). In that, possible categorical values for a single feature are transposed and become values themselves, usually adding values of 1 or 0 for respectively belonging or not to a particular class. Table 4.3 shows a sample of this *dummification* for a sample of CITs with the Design Stage category. In this particular implementation, the transposition process accounted not only with a binary belong (1) / not belong (0) possibility, but also an intermediate 0.5 value meaning that the CIT can be adapted to that end.

The same logics can be applied to another mutually exclusive factor beyond the Design Stage. Innovation Focus also required this preparation, since no team can intend to achieve incremental and radical innovations during the same design process. Team factor of Participants was also divided since, for instance, Contextual Interview can be applied to a wide range of different stakeholders, not necessarily with all at the same time. Last but not least, Creative Components category was also *dummified* following the same pattern.

Table 4.3 – Representation of *dummification* process on 5 CITs on the Design Stage category.

CIT Name	Design Stage	Design Stage - Discover	Design Stage - Define	Design Stage - Develop	Design Stage – Deliver
5 Whys	Discover Define	1	0.5	0	0
Affinity Diagram	Define Deliver	0	1	0	1
Alpha Prototyping	Deliver	0	0	0	1
Bio-inspiration	Develop	0	0	1	0
Brainwriting	Develop	0	0	1	0

Source: author

As closing category to be dealt with, Team Size was preprocessed differently in the two cycles. The first considered only the minimal team size needed for the execution of the CIT. For instance, Bio-Inspiration is recommended for teams with 4 to 8 members, so only the lower value was considered. The intention was to devise CITs that were able to be performed individually against ones required larger groups, but the approach was changed based on experts' validation. Following feedback, for the second data preparation Team Size was unfolded based on the range of possible team sizes that are recommended for the execution of the CITs, against using only the minimal possible team size as in the previous cycle. For the same example above, regarding Team Size, the CIT Bio-Inspiration was considered in fact five different cases, one for each number.

This unfolding of cases was applied similarly to both implementation cycles, the first one resulting in 543 samples for the 21 CITs while the second cycle, considering the approach change to Team size, resulted in 4724 samples to the 26 implemented CITs. A strong unbalancing of the dataset was evidenced in the second cycle, what would hamper the following stage of modeling (FERNÁNDEZ *et al.*, 2018). Considering all samples of cycle two, Journey Map was the most prevailing CIT with a total of 864 use cases while Reverse Brainstorming appeared in only 14 cases. During first implementation cycle this unbalancing was the probable cause of the system inability for asserting one of the CITs as the most plausible one.

Thus an oversampling SMOTE approach was used to rebalance the dataset (FERNÁNDEZ *et al.*, 2018), which uses the majority class as basis to enhance the number of all others through combination of cases via k-nearest neighbors averaging. This approach resulted in a new expanded and balanced dataset with 22464 samples, equalizing 864 cases for each CIT. Undersampling approaches were not considered given the low samples size for the CIT with lowest number of cases. Other mixed oversampling approaches for multiclass scenarios may be investigated and result in better data preparation (FERNÁNDEZ *et al.*, 2018), but this analysis was out of the scope of this research. For both cycles, this expanded dataset had its features scaled between 0 and 1 to avoid feature unbalancing regardless of the Machine Learning algorithm used, leaving a ready dataset to be used for modeling. Table 4.4 depicts a truth table fragment with 2 first and 2 last samples for the second cycle to better represent the expanded dataset, as finished inputs to modeling.

Table 4.4 – Samples cases for the expanded final dataset used in the second implementation cycle.

	Id	**0**	**1**	**22462**	**22463**
	Adequate CIT	5 Whys	5 Whys	Traditional Brainstorming	Traditional Brainstorming
Project and team factors (Design context)	Design Step – Discover	1	1	0.5	0.5
	Design Step – Define	0	0	0	0
	Design Step – Develop	0	0	0	0
	Design Step – Deliver	0	0	0	0
	Innovation Focus – Incremental	0.5	0.5	0	0
	Innovation Focus – Evolutive	0	0	1	1
	Innovation Focus – Radical	0	0	0	0
	Team Cohesion	0	0	1	1
	Team Size	0.0	0.1	0.3	0.4
	Expected Solution – Product	1	1	1	1
	Expected Solution - Service	1	1	1	1
	Participants – Users	0.75	0.75	0.5	0
	Participants – Experts	0.5	0.5	0	0.5
	Participants – Service Staff	0.5	0.5	0	0
	Participants – Other Stakeholders	0	0	0.5	0.5
	Virtual Platform	1	1	1	1
	Team Diversity	0.3	0.3	0.9	0.9
CIT Characteristics	Execution Time	0	0	0.1	0.1
	Difficulty of Use	0	0	0	0
	CIT Structure	0	0	0	0
	Creative Component – Users	1	1	0.5	0.5
	Creative Component – Organization	0	0	0.5	0.5
	Creative Component – Business	0	0	0.5	0.5
	Creative Component – Frame	1	1	0	0
	Creative Component – Concepts	0	0	1	1
	Creative Component – Prototypes	0	0	0	0
	Domain – Problem	1	1	0.5	0.5
	Domain – Solution	0	0	1	1

Source: author

Samples 0 and 1 are unfolding of a same CIT, and the sole difference stands on team size, since 5 Whys can be performed individually or in groups (CLEGG; BIRCH, 2007). Since the dataset was scaled between 0 and 1 to avoid feature unbalancing, the first sample (Team Size 0) indicates that there was only one person in the design effort (individual development), while the second samples (Team Size 0.1) represents that a team of 2 was involved. For other categories, Design Step, Innovation Focus, Expected Solution, Participants, Creative Component, and Domain were separated in their possible values. For example, sample 0 depicts a use case for the Design Step of Discover (which received value 1 while others received 0), inferring the case methodological phase. Intermediate values between 0 and 1 for these categories infer mild usefulness, for instance sample 22462 depicting that the presence of users as participants of the creation process has potential benefits, but is not mandatory.

With the data better understood and represented, attention was given on implementing Machine Learning modeling to predict useful CITs given a context. As said, first cycle of implementation focused on model testing and parameters tuning, while second one underwent a simple re-evaluation of the previously defined models and, if necessary, re-parametrization.

5 TWO-STAGED MACHINE LEARNING MODEL DESIGN

As a core for the prototype, a two-staged inference process was foreseen during knowledge representation. Core model design was developed during first cycle, including a wide test with a total of 12 different Machine Learning models. The second cycle modeling phase retried models to guarantee that their parameters were still adequate to the improvements due to the increased number of samples, with no intention of changing the used models themselves. This chapter presents the main aspects of implementation in both cycles taking as basis all knowledge acquired, represented and translated into data as presented in previous sections. Since both cycles were similar in structure and implementation methodology, focus is given to the second validation process, comparing with the first when needed.

The first part of the two-staged model used the design team scenario to evaluate the best fitting values for CITs characteristics, which were structured as continuous variables and required a multiple output regression approach to find values for each variable individually (PEDREGOSA *et al.*, 2011). The second part retrieved such outputted characteristics and merged selected project and team categories, using them to define the most appropriate CITs to match the context through a raking-classification multinomial approach. The ranking-classification implies finding a rank or descendent sequence of class probabilities estimates making possible the selection of top options as adequate, while the multinomial approach predicts simultaneously through a loss function the probability of the inputted data belonging to each class (in this case CITs), considering the sum of probabilities being necessarily one due to the mathematical approach employed by the algorithm (BROWNLEE, 2021). Section 5.1 addresses the full two-staged modeling for the first development cycle.

It is important to mention that, though the term "probabilities estimates" is used here, it does not imply that the final prototype will infer the probability of usefulness of a CIT. The asserted techniques are considered "plausible" to the given situation, and will be treated using this term when adequate. The use of the term "probability" is based on the terminology used in the Machine Learning field and by the library used to implement this prototype, under the [predict_proba(X)] function[1].

After modeling using appropriate tools and achieving sufficient training and testing results, a second cycle of development with changes and improvements on the prototype was

[1] https://scikit-learn.org/stable/modules/generated/sklearn.linear_model.LogisticRegression.html

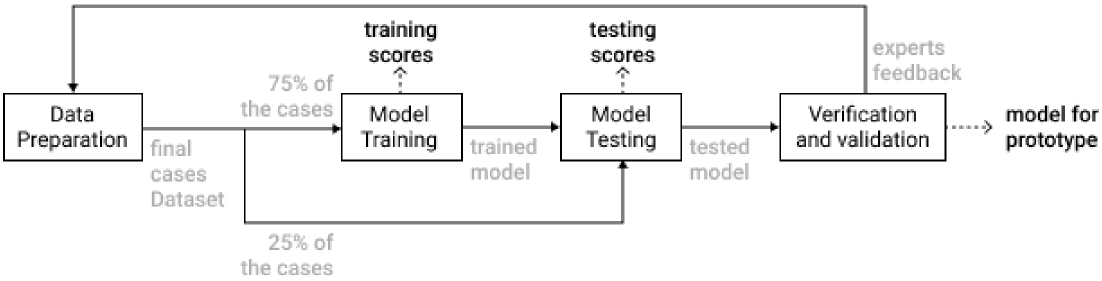
performed and is presented in Section 5.2, which included a Graphic User Interface development embedded on a web-application, described in Section 5.3. This development was also validated and is presented in-depth in Section 5.4, contrasting the results obtained in both cycles. Section 5.5 presents some introductory analyses and findings derived from the ML implementation based on data extracted from the models.

5.1 FIRST CYCLE – MODELS DEVELOPMENT

The objective of this first model was to perceive which CITs characteristics would benefit the design scenario based on the contextual information given through by users themselves about project and team. To allow more rigid testing of the achieved model adequacy and avoid over and underfitting, an approach of Holdout Evaluation is commonly used by Data Scientists (PROVOST; FAWCETT, 2013). It consists on withholding a part of the dataset and training the model only with the remaining samples. The achieved model is then submitted to testing using the holdout data, which was hidden during training and check if the model is able to predict adequately outcomes for this testing dataset. If the model does not predict well neither training nor testing data, it is considered underfitted, meaning it was unable to perceive trends and generalizations in the data, while if the model is able to predict well the training data and has bad scores for testing, it is considered overfitted, meaning it has memorized training samples instead of generalizing well even for unseen data (BASHIR *et al.*, 2020).

Modeling followed standard train-test procedure using 25% of the dataset as test samples, which is default value (PEDREGOSA *et al.*, 2011). A description of the procedure used can be seen in Figure 5.1. Having the dataset ready, the data is separated into training and testing, the first imputed to the model being tried-out to achieve a potential inference process, and the second used to test if such inference process can deal with new data. Scores for train and test are extracted in each of these phases. When achieved the best possible model, it can be submitted to verification and validation with experts to obtain feedback and assure that the model is adequate to be used by the prototype wide use.

Figure 5.1 – Graphic visualization of the train-test process used for achieving the models.



Source: author

Eight regression machine learning models were tried out using Scikit-Learn grid search model selection algorithm with 10-fold cross validation (PEDREGOSA *et al.*, 2011) to compare values and define which model to use. Models were chosen given the potential application for this particular modeling effort (PEDREGOSA *et al.*, 2011). Train and test scores were evaluated using a R^2 metric, as it measures the likelihood of an unseen samples to be predicted by the model and has a cap value of 1.0 (PEDREGOSA *et al.*, 2011). This implies that a higher R^2 value would represent a better suitability of the model to convert the design scenario into CITs characteristics. When considering the Standard Deviation of results achieved by subsequent tryouts (cross validation), higher values imply that the model under analysis presented a higher instability, given that it reached different predictions for a same input in different execution attempts. Attempted models are presented in Table 5.1 with respective results. As it can be seen, K-Nearest Neighbors, Support Vector (using rbf and poly kernels), Gaussian Process and AdaBoost Regressors could not achieve satisfactory results for some of the CITs characteristics and, when compared to other 3 models (Decision Tree, Random Forest and Gradient Boosted Trees), are clearly inferior in this application.

Table 5.1 – Results achieved at Regression Models training and testing.

	Train scores		**Test scores**	
Model (Regressor)	Mean R^2	SD	Mean R^2	SD
AdaBoost	0.765	0.034	0.644	0.211
Decision Tree	0.986	0.003	0.913	0.109
Gaussian Process	0.994	0.001	0.590	0.318
Gradient Boosted Trees	0.975	0.002	0.896	0.148
K-Nearest Neighbors	0.824	0.011	0.602	0.463
Random Forest	0.987	0.002	0.936	0.092
Support Vector (poly)	0.764	0.008	0.580	0.192
Support Vector (rbf)	0.902	0.007	0.665	0.316

Source: author

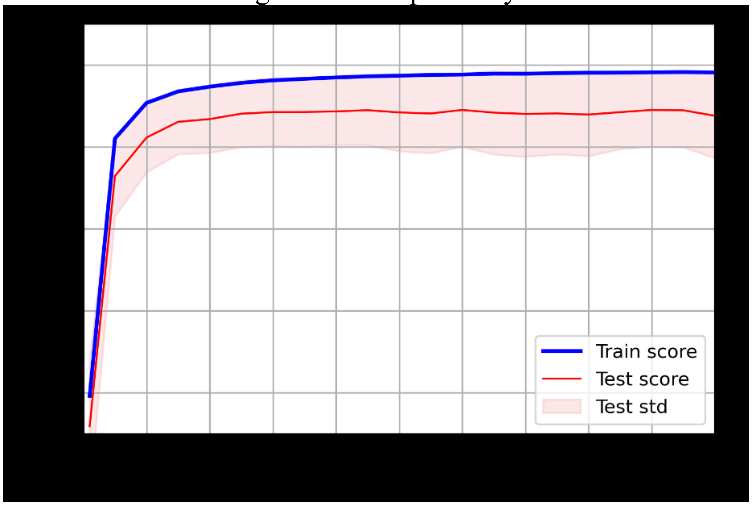
To define a model to be used, Decision Trees, Random Forest and Gradient Boosted Regression Trees (GBRT) were further explored, all achieving test scores around 0.9 in the first non-parameterized runs. The first is computationally faster, but parameters tuning was unable to lower standard deviations for cross validation, meaning a more unstable model and making it less adequate. Due to its training speed, the Decision Trees model should be revisited when a greater number of cases due to Case-Based Reasoning case retention is achieved, which can corroborate to lower the standard deviation. Random Forest, which provided very good results during evaluation, provided the highest running time. Another conflicting factor for Random Forest is the lower interpretability of the results, which hampers the system explicability skills. GBRT, on the other hand, showed promising results for testing during parameters tuning, though at the cost of higher computational costs if the estimators' number is too high. With the increasing number of samples due to the retention of new cases on the Case-Based Reasoning approach, model training time may become prohibitive for GBRT in the future.

Even so, GBRT was chosen as the first inference model considering the outstanding results achieved and intermediate execution time, since this algorithm deals better with higher bias that may result from the knowledge acquisition process (BOEHMKE; GREENWELL, 2019). By hyperparameter tuning, this model is prone to reduce running time by lowering the number of estimators while still achieving satisfactory scores. This result implies in a prototype quicker to train and test, and allows a more sustainable increase of CITs and cases as the database grows through case retention. Another advantage of this model, shared by Decision Tree, is the ability to explain the inference by plotting the used trees or providing a feature importance score, which brings information on which input variables were more relevant on defining results. The rationale behind the inference process is fundamental to give the prototype more credibility over the results and even to offer insights to users on the whys behind the assertion.

Using R^2 metric as a comparison basis, three parameters were tuned: learning rate and number of trees as boosting parameters and maximum tree depth as tree-specific parameters. This parameters regulation intended to achieve the best possible results and reinforce an adequate fitting balance. First tuning involved finding an adequate learning rate (LR) or shrinkage for the model that guarantees convergence, leaving other parameters as default. This parameter controls the speed of the convergence process in gradient descent approach, typically ranging from zero to one. Preference is usually given for smaller values since they allow better generalization and stability, avoiding overfitting, although excessively small LR may become too slow given the increased number of trees (BOEHMKE; GREENWELL, 2019).

The parameter was tested with 10 executions for each LR between 0.05 to 1 with a step of 0.05, while letting number of trees and max depth with default values (100 and 3 respectively). As expected, LR lower than 0.1 tended to underfit barely reaching 0.9 of R^2 in testing score (Figure 5.2). This means that the model was unable to perceive trends and generalizations in the CIT dataset to infer the adequate characteristics, missing correct values by wider ranges. At LR of 0.1 forward results were satisfactory, R^2 testing score staying between 0.91 and 0.94 and standard deviation below 0.06. Since high LRs perform bigger steps that may cause instabilities, adding randomness to the model, which would mean that the inferred CITs characteristics could become unstable with low repeatability. Following LR recommended values (BOEHMKE; GREENWELL, 2019), for this model values between 0.1 and 0.6 were chosen for further evaluation.

Figure 5.2 – Graphic representation of R^2 scores per essayed Learning Rate for the GBRT model during first development cycle.

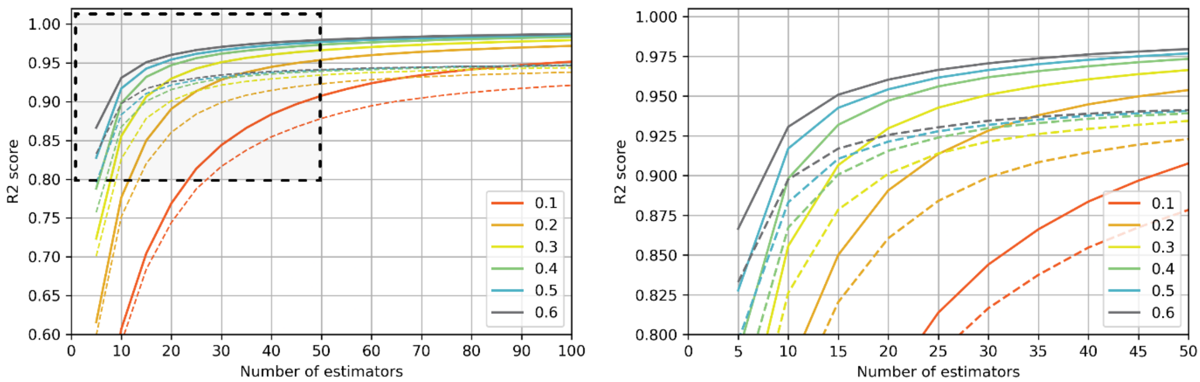


Source: author

Second tuning involved understanding the effect of LR on the number of trees. This parameter indicates the number of estimators used for the ensemble, each tree using results from previous to improve overall output (MAKLIN, 2019). Though usually requiring many trees, an excessively high number may cause overfitting and increase drastically training times (BOEHMKE; GREENWELL, 2019). With adequate tuning, the model can be truncated earlier without sacrificing results.

Thus LR was discretized in a 0.1 step from 0.1 to 0.6, running iteratively from 5 to 100 trees in a 5-step pattern with 10 iterations for each pair of parameters, retrieving mean and standard deviation. Results are shown in the left part of Figure 5.3, with highlight in the right part to a cropped view of the results at 50 trees to enhance visualization. As expected, lower LR required a higher number of trees to converge for a value of R^2 over 0.9, though all LR essayed reached satisfactory scores at 100 trees. Results for learning rate 0.6 show that test scores are well stabilized at 20 estimators. This would result in a great reduction of the number of estimators necessary and, consequently, a reduction of processing time. However, results for higher learning rates tend to have higher standard deviations, which may result in an instability of the system over time and incur in low repeatability for CIT assertion. To avoid inaccuracy but also lower execution time while maintaining satisfactory scores, a trade-off was necessary. Therefore, the LR of 0.4 was defined, reaching stable results with a good safety margin around 30 estimators.

Figure 5.3 – Graphic representation of R^2 scores per essayed Number of Estimators and Learning Rate for the GBRT model during first development cycle. Full results are presented in the left part and a zoomed view on the right.

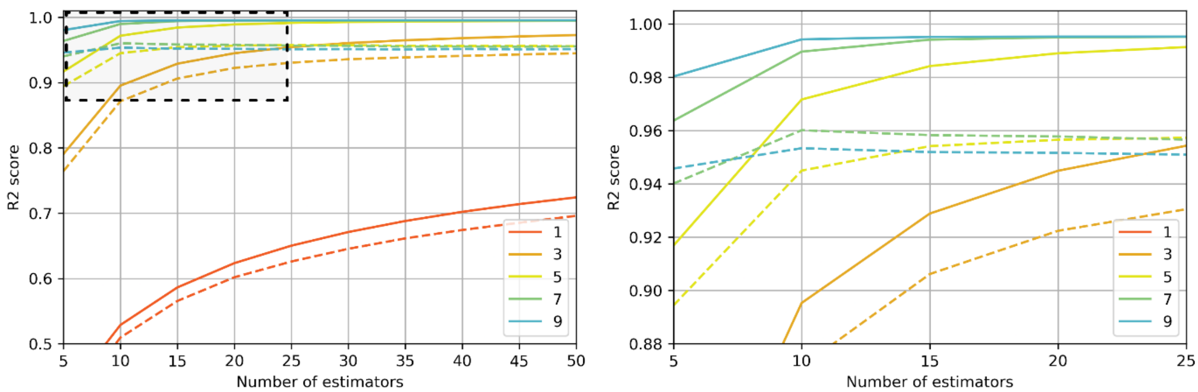


Source: author

Last hyperparameter of tree depth was tuned to attempt a better fitting balance, as its value has a great impact for avoiding both over and underfitting. Trees with small roots tend to be better for generalization and are computationally more efficient, though they can result in underfitting if not enough trees are used (BOEHMKE; GREENWELL, 2019). On the opposite end, deeper roots improve the capture of particular behaviors of the data at the expense of overfitting the data. Typical tree depth values range from 3 to 8 (BOEHMKE; GREENWELL, 2019), though other values can be used in particular circumstances.

For finding an adequate maximal tree depth that allows a good generalization for the regression algorithm, the GBRT model was tested in odd numbers from 1 to 9 for better tie-breaking (PROVOST; FAWCETT, 2013), ranging from 1 to 50 trees with a step of 1, also following 10 executions for each condition and taking mean and standard deviation. Results are shown in Figure 5.4. As expected, it was perceived that depth 1 and 3 trees tended to underfit, being unable to reach their best R^2 scores with only 50 trees. This means they would require more estimators, which would demand more processing time. For higher depths of 7 and 9, training and testing scores had a slight distancing and increase in standard deviation, which is indicative of overfitting (PROVOST; FAWCETT, 2013). With that the model tended more to memorize training data instead of perceiving generalizations on the data to infer CIT characteristics from design scenarios, meaning that the inference process would not achieve correct predictions for data other the ones used in training. As a middle ground, max tree depth of 5 reached well stabilized R^2 scores over 0.99 and was thus chosen as value for this parameter. This definition also allowed a reduction in the number of estimators, since the R^2 score reached its plateau with 25 trees.

