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Characterizing design thinking towards integration with product-service system development process

(partial version – until literature review)

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ABSTRACT

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Many companies have been trying to shift their business core from offering products to offer product-service systems (PSS), what requires not only a shift in the business model, but also in the culture and mindset. Using user-centered methods to support the PSS development process is a way to support this shift and to enhance perceived value of PSS offerings. One possible approach to support PSS development on becoming more user-centered is design thinking (DT). It is a user-centric approach used by many leader enterprises to support innovation and described by several methodologies with practical focus. However, it is not clear in literature how to integrate DT and development process models already used by companies, leading to cases where practitioners may replace complete phases, or even the whole development process, by DT. This replacement does not seem appropriate, since DT may lack aspects that are considered by PSS development processes. The main objective of this work is to identify how the DT approach can be applied in PSS development processes. The methodology of this research combines the following methods: case research, corpus linguistics, frame semantics and matrix-based methods. One of the results of this work is the characterization of DT based on the linguistic analysis, which was derived from content extracted from more than 1500 pages of 8 DT methodologies. This analysis resulted in 46 recurrent activities, associated with 458 specific guidelines, and the identification of 182 relevant activities that synthetize the DT methodologies. Those activities were compared to 14 PSS development process models from literature, concluding, among other findings, that DT cannot replace the PSS design process models, and that the compatibility for integration of DT into PSS development process models is greater on the front-end of innovation (FEI). FEI activities from 14 PSS and 7 product development process models were compared with DT recurrent and relevant activities to provide understanding on how DT can be integrated into PSS development process models. Finally, the findings of this last comparison led to the creation of a 4-step method for integrating DT into PSS development process models based on activities similarity.

Keywords: design thinking, design process, Product-Service System, PSS, Front-End of Innovation, FEI.

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LIST OF ABBREVIATIONS

B2B	Business-to-Business
B2C	Business-to-Customer
C1	DT Recurrent Activities Cluster 1
C2	DT Recurrent Activities Cluster 2
C3	DT Recurrent Activities Cluster 3
C4	DT Recurrent Activities Cluster 4
C5	DT Recurrent Activities Cluster 5
C6	DT Recurrent Activities Cluster 6
C7	DT Recurrent Activities Cluster 7
C8	DT Recurrent Activities Cluster 8
C9	DT Recurrent Activities Cluster 9
CoNEKTR	Complex Network Electronic Knowledge Translation Research
DMM	Domain Mapping Matrix
DSM	Design Structure Matrix
DRM	Design Research Methodology
DT	Design Thinking
DS	Descriptive Study
E&P	Empathy Generation and Problem Definition
FEI	Front-End of Innovation
FFE	Fuzzy Front-End
ID	Ideation
IMP	Implementation
IT	Information Technology

NPD	New Product Development
OECD	Organization for Economic Co-operation and Development
PDP	Product Development Process
P&T	Prototype and Test
PS	Prescriptive Study
PSS	Product-Service System
RC	Research Clarification
SDP	Service Development Process
UCD	User-Centered Design
UX	User Experience

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1. Introduction

This chapter is divided in three sections. The first section (1.1 Context and Justification) aims to contextualize the reader about the main themes covered in this work and to justify this work in the literature context. The second section (section 1.2) of this chapter points out the primary and secondary goals of this work. Finally, the third section (section 1.3) supports the reader on overviewing the content of this work by presenting how it is structured.

1.1 Context and Justification

Literature has been providing evidence that perceived value increment is reached when products and services are associated (BAINES et al., 2007, p. 1; MANZINI; VEZZOLI, 2003, p. 851; MONT, 2002, p. 237; MOSER et al., 2015, p. 18; VIJAYKUMAR et al., 2015, p. 429), what may be achieved by offering product-service systems (PSS). PSS is “a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs” (TUKKER; TISCHNER, 2006, p. 1552). The core idea of a PSS is to offer value in use, expanding the value brought exclusively by the products to value proposed by associated services (VIJAYKUMAR et al., 2015, p. 429).

Xing, Wang and Qian (2013, p. 5912-5913) propose that the total value brought by PSS offerings to the stakeholders may be divided in four value dimensions: functional, “determined by how effectively they can satisfy the required performance specifications translated from the Voice-of-Customer”; physical, related to its reliability; economic, related to investments, costs and revenue; and, finally, environmental, related to the sustainability aspects of the solution.

Focusing the scope on improving the first value dimension (functional), the development process needs to become more creative and customer-centered, considering intense involvement of stakeholders and shifting the product-centered core that the companies have been used to in the last decades in order to provide successful solutions (VASANTHA et al., 2012, p. 24-25). One way that enterprises have been changing their development process is by applying user-centered methods.

Indeed, many publications in literature present single methods and evaluation tools to support the PSS development process, including several user-centered ones (KIMITA; SHIMOMURA, 2014, p. 348). For requirements elucidation, for example, there is recent work proposing from new isolated methods (OTA et al., 2013, p. 64) up to completely new approaches composed by associations of existing methods (PERUZZINI; MARILUNGO; GERMANI, 2015, p. 191). Some authors in literature also suggest that design thinking (DT) may be a proper user-centered approach to support PSS development (DE LILLE; ROSCAM ABBING; KLEINSMANN, 2012, p. 462; HENZE; MULDER; STAPPERS, 2011, p. 8; WEST; DI NARDO, 2016, p. 97).