Figure 5.4 – Graphic representation of R^2 scores per essayed Number of Estimators and Maximal Tree Depth for the GBRT model during first development cycle. Full results are presented in the left part and a zoomed view on the right.



Source: author

With that, all hyper parameters were tuned, reaching final values of 0.4 for LR, 25 for number of estimators and 5 for maximal tree depth. The parametrization process achieved model fitting time 2.7 times lower that the default one, as well as a better balance to avoid both under and overfitting, which could result in a prototype more prone to misunderstand the design context, infer inaccurate CITs characteristics and, based on that, chose the wrong CITs to the given scenario. Having the first inference model ready, effort was put on choosing and tuning the second model for the prototype. As said, this inference stage required to use the results obtained from the first model, combined with other CIT characteristics extracted from users' inputs, to reach values of adequacy or plausibility of use for each CIT, ranking them and selecting the best alternatives. Thus a ranking-classification model was needed, especially one that predict class probabilities.

Considering the two-staged inference structure presented, the second model premise was to use the achieved values of CIT characteristics by the previous model as input to rank the 3 most plausible CITs. Though the models use of statistical probabilities to infer which techniques would be more adequate, the CITs selected are considered plausible to the given scenario and the probability values are not externalized to the user since they may not reflect reality due to the way knowledge was acquired. The number of 3 CITs was considered reasonable to give sufficient options to users while not overwhelming them, not demanding excessive time for them to select which of the alternatives they would prefer using. This number can be further evaluated and established in future implementation cycles. With this goal, effort was put into finding a model with sufficient flexibility to achieve not only the best CIT, but to perceive other nuances that indicate that other less obvious techniques could also be useful in the given scenario. To measure that, three metrics were combined:

- Accuracy (Acc): as variation of the traditional accuracy score (PROVOST; FAWCETT, 2013), this metric is given by checking the total percentage of predictions that matched the expected CIT (truth value), considering correct if the expected value is contained in any position of the top 3 chosen CITs;

$$Acc = \frac{\sum_{i=1}^{n}(truth\ value_i \subseteq selected\ CITs_i)}{n} \tag{5.1}$$

- Sum of probabilities (SoP): represents the sum of class probabilities of the 3 selected CITs as obtained by the LogReg model prediction of probabilities function. This evaluates if the model is not too loose, considering CITs that should not be used for the given scenario (underfitting);

$$SoP = \frac{\sum_{i=1}^{n}(P_i(first\ CIT) + P_i(second\ CIT) + P_i(third\ CIT))}{n} \tag{5.2}$$

- Empty outputs (EO): this metric evaluates the number of assertions left blank due to not achieving tolerance. For this implementation, if a CIT in the top 3 does not achieve a minimal class probability of 0.01 it is considered noise and discarded. As a result, this metric measures the ratio of empty outputs to the total number of predictions made. Higher numbers of empty outputs indicate that the model is reaching just one best CIT and disregarding neighboring ones, which is considered here an overfit.

$$EO = \sum_{i=1}^{n} \begin{cases} 0, if\ P_i(third\ CIT) > 0.01 \\ 1, if\ P_i(third\ CIT) < 0.01\ and\ P_i(second\ CIT) > 0.01 \\ 2, if\ P_i(second\ CIT) < 0.01\ and\ P_i(first\ CIT) > 0.01 \\ 3, if\ P_i(first\ CIT) < 0.01 \end{cases} \quad (5.2)$$

These three metrics were considered during model training and testing. Benchmark results were established, seeking accuracies over 0.95 meaning that from all results only 5% could be wrong, sum of probabilities over 0.8 to ensure that the chosen CITs have a good plausibility of being useful for the user, and empty outputs lower than 5%, ensuring that the model is consistently giving more than one technique option for the user to decide.

During first cycle, four models were chosen to be tested based on adequacy for the proposed effort (PEDREGOSA *et al.*, 2011): K-Nearest Neighbors Classifier (KNN), Decision Tree Classifier (DT), Support-Vector Classifier (SVC) and Logistic Regression Classifier (LogReg). At first, models were evaluated without any parameters tuning, using default values. Train-test split approach was also used separating 25% as testing samples. Results are presented in Table 5.2.

Table 5.2 – Results achieved for Classification Models training and testing during first cycle.

	Train Scores			**Test Scores**		
Model (Classifier)	Accuracy	Sum of probabilities	Empty outputs	Accuracy	Sum of probabilities	Empty outputs
Decision Tree	1.000	1.000	0.644	1.000	1.000	0.647
K-Nearest Neighbors	1.000	1.000	0.628	1.000	1.000	0.635
Logistic Regression	0.997	0.868	0.026	0.992	0.858	0.017
Support Vector	1.00	0.775	0.000	1.000	0.776	0.000

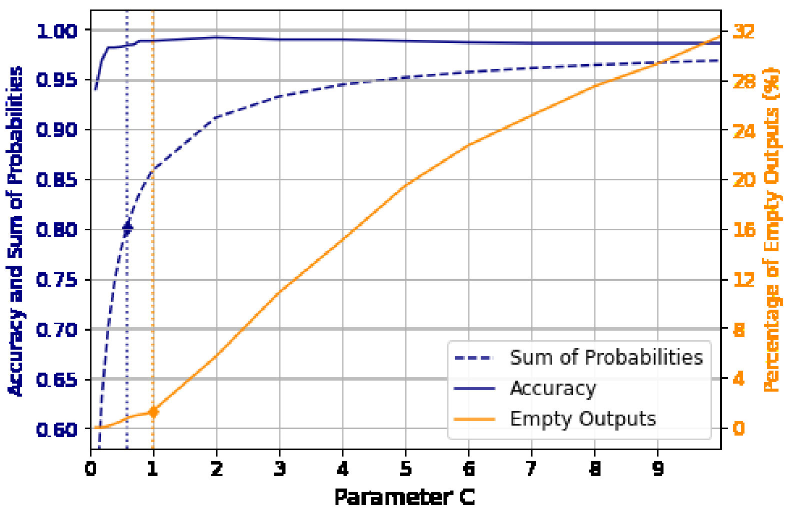
Source: author

It can be seen that KNN and DT overfit the result and return only the best CIT. Even though these algorithms had perfect accuracy scores, they disregarded other options of techniques, and ended up with a high empty output score both in training and testing. Even when pursuing improved results with hyperparameter tuning, both KNN and DT only presented slight improvement, but remained unable to reach the set benchmarking.

On the other hand, SVC and LogReg presented lower sums of probabilities, but have shown great flexibility to perceive the surrounding options. In general, these models were able to select the truth value both in training and testing, but also to find similar CITs that could be beneficial for the user's scenario. Thus became a trade-off between the number of empty results, meaning inability to perceive other neighboring CITs, and sum of probabilities, meaning that the selected CITs may not represent the best ones. Even so, considering the previously established requirements, the model that demonstrated the best potential for balancing both is LogReg, and was thus chosen for further investigation.

LogReg has traditionally one main hyperparameter for tuning: the regularization coefficient (λ). This value penalizes complexity, with large λ increasing simplicity by pushing the coefficients towards zero and allowing the occurrence of more errors and underfitting, while small λ diminishing error while risking overfitting (PROVOST; FAWCETT, 2013). For the chosen algorithm, the parameter tuning was based on the inverse regularization coefficient $C = 1/\lambda$ (PEDREGOSA *et al.*, 2011). In this scenario, a range of values for C using step 0.1 from 0.1 to 1 and step 1 from 1 to 10 was tested using once again 10 executions to calculate mean results. Achieved results are shown in Figure 5.5.

Figure 5.5 – Graphic representation of the achieved scores per essayed parameter C for the LogReg model during first development cycle.



Source: author

As it can be seen, a range from 0.6 and 1 presented results that fit the pre-established requirements. Since accuracy is sufficiently stable over 0.5, the trade-off was set between empty outputs and sum of probabilities. In this case, having lower empty outputs was considered better since the main aim of this prototype is to provide options to the user. Hence, the C value chosen was 0.7, giving a safety margin from 0.6 that had borderline results of sum of probabilities and priming underfitting over overfitting.

Having both models individually established, focus was given to compose the final prototype that includes both models in sequence. This last testing served as first verification attempt to check if the full model is also able to achieve expected threshold results. The double-inference model is also subjected to the same criteria as the second model, aiming for accuracy above 0.9, sum of probabilities above 0.8 and empty outputs below 5%. The assembled prototype was submitted to a verification "white-box" process intending to evaluate if all answers provided by the system matches the original knowledge represented (KNAUF; GONZALEZ; ABEL, 2002).

As last stages of the first cycle development, verification and validation provided important feedback to guide the second implementation. Since the process and results achieved are similar in both cycles, both evaluation processes will be presented simultaneously in Section 5.4, contrasting results achieved in both developments. As fundamental aspects that guided following implementation, analysis results pointed at an unbalance between CITs in the first cycle, probably driven by a different number of total cases in the dataset for different techniques. While Traditional Brainstorming represented 50 out of the 543 cases on the expanded dataset used to train and test the models, Bio-inspiration amounted only 5 of them. This skew is expected since Traditional Brainstorming is a much more flexible CIT than Bio-inspiration, but this difference was considered excessive and was addressed in the new implementation cycle.

During validation, evaluators mentioned further CITs they considered important to be included in the prototype, and other potential categories for expanding the analysis. Evaluators indicated the removal of Mind Map for being an excessively generic approach. As said, this first "raw" prototype still lacked many functionalities of an autonomous system, and matters of interface, usability and explainability were left to the second implementation cycle. Further points on verification and validation of the first cycle are presented when needed during the second cycle presentation.

5.2 SECOND CYCLE – MODELING AND VERIFICATION

First cycle development illustrated the capability of the prototype to represent expert knowledge on indicating adequate CITs to the user. Even so, many improvement possibilities were perceived and served as stepping stones to the second cycle. Main focus of this new iteration was to upgrade the overall system, seeking adjacent functionalities to build a self-sustaining prototype by adding a Graphic User Interface with adequate usability on a web based platform that encompassed the whole case-based process: from retrieving adequate options to the given design scenario to retaining the new case in the database as to retrain the models in the future.

As said, the second cycle incorporated 6 new CITs and 3 new categories. As indicated by evaluators, Mind Map was removed from the dataset for being more of an organization form than a CIT itself, leaving a total of 26 techniques. The 6 new CITs were selected based on information availability and indication from experts during first cycle validation, adding to the system CSD Matrix, Desk research, Empathy Map, Customer journey map, Roadmap and Roleplay. The 3 new categories added were “Virtual Platform”, “Team Diversity”, and “Domain”. The choice for these 3 variables was based on evaluators’ feedback for lacking dimensions of analysis, information availability for defining values to each CITs, and other complementary studies (MAFFEZZOLLI, 2019). All CITs, including the new ones, were once more studied to define values for the new categories based on literature and experts input.

Previously defined AHP values for difficulty of use, execution time, CIT structure and team cohesion were rebalanced using evaluators ranking provided during the validation process. Following on evaluators’ feedback, for this second knowledge representation Team Size was unfolded based on the range of possible team sizes that are recommended for the execution of the CITs, against using only the minimal possible team size as in the previous cycle. For instance, a CIT that can be performed by a team of 5 to 8 people was considered in fact four different cases, one for each team size.

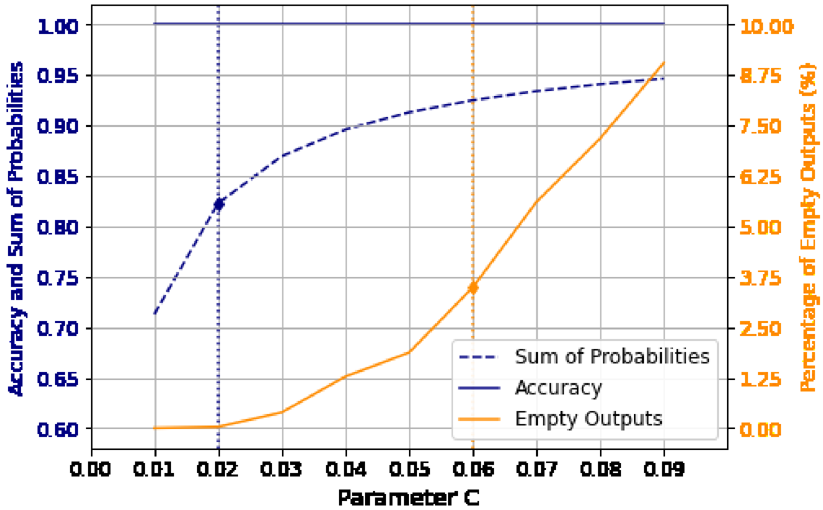
All other data preparation mirrored the first cycle development. When expanding the new condensed dataset to individual scenarios, the total number of cases reached a total of 4724 for the 26 CITs, resultant mainly from the change in team size organization. Similar to first cycle, a strong unbalancing of the dataset was perceived, what would hamper the following stage of modeling (FERNÁNDEZ *et al.*, 2018). For instance, Journey Map had 864 cases while Reverse Brainstorming only 14.

Thus an oversampling SMOTE approach was used to rebalance the dataset (FERNÁNDEZ *et al.*, 2018), which uses the majority class as basis to enhance the number of all others through combination of cases via k-nearest neighbors averaging. This resulted in a new expanded and balanced dataset with 22464 samples, equalizing 864 cases for each CIT. Undersampling approaches were not considered given the low samples size for the CIT with lowest number of cases. Other mixed oversampling approaches for multiclass scenarios may be investigated and result in better data preparation (FERNÁNDEZ *et al.*, 2018), but this analysis was out of the scope of this work. Following the procedure established in the first cycle, this expanded dataset also had its values scaled from 0 to 1 to avoid feature unbalancing regardless of the Machine Learning algorithm used, leaving a ready dataset to be used for modeling.

Since the composed model was already defined in the previous cycle, this iteration attempted to replicate the same approach, checking if the models would achieve similar results and fulfill benchmarking criteria. First model using previously parametrized GBRT to infer required CITs characteristics given the design team context reached testing mean R^2 scores of 0.997 with 10 iterations, being considered sufficient and not requiring any adjustment. As for the LogReg model used in the second inference to rank and select adequate CITs given the characteristics, accuracy results reached 1, with Sum of Probabilities 0.986. Unfortunately, these high results concealed what is considered for this work an overfitting: the number of Empty Outputs reached 48.2%, strongly higher than the 5% threshold. As an effect of the increased number of samples, LogReg model may incur in overfitting problems (HECKMANN *et al.*, 2014). The used model with its set C hyperparameter became unable to perceive surrounding useful CITs, resulting in only finding the best instead of 3 possible techniques for the user to choose. Thus this second model was re-parameterized.

Seeking the same thresholds of over 0.9 accuracy, over 0.8 sum of probabilities and empty outputs lower than 5% of total, LogReg model main parameter C was re-essayed. With the increased number of samples, lower values of C were tried out to allow a reduction of what is here considered overfitting. Results are presented in Figure 5.6, using also the mean value of 10 iterations for C values from 0.01 to 0.09 on a step of 0.01.

Figure 5.6 – Graphic representation of the achieved scores per essayed parameter C for the LogReg model in second development cycle.



Source: author

As it can be seen, values for C that fit the prerequisites are between 0.02 to 0.06, and the final decision to use C as 0.03 is to provide a small buffer for Sum of Probabilities while still providing low Empty Outputs. The use of LogReg may become a concern with the increased number of samples as the system stores new cases. This may demand a periodic retuning of parameters or even a change on the model to select a more robust one to deal with increasing number of cases.

With models re-parametrized and achieving adequate results independently, effort was put into analyzing the two-staged model. Verification aimed once again to perceive if the full system is performing adequately its inference process. Samples were once again divided in train and test, using 25% of cases for the second. The full model fitness to thresholds was evaluated with 10 iterations. Table 5.3 presents a comparison between the two cycles models with their results. The improved prototype reached scores of accuracy, sum of probabilities, and empty output inside the benchmarking expectations, with results being considered an improvement from previous cycle.

Table 5.3 – Comparison of both cycles models and scores achieved.

		First cycle	Second cycle
	Total number of possible inputs combinations	25344	304128
	Most frequent CIT as output during verification	Traditional Brainstorming (53.9% of total executions)	Journey Map (32.7% of total executions)
	Least frequent CIT as output during verification	Bio-inspiration (0.11% of total executions)	Desk Research (2.38% of total executions)
Models	**First (regression): inter CITs characteristics from Users' Design Scenario**	Gradient Boosted Regression Trees: Learning Rate: 0.4 Number of trees: 25 Max depth 5	Gradient Boosted Regression Trees: Learning Rate: 0.4 Number of trees: 25 Max depth 5
	Second (classification): rank adequate CITs based on needed characteristics	Logistic Regression C: 0.7	Logistic Regression C: 0.03
	Number of cases in the Dataset	543	4724 (22464 after oversampling)
Scores	**Accuracy**	0.979	0.999
	Sum of probabilities (mean)	0.812	0.867
	Empty outputs	0.7%	0.3%

Source: author

Again, a verification dataset containing all possible combinations of inputs was created. Mimicking the verification process used in the first cycle, inputs possibilities for each variable were automatically combined resulting in 304128 combinations, which were submitted one by one to the prototype retrieving inferred CITs characteristics and class probabilities estimates to each technique, storing the values in a spreadsheet. A sample of this verification dataset, selected CITs and truth values (values extracted directly from the dataset achieved after data preparation) are presented in Table 5.4. It is important to notice that not all combinations of inputs present in the verification dataset have a truth value, since the dataset used for training the model contains only 22464 cases. Results for other combinations of inputs can be inferred by the prototype but there is no way to define whether the proposed CITs are adequate besides a human expert evaluation, which would be excessively demanding.

Table 5.4 – Comparison of prototype’s outputs to truth values for randomly selected cases during second cycle.

		Example 1	**Example 2**	**Example 3**
	Truth value	Desk Research	Bio Inspiration	Journey Map
	Selected CITs (class probability)	1st Desk Research (0.599) 2nd Stakeholder Map (0.127) 3rd CSD Matrix (0.070)	1st Bio Inspiration (0.646) 2nd Morphological Analysis (0.153) 3rd Reverse Brainstorming (0.023)	1st Journey Map (0.833) 2nd Empathy Map (0.033) 3rd Affinity Diagram (0.032)
Possible user inputs	**Design Step – Discover**	1	0	0
	Design Step – Define	0	0	1
	Design Step – Develop	0	1	0
	Design Step – Deliver	0	0	0
	Innovation Focus – Incremental	1	0	0
	Innovation Focus – Evolutive	0	0	1
	Innovation Focus – Radical	0	1	0
	Team Cohesion	0.3	0.1	1
	Team Size	0	0.2	0.6
	Expected Solution – Product	1	1	0
	Expected Solution – Service	0	0	1
	Participants – Users	0	0	1
	Participants – Experts	0	1	0
	Participants – Service Staff	0	0	0
	Participants – Other Stakeholders	0	0	0
	Virtual Platform	1	1	1
	Team Diversity	0.2	0.3	0.9

Source: author

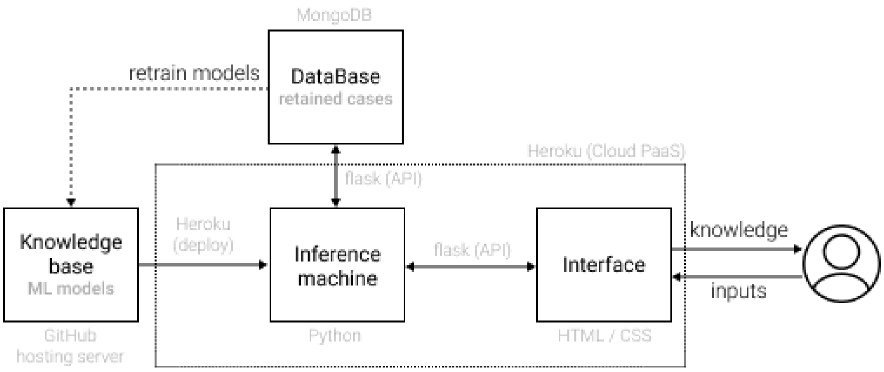
Considering all executions, every CIT was selected as “the best” at least once even with the addition of 6 new ones. Out of all selected techniques, the CIT that appeared the least was Desk Research with 7244 occurrences (2.38% of total executions). These results are considered an improvement since in the last cycle one CIT was left out and assertion of CITs became less discrepant. Naturally a perfect balancing is impossible since some techniques are more flexible than others, which can be seen by Journey Map being selected a total of 99492 times (32.7% of total executions). Even so the most frequent CIT was proportionally lower in second cycle when comparing with the first, which also indicates a better balancing in results.

The basis of the two-staged model developed in the first cycle was thus reviewed and improved to fit the needs for this second cycle. The inference process performs better than previously seen, and this cycle closed the gap of unbalance among different CITs. With the model considered sufficiently adequate, effort was made into developing a web-based application to ease users' access to the prototype.

5.3 SECOND CYCLE – GRAPHIC USER INTERFACE DEVELOPMENT

Main requirements for the development of the application were to be accessible anywhere and anytime through the internet and to retain new cases into a database to allow the retraining of the model in the future. The following section describes graphic user interface and software architecture developed during the second cycle, helping users and evaluators accessing the web-application and making the prototype available online. Implementation followed the separation of database, back-end and front-end, and technologies were selected due to applicability to the needs of this development and authors' familiarity to them. Used technologies are presented in Figure 5.7.

Figure 5.7 – Developed system architecture for web-based deployment.



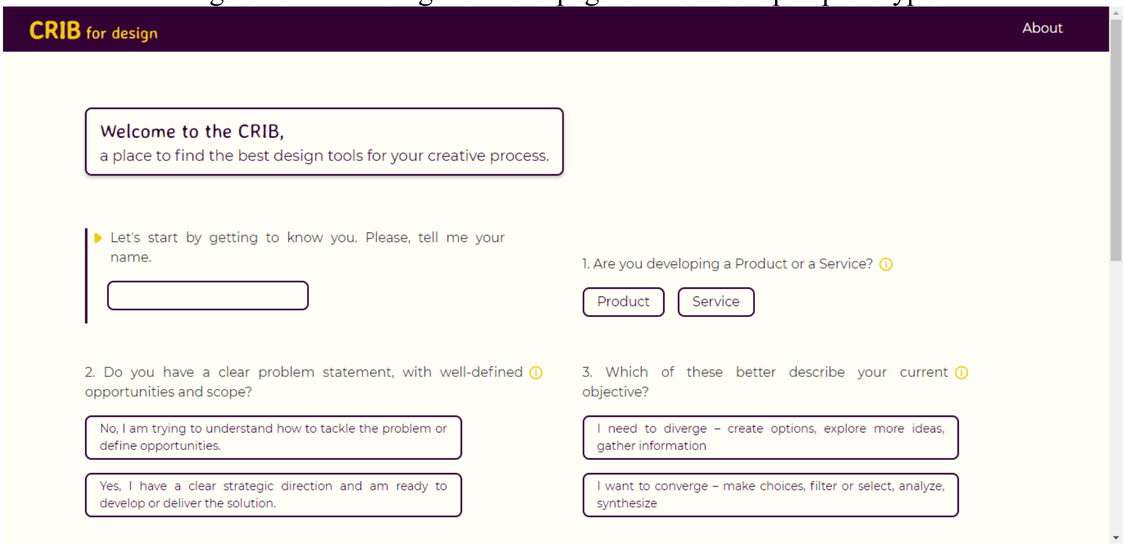
Source: author

Back-end development used Python v3.6 as the main programming language for back-end. Several other python libraries made possible the back-end processing such as pandas v1.1.2 for user inputs preparation to be used by the model, Scikit Learn v0.23.1 for Machine Learning models execution and Flask v1.1.2 for API (Application Programming Interface) communication. Machine Learning models achieved after validation were serialized using pickle native library to be deserialized during execution. Connection to MongoDB was possible using pymongo v3.11 and the front-end was developed using React 4.3.0 added to

HTML 5 and CSS 3. Code and its sources were uploaded to a GitHub repository[2] and continuous deployment for the web application[3] was performed by Heroku Cloud Platform as a Service (PaaS).

On accessing the online application, the user is prompted with a landing graphic interface as shown in Figure 5.8, which inquires name and 10 other questions about the design scenario, which are presented in Table 5.5. This entry questionnaire is an explicitation of the information required for the model to be executed and contains a more accessible language for any user to be able to answer the proposed questions. Each question has a "help" button to further explain its intention and resolve doubts.

Figure 5.8 – Landing front-end page of the developed prototype.



Source: author

[2] https://github.com/luiz-botega/crib/tree/master
[3] https://cribdesign.herokuapp.com/

Table 5.5 – Entry questionnaire presented to users in the web-application.

Question	Possible values	Explanation
Let's start by getting to know you. Please, tell me your name.	Open field	-
1. Are you developing a Product or a Service?	Product Service	By Product we mean physical or virtual items that can be sold, including manufacturing goods, tangible artifacts, or even intangible software, usually implying in ownership. In opposition, by Service we mean intangible offerings that may or may not orbit a product, including communication means, maintenance, processes and experiences, usually not resulting in direct ownership.
2. Do you have a clear problem statement, with well-defined opportunities and scope?	No, I am trying to understand how to tackle the problem or define opportunities. Yes, I have a clear strategic direction and am ready to develop or deliver the solution.	A clear Problem Statement usually derives from quantitative and qualitative research from users and/or market, resulting in a deep understanding of which pains are you trying to solve, which opportunities derive from them, and how you can objectively provide value as a solution, including what will be developed, how, when, by whom and why. It may depend on making interviews, developing personas, articulating with stakeholders, creating Business Canvas, and many others design, marketing and managerial approaches.
3. Which of these better describe your current objective?	I need to diverge – create options, explore more ideas, gather information I want to converge – make choices, filter or select, analyze, synthesize	The objective of the creative effort may be: to diverge, meaning expanding horizons, acquire more information/knowledge, generate and discuss ideas, co-create, and explore options; or to converge, meaning analyzing and synthesizing quantitative or qualitative data, narrow down options, chose paths to go forward, and define strategies of action.
4. How many people will be able to participate in this creative session?	Open question (number only)	This includes all people who will participate directly in the current creative effort, regardless of time. If the process includes gathering ideas and co-creating with users, experts or any other people outside of the team, they should also be counted in, but if they will be required only for knowledge acquisition or validation they should not be included in the sum.
5. Is it possible to include other participants in this creative effort? (you can select as many as you wish)	Users Experts Service Staff Other Stakeholders	You may select them regardless of the role they will have in the creative process. Users or customers can be considered anyone who will benefit directly from the solution being developed. Experts are people with notorious knowledge in any area relevant to the design process. Service Staff are members of the company that acts in the front or backline of the value delivery process. Other Stakeholders include, but are not limited to, managers, directors, shareholders, and providers.
6. In your opinion, how good is your team's relationship? (chose a number from 0 to 10 in the scale below)	Slider from 0 to 10	We consider a team's relationship good (10) if every member (every single one) can express their ideas and opinions freely without any barriers, judgement or negative feelings, usually deriving from everyone working together for some time, having mutual trust and sense of team-work, and being in a receptive physical and social environment. On the opposite end, a team with bad relationship (0) have great animosity, generating conflict, mistrust, constant personal judgement, fear of backlash from presenting opinions, personal or professional insecurity, and even when members have a tendency to interrupt or

		speak over each other, disregarding others' opinions.
7. How diverse do you consider your team to be? (choose a number from 0 to 10 in the scale below)	Slider from 0 to 10	A diverse team (10) is necessary multi- or interdisciplinary, gathering people with different professional qualifications, personalities, gender, race, sexual orientation, age, and many other individual backgrounds and perspectives. A not-diverse team (0) would mean a team with all having the same specialties, backgrounds and perspectives, including when designing alone.
8. Which of the following better describe the solution you intend to achieve:	A solution that I or my direct competitors already deliver. A brand-new solution opportunity with little or no direct competition.	In the axis of solution from Tim Brown's "Ways to Grow" matrix (presented in the book Change by Design), this question inquires if the offering you are developing is existing (meaning you already commercialize a same product or service and wishes for trivial improvements or you are trying to internalize an already consolidated solution from competitors), or brand-new (meaning you are aiming for a still unseen solution in a blue ocean of needs in the region of interest).
9. And what about user and market, which of these better describe what you expect to reach:	Improve loyalty of my customers; enter or remain in a market already served. Reach new users; uncover a potential market with unmet needs.	In the axis of user/market from Tim Brown's "Ways to Grow" matrix (presented in the book Change by Design), this question aims for understanding for whom you are developing: if for an already known and loyal clientele that you or your competitors deliver value constantly; or if for a still non-existing and diffuse new market with little or no competition.
10. Will this step of the creative effort occur in person or virtually?	In Person Virtually	A creative effort that occurs in person is set in a meeting where information will be verbally shared, and can be supported by projections, whiteboards, canvases, or any other physical or virtual material. In opposition, a virtual creative effort is held inside virtual platforms, and can be supported by a variety of software for drawing, diagramming, consolidating information, or improving communication.

Source: author

After the user answers the questions, responses are sent via API to the back-end and suffer minimal adjustments for composing the array that is imputed to the hybrid model. For instance, questions 2 and 3 are combined do define the 4 Design Step possibilities:

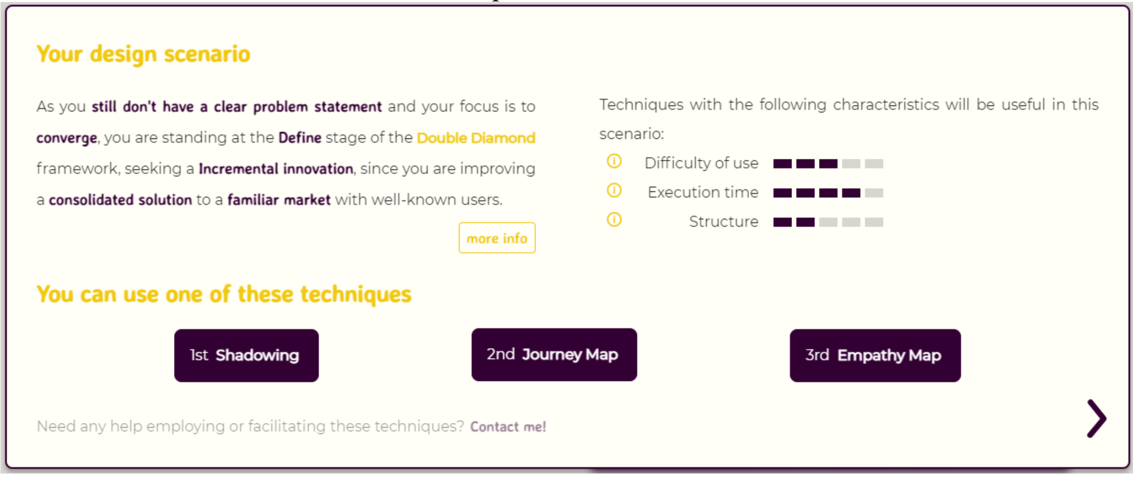
- If the team **does not have** a clear problem statement and is **diverging**, Design Step is set to “Discover”;
- If the team **does not have** a clear problem statement and is **converging**, Design Step is set to “Define”;
- If the team **already has** a clear problem statement and is **diverging**, Design Step is set to “Develop”;
- If the team **already has** a clear problem statement and is converging, Design Step is set to “Deliver”.

On a similar note, values for Innovation Focus also depend on answers to questions 8 and 9, which are combined during data preparation as following:

- If dealing with an **existing solution** inside an **already known market**, Innovation Focus is set to “Incremental”;
- If dealing with an **existing solution** targeting **new markets**, Innovation Focus is set to “Evolutive”;
- If dealing with a **brand new solution** inside an **already known market**, Innovation Focus is also set to “Evolutive”;
- If aiming for a **brand new solution** targeting **new markets**, Innovation Focus is set to “Radical”.

Other answers suffer minor adjustments such as scaling or binning to fit the needed format to input in the model. The models are serialized inside the back-end structure and predictions are chained automatically, returning to the front-end the inferred CIT characteristics and top three adequate CITs as response to the request made via API, as shown in Figure 5.9.

Figure 5.9 – Popup page with inference results prompted to the user after submitting the answers to the questionnaire.



Source: author

Results are presented to the user as a popup containing: 1) the design scenario as a textual depiction of user's answers; 2) CITs characteristics with the inferred attributes of a CIT that the model considered to be adequate to user's needs; and 3) the three selected CITs. The first area also contains a "more info" button that directs the user to a screen that explains further the reasoning behind the model, presenting graphically the feature importance for the regression model and assigned weights in the classification models responsible for the three chosen CITs. Along the CITs characteristics a "help" button can also be found with further information about the meaning of these categories. By clicking at the button assigned to each CIT, the user is redirected to a page containing more information about the technique, its use and facilitation means.

An arrow button on the bottom right corner prompts the user to another screen in which he/she can address which CIT was used in the design effort. Users may also answer that no technique was considered helpful. Either way, this selection triggers an update of the database by sending the answer through API to back-end, which is added to users answers, asserted CITs and the technique chosen by the user (if any), and stores it in the database, closing the Case-Based Reasoning retention cycle. With that the models can be periodically retrained and tested to perceive if scores are still adequate or if changes on the inference structure are needed.

5.4 SECOND CYCLE – VALIDATION

Following the chosen validation approach of "Technical Risk & Efficacy" (VENABLE; PRIES-HEJE; BASKERVILLE, 2016), both validation cycles were of artificial nature, the prior being more formative while the later more summative, since the study object of this work is knowledge-intensive and requires evaluation of the technical system characteristics to perform as experts. At the first, it was not the intention to validate interface, usability or explainability of outputs, since the prototype was still in its simplified form. Main focus was to collect feedback on whether the models perform adequately and point out adequate CITs for the design scenario proposed.

During second iteration, effort was put in giving evaluators more autonomy for using the system, still based on proposed cases but allowing more freedom of interpretation to evaluate the prototype. This validation cycle placed more attention on checking whether outcomes matched expectations, against the first validation approach that intended to directly improve outcomes (VENABLE; PRIES-HEJE; BASKERVILLE, 2016). Knowledge-base validation was performed using an adapted Turing test (KNAUF; GONZALEZ; ABEL, 2002), employing a similar approach as used by (MATELLI; BAZZO; SILVA, 2011). Outputs provided by the prototype were compared to answers given by experts to a same case-base, checking whether the system would perform as well as human experts.

Six experts were contacted to answer the validation questionnaire: three engineers and three designers, mixing both academic (one master and two doctors in design methodology) and market profiles (above 5 years of experience with design processes in practice). First cycle validation was performed through a structured interview process, with a guided execution process to help evaluators use the “raw” notebook containing the system. During this second validation, effort was put in giving evaluators more autonomy for use of the system, being still based on cases but allowing more freedom of interpretation to evaluate the prototype. This validation cycle placed more attention on checking whether outcomes matched expectations, against the first validation approach that intended to directly improve outcomes (VENABLE; PRIES-HEJE; BASKERVILLE, 2016).

For the autonomous validation process, each received an online form containing the walkthrough of validation process. The form inquired once again which CITs the evaluator knew and instructed them to navigate through the online prototype for acclimation as long as they felt necessary, asking them to share their first impressions. After, five cases were proposed, to which each evaluator was asked to choose at least 3 to assess. This definition was needed to guarantee that no evaluator would test on a scenario where he or she felt uncomfortable or unsure. Chosen cases were iteratively shown, asking which CITs they would use in the given scenario before redirecting the user to the web-application. After interacting finishing running the case in the prototype, evaluators were inquired back in the form about the presented information over the design scenario, and whether they disagreed with any chosen technique. After the cases validation, form closing questions inquired about other impact factors and missing techniques to be implemented, as well as critics, recommendations, feedback or any other information evaluators considered important.

On first impressions, evaluators mentioned interface aspects and gave positive feedback as “I felt motivated to use the tool. The interface is very pleasant, the contrast of the background and font colors makes reading pleasant.” and “Very intuitive interface, simple to understand and use. I thought it was good to put all the questions on a single page, it avoids the doubt of how long the questionnaire will be.” There was no criticism to the overall aesthetic of the application or its usability, though some improvements were mentioned such as adding an answers validation before submitting, changing the scaling questions options from numbers to texts, and adding a brief introduction on the top to better guide users.

As for the knowledge-base validation, evaluators’ responses in each case were contrasted to model outputs to check whether the system inferred similar solutions. From a total of 18 cases were evaluated by the experts, in 14 at least one of the CITs mentioned by the evaluator before the execution was selected by the system. When contrasting these results with first cycle, as presented in Table 5.6, the first one achieved a better match between prototype and evaluators response. Even so, it is important to mention that this reduction in second cycle can derive from validation process being more autonomous, with experts conducing it without supervision while in first cycle validation the process was guided. Even so, in both cycles the system and experts agreed in over 75% of the cases, result that highlights a good performance of the model.

Table 5.6 – Compilation of main validation results contrasting both cycles.

	1st cycle validation	**2nd cycle validation**
Number of variables considered by the models	10	13
Number of CITs	21	26
Number of evaluators	6	6
Mean of implemented CITs known by evaluators	16	21
Total of cases evaluated during validation	18	18
Number of cases in which evaluator mentioned one of the chosen CITs before execution	16	14
Number of cases in which evaluator would prefer to use other CIT than the ones asserted by the system	4	2

Source: author

The main improvement of second cycle can be seen in the cases in which evaluators would disregard the system selected CITs at the expense of other techniques. After being prompted with the system outputs, evaluators were asked whether they agreed with the assertions and to point out which would be their final decision. During the first cycle, in four cases evaluators agreed with the proposed CITs, but would rather use another. In the second cycle this happened only twice. That implies that experts agreed more with the second cycle system, including remarks that it “brought a very interesting suggestion that maybe I wouldn't choose... But I think the system was better”. In fact, in two cases in this last cycle evaluators ended up tossing aside their original recommendations and choosing one of the techniques proposed by the prototype instead.

It is important to mention that, in both cycles, in most of the cases where there was divergence between evaluators and system, they mentioned that the prototype asserted techniques would also be useful or could be adapted, though not their first choices. In only 2 executions in each cycle evaluators disagreed fully with the system, pointing that they interpreted the case differently and would recommend other lines of action. Even in face with the same 5 cases, evaluators had different interpretations of the scenario and in some situations strongly diverged in their assertions. A CIT considered inaccurate by an expert was considered adequate by others, demonstrating the lack of consensus in the process of CIT selection.

5.5 RESULTS AND MAIN FINDINGS REGARDING CIT SELECTION

Even though other works already put effort on forms of taxonomy for CITs (ALVES; NUNES, 2013; MENDEL, 2012; WANG, 2019) or the use of other computational approaches to help using creativity techniques (ALBERS *et al.*, 2015), to the best of our efforts no other research was found to link AI to the information-demanding task of creativity enhancement by the selection of CITs. Experts on design and engineering use such techniques during problem solving efforts and, when adequately used, they are related to better outcomes on innovative endeavors (BAXTER, 2011; MAREIS, 2018). On the other hand, when considering the number of CITs available in literature and internet, allied to the complex multivariate expertise needed to select them, a robust and scalable computational approach becomes necessary.

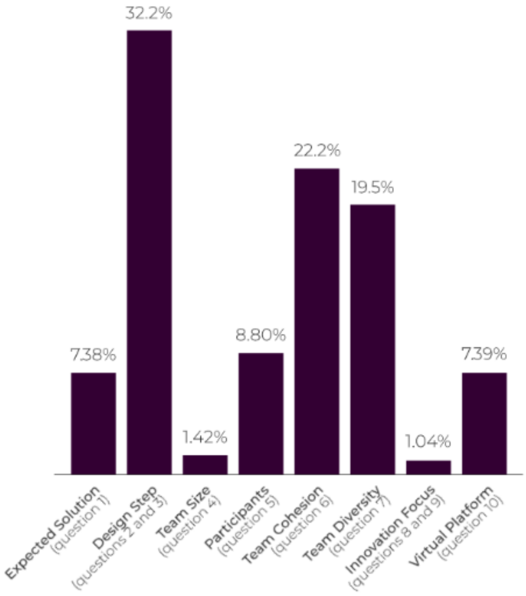
Beyond the accuracy of pinpointing one perfect CIT, the ability of matching CIT to context is currently highly empirical. Creative efforts are complex and influenced by multiple factors, so finding ways to categorize them is in itself challenging. This aspect was the main reason to direct the developed prototype to the selection of the most adequate CITs instead of only one technique, even if accuracy had to be sacrificed. Techniques can be adapted and are highly dependent on the facilitator, and the system has no intention of replacing the human expert that guides the creative effort. While experts may find it difficult to clarify the *whys* and *hows* of choosing a CIT, supervised AI approaches require a more logical structure of knowledge-representation to serve as basis for the inference process. When considering the CBR approach used in this effort, knowledge was structured based on possible cases of use for each CIT drawing from literature, internet and experts' empirical experiences to delineate possible use scenarios.

As a side-effect of the use of AI methods with traceability for this particular development, the achievement of feature importance in the GBRT model and weights on the LogReg help understanding the inference process of the models, which in turn can serve as an illustration of how the human process of CITs selection work. These values are obtained during models training and represent how the model interprets data to achieve results. For instance, in the GBRT case that uses Decision Trees structure, a new case "trails" one of the branches of the tree and, when reaching a leaf node, triggers the prediction. The way the tree is tailored to the data can be accessed through the feature importance, checking how each variable influences this automatic "decision-making".

Diving into the inference process used by the models, the rationale behind the assertions can be better understood, making knowledge more explicit. When analyzing the achieved models, it can be seen that the most important feature used by the GBRT for understanding the CITs characteristics is the Design Step, as shown in

Figure 5.10. This result is reasonable given that this is a transversal category in sources about CITs and the main methodological basis for a design process (BAXTER, 2011; IDEO, 2015; STICKDORN; SCHNEIDER, 2012; ULRICH; EPPINGER, 2012).

Figure 5.10 – Feature importance values achieved by GBRT model during training.

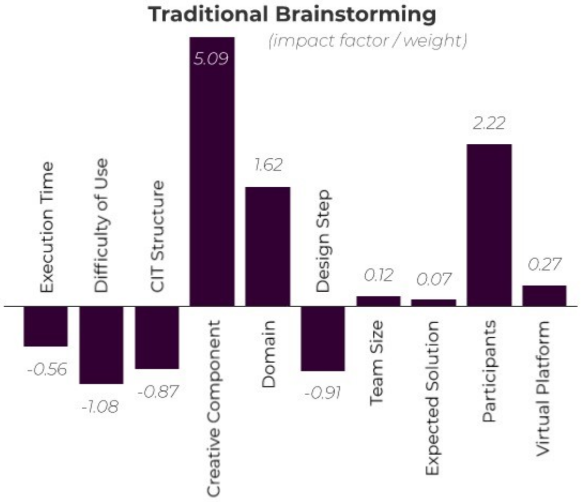


Source: author

When considering the team categories, Cohesion and Diversity had more importance. Both are commonly mentioned in literature as of great importance for a successful creative effort (MOSTERT, 2007), which is depicted by their importance in the model. Lowest importance values were attributed to Innovation Focus, meaning that CITs seem to be rather agnostic to more incremental or radical innovation efforts and Team Size. This last outcome may be an effect of over-segmentation of this impact factor during data preparation and should be better evaluated in future cycles.

As for the second model, weights achieved for each mathematical variable during LogReg training is different for each class, which means that each technique may have different coefficients. Appendix B presents all values for all CITs, but an elucidative sample is provided in Figure 5.11 depicting the weights calculated to the last CIT: Traditional Brainstorming.

Figure 5.11 – Weights achieved by the Logistic Regression model during training.



Source: author

Considered a quick, easy and participative technique (HAVERGAL; EDMONSTONE, 2017; STICKDORN; SCHNEIDER, 2012), the negative coefficients for Execution Time, Difficulty of Use and CIT Structure are good indicators that the used model adequately captured this behavior. Negative values to Domain and Design Step also indicate that this CIT is better suited to the problem space, at the beginning of the design process as to better understand the design problem. The strongly positive value for Participants also indicates that this technique is better suited to include people from outside of the design team, which links back to a higher Team Diversity.

Having the dataset with all execution cases of the system, several other data science conclusions could be drawn over the use of CITs. Each variable can be analyzed individually, and CITs can be compared in their best situations of use. Even though this analysis is out of the scope, it is important to mention the rich material this data provides for better understanding the empirical art of CIT selection. With the used categorization and information gathering, a step towards elucidating the complex behavior of CITs and creative efforts was taken and may nucleate several other insights for helping designers in the generation of new and adequate ideas, thus boosting innovation.

6 CONCLUSIONS

This work presented the state-of-the-art of a Decision Support System application using CBR approach to help design teams on the selection of CITs that better fit the proposed scenario. After the two implementation cycles discussed here, the prototype includes 13 factors that act as dimensions for categorizing the 26 CITs available. In the prototype core stands two AI models, the first a multioutput regressor that infers the best CIT characteristics to the given user inputs and the second a ranking-classification model to evaluate the three most promising CITs to help the user.

The complexity of developing this project was two-fold: gather sufficient data on such empirical matter, and translate such a complex skill into a seamless application. The first was addressed by using a wide range of literature, internet and experience sources and producing a dataset from scratch based on solid evidence about the situations in which each CIT would better perform. The second was undertaken by a double-inference AI model, putting the complexity into the back-end and developing an intuitive front-end interface for users to access, choose CITs and understand the process in a simplified fashion, since explainability is fundamental for any Expert System.

Along its development, the prototype was submitted to two verification and validation efforts, which demonstrate the system capability of performing adequately on a computational level the selection of CITs as displayed by the achieved modeling scores, and also on a use level to fit its original intention as attested by evaluators. A point to mention is that, giving evaluators varied backgrounds and experiences, they occasionally interpreted cases differently, even indicating contrasting CITs to the same proposed situation. This fact is a manifestation of the complexity of CITs selection, since many may be useful to a given design situation depending on the facilitator's intention. CITs can be adapted and suffer often from variations on their form or use. Even so, the application described in this work offers counseling and even highlights options that a human expert would overlook, considering the high amount of techniques to remember.

Overall, the developed system was well received by evaluators and other users. The cycles presented the capacity of the application to grow with low effort, with potential of becoming an extensive aggregation base for CITs. The proposed taxonomy and classification means were also effective and validated by experts, being considered useful forms for identifying situations of interest for each technique. As implied by evaluators, since the system is already with a good breadth of factors and CITs, it would be interesting to start tryouts in more naturalistic environments, submitting the application to a wider range of users with different levels of experience.

On future research possibilities, launching of the developed application to real situations of use would provide valuable feedback to improve the prototype even further, especially by increasing the cases database. This initiative would be a natural next-step of evaluation following the chosen validation approach (VENABLE; PRIES-HEJE; BASKERVILLE, 2016). Further validation might also highlight important changes on the system usability, function and knowledge-representation. This work did not intend to be exhaustive both in CITs and classification factors, and naturally other base taxonomies are also important and can be hereafter included in the system. Other possibility for future works would include new incremental cycles of development for adding functionalities proposed by evaluators, implementation of better explanation methods to the use of the CITs (such as videos or infographics), and, with the increase on the number of retained cases from executions, evaluate new modeling possibilities with a single model, other algorithms or the use of unsupervised models to allow a more flexible selection method for CITs.

Being an innovative approach to CIT selection, the data gathered and approaches used give way to several other analysis intra and inter categories, which may provide valuable insight for better understanding the empirical art of CITs use, especially when considering the growth of the database give case retention. This approach may provide a less “text book” view on how the techniques are being used in real scenarios, which opens several paths for improvement. The system can also grow in terms of design process, reaching categories on the organizational or social level, or going through to further phases of the design process that also involve creativity such as production detailing and market launching.

Further analysis could also be conducted on data preparation and model selection. On the first, different ways of organizing data may provide a better stepping stone for modeling, while the second may unveil new models and architectures to process such data and promote a more intelligent system. This goes especially when considering the possibility of removing the intermediate CITs characteristics part and use Neural Networks to deal with more nuanced circumstances. The SMOTE oversampling approach can also be revisited to find better ways of balancing the training dataset, especially considering the complexity of multiclass classification of naturally unbalanced data.

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APPENDIX A – Categories on CIT assertion

Literature provides a varied set of categories that can be used to understand or create taxonomies for CITs and their use. Three families of categories identified are related to the design scenario (inputs of the DSS). Ten discovered project categories are presented in Table A.1. Factors of "Number of stages", "Process formalization", "Process novelty", and "Available resources" were explicitly evaluated in literature as having a positive impact on CITs diversity and efficacy, raising creative and innovation thresholds. This means that a high number of stages, formalization practices, higher level of intended innovation and sufficient resources benefit creativity and innovation by removing barriers.

Table A.1 – Project-dependent impact factors for CIT categorization.

Impact factor	Explanation	Possible values	Source
Methodological stage (design step)	In which part of the development process the team is currently working	**	(BACK *et al.*, 2008; IDEO, 2011; 2012; 2015; SILVERSTEIN; SAMUEL; DECARLO, 2013; ULRICH; EPPINGER, 2012)
Number of stages	Related to the formalization of the process and maturing of the used methodology	*	(NIJSSEN; FRAMBACH, 2000)
Design activity	Activities that can occur several times inside each methodological stage	Co-design	(TASSI, 2009)
		Envisioning	
		Testing & prototyping	
		Implementing	
Domain	Which part main phase of the development the team is developing	Problem	(ALVES; NUNES, 2013)
		Solution	
Process formalization	How formal and structured is the project's management and environment	*	(GRANER; MIßLER-BEHR, 2013)
Available financial resources	The project receives sufficient funds to be used throughout the development	*	
Project novelty (intended innovation)	Aimed innovation impact of the solution in the organization's portfolio	Incremental	(BROWN, 2009; D'ALVANO; HIDALGO, 2012; HENDERSON; CLARK, 1990; THIA *et al.*, 2005)
		Evolutive	
		Architectural	
		Radical	
Creative components	Stage of the creative process requiring development	User	(proposed by the author)
		Organization	
		Business	
		Requirements	
		Concepts	

		Prototypes
Available time	The project has as adequate timeframe to be executed	Sufficient
		Lacking
Available infrastructure	The project is provided with an adequate physical and virtual infrastructure to the development	Individual rooms
		Dedicated room
		Virtual connection
Expected solution	Which artifact or solution the project is expected to achieve	Product
		Service
		Software

* Values not provided by literature
** methodological stage can be based on any design methodology and, therefore, has a wide variety of possible values
Source: author

The twelve found team-dependent factors are presented in Table A.2, alongside their explanations, possible values, and literature source. Factors of "Team experience in CIT", "Technical expertise", "Team cohesion", "Team composition", "Available human resources", "Integrated virtual platform", and "Trust" were explicitly described in literature as having positive impacts on the use of CITs, including number and efficacy of the employed techniques and consequent raise on creativity and innovation levels. This means that experienced and cohesive teams with adequate expertise, composition and trust that have adequate virtual communication have higher creativity and innovation potentials.

Table A.2 – Team-dependent impact factors for CITs categorization.

Impact factor	Explanation	Possible values	Source
Team size	Number of people participating on current creative effort/session	Range of numbers	(IDEO, 2012)
Participants / recipients	Different stakeholders involved in the design process	Design team	(IDEO, 2015)
		Project lead	
		Partners	
		Users	
		Experts	
		Stakeholders	(ALVES; NUNES, 2013; TASSI, 2009)
		Experts	
		Service staff	
		Users	
		*	(VACCARO; PARENTE; VELOSO, 2010)
Manager experience	How knowledgeable is the project manager or leader in handling the team and it's creative efforts	*	(GRANER; MIßLER-BEHR, 2013)
Available human resources	The number of people involved in the design effort is sufficient to achieve goals in the defined timeframe	*	

Team experience in CIT	How versed is the team in different CIT (meaning having a creativity expert on the team or the members having experience in the use of several CITs)	*	(NIJSSEN; FRAMBACH, 2000)
Team technical expertise	The level of knowledge of a team to solve the specific problem, meaning the relation of what team members know to what is expected of them to perform	*	(THIA *et al.*, 2005)
Team cohesion (relationship)	Involves personal relationships, friendship, trust, ability to share knowledge and freely discuss/critique each other	*	
Integrated virtual platform	The presence of virtual integrated platforms to share and retain knowledge, communicate work developments, among others	*	(VACCARO; PARENTE; VELOSO, 2010)
Trust	Deeply related to team cohesion but focusing on a personal trust among team members	*	
Team diversity	The design team is composed of only one specific area or involves other specialties	Specialized Multidisciplinary	(proposed by the author)
Team contact	How often is the team reunited and discussing about the project in close range.	Constant Intermittent No contact	
Contact nature	The which environment the contact of the team mainly occurs.	Physical Virtual	

* Values not provided by literature
Source: author

Closing the input impact factor families, the six organization-dependent factors are presented in Table A.3, alongside their explanations, possible values, and literature source. Literature relates positive influences in creativity and innovation thresholds of “Organization size”, “Innovation strategy”, “Managerial support”, “Number of departments”, and level of communication. This means that larger and innovation-oriented organizations, with projects involving multiple departments and with adequate managerial support are more likely to have a good creative process and use of CITs.

Table A.3 – Organization-dependent impact factors for CITs categorization.

Impact factor	Explanation	Possible values	Source
Organization size	How large the organization is (based on number of employees)	Startup Small Medium Large	(CHAI; XIN, 2006; GRANER; MIßLER-BEHR, 2013; NIJSSEN; FRAMBACH, 2000)
Managerial support	Commitment of high management to creativity and innovation efforts, allowing sufficient resources and a	Supportive	

	good environment to the development of solutions	Unsupportive	
Innovation strategy	The organization has cycles of innovation strategy or particular approaches of market positioning, mixing maintenance of status-quo and reaching of new markets/users	Innovation oriented	(CHAI; XIN, 2006; NIJSSEN; FRAMBACH, 2000)
		Preservation oriented	
Innovation culture	The organization has a transversal commitment to innovation	Developed	(VACCARO; PARENTE; VELOSO, 2010)
		Lacking	
Number of departments	How many departments inside the organization participate actively on the project, in relation to the total number of departments	Range of numbers	(NIJSSEN; FRAMBACH, 2000)
Level of communication	How easy is the interdepartmental communication.	Adequate	
		Inadequate	

Source: author

Besides these presented categories related to the design scenario, another twenty-eight were retrieved and are more deeply related to techniques themselves. Presented in Table A.4, they represent idiosyncratic characteristics of each CIT.

Table A.4 – Technique categories for CIT categorization.

Impact factor	Explanation	Possible values	Source
Execution time	How long does it take to perform adequately a technique.	Range of numbers in minutes, hours, days or weeks	(IDEO, 2011; 2012; 2015; SILVERSTEIN; SAMUEL; DECARLO, 2013)
Difficulty of use	Impediments for a person or team to master the CIT's use, or how much expertise is it necessary for a team to perform adequately the CIT.	1 to 5 stars (1 being easy and 5 being difficult)	(IDEO, 2011; 2012)
		Easy	(IDEO, 2015)
		Moderate	
		Hard	
CIT intention	CITs can be used to promote discussion, generate artifacts or to interact and collect feedback	Reflective	(IDEO, 2012)
		Hands on	
		Interaction	
Necessary resources	What is necessary to perform the CIT, ranging from physical resources, to templates and previous techniques.	Varied objects / resources such as pen, paper, whiteboards, templates	(IDEO, 2015; SILVERSTEIN; SAMUEL; DECARLO, 2013)
Required team	Necessity of one or more person to perform the technique	Individual	(SILVERSTEIN; SAMUEL; DECARLO, 2013)
		Team	
		Both	
Required expertise	(see "Difficulty of use" above)	1 to 4 points (1 being lowest and 4 being	

		highest)	
Direction setting	CITs can be graded on how effective they are to discover the way forward during development	1 to 4 points	
Idea generation	CITs may be used to enhance the pure generation of ideas, or to analyze/synthesize them	1 to 4 points	
Problem solving	CITs can be graded on how effective they are for solving problems, in opposition to mind-wandering CITs	1 to 4 points	
Fun	CITs may be more or less enjoyable to use	1 to 4 points	
Representation means	Specific means (systems) required to describe or portray a CIT and its development	Texts	(TASSI, 2009)
		Graphs	
		Narratives	
		Games	
		Models	
Contents	Focuses on which part of the value proposition the CIT is inherently related	Context	
		System	
		Offering	
		Interaction	
Knowledge area	From which field the CIT derived or is more commonly connected	Technology	
		Design	
		Business	
		Social science	
Main purpose	CITs might be used to acquire or to embody knowledge	Know/learn	(MENDEL, 2012)
		Make/create	
Main activity	CITs might be used to generate or explore knowledge	Act	
		Reflect	
Domain	Which part of the design process the CIT focuses on developing	Problem	(ALVES; NUNES, 2013)
		Solution	
Targeted content	(see “Contents” above)	User	
		System	
		Offering	
		Context	
Representation (formality)	CITs have different levels of formalization; some are more casual, others are more adequate to formal situations	Formal	
		Informal	
Representation (users’ inclusion)	CITs might include or require the presence of users	Participatory	
		Non-participatory	
Location	Which physical environment is required for the execution of a CIT	Public	
		Private	
		Indoor	
		Outdoor	
Implementation time	How long a CIT requires to integrate the organization’s body of knowledge	*	(THIA *et al.*, 2005)
Technique flexibility	In how many different situations each CIT can be used	*	
Monetary costs	The inherent costs from human, physical and knowledge resources to implement the CIT	*	

Popularity	How well known the CIT is	*	
User-friendliness	The easiness to be acquainted to the CIT (related to the learning curve)	*	(CHAI; XIN, 2006; THIA *et al.*, 2005)
Technique structure	CIT might be performed using a strict structure or be based on more spontaneous provocations	Systematic	(BACK *et al.*, 2008)
		Intuitive	
Creative process stage	For what stage of the creative process is the CIT adequate	Preparation	(MOSTERT, 2007)
		Incubation	
		Illumination	
		Verification	
Technique focus	Different CITs generate different kind of ideas, depending on situational requirements	Capabilities identification	(proposed by the author)
		Project organization	
		Divergence	
		Convergence	

* Values not provided by literature
Source: author

Most of these categories are mentioned and used in literature without any formal definition. Explanations are based on the values provided (when available) or in the context, intending to make explicit the contours of each category. For instance, in "Technique focus" a CIT such as SWOT Matrix can be useful to identify capabilities of the organization, while Gant Chart and Checklists are used to organize the project; Brainstorming is a classical divergent technique, while Dot Voting is used to converge into solutions. This can be verified for each of the presented factors, attributing one or more values to each CIT in each category.

When organizing these categories and relating them to each implemented CIT in the prototype, a set of use cases can be devised, as presented in Table A.5. These condensations of literature information showcase situations in which the techniques present particular usefulness based on values for each category.

Table A.5 – Representation of the condensed dataset containing the categories used in the prototype with values for each implemented CIT.

CIT Name	Design Step	Innovation Focus	Team cohesion	Team size	Expected solution	Participants	Virtual platform	Team Diversity	Execution time	Difficulty of use	CIT structure	Creative components	Domain
5 Whys	Discover Define	Incremental Evolutive Radical	0.0	1 to 8	Product Service	Users Experts Service Staff	Yes	0.3	0.0	0.0	0.0	Users Frame	Problem
Affinity Diagram	Define Deliver	Incremental Evolutive Radical	1.0	2 to 12	Product Service	Experts	Yes	0.5	0.1	0.3	0.1	Users Frame Concepts	Problem Solution
Alpha Prototyping	Deliver	Evolutive Radical	0.5	3 to 10	Product	Users Experts Service Staff Stakeholders	No	0.3	1.0	1.0	0.6	Users Organization Prototype	Solution
Bio-inspiration	Develop	Evolutive Radical	0.1	4 to 8	Product	Experts	Yes	0.3	0.5	0.5	0.2	Concepts	Solution
Brainwriting	Develop	Incremental Evolutive Radical	0.0	4 to 8	Product Service	Users Experts Service Staff	Yes	0.0	0.0	0.1	0.2	Concepts	Solution
Contextual Interview	Discover	Incremental Evolutive Radical	0.7	1 to 3	Product Service	Users Experts Service Staff Stakeholders	No	0.1	0.5	0.6	0.4	Users Organization	Problem
CSD Matrix	Discover	Incremental Evolutive Radical	0.1	1 to 9	Product Service	Design Team alone	Yes	0.4	0.0	0.2	0.2	Users Organization Business Frame	Problem
Desk research	Discover	Incremental Evolutive Radical	0.3	1 to 5	Product Service	Design Team alone	Yes	0.2	0.4	0.2	0.0	Users Organization Business	Problem
Dot Voting	Define	Incremental	0.1	5 to 20	Product	Experts	Yes	0.2	0.0	0.0	0.0	Frame	Problem

	Deliver	Evolutive Radical			Service							Concepts	Solution
Empathy Map	Define	Incremental Evolutive Radical	0.7	3 to 10	Product Service	Stakeholders	Yes	0.8	0.1	0.3	0.5	Users Frame	Problem
Functional Analysis	Discover Develop	Incremental Evolutive	0.7	1 to 6	Product	Users Experts Service Staff	Yes	0.1	0.6	0.5	0.7	Organization Frame Concepts	Problem Solution
How Might We	Define	Incremental Evolutive Radical	0.3	2 to 8	Product Service	Experts	Yes	0.8	0.2	0.3	0.0	Frame	Problem
Impact Effort Matrix	Define Deliver	Incremental Evolutive Radical	0.9	2 to 10	Product Service	Experts Stakeholders	Yes	0.2	0.3	0.5	0.2	Organization Business Frame	Problem Solution
Journey map	Discover Define	Incremental Evolutive Radical	1.0	4 to 12	Product Service	Users Experts Service Staff Stakeholders	Yes	0.9	0.9	0.7	0.3	Users Frame	Problem
Morphological Analysis	Develop	Incremental Evolutive	0.3	1 to 5	Product	Experts	Yes	0.0	0.5	0.3	0.7	Concepts	Solution
Persona	Discover Define	Evolutive Radical	0.8	2 to 8	Product Service	Experts	Yes	0.7	0.4	0.7	0.6	Users	Problem
Pugh Matrix	Deliver	Incremental Evolutive	0.0	1 to 8	Product	Experts	Yes	0.0	0.4	0.6	1.0	Concepts	Solution
Reverse Brainstorming	Develop	Incremental Evolutive	0.1	4 to 10	Product Service	Design Team alone	Yes	0.1	0.0	0.1	0.0	Concepts	Solution
Roadmap	Define Deliver	Incremental Evolutive Radical	0.1	1 to 7	Product Service	Stakeholders	Yes	0.4	0.5	0.5	0.2	Frame	Solution
Roleplay	Develop Deliver	Incremental Evolutive Radical	1.0	3 to 20	Product Service	Users Service Staff	No	1.0	0.2	0.4	0.0	Organization Prototype	Solution
Rough Prototyping	Develop Deliver	Incremental Evolutive Radical	0.4	1 to 10	Product	Design Team alone	No	0.7	0.5	0.3	0.0	Concepts Prototype	Solution
Service Blueprint	Define Deliver	Incremental Evolutive	1.0	4 to 12	Service	Users Experts Service Staff	Yes	1.0	0.9	0.9	0.8	Users Organization Prototype	Problem Solution

						Stakeholders							
Shadowing	Discover	Evolutive Radical	0.3	1 to 3	Product Service	Users Service Staff	No	0.1	0.7	0.2	0.1	Users	Problem
Stakeholder Map	Discover	Evolutive Radical	0.3	1 to 20	Product Service	Users Experts Service Staff Stakeholders	Yes	0.5	0.3	0.2	0.2	Users Organization Business	Problem
Storyboard	Define Deliver	Evolutive Radical	0.4	1 to 5	Product Service	Experts	Yes	0.5	0.5	0.3	0.0	Users Prototype	Problem Solution
Traditional Brainstorming	Discover Develop	Incremental Evolutive	1.0	4 to 10	Product Service	Users Experts Service Staff Stakeholders	Yes	0.9	0.1	0.0	0.0	Users Organization Business Concepts	Problem Solution

Source: author

Values were collected and/or inferred based on varied sources, as presented in Table A.6. Main constraint here was that the CIT must have at least 5 different sources providing information on its contexts of use, including books, papers, webpages, cases, or any other mean necessary. Values for Team cohesion, Team Diversity, Execution time, Difficulty of use, and CIT structure were established through AHP but using these sources as basis. For some CITs, it could not be necessary or recommended the presence of other Participants besides the Design Team. It is important to mention that, since the table above was based on data/information correlation and knowledge inferences mediated by the author's own experience, values are not absolute and other perspectives may reach different conclusions for the same CITs.

Table A.6 – Sources used to gather information for each CIT implemented in the prototype.

CIT Name	Sources
5 Whys (also known as Compass in 2)	1. Book: **The facilitator's toolkit** by M. Havergal and J. Edmonstone, 2017 2. Book: Instant Creativity: Simple Techniques to Ignite Innovation and Problem Solving by B. Clegg and P. Birch, 2007 3. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 4. Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012 5. Book: **The Lean Startup** by E. Ries, 2011 6. Webpage: **Mycoted** accessible via https://www.mycoted.com 7. Webpage: **Mind Tools** accessible via https://www.mindtools.com 8. Article: **The 5 Whys Process We Use to Understand the Root of Any Problem** by Courtney Seiter accessible via https://open.buffer.com/5-whys-process/
Affinity Diagram (also known as Find Themes in 2 and 4, Affinity Process in 3, KJ Method in 6, and Synthesis Wall in 8)	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: Design Thinking for Educators by IDEO, 2012 3. Book: **The facilitator's toolkit** by M. Havergal and J. Edmonstone, 2017 4. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 5. Book: Human Centered Design: Toolkit by IDEO, 2011 6. Book: The innovator's toolkit: 50+ techniques for predictable and sustainable organic growth by D. Silverstein, P. Samuel and N. DeCarlo, 2013 7. Paper: **Towards a taxonomy of service design methods and tools** by R. Alves and N. Nunes at International Conference on Exploring Services Science, 2013 8. Webpage: **Service Design Tools** accessible via http://www.servicedesigntools.org/ 9. Article: **Affinity Diagrams – Learn How to Cluster and Bundle Ideas and Facts** by R. Dam and T. Siang accessible via https://www.interaction-

	design.org/literature/article/affinity-diagrams-learn-how-to-cluster-and-bundle-ideas-and-facts
Alpha Prototyping (also known as Live Prototyping in 1 and 4, and Experience Prototyping in 3 and 5)	1. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 2. Book: **Product Design and Development** by K. Ulrich and S. Eppinger, 2012 3. Webpage: **Service Design Tools** accessible via http://www.servicedesigntools.org/ 4. Paper: **Live Prototyping** by W. Horst and B. Matthews at ACM Conference, 2016 5. Paper: **Experience prototyping** by M. Buchenau and J, Suri at Proceedings of the Conference on Designing Interactive Systems, 2000 6. Article: **Understanding Prototype Development Phases by Cooper Consulting Service** accessible via https://www.cooperconsultingservice.com/understanding-prototype-development-phases/ 7. Article: **The 5 Stages of Product Prototyping** by J. Jones and S. Waddell accessible via https://uxplanet.org/the-5-stages-of-product-prototyping-ebb276004640
Bio-inspiration (also known as Biotechniques in 1, Biomimicry in 2 and 5, and Biomimetics in 4)	1. Book: **Criatividade: Uma Vantagem Competitiva** by H. Schlicksupp and B. King, 1999 2. Book: The innovator's toolkit: 50+ techniques for predictable and sustainable organic growth by D. Silverstein, P. Samuel and N. DeCarlo, 2013 3. Paper: **A comparative analysis of six bionic design methods** by D. Coelho and C. Versos at International Journal of Design Engineering, 2011 4. Paper: A Biomimética no Desenvolvimento de Produtos: A relação entre forma e função para obtenção de leiautes iniciais by L. Melo and A. Ogliari at DAPesquisa, 2016 5. Webpage: **Biomimicry Toolbox** accessible via https://toolbox.biomimicry.org/
Brainwriting	1. Book: **The facilitator's toolkit** by M. Havergal and J. Edmonstone, 2017 2. Book: **Criatividade: Uma Vantagem Competitiva** by H. Schlicksupp and B. King, 1999 3. Book: The innovator's toolkit: 50+ techniques for predictable and sustainable organic growth by D. Silverstein, P. Samuel and N. DeCarlo, 2013 4. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 5. Webpage: **Creating Minds** accessible via http://creatingminds.org/ 6. Article: **Method 2 of 100: Brainwriting** by C. Wilson accessible via https://dux.typepad.com/dux/2011/01/method-2-of-100-brainwriting-brainwriting-is-an-ideation-method-for-quickly-generating-ideas-by-asking-people-to-write-thei.html 7. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/

Contextual Interview	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: Design Thinking for Educators by IDEO, 2012 3. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 4. Book: Human Centered Design: Toolkit by IDEO, 2011 5. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 6. Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012 7. Book: **Product Design and Development** by K. Ulrich and S. Eppinger, 2012 8. Paper: **Towards a taxonomy of service design methods and tools** by R. Alves and N. Nunes at International Conference on Exploring Services Science, 2013
CSD Matrix	1. Article: **Matriz Certezas, Suposições e Dúvidas** by A. Bretas accessible via https://medium.com/educa%C3%A7%C3%A3o-fora-da-caixa/matriz-certezas-suposi%C3%A7%C3%B5es-e-d%C3%BAvidas-fa2263633655 2. Webpage: **Livework Tools** accessible via http://liveworktools.webflow.io/ 3. Article: **CSD Matrix: kill your doubts, multiply your certainties** by C. Olival accessible via https://angry.ventures/blog/csd-matrix/ 4. Article: **Já ouviu falar da Matriz CSD?** by E. Ferreira accessible via https://www.linkedin.com/pulse/j%C3%A1-ouviu-falar-da-matriz-csd-eveline-ferreira/ 5. Article: **Matriz CSD: tudo o que você precisa saber** by K. Fonseca accessible via https://brasil.uxdesign.cc/matriz-csd-tudo-o-que-voc%C3%AA-precisa-saber-897e39c797e7
Desk research (also known as Secondary Research in 2)	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 3. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 4. Article: **Secondary Research- Definition, Methods and Examples** by Question Pro accessible via https://www.questionpro.com/blog/secondary-research/ 5. Article: **Desk Research (Pesquisa Desk): como utilizar no processo de Design Thinking** by DTI Digital accessible via https://www.dtidigital.com.br/blog/desk-research-design-thinking/
Dot Voting (also known as Multivoting in 5, and Dot-Mocrazy in 6)	1. Book: Design Thinking for Educators by IDEO, 2012 2. Book: **The facilitator's toolkit** by M. Havergal and J. Edmonstone, 2017 3. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 4. Book: Sprint: How to Solve Big Problems and Test New Ideas in Just Five Days by J. Knapp, 2016 5. Book: **Product Design and Development** by K. Ulrich and S. Eppinger, 2012 6. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/

Empathy Map	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book Gamestorming: A Playbook for Innovators, Rulebreakers, and Changemakers by D. Gray, S. Brown and J. Macanufo, 2010 3. Webpage: **Service Design Tools** accessible via http://www.servicedesigntools.org/ 4. Paper: **Designing Personas with Empathy Map** by B. Ferrerira et al. at International Conference on Software Engineering and Knowledge Engineering, 2015 5. Webpage: **Nielsen Norman Group** accessible via https://www.nngroup.com/ 6. Article: **What is an empathy map?** by D. Bland accessible via https://www.solutionsiq.com/resource/blog-post/what-is-an-empathy-map/ 7. Article: **Updated Empathy Map Canvas** by D. Gray accessible via https://medium.com/the-xplane-collection/updated-empathy-map-canvas-46df22df3c8a
Functional Analysis	1. Book: **The facilitator's toolkit** by M. Havergal and J. Edmonstone, 2017 2. Book: The innovator's toolkit: 50+ techniques for predictable and sustainable organic growth by D. Silverstein, P. Samuel and N. DeCarlo, 2013 3. Book: Projeto integrado de produtos: Planejamento, Concepção e Modelagem by N. Back et al., 2008 4. Thesis: The Function Tree Analysis for New Product Development and Its Applications by Y. Kang, 2010 5. Book Chapter: **Functional Analysis in Systems Engineering: Methodology and Applications** by N. Viola et al. at Systems Engineering - Practice and Theory, 2011
How Might We	1. Book: Design Thinking for Educators by IDEO, 2012 2. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 3. Book: Human Centered Design: Toolkit by IDEO, 2011 4. Book: **Criatividade: Uma Vantagem Competitiva** by H. Schlicksupp and B. King, 1999 5. Book: Sprint: How to Solve Big Problems and Test New Ideas in Just Five Days by J. Knapp, 2016 6. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 7. Webpage: **Creating Minds** accessible via http://creatingminds.org/
Impact Effort Matrix (also known as Ways to Grow Framework in 2)	1. Book: **The facilitator's toolkit** by M. Havergal and J. Edmonstone, 2017 2. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 3. Book: **Black Belt Training** by Denver Peak Academy, 2018 4. Article**: Enter The Matrix – Lean Prioritisation** by A. Wicks accessible via https://www.mindtheproduct.com/2017/07/enter-matrix-lean-prioritisation/ 5. Article: **Impact & Effort Matrix** by D. Gray accessible via

	https://gamestorming.com/impact-effort-matrix-2/ 6. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/
Journey map	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 3. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 4. Webpage: **Service Design Tools** accessible via http://www.servicedesigntools.org/ 5. Webpage: **Nielsen Norman Group** accessible via https://www.nngroup.com/
Morphological Analysis	1. Book: **Criatividade: Uma Vantagem Competitiva** by H. Schlicksupp and B. King, 1999 2. Book: The innovator's toolkit: 50+ techniques for predictable and sustainable organic growth by D. Silverstein, P. Samuel and N. DeCarlo, 2013 3. Book: Projeto integrado de produtos: Planejamento, Concepção e Modelagem by N. Back et al., 2008 4. Webpage: **Creating Minds** accessible via http://creatingminds.org/ 5. Paper: **Morphological Analysis in Inventive Engineering** by T. Arciszewski at Technological Forecasting and Social Change, 2018 6. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/
Persona	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 3. Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012 4. Webpage: **Service Design Tools** accessible via http://www.servicedesigntools.org/ 5. Paper: **Towards a taxonomy of service design methods and tools** by R. Alves and N. Nunes at International Conference on Exploring Services Science, 2013 6. Webpage: **Nielsen Norman Group** accessible via https://www.nngroup.com/
Pugh Matrix (also known as Criteria Matrix on 1, Pugh Concept Selection in 2 and Concept Screening in 6)	1. Book: **The facilitator's toolkit** by M. Havergal and J. Edmonstone, 2017 2. Book: **Product Design and Development** by K. Ulrich and S. Eppinger, 2012 3. Book: **Criatividade: Uma Vantagem Competitiva** by H. Schlicksupp and B. King, 1999 4. Book: The innovator's toolkit: 50+ techniques for predictable and sustainable organic growth by D. Silverstein, P. Samuel and N. DeCarlo, 2013 5. Book: Projeto integrado de produtos: Planejamento, Concepção e Modelagem by N. Back et al., 2008 6. Webpage: **Creating Minds** accessible via http://creatingminds.org/

	7. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/
Reverse Brainstorming (also known as Reversal in 1)	1. Book: Instant Creativity: Simple Techniques to Ignite Innovation and Problem Solving by B. Clegg and P. Birch, 2007 2. Article: **How to Use Reverse Brainstorming to Develop Innovative Ideas** by L. Rudy accessible via https://business.tutsplus.com/tutorials/how-to-use-reverse-brainstorming-to-develop-innovative-ideas--cms-27531 3. Webpage: **Creating Minds** accessible via http://creatingminds.org/ 4. Article: **Method 4 of 100: Reverse Brainstorming** by C. Wilson accessible via ttps://dux.typepad.com/dux/2011/01/this-is-the-fourth-in-a-series-of-100-short-articles-about-ux-design-and-evaluation-methods-todays-method-is-called-rever.html 5. Article: **Reverse Brainstorming** by P. Mulder accessible via https://www.toolshero.com/creativity/reverse-brainstorming/
Roadmap	1. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 2. Webpage: **Service Design Tools** accessible via http://www.servicedesigntools.org/ 3. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/ 4. Article: **Best Practices and Expert Tips for Creating Product Roadmaps** by K. Eby accessible via https://www.smartsheet.com/best-practices-and-expert-tips-creating-product-roadmaps 5. Webpage: **Nielsen Norman Group** accessible via https://www.nngroup.com/
Roleplay (also known as Bodystorming in 5)	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 3. Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012 4. Paper: **Towards a taxonomy of service design methods and tools** by R. Alves and N. Nunes at International Conference on Exploring Services Science, 2013 5. Webpage: **Service Design Tools** accessible via http://www.servicedesigntools.org/ 6. Webpage: **Creating Minds** accessible via http://creatingminds.org/ 7. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/
Rough Prototyping (also known as Modeling in 1 and 6, Rapid Prototyping in 2, and Explorative / Cardboard Prototyping in 5)	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 3. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/ 4. Book: **Product Design and Development** by K. Ulrich and S. Eppinger, 2012 5. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 6. Webpage: **Creating Minds** accessible via http://creatingminds.org/

Service Blueprint	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 3. Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012 4. Paper: **Towards a taxonomy of service design methods and tools** by R. Alves and N. Nunes at International Conference on Exploring Services Science, 2013 5. Webpage: **Service Design Tools** accessible via http://www.servicedesigntools.org/ 6. Webpage: **Nielsen Norman Group** accessible via https://www.nngroup.com/
Shadowing	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 3. Webpage: **Ask Flip** accessible via https://www.ask-flip.com/ 4. Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012 5. Paper: **Towards a taxonomy of service design methods and tools** by R. Alves and N. Nunes at International Conference on Exploring Services Science, 2013
Stakeholder Map (also known as Net-map in 6)	1. Article: **Complete Stakeholder Mapping Guide** by A. Savina accessible at https://miro.com/blog/stakeholder-mapping/ 2. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 3. Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018 4. Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012 5. Paper: The stakeholder map: A conversation tool for designing people-led public services by F. Giordano et al. at ServDes2018, 2018 6. Article: **How Net-Map works** by E. Schiffer accessible via https://netmap.wordpress.com/about/
Storyboard	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012 2. Book: Design Thinking for Educators by IDEO, 2012 3. Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015 4. Book: Sprint: How to Solve Big Problems and Test New Ideas in Just Five Days by J. Knapp, 2016 5. Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012 6. Paper: **Towards a taxonomy of service design methods and tools** by R. Alves and N. Nunes at International Conference on Exploring Services Science, 2013 7. Webpage: **Creating Minds** accessible via http://creatingminds.org/
Traditional	1. Book: Design Thinking: Inovação em Negócios by M. Vianna et al., 2012

Brainstorming	2.	Book: Design Thinking for Educators by IDEO, 2012
	3.	Book: **The facilitator's toolkit** by M. Havergal and J. Edmonstone, 2017
	4.	Book: The Field Guide to Human-centered Design: Design Kit by IDEO, 2015
	5.	Book: Human Centered Design: Toolkit by IDEO, 2011
	6.	Book: **Criatividade: Uma Vantagem Competitiva** by H. Schlicksupp and B. King, 1999
	7.	Book: This Is Service Design Doing: Applying Service Design Thinking in the Real World by by M. Stickdorn et al., 2018
	8.	Book: This is Service Design Thinking: Basics, Tools, Cases by M. Stickdorn and J. Schneider, 2012
	9.	Paper: **Towards a taxonomy of service design methods and tools** by R. Alves and N. Nunes at International Conference on Exploring Services Science, 2013
	10.	Book: Projeto integrado de produtos: Planejamento, Concepção e Modelagem by N. Back et al., 2008

Source: author

A distinction was made between Papers (published in an academic journal) and Articles (published online in blogs), while Webpages are online toolkits containing several CITs and curated information about them.

APPENDIX B – Weights achieved by the Logistic Regression for each CIT

As an additional benefit from the models used to develop the prototype, it is possible to partially retrieve the inference rationale used by the algorithms. Logistic Regression algorithm, used in the second stage of the prototype, returns a list of weights for input variables, which indicates the mathematical "importance" of each in the inference process. Since the multinomial approach was used, each CIT receives different weights in its mathematical function, which are represented in Figures B.1 to B.26. Values presented are condensations of the particular category, meaning that weights for all four design steps were added to build the importance of the category itself. Higher weights mean the category is more relevant during inference. It is important to mention that the value should be analyzed regardless of the signal, meaning that positive or negative signs represent solely the direction of the vector. For instance, the first CIT 5 Whys is a quick and simple technique, which is represented by strongly negative values for Execution Time and Difficulty of Use. At the same time, having different Participants in the team is beneficial for its execution, which can be seen by the high positive value of this category. Similar analysis can be performed to all CITs, revealing nuances of their applications.

Figure B.1 – Weights achieved by the Logistic Regression model during training for 5 Whys.

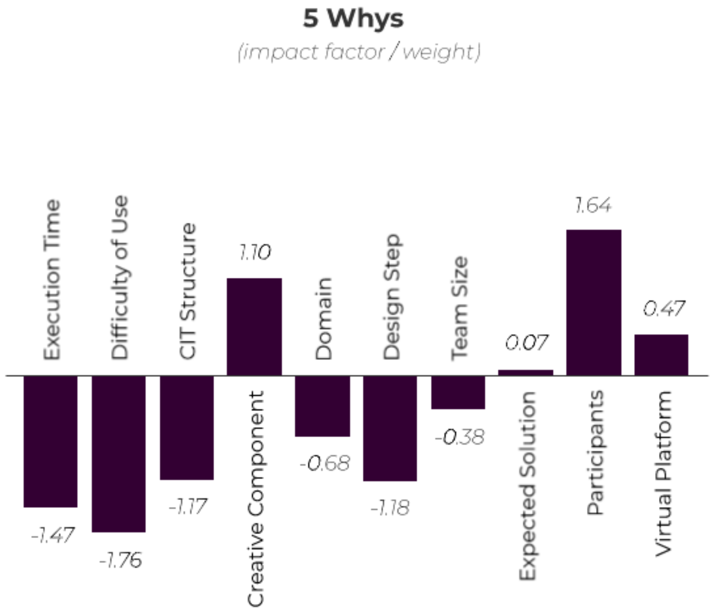


Figure B.2 – Weights achieved by the Logistic Regression model during training for Affinity Diagram.

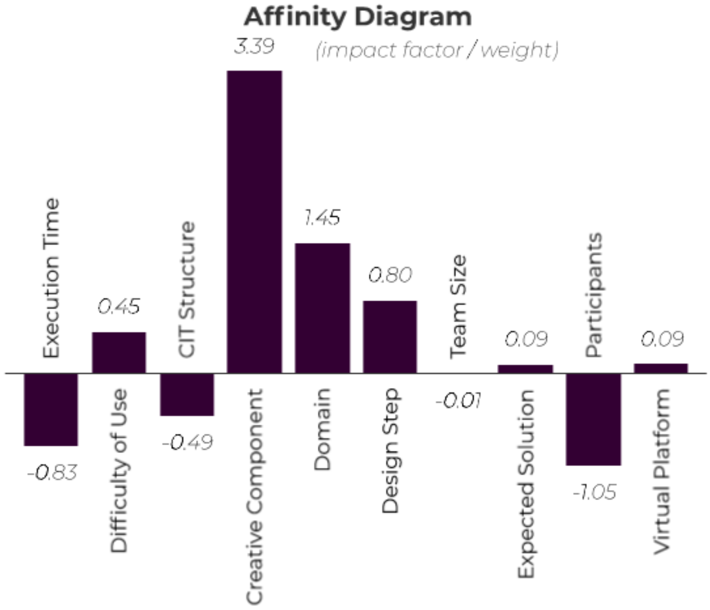


Figure B.3 – Weights achieved by the Logistic Regression model during training for Alpha Prototyping.

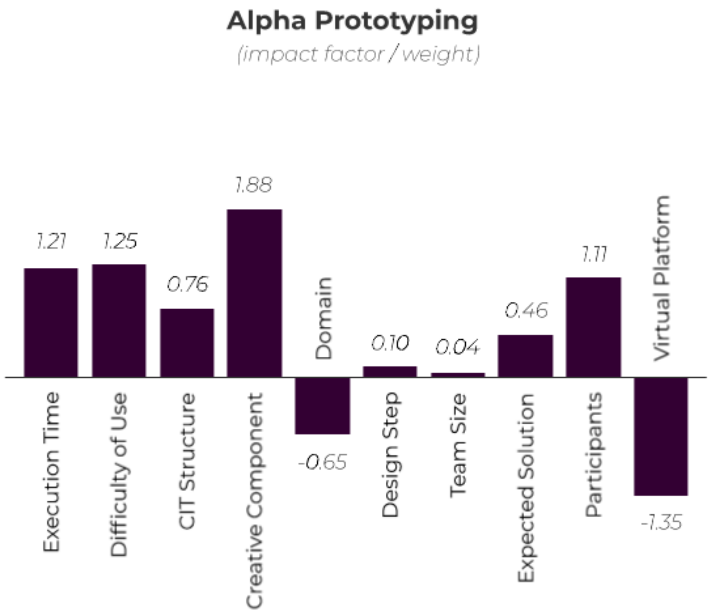


Figure B.4 – Weights achieved by the Logistic Regression model during training for Bio Inspiration.

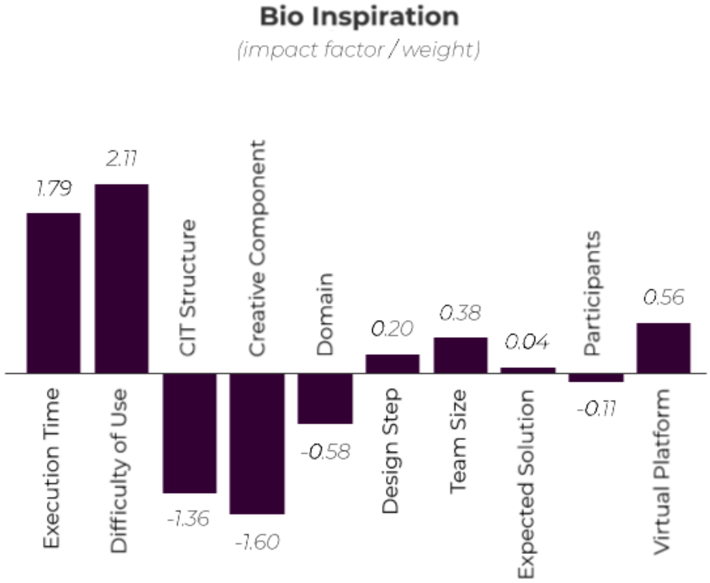


Figure B.5 – Weights achieved by the Logistic Regression model during training for Brainwriting.

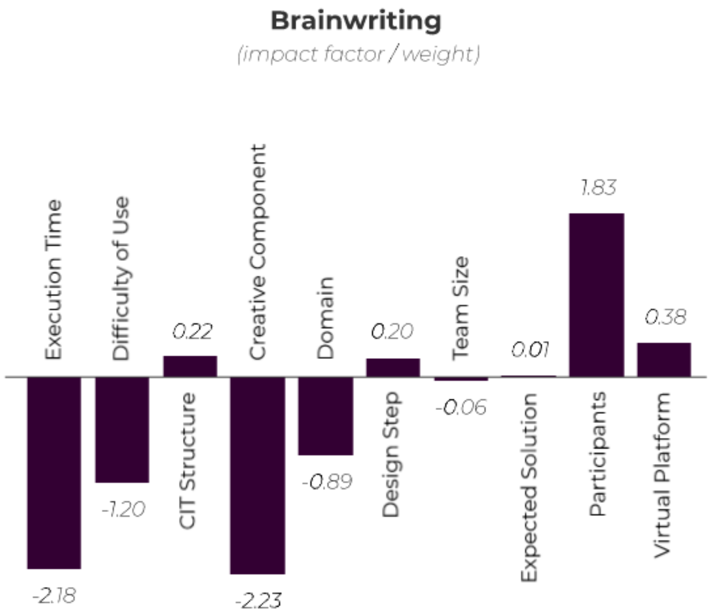


Figure B.6 – Weights achieved by the Logistic Regression model during training for Contextual Interview.

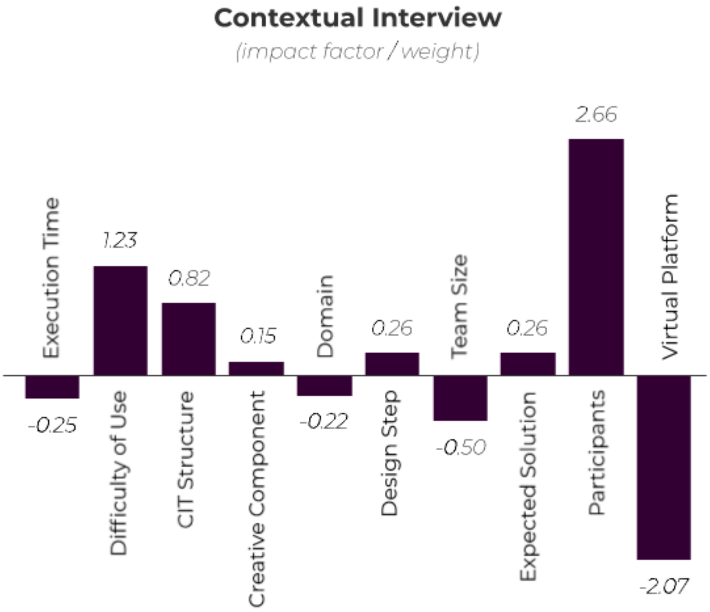


Figure B.7 – Weights achieved by the Logistic Regression model during training for CSD Matrix.

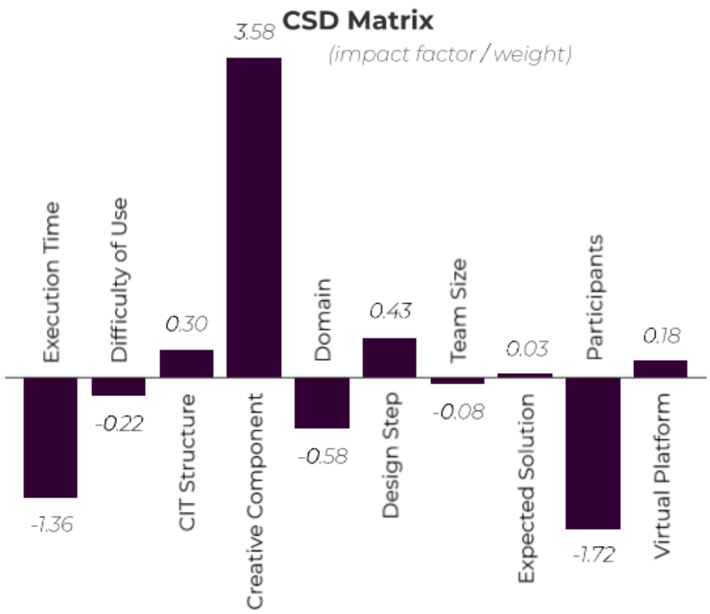


Figure B.8 – Weights achieved by the Logistic Regression model during training for Desk Research.

Figure B. 9 – Weights achieved by the Logistic Regression model during training for Dot Voting.

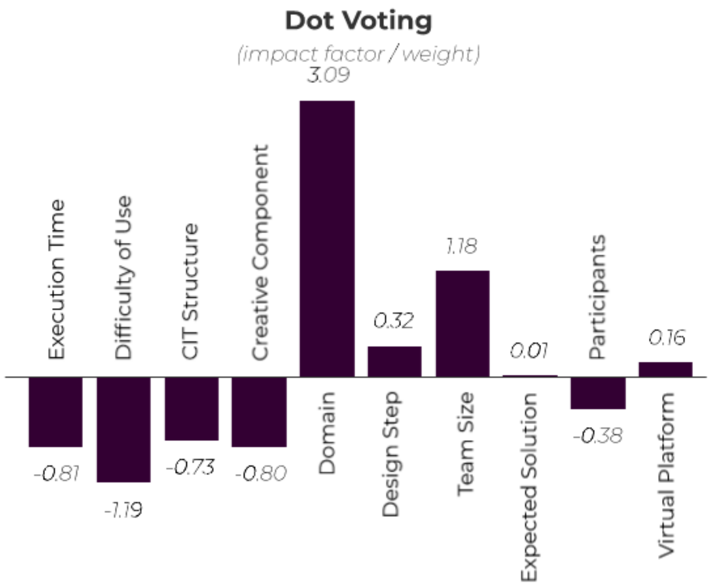


Figure B.10 – Weights achieved by the Logistic Regression model during training for Empathy Map.

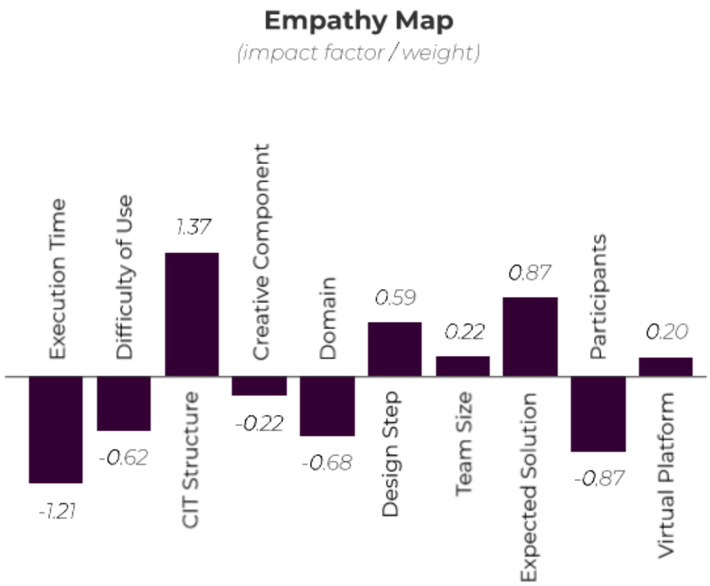


Figure B. 11 – Weights achieved by the Logistic Regression model during training for Functional Analysis.

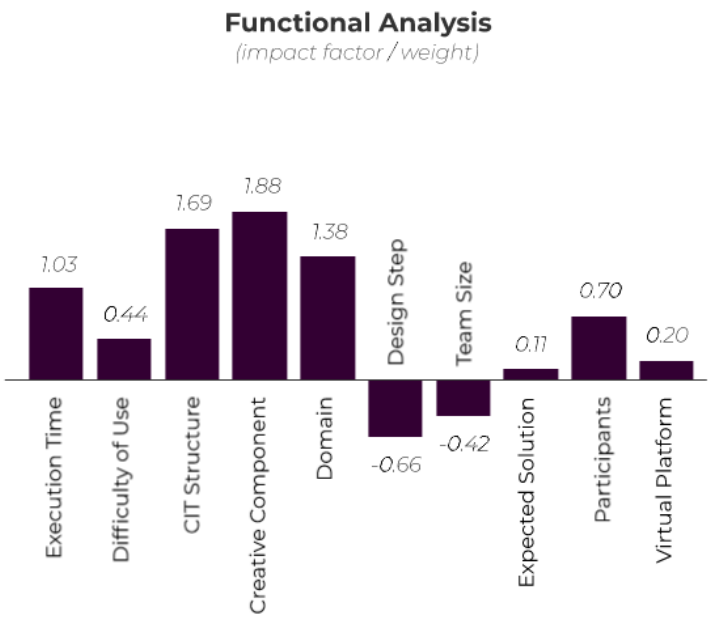


Figure B. 12 – Weights achieved by the Logistic Regression model during training for How Might We.

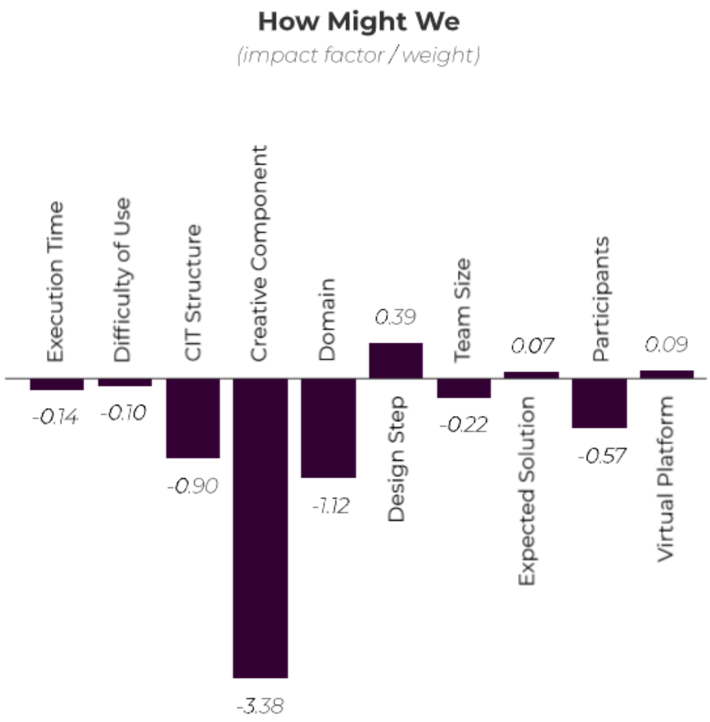


Figure B. 13 – Weights achieved by the Logistic Regression model during training for Impact Effort Matrix.

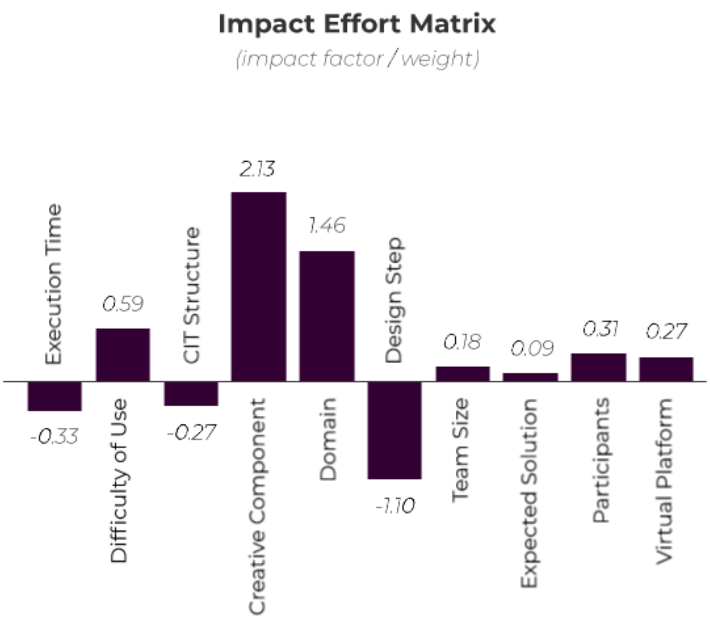


Figure B.14 – Weights achieved by the Logistic Regression model during training for Journey Map.

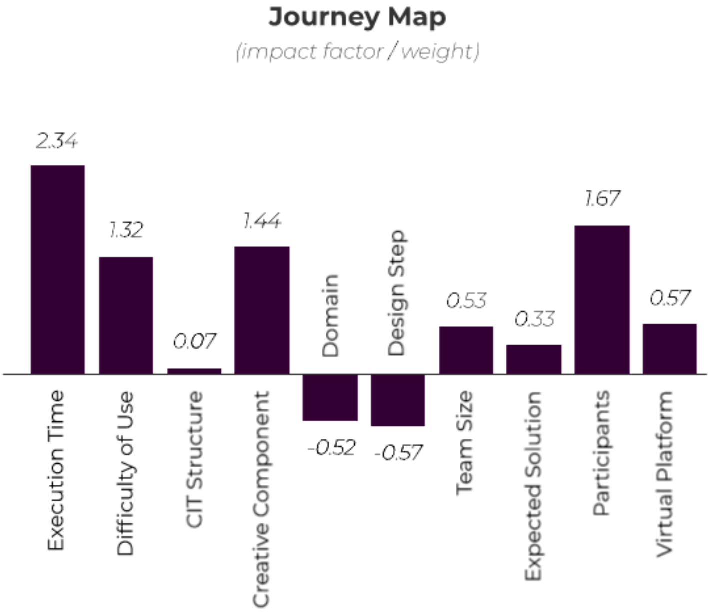


Figure B.15 – Weights achieved by the Logistic Regression model during training for Morphological Analysis.

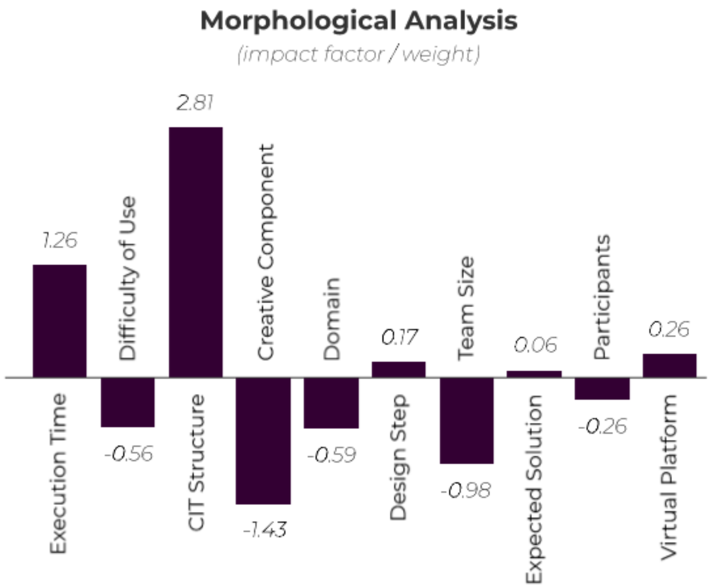


Figure B.16 – Weights achieved by the Logistic Regression model during training for Persona.

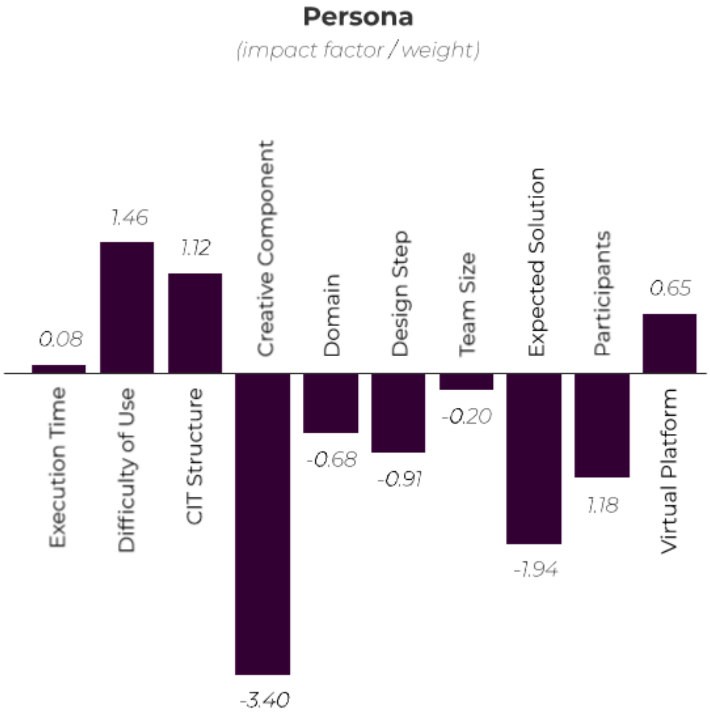


Figure B.17 – Weights achieved by the Logistic Regression model during training for Pugh Matrix.

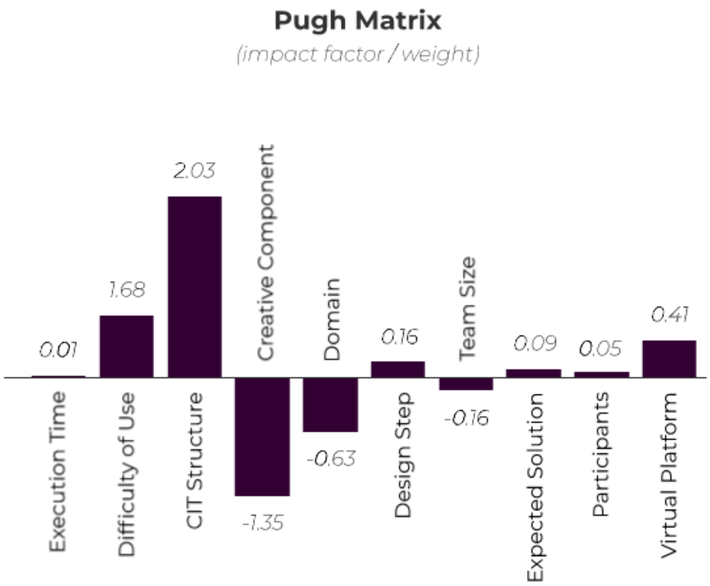


Figure B.18 – Weights achieved by the Logistic Regression model during training for Reverse Brainstorming.

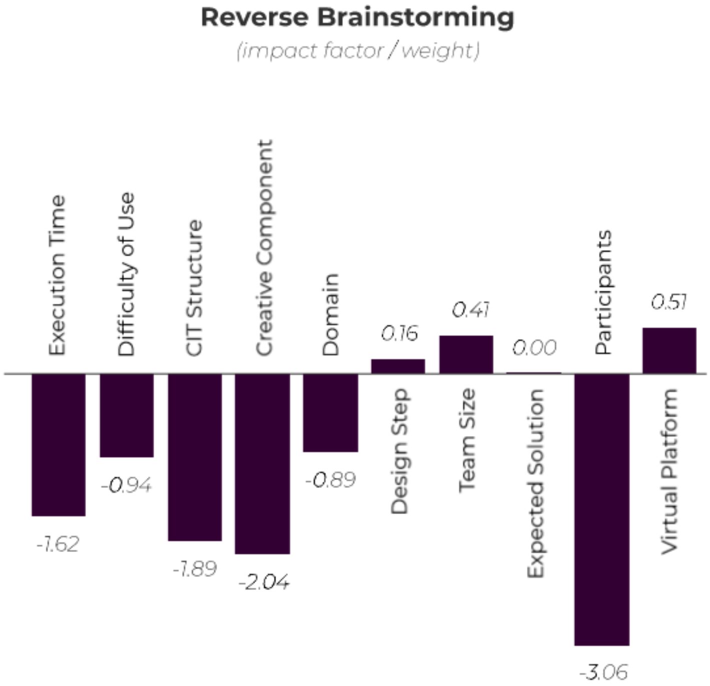


Figure B.19 – Weights achieved by the Logistic Regression model during training for Roadmap.

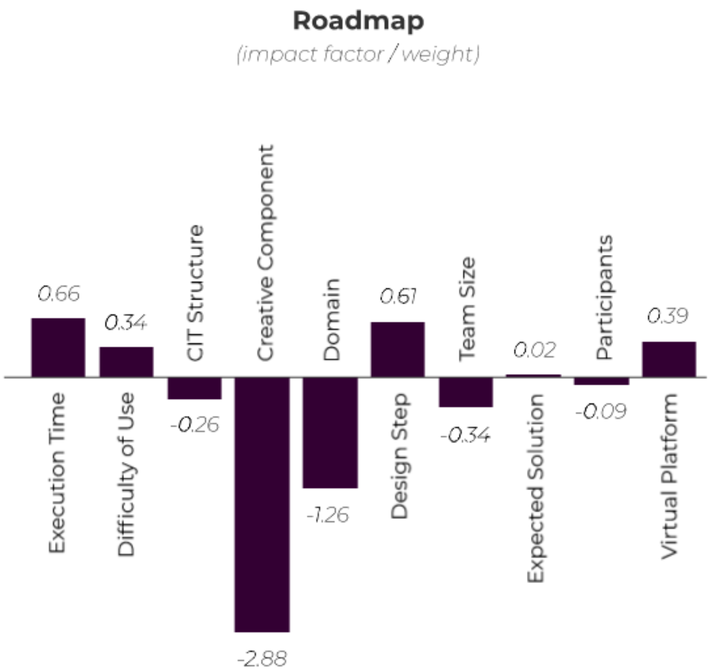


Figure B.20 – Weights achieved by the Logistic Regression model during training for Roleplay.

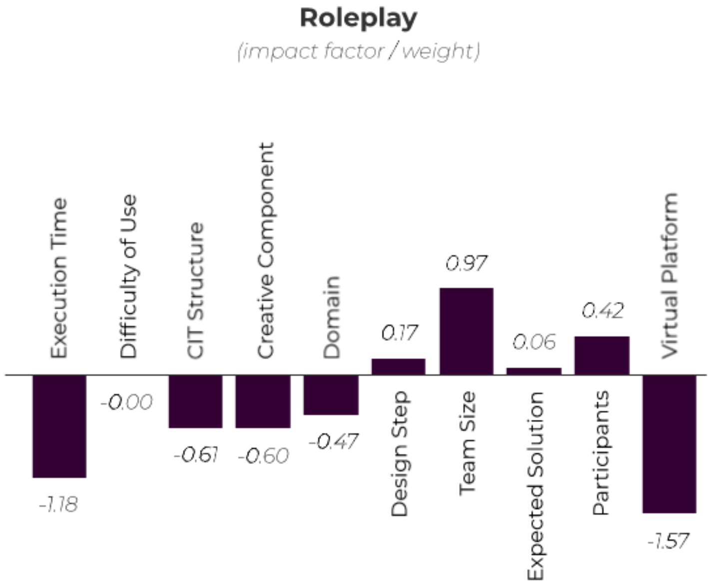


Figure B.21 – Weights achieved by the Logistic Regression model during training for Rough Prototyping.

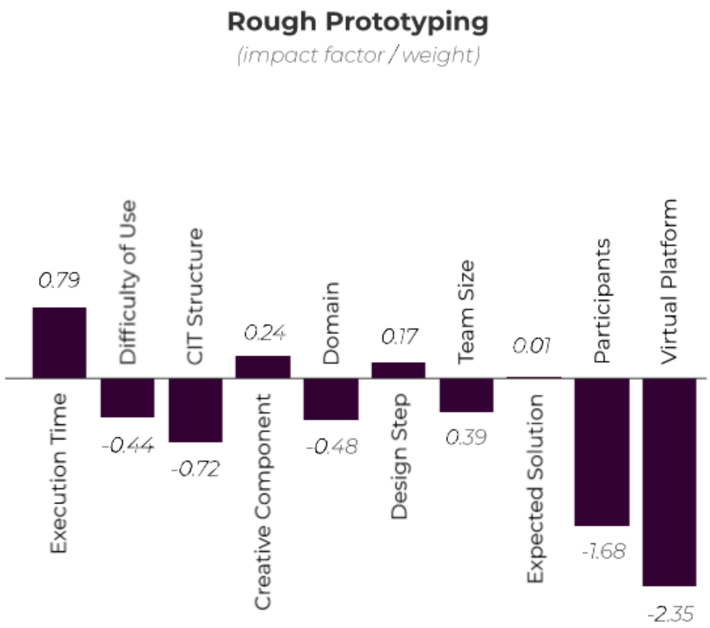


Figure B.22 – Weights achieved by the Logistic Regression model during training for Service Blueprint.

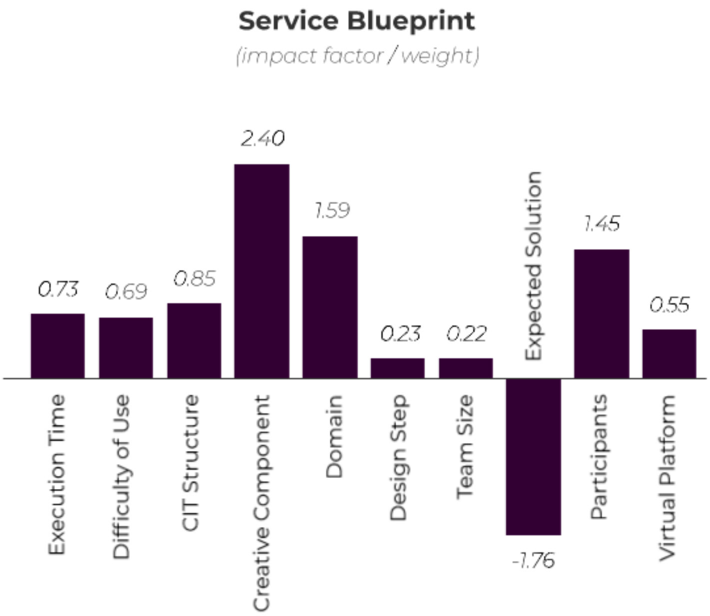


Figure B.23 – Weights achieved by the Logistic Regression model during training for Shadowing.

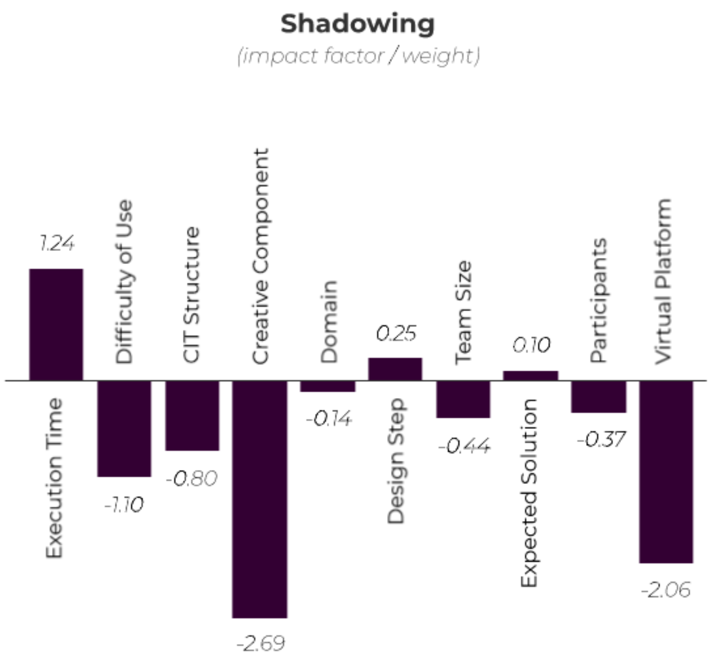


Figure B.24 – Weights achieved by the Logistic Regression model during training for Stakeholder Map.

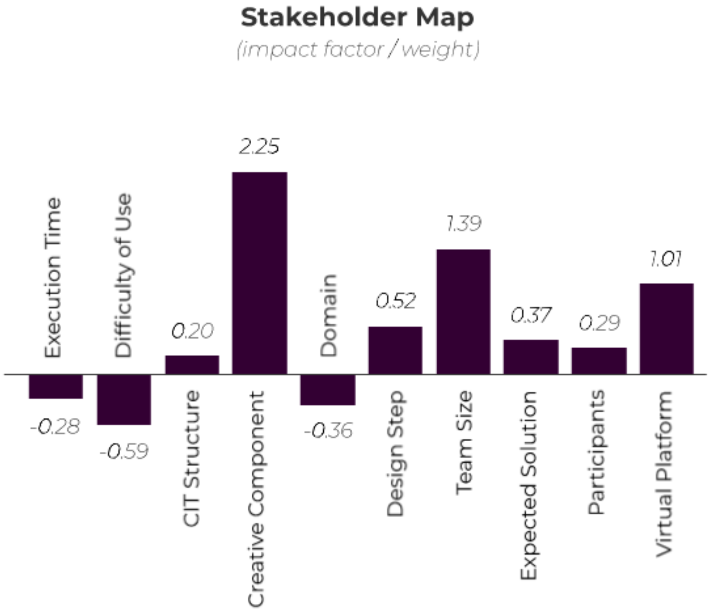


Figure B.25 – Weights achieved by the Logistic Regression model during training for Storyboard.

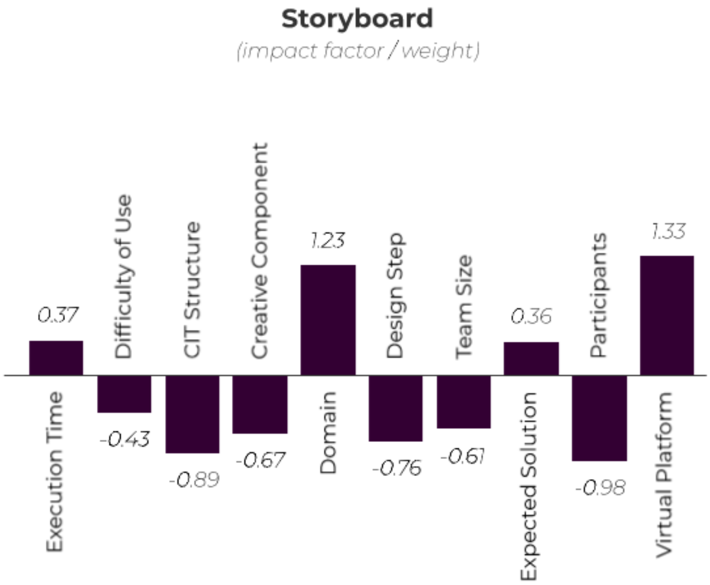
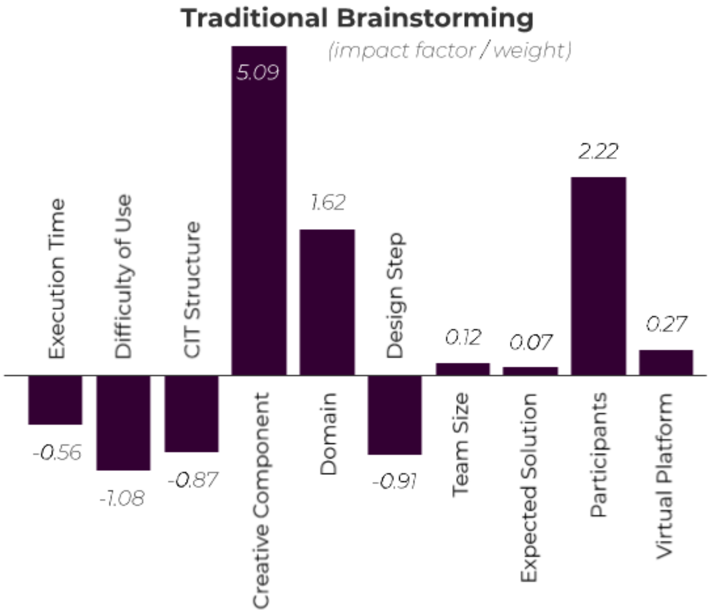


Figure B.26 – Weights achieved by the Logistic Regression model during training for Traditional Brainstorming.



APPENDIX C – Validation questionnaires

During both implementation cycles, validation was performed using an adapted Turing test (KNAUF; GONZALEZ; ABEL, 2002). Experts received a questionnaire individually with instructions and questions to be answered regarding the DSS and its application. At the core of the questionnaire, 5 cases were presented to evaluators, which had to indicate which CITs they would recommend to the given situation. Experts answers were then contrasted to DSS outputs to check consistency, assuming that if the system outputs at least one CIT that experts previously chose it passes the test. Questionnaire used in the first cycle is presented below and one used in the second cycle, and were performed in Portuguese to avoid language barriers for the evaluators.

Questionnaire used in cycle 1

NOME:	DATA:

PRIMEIRA PARTE

Quais das seguintes técnicas você conhece

5 Whys	☐	Mind Map	☐
Affinity Diagram	☐	Morphological Analysis	☐
Alpha Prototyping	☐	Persona	☐
Bio-inspiration	☐	Pugh Matrix	☐
Blueprint	☐	Reverse Brainstorming	☐
Brainwriting	☐	Rough Prototyping	☐
Contextual Interview	☐	Shadowing	☐
Dot Voting	☐	Stakeholder Map	☐
Functional Analysis	☐	Storyboard	☐
How Might We	☐	Traditional Brainstorming	☐
Impact Matrix	☐		

Preencha as tabelas abaixo comparando as técnicas da linha com as das colunas de acordo com a tabela, conforme os exemplos.

1.Dificuldade de uso

Mais difícil	

Mais fácil	

2.Tempo de execução

Mais lenta	
Mais rápida	

3.Estrutura da técnica

Mais estruturada	
Mais livre	

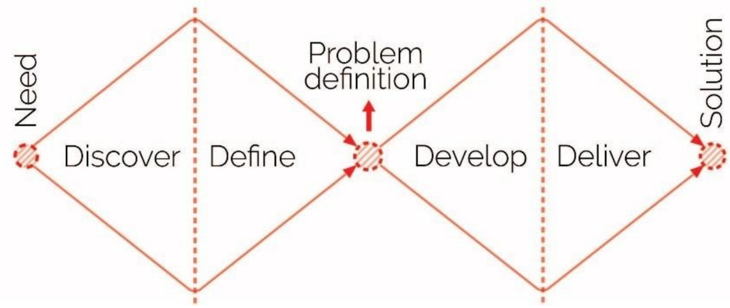
4.Coesão da equipe

Mais coesa	
Menos coesa	

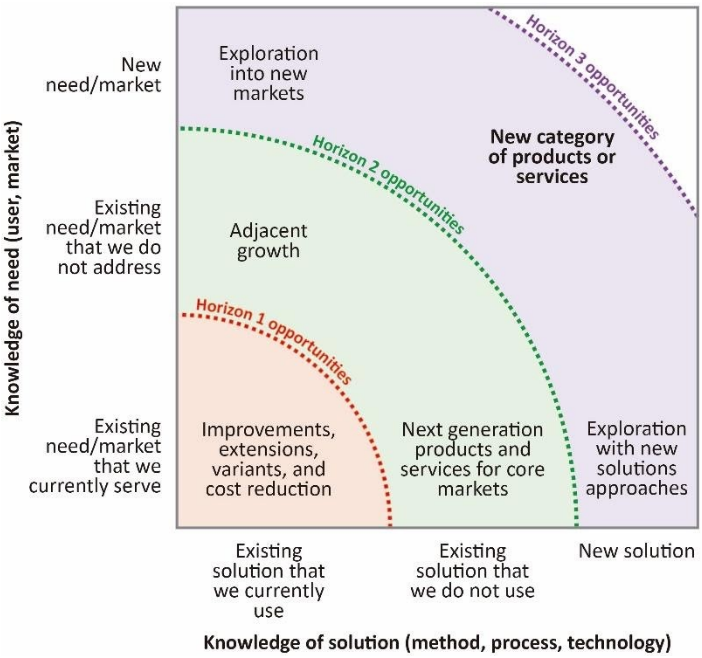
SEGUNDA PARTE

Fatores de seleção das técnicas utilizado:

- Estágio do desenvolvimento



- Novidade do projeto (inovação)



- Relacionamento da equipe
- Equipe coesa: facilidade em se comunicar, boa troca de informações, ambiente aberto e sem conflitos, trabalho mais coletivo
- Equipe não-coesa: bloqueios de comunicação, briga de egos, ambiente não convidativo, trabalho mais individual

  Número de participantes
- Número de pessoas participando do processo de criação presente

  Solução esperada – a equipe está desenvolvendo:
- Produto
- Serviço

  Participantes – presença de algum(ns) do(s) seguinte(s):
- Usuários
- Especialistas
- Equipe de serviço (funcionários)
- Stakeholders parceiros

CENÁRIO 1

Uma startup pivotou e está re-desenvolvendo sua solução para atender a um público diferente (inovação **evolutiva**). Estão no momento buscando como adequar o conceito do **serviço** a este novo público (etapa **develop**) e para isso buscaram a ajuda de **1 especialista.** Os **4 membros** da equipe estão muito motivados e trabalhando em conjunto todos os dias para fechar a solução o mais rápido possível e entrar no mercado, mas o especialista por vezes demora a responder (**relacionamento 8**).

- Quais das 21 técnicas anteriores (dentre as que conheces) consideras úteis para o cenário? Por quê?

- Quais outras técnicas que conheças seria útil? Por quê?

Rodar o sistema

- Concordas com as características das técnicas apresentadas? Comente
- Tu concordas com estas técnicas selecionadas? Por quê?
- Qual delas escolherias?

CENÁRIO 2

Uma indústria tradicional busca melhorar seu **produto** "carro-chefe" (inovação **incremental**). Para isso, o gerente de projetos optou por separar diferentes componentes entre diferentes especialistas membros da equipe para desenvolver o conceito (**develop**). A divisão de tarefas se deu de forma mais individual (**1 membro**), com o gerente de projeto atuando como ponto entre as partes (**relacionamento 0**).

- Quais das 21 técnicas anteriores (dentre as que conheces) consideras úteis para o cenário? Por quê?
- Quais outras técnicas que conheças seria útil? Por quê?

Rodar o sistema

- Concordas com as características das técnicas apresentadas? Comente
- Tu concordas com estas técnicas selecionadas? Por quê?
- Qual delas escolherias?

CENÁRIO 3

Uma empresa de consultoria conta com **2 membros** foi procurada para melhorar o **serviço** de uma empresa de pequeno porte local. Estão nas fases iniciais do processo buscando convergir para quais os reais problemas da empresa (**define**), mas vislumbram que terão que modificar boa parte dos processos internos (inovação **evolutiva**). A equipe está focada e engajada em definir o problema (**relacionamento 10**) e, para fechar esta etapa, pode contar com a ajuda dos **funcionários**.

- Quais das 21 técnicas anteriores (dentre as que conheces) consideras úteis para o cenário? Por quê?
- Quais outras técnicas que conheças seria útil? Por quê?

Rodar o sistema

- Concordas com as características das técnicas apresentadas? Comente
- Tu concordas com estas técnicas selecionadas? Por quê?
- Qual delas escolherias?

CENÁRIO 4

Três colegas se reuniam para criar uma startup com base numa tecnologia recém desenvolvida por um deles (inovação **radical**). A equipe com **3 membros** (um deles **especialista**) está engajada e em busca de entender melhor o mercado e as oportunidades de inserção de um novo **produto** (etapa de **discover**), mas existe discordância de que caminho tomar (**relacionamento 9**).

- Quais das 21 técnicas anteriores (dentre as que conheces) consideras úteis para o cenário? Por quê?
- Quais outras técnicas que conheças seria útil? Por quê?

Rodar o sistema

- Concordas com as características das técnicas apresentadas? Comente
- Tu concordas com estas técnicas selecionadas? Por quê?
- Qual delas escolherias?

CENÁRIO 5

Uma equipe de 2 pessoas, que trabalham em conjunto há anos (**relacionamento 10**), está engajada em finalmente entregar (**deliver**) a nova versão de seu **serviço** (inovação **incremental**). Para isso convidaram alguns clientes seletos para experienciar a novidade e colher feedback. Este processo de cocriação final será individual com cada cliente, sendo então **3 participantes** na seção sendo um dele **usuário**.

- Quais das 21 técnicas anteriores (dentre as que conheces) consideras úteis para o cenário? Por quê?
- Quais outras técnicas que conheças seria útil? Por quê?

Rodar o sistema

- Concordas com as características das técnicas apresentadas? Comente
- Tu concordas com estas técnicas selecionadas? Por quê?
- Qual delas escolherias?

TERCEIRA PARTE

- Quais outros fatores levarias em conta além dos 6 citados?
- Quais outras características consideras importantes ao definir qual técnica usar?
- Quais técnicas gostarias de ver implementadas?
- Quais situações consideras o sistema interessante?
- O que ele tem que ter para se tornar útil para as equipes de projeto?
- Críticas, pontos fortes, fracos, ...

Questionnaire used in cycle 2

Olá, tudo certo? Antes de mais nada, muito obrigado por participar deste processo de validação!
Este questionário faz parte da minha pesquisa de Doutorado na UFSC em processos criativos apoiados por inteligência artificial, sob orientação do Prof. Jonny Silva. As suas respostas a este questionário, como

especialista em Design, Criatividade e/ou Metodologia de Projeto, me ajudarão a aperfeiçoar o sistema que desenvolvi ao longo da minha pesquisa.

Qualquer dúvida a qualquer momento do processo, sinta-se à vontade de me contatar por email ou telefone/whatsapp.

* Required

1. Primeiramente, qual o seu nome? *

2. Quais das técnicas abaixo você conhece? *

Abaixo segue a lista com todas as técnicas atualmente implementadas no sistema. Marque todas as técnicas de criatividade/inovação que você já teve contato direto. Isso inclui ter utilizado e/ou facilitado a técnica, ou mesmo um contato teórico, desde que você se sinta confortável/confiante em empregá-la hoje.

☐ 5 Whys (5 Porquês)

☐ Affinity Diagram (Diagrama de Afinidade / KJ Diagram)

☐ Alpha Prototyping (Protótipo Alfa / Primeiro Protótipo Funcional ou Testável)

☐ Bio-inspiration (Biomimética / Bio-inspiração)

☐ Brainwriting

☐ Contextual Interview (Entrevista contextual primária, podendo ser com usuário, cliente, funcionários, ...)

☐ CSD Matrix (Matriz Certezas, Dúvidas e Suposições)

☐ Desk research (Pesquisa Desk / Pesquisa Secundária pela Internet)

☐ Dot Voting (Votação Dot / Multivoting)

☐ Empathy Map (Mapa de Empatia)

☐ Functional Analysis (Análise Funcional / Estrutura Funcional)

☐ How Might We (Como Poderíamos / Redefinição Heurística)

☐ Impact Effort Matrix (Matriz Esforço-Impacto / Ways to Grow Framework / 2x2 Prioritization Matrix)

☐ Journey Map (Mapa da Jornada / Jornada do Usuário)

☐ Morphological Analysis (Análise Morfológica / Matriz Morfológica)

☐ Persona

☐ Pugh Matrix (Matriz de Pugh)

☐ Reverse Brainstorming (Brainstorming Reverso / Negative Brainstorming)

☐ Roadmap

☐ Roleplay

☐ Rough Prototyping (Protótipo Rápido ou Explorativo / Quick&Dirty Prototyping / Protótipo de Baixa-Fidelidade)

☐ Service Blueprint (Blueprint do Serviço)

☐ Shadowing (Sombra)

☐ Stakeholder Map (Mapa de Stakeholders)

☐ Storyboard

☐ Traditional Brainstorming (Brainstorming Clássico ou Tradicional)

Usando o CRIB

Para começar a colocar a mão na massa, segue abaixo o link. Acesse e use a aplicação livremente pelo tempo que sentir necessidade, visando se ambientar e explorar as opções.

https://cribdesign.herokuapp.com/

Obs: devido ao servidor utilizado, o site pode demorar alguns segundos para carregar.

3. Quais foram as suas primeiras impressões? Relate abaixo este primeiro contato, abordando por exemplo a linguagem utilizada, estética da página, funcionalidades percebidas, dificuldades ou outros pontos que você considerar relevante *

Validação por cenários
Abaixo existem 5 cenários distintos apresentando situações de projeto nas quais o uso de técnicas de criatividade/inovação podem ser benéficos. Para a validação, você deverá escolher ao menos 3 dentre eles para responder às perguntas propostas neste questionário, levando em conta os cenários sobre os quais você se sente mais confortável ou preparado/a para opinar. Os cenários são abertos à interpretação e você não será de forma alguma comparado com respostas pré-determinadas, tendo em vista que diferentes interpretações do texto apresentado podem levar a diferentes respostas de entrada no sistema, que resultarão em múltiplos outputs de técnicas. A pergunta balizadora para a validação é: o que você faria se estivesse na situação descrita, que técnicas ou abordagens utilizaria para resolver a dificuldade apresentada?

O link para o sistema (o mesmo apresentado no começo deste questionário) será fornecido no momento adequado do processo de validação. Para a aplicação recomendar técnicas adequadas, primeiramente você terá que responder a algumas perguntas sobre o cenário em questão. As perguntas incluem:

- o que está sendo desenvolvido (produto ou serviço)
- a definição do problema de projeto
- se estrategicamente a equipe deseja divergir ou convergir
- quantas pessoas compõem a equipe
- como é o relacionamento da equipe
- se a equipe pode ser considerada diversa
- o mercado no qual a solução almejada se insere
- se a sessão de criação ocorrerá em pessoa ou virtualmente

Vale ressaltar que o sistema recomenda técnicas úteis para a situação corrente/atual da equipe, não visando um processo encadeado de técnicas. Então, ao ler os cenários, tenha em mente essas indagações. Caso você fique em dúvida sobre alguma informação para responder às perguntas do sistema, você pode inferir respostas com base na sua percepção.

Leia primeiro todos os cenários antes de avançar para a próxima página :)

Cenário 1
Uma empresa de consultoria em Transformação Digital alocou 3 especialistas para um projeto de 2 meses dentro de um cliente a fim de impulsionar uma cultura de dados. Ao longo do primeiro mês a equipe conduziu uma série de pesquisas (entrevistas, observações, desk research) e descobriu várias possibilidades de melhoria, definindo em parceria com os gestores o principal problema a ser resolvido no mês seguinte. Agora a equipe prepara uma sessão de co-criação presencial com 5 membros da equipe-cliente para buscar formas de resolver o problema proposto, mas estão em dúvida em quais técnicas deveriam utilizar nesse contexto. Os participantes foram selecionados de áreas diferentes da empresa e com formações distintas, mas, devido a desalinhamentos entre as áreas, não gostam de trabalhar em conjunto.

Cenário 2
A equipe de desenvolvimento de produto de uma empresa de software para portos está desenvolvendo uma nova aplicação para alcançar um novo mercado tecnológico de transporte de carga. Mesmo sendo um produto existente no mercado, a empresa visa adentrar esse novo ramo para se consolidar, entregar soluções mais abrangentes e fidelizar clientes. Após a definição dos objetivos do projeto, várias ideias de produto surgiram ao longo da ideação e a equipe, composta por 4 desenvolvedores com background em TI, se encontra com várias opções de solução sem conseguir convergir. A equipe está engajada e muito unida para debater e construir o produto mesmo trabalhando de forma virtual.

Cenário 3
Durante um hackathon promovido por um laboratório médico, 4 pessoas que não se conheciam

previamente se juntaram virtualmente em uma equipe para participar do evento: um Product Owner, um UX Designer, um Cientista de Dados e um Back-end Dev. O objetivo do Hackathon é desenvolver um produto web inovador para resolver problemas de vacinação em SC. A equipe, recém-formada, está com o briefing em mãos sem saber por onde começar. Nas diretrizes já constam informações sobre público alvo, categorias prioritárias para vacinação e um escopo amplo de objetivos esperados, mas sem direcionar o potenciais soluções ou mesmo quais as necessidades específicas que devem ser atendidas. A equipe tem contato com alguns clientes, médicos, enfermeiros e técnicos em vacinação, e é incentivada entrar em contato com quaisquer pessoas que julgarem necessário.

Cenário 4
Um Designer de Serviço trabalhando em tempo integral em uma empresa foi encarregado de melhorar o processo de desenvolvimento de soluções atualmente adotado. Após uma série de entrevistas com colegas e pesquisas secundárias, o designer precisa começar a afunilar quais os principais problemas existentes e qual ele deve priorizar. Por conta da alocação, ele está atuando sozinho, com contatos esporádicos com o gestor de operações, mas possui um um espaço físico dedicado na sede no qual ele está conduzindo todo o trabalho abertamente. No momento ele possui várias anotações, diagramas e post-its, mas está perdido em como começar a fazer sentido de toda a informação coletada.

Cenário 5
Após meses de pesquisa e imersão das equipes de marketing e design, a equipe técnica de uma empresa de iluminação (que produz lustres e luminárias) recebeu um briefing para o desenvolvimento de um novo produto físico até o momento inexistente no mercado. A estratégia é em poucos meses começar a produção mirando clientes já fidelizados, para no futuro abrir para novos mercados. Os 5 membros alocados, engenheiros de diversas áreas e designers de produto, foram escolhidos por terem um ótimo relacionamento e serem bastante ágeis. No momento eles estão em uma sala dedicada trabalhando todos os dias em estratégias para a tangibilização do produto buscando alternativas de como será de fato o MVP, mas estão encontrando dificuldade em produzir ideias coerentes de como construir tecnicamente o produto.

4. Qual o primeiro cenário que você escolheu validar? * (*Mark only one oval)*

◯ Cenário 1 *(Skip to question 5)*
◯ Cenário 2 *(Skip to question 10)*
◯ Cenário 3 *(Skip to question 15)*
◯ Cenário 4 *(Skip to question 20)*
◯ Cenário 5 *(Skip to question 25)*

Cenário 1
Uma empresa de consultoria em Transformação Digital alocou 3 especialistas para um projeto de 2 meses dentro de um cliente a fim de impulsionar uma cultura de dados. Ao longo do primeiro mês a equipe conduziu uma série de pesquisas (entrevistas, observações, desk research) e descobriu várias possibilidades de melhoria, definindo em parceria com os gestores o principal problema a ser resolvido no mês seguinte.
Agora a equipe prepara uma sessão de co-criação presencial com 5 membros da equipe-cliente para buscar formas de resolver o problema proposto, mas estão em dúvida em quais técnicas deveriam utilizar nesse contexto. Os participantes foram selecionados de áreas diferentes da empresa e com formações distintas, mas, devido a desalinhamentos entre as áreas, não gostam de trabalhar em conjunto.

5. Quais das técnicas abaixo você utilizaria neste cenário? *

Abaixo segue a lista com todas as técnicas atualmente implementadas no protótipo. Levando em conta as que você conhece, marque as técnicas de criatividade/inovação que você utilizaria neste cenário específico. Caso não considere nenhuma relevante, marque a última opção. (*Check all that apply)*

☐ 5 Whys (5 Porquês)

☐ Affinity Diagram (Diagrama de Afinidade / KJ Diagram)

☐ Alpha Prototyping (Protótipo Alfa / Primeiro Protótipo Funcional ou Testável)

☐ Bio-inspiration (Biomimética / Bio-inspiração)

☐ Brainwriting

☐ Contextual Interview (Entrevista contextual primária, podendo ser com usuário, cliente, funcionários, ...)
☐ CSD Matrix (Matriz Certezas, Dúvidas e Suposições)
☐ Desk research (Pesquisa Desk / Pesquisa Secundária pela Internet)
☐ Dot Voting (Votação Dot / Multivoting)
☐ Empathy Map (Mapa de Empatia)
☐ Functional Analysis (Análise Funcional / Estrutura Funcional)
☐ How Might We (Como Poderíamos / Redefinição Heurística)
☐ Impact Effort Matrix (Matriz Esforço-Impacto / Ways to Grow Framework / 2x2 Prioritization Matrix)
☐ Journey Map (Mapa da Jornada / Jornada do Usuário)
☐ Morphological Analysis (Análise Morfológica / Matriz Morfológica)
☐ Persona
☐ Pugh Matrix (Matriz de Pugh)
☐ Reverse Brainstorming (Brainstorming Reverso / Negative Brainstorming)
☐ Roadmap
☐ Roleplay
☐ Rough Prototyping (Protótipo Rápido ou Explorativo / Quick&Dirty Prototyping / Protótipo de Baixa-Fidelidade)
☐ Service Blueprint (Blueprint do Serviço)
☐ Shadowing (Sombra)
☐ Stakeholder Map (Mapa de Stakeholders)
☐ Storyboard
☐ Traditional Brainstorming (Brainstorming Clássico ou Tradicional)

6.. Você utilizaria/indicaria alguma outra técnica que não esteja listada acima para este cenário? *

Agora sim, você pode acessar o sistema :)
Use o link para acessar e responder às perguntas do sistema. Já dentro do sistema peço que, na pergunta relativa ao seu nome, indique também qual cenário você está validando. Por exemplo, "Luiz - Cenário 1". Fique à vontade para ler e reler o cenário apresentado a qualquer momento se for necessário :)

Após responder a todas as perguntas, atente à primeira tela de resultado que relata o seu cenário atual (Your Design Scenario) e indica quais técnicas são recomendadas. Após essa análise, avance (seta inferior direita) para responder qual técnica você, como especialista, escolheria como ideal para este caso (ou indicar que não utilizaria nenhuma delas). É muito importante que você escolha alguma das opções para que apareça uma tela de agradecimento, representando o fim desta etapa. Apenas depois disso você poderá voltar para este questionário.

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Obs: devido ao servidor utilizado, o site pode demorar alguns segundos para carregar.

7. O que você achou das informações presentes no "Your Design Scenario", apresentado na primeira tela de resultado? Fez sentido em relação ao cenário imaginado por você? *

8. Caso tenha entendido que nenhuma das 3 técnicas recomendadas seria ideal, explique o porquê e indique quais você utilizaria.

9. Qual o próximo cenário que você escolheu? *

Caso você já tenha respondido a um mínimo de 3 cenários e deseje encerrar o processo, escolha a última opção. Se for do seu interesse, pode validar os 5 cenários :) (*Mark only one oval)*

◯ Cenário 2 - Empresa de software para portos com sistema de transporte de carga *(Skip to question 10)*

◯ Cenário 3 - Hackathon sobre vacina promovido por um laboratório médico *(Skip to question 15)*

◯ Cenário 4 - Designer em tempo integral trabalhando sozinho para melhorar o processo de desenvolvimento interno *(Skip to question 20)*

◯ Cenário 5 - Novo produto físico para novos mercados no ramo de iluminação *(Skip to question 25)*

◯ Já validei ao menos três cenários e desejo finalizar (*Skip to question 30)*

Cenário 2

A equipe de desenvolvimento de produto de uma empresa de software para portos está desenvolvendo uma nova aplicação para alcançar um novo mercado tecnológico de transporte de carga. Mesmo sendo um produto existente no mercado, a empresa visa adentrar esse novo ramo para se consolidar, entregar soluções mais abrangentes e fidelizar clientes. Após a definição dos objetivos do projeto, várias ideias de produto surgiram ao longo da ideação e a equipe, composta por 4 desenvolvedores com background em TI, se encontra com várias opções de solução sem conseguir convergir. A equipe está engajada e muito unida para debater e construir o produto mesmo trabalhando de forma virtual.

10. Quais das técnicas abaixo você utilizaria neste cenário? *

Abaixo segue a lista com todas as técnicas atualmente implementadas no protótipo. Levando em conta as que você conhece, marque as técnicas de criatividade/inovação que você utilizaria neste cenário específico. Caso não consideres nenhuma relevante, marque a última opção. *(Check all that apply).*

☐ 5 Whys (5 Porquês)

☐ Affinity Diagram (Diagrama de Afinidade / KJ Diagram)

☐ Alpha Prototyping (Protótipo Alfa / Primeiro Protótipo Funcional ou Testável)

☐ Bio-inspiration (Biomimética / Bio-inspiração)

☐ Brainwriting

☐ Contextual Interview (Entrevista contextual primária, podendo ser com usuário, cliente, funcionários, ...)

☐ CSD Matrix (Matriz Certezas, Dúvidas e Suposições)

☐ Desk research (Pesquisa Desk / Pesquisa Secundária pela Internet)

☐ Dot Voting (Votação Dot / Multivoting)

☐ Empathy Map (Mapa de Empatia)

☐ Functional Analysis (Análise Funcional / Estrutura Funcional)

☐ How Might We (Como Poderíamos / Redefinição Heurística)

☐ Impact Effort Matrix (Matriz Esforço-Impacto / Ways to Grow Framework / 2x2 Prioritization Matrix)

☐ Journey Map (Mapa da Jornada / Jornada do Usuário)

☐ Morphological Analysis (Análise Morfológica / Matriz Morfológica)

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☐ Service Blueprint (Blueprint do Serviço)

☐ Shadowing (Sombra)

☐ Stakeholder Map (Mapa de Stakeholders)

☐ Storyboard

☐ Traditional Brainstorming (Brainstorming Clássico ou Tradicional)

11. Você utilizaria/indicaria alguma outra técnica que não esteja listada acima nessa situação? *

Agora sim, você pode acessar o sistema :)
Use o link para acessar e responder às perguntas do sistema. Já dentro do sistema peço que, na pergunta relativa ao seu nome, indique também qual cenário você está validando. Por exemplo, "Luiz - Cenário 2". Fique à vontade para ler e reler o cenário apresentado a qualquer momento se for necessário :)

Após responder a todas as perguntas, atente à primeira tela de resultado que relata o seu cenário atual (Your Design Scenario) e indica quais técnicas são recomendadas. Após essa análise, avance (seta inferior direita) para responder qual técnica você, como especialista, escolheria como ideal para este caso (ou indicar que não utilizaria nenhuma delas). É muito importante que você escolha alguma das opções para que apareça uma tela de agradecimento, representando o fim desta etapa. Apenas depois disso você poderá voltar para este questionário.

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12. O que você achou das informações presentes no "Your Design Scenario", apresentado na primeira tela de resultado? Fez sentido em relação ao cenário imaginado por você?*

13. Caso tenha entendido que nenhuma das 3 técnicas recomendadas seria ideal, explique o porquê e indique quais você utilizaria.

14. Qual o próximo cenário que você escolheu? *

Caso você já tenha respondido a um mínimo de 3 cenários e deseje encerrar o processo, escolha a última opção. Se for do seu interesse, pode validar os 5 cenários :) (*Mark only one oval)*

◯ Cenário 1 - Empresa de consultoria em Transformação Digital para impulsionar a cultura de dados *(Skip to question 5)*

◯ Cenário 3 - Hackathon sobre vacina promovido por um laboratório médico *(Skip to question 15)*

◯ Cenário 4 - Designer em tempo integral trabalhando sozinho para melhorar o processo de desenvolvimento interno *(Skip to question 20)*

◯ Cenário 5 - Novo produto físico para novos mercados no ramo de iluminação *(Skip to question 25)*

◯ Já validei ao menos três cenários e desejo finalizar (*Skip to question 30)*

Cenário 3

Durante um hackathon promovido por um laboratório médico, 4 pessoas que não se conheciam previamente se juntaram virtualmente em uma equipe para participar do evento: um Product Owner, um UX Designer, um Cientista de Dados e um Back-end Dev. O objetivo do Hackathon é desenvolver um produto web inovador para resolver problemas de vacinação em SC. A equipe, recém-formada, está com o briefing em mãos sem saber por onde começar. Nas diretrizes já constam informações sobre público alvo, categorias prioritárias para vacinação e um escopo amplo de objetivos esperados, mas sem direcionar o potenciais soluções ou mesmo quais as necessidades específicas que devem ser atendidas. A equipe tem contato com alguns clientes, médicos, enfermeiros e técnicos em vacinação, e é incentivada entrar em contato com quaisquer pessoas que julgarem necessário.

15. Quais das técnicas abaixo você utilizaria neste cenário? *

Abaixo segue a lista com todas as técnicas atualmente implementadas no protótipo. Levando em conta as que você conhece, marque as técnicas de criatividade/inovação que você utilizaria neste cenário específico. Caso não consideres nenhuma relevante, marque a última opção. *(Check all that apply).*

☐ 5 Whys (5 Porquês)

☐ Affinity Diagram (Diagrama de Afinidade / KJ Diagram)

☐ Alpha Prototyping (Protótipo Alfa / Primeiro Protótipo Funcional ou Testável)

☐ Bio-inspiration (Biomimética / Bio-inspiração)

☐ Brainwriting

☐ Contextual Interview (Entrevista contextual primária, podendo ser com usuário, cliente, funcionários, ...)

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☐ Desk research (Pesquisa Desk / Pesquisa Secundária pela Internet)

☐ Dot Voting (Votação Dot / Multivoting)

☐ Empathy Map (Mapa de Empatia)

☐ Functional Analysis (Análise Funcional / Estrutura Funcional)

☐ How Might We (Como Poderíamos / Redefinição Heurística)

☐ Impact Effort Matrix (Matriz Esforço-Impacto / Ways to Grow Framework / 2x2 Prioritization Matrix)

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☐ Stakeholder Map (Mapa de Stakeholders)

☐ Storyboard

☐ Traditional Brainstorming (Brainstorming Clássico ou Tradicional)

16. Você utilizaria/indicaria alguma outra técnica que não esteja listada acima nessa situação? *

Agora sim, você pode acessar o sistema :)
Use o link para acessar e responder às perguntas do sistema. Já dentro do sistema peço que, na pergunta relativa ao seu nome, indique também qual cenário você está validando. Por exemplo, "Luiz - Cenário 3". Fique à vontade para ler e reler o cenário apresentado a qualquer momento se for necessário :)

Após responder a todas as perguntas, atente à primeira tela de resultado que relata o seu cenário atual (Your Design Scenario) e indica quais técnicas são recomendadas. Após essa análise, avance (seta inferior direita) para responder qual técnica você, como especialista, escolheria como ideal para este caso (ou indicar que não utilizaria nenhuma delas). É muito importante que você escolha alguma das opções para que apareça uma tela de agradecimento, representando o fim desta etapa. Apenas depois disso você poderá voltar para este questionário.

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17. O que você achou das informações presentes no "Your Design Scenario", apresentado na primeira tela de resultado? Faz sentido em relação ao cenário imaginado por você? *

18. Caso tenha entendido que nenhuma das 3 técnicas recomendadas seria ideal, explique o porquê e indique quais você utilizaria.

19. Qual o próximo cenário que você escolheu? *

Caso você já tenha respondido a um mínimo de 3 cenários e deseje encerrar o processo, escolha a última opção. Se for do seu interesse, pode validar os 5 cenários :) (*Mark only one oval)*

◯ Cenário 1 - Empresa de consultoria em Transformação Digital para impulsionar a cultura de dados *(Skip to question 5)*

◯ Cenário 2 - Empresa de software para portos com sistema de transporte de carga *(Skip to question 10)*

◯ Cenário 4 - Designer em tempo integral trabalhando sozinho para melhorar o processo de desenvolvimento interno *(Skip to question 20)*

◯ Cenário 5 - Novo produto físico para novos mercados no ramo de iluminação *(Skip to question 25)*

◯ Já validei ao menos três cenários e desejo finalizar (*Skip to question 30)*

Cenário 4

Um Designer de Serviço trabalhando em tempo integral em uma empresa foi encarregado de melhorar o processo de desenvolvimento de soluções atualmente adotado. Após uma série de entrevistas com colegas e pesquisas secundárias, o designer precisa começar a afunilar quais os principais problemas existentes e qual ele deve priorizar. Por conta da alocação, ele está atuando sozinho, com contatos esporádicos com o gestor de operações, mas possui um um espaço físico dedicado na sede no qual ele está conduzindo todo o trabalho abertamente. No momento ele possui várias anotações, diagramas e post-its, mas está perdido em como começar a fazer sentido de toda a informação coletada.

20. Quais das técnicas abaixo você utilizaria neste cenário? *

Abaixo segue a lista com todas as técnicas atualmente implementadas no protótipo. Levando em conta as que você conhece, marque as técnicas de criatividade/inovação que você utilizaria neste cenário específico. Caso não consideres nenhuma relevante, marque a última opção. *(Check all that apply).*

☐ 5 Whys (5 Porquês)

☐ Affinity Diagram (Diagrama de Afinidade / KJ Diagram)

☐ Alpha Prototyping (Protótipo Alfa / Primeiro Protótipo Funcional ou Testável)

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☐ Brainwriting

☐ Contextual Interview (Entrevista contextual primária, podendo ser com usuário, cliente, funcionários, ...)

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☐ Desk research (Pesquisa Desk / Pesquisa Secundária pela Internet)

☐ Dot Voting (Votação Dot / Multivoting)

☐ Empathy Map (Mapa de Empatia)

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21. Você utilizaria/indicaria alguma outra técnica que não esteja listada acima nessa situação? *

Agora sim, você pode acessar o sistema :)
Use o link para acessar e responder às perguntas do sistema. Já dentro do sistema peço que, na pergunta relativa ao seu nome, indique também qual cenário você está validando. Por exemplo, "Luiz - Cenário 4". Fique à vontade para ler e reler o cenário apresentado a qualquer momento se for necessário :)

Após responder a todas as perguntas, atente à primeira tela de resultado que relata o seu cenário atual (Your Design Scenario) e indica quais técnicas são recomendadas. Após essa análise, avance (seta inferior direita) para responder qual técnica você, como especialista, escolheria como ideal para este caso (ou indicar que não utilizaria nenhuma delas). É muito importante que você escolha alguma das opções para que apareça uma tela de agradecimento, representando o fim desta etapa. Apenas depois disso você poderá voltar para este questionário.

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22. O que você achou das informações presentes no "Your Design Scenario", apresentado na primeira tela de resultado? Fez sentido em relação ao cenário imaginado por você? *

23. Caso tenha entendido que nenhuma das 3 técnicas recomendadas seria ideal, explique o porquê e indique quais você utilizaria.

24. Qual o próximo cenário que você escolheu? *

Caso você já tenha respondido a um mínimo de 3 cenários e deseje encerrar o processo, escolha a última opção. Se for do seu interesse, pode validar os 5 cenários :) (*Mark only one oval*)

◯ Cenário 1 - Empresa de consultoria em Transformação Digital para impulsionar a cultura de dados *(Skip to question 5)*

◯ Cenário 2 - Empresa de software para portos com sistema de transporte de carga *(Skip to question 10)*

◯ Cenário 3 - Hackathon sobre vacina promovido por um laboratório médico *(Skip to question 15)*

◯ Cenário 5 - Novo produto físico para novos mercados no ramo de iluminação *(Skip to question 25)*

◯ Já validei ao menos três cenários e desejo finalizar (*Skip to question 30)*

Cenário 5
Após meses de pesquisa e imersão das equipes de marketing e design, a equipe técnica de uma empresa de iluminação (que produz lustres e luminárias) recebeu um briefing para o desenvolvimento de um novo produto físico até o momento inexistente no mercado. A estratégia é em poucos meses começar a produção mirando clientes já fidelizados, para no futuro abrir para novos mercados. Os 5 membros alocados, engenheiros de diversas áreas e designers de produto, foram escolhidos por terem um ótimo relacionamento e serem bastante ágeis. No momento eles estão em uma sala dedicada trabalhando todos os dias em estratégias para a tangibilização do produto buscando alternativas de como será de fato o MVP, mas estão encontrando dificuldade em produzir ideias coerentes de como construir tecnicamente o produto.

25. Quais das técnicas abaixo você utilizaria neste cenário? *

Abaixo segue a lista com todas as técnicas atualmente implementadas no protótipo. Levando em conta as que você conhece, marque as técnicas de criatividade/inovação que você utilizaria neste cenário específico. Caso não consideres nenhuma relevante, marque a última opção. *(Check all that apply).*

☐ 5 Whys (5 Porquês)

☐ Affinity Diagram (Diagrama de Afinidade / KJ Diagram)

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26. Você utilizaria/indicaria alguma outra técnica que não esteja listada acima nessa situação? *

Agora sim, você pode acessar o sistema :)
Use o link para acessar e responder às perguntas do sistema. Já dentro do sistema peço que, na pergunta relativa ao seu nome, indique também qual cenário você está validando. Por exemplo, "Luiz - Cenário 5". Fique à vontade para ler e reler o cenário apresentado a qualquer momento se for necessário :)

Após responder a todas as perguntas, atente à primeira tela de resultado que relata o seu cenário atual (Your Design Scenario) e indica quais técnicas são recomendadas. Após essa análise, avance (seta inferior direita) para responder qual técnica você, como especialista, escolheria como ideal para este caso (ou indicar que não utilizaria nenhuma delas). É muito importante que você escolha alguma das opções para que apareça uma tela de agradecimento, representando o fim desta etapa. Apenas depois disso você poderá voltar para este questionário.

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27. O que você achou das informações presentes no "Your Design Scenario", apresentado na primeira tela de resultado? Fez sentido em relação ao cenário imaginado por você? *

28. Caso tenha entendido que nenhuma das 3 técnicas recomendadas seria ideal, explique o porquê e indique quais você utilizaria.

29. Qual o próximo cenário que você escolheu? *

Caso você já tenha respondido a um mínimo de 3 cenários e deseje encerrar o processo, escolha a última opção. Se for do seu interesse, pode validar os 5 cenários :) (*Mark only one oval)*

- Cenário 1 - Empresa de consultoria em Transformação Digital para impulsionar a cultura de dados *(Skip to question 5)*
- Cenário 2 - Empresa de software para portos com sistema de transporte de carga *(Skip to question 10)*
- Cenário 3 - Hackathon sobre vacina promovido por um laboratório médico *(Skip to question 15)*
- Cenário 4 - Designer em tempo integral trabalhando sozinho para melhorar o processo de desenvolvimento interno *(Skip to question 20)*
- Já validei ao menos três cenários e desejo finalizar (*Skip to question 30)*

Fechamento

O software emprega atualmente 10 perguntas simples para inferir 7 fatores de entrada:

- Etapa do projeto (seguindo o Double Diamond)
- Foco inovativo (se a inovação será mais incremental ou radical
- Coesão da equipe
- Tamanho da equipe
- Solução esperada (produto ou serviço)
- Participantes
- Plataforma virtual
- Diversidade da equipe

Estes 7 se combinam para buscar as principais características de uma técnica que seria útil para o dado cenário, sendo elas:

- Tempo de execução da técnica
- Dificuldade de uso
- Estrutura da técnica (mais sistemática ou livre)
- Componente criativo (usuários, business, técnico, definição do problema/solução, conceito, protótipo)

- Domínio de exploração (problema ou solução)

Estes fatores então são combinados para buscar quais das técnicas disponíveis se encaixam nestas características, sendo as 3 mais promissoras apresentadas ao fim.

30. Existe algum fator que você considera importante e que o sistema não está levando em conta no momento?

31. Que outras técnicas você gostaria de ver implementadas?

32. Use o espaço abaixo para críticas, feedbacks, recomendações ou qualquer informação que você considera importante para evoluir o sistema e/ou minha pesquisa :)

Obrigado!
Agora é só submeter clicando no botão abaixo.

Suas respostas serão analisadas em breve e contribuirão muito para a minha pesquisa e para a consolidação de conhecimento em criatividade. Fico à disposição para quaisquer dúvidas e, se você tiver interesse, pode me contactar a qualquer momento para mais informações ou para conhecer melhor meu trabalho. Obrigado novamente e até a próxima :D