Design thinking is a term used in three different ways in literature. The first one is “design thinking as cognitive style” (KIMBELL, 2011a, p. 297), usually called as designerly thinking, which approaches the logic patterns of designing and derives from the work of Simon (1969). The second one is “design thinking as a general theory of design” (KIMBELL, 2011a, p. 297), derived from the work of Buchanan (1992), approaching design as a way to deal with wicked problems. The third one is “design thinking as an organizational resource” (KIMBELL, 2011a, p. 297), which is the way it is dealt with in this work.

The generic term “design thinking”, approached here as an organizational resource, has been labeling fashionable toolboxes filled with creative user-centered methods. It has become a popular, flexible and creative approach used by many leader enterprises to support innovation. The DT procedure basically employs design methods and reasoning patterns towards problem solving. It is a user-centered approach that aims to generate innovation by means of the so-called integrative thinking[1] (BROWN, 2008, p. 3), emphasizing, according to Lockwood (2009, p. 32), “observation, collaboration, fast learning, visualization of ideas, rapid concept prototyping, and concurrent business analysis”.

The DT process conducts a team through divergent and convergent stages to guarantee observation-based knowledge about users and empathy creation, good problem definition, idea generation maximization and iteration towards the best

[1] Integrative thinking is the informal term that refers to the thinking process that employs abductive thinking to creatively solve problems (DUNNE; MARTIN, 2006, p. 513). More about this issue will be discussed in subsection 2.5.1.

solution. Due to its characteristics, DT is a potential approach to support the PSS development process phases that require creativity and provide innovation opportunities, such as the front-end of innovation[2] (FEI) (GERICKE; MAIER, 2011, p. 5; KIMBELL; JULIER, 2012, p. 16).

DT as an organizational resource has been extremely popularized, however, it is not yet well characterized by literature. According to Dorst (2011, p. 521), literature on DT has been oversimplified and lacks of a "clear and definite knowledge about design thinking". The amount of new work covering DT for practitioners, such as models and methodologies[3], has increased, while little has been done to improve knowledge on DT as a problem-solving approach (LIEDTKA, 2014a, p. 1).

Much criticism is also done in literature about DT. Some authors claim that DT is nothing new, but a better articulation of other design approaches, such as participatory design (BJÖGVINSSON; EHN; HILLGREN, 2012, p. 101). Norman (2010), in a direct criticism, even says that "what is being labeled as 'design thinking' is what creative people in all disciplines have always done". However, literature lacks a systematic study on what characterizes DT. This fact brings the first research question for this work:

RQ1: What are the commonalities among DT methodologies that characterize the DT approach?

Additionally, some practitioners have been thinking of DT as a replacement for the development process, while DT should be seen as a complement to support it. The coupling of DT and product development process has been analyzed in literature by Gericke and Maier (2011, p. 2-3) based on consultants interviews, noticing that DT greatest contribution would be on early phases of project development, leaving concept refinement and detailed design out of scope. In the service perspective, Kimbell and Julier (2012, p. 16) also suggest that DT is an approach compatible with early cycles of research in the front-end of innovation. In a PSS perspective, some

[2] The Front-end of innovation (FEI), also know and Fuzzy front-end (FFE) or front-end in literature, is the set of the initial phases that precede the technical development, i.e., all phases that precede specification and design (KHURANA; ROSENTHAL, 1997, p. 105), covering up to the point where concept is defined and architecture will start to be developed.

[3] Methodology is a set of associated methods and tools. Method is "a resource that is deployed and enacted in a local situation, where a number of participants produce, or attempt to produce, social order" (JENSEN; ANDREASEN, 2010, p. 23). Tools are tangible components used to support an activity.

authors approach in literature the application of DT to develop PSS concepts. West and Di Nardo (2016, p. 100) propose a combination of DT tools in the shape of a process to support PSS discovery. Henze, Mulder and Stappers (2011, p. 7–8) propose an initial “framework of methods, techniques and tools” for conceptualizing PSS. On a different approach, more focused on the business model of a company, De Lille, Roscam Abbing and Kleinsmann (2012, p. 468–469) provide suggestions on how to use a DT approach to shift product-centered companies towards PSS offerings. However, there is no systematic research on how could DT complement PSS development process models. DT may not be able to replace a whole development phase. If this hypothesis is true, other activities of the development process model would have to keep on being performed.

By comparing DT elements with PSS development models, it is possible to identify what DT elements are already existent in PSS development processes and what are not. The similar elements may represent integration opportunities, showing where the greatest compatibility of DT and PSS development process is. The non-similar elements may represent complementation opportunities, providing new information for the PSS development process.

All factors provided so far lead to the last research question:

RQ2: How to integrate Design Thinking and PSS Development so that it becomes more user-centered?

1.2 Research Objectives

The primary objective of this work is to identify how the design thinking approach can be applied in PSS development processes. Based on the research questions provided in section 1.1, the specific goals are the following:

- (G1) Characterize the DT approach based on the recurrent elements, aiming at comparing them with PSS development process models;
- (G2) Compare the DT approach with FEI models and PSS development process models;

- (G3) Identify for what phases or activities of the PSS development process the application of DT is appropriate as a complementary approach.

1.3 Document Structure

This work is structured in nine chapters, as illustrated in Figure 1.

Chapter 1 introduces the content of this document, providing the context and justification of this work, besides the research objectives and an overview of the content of this work.

Chapter 2 is the literature review of the most important themes that must be approached by this work, including the following sections: PSS; PSS Development Process; Front-End of Innovation; Embodiment Design; Design Thinking; Design Thinking Methodologies; and Foundations of development process models.

Chapter 3 presents the methodology by which this research was structured.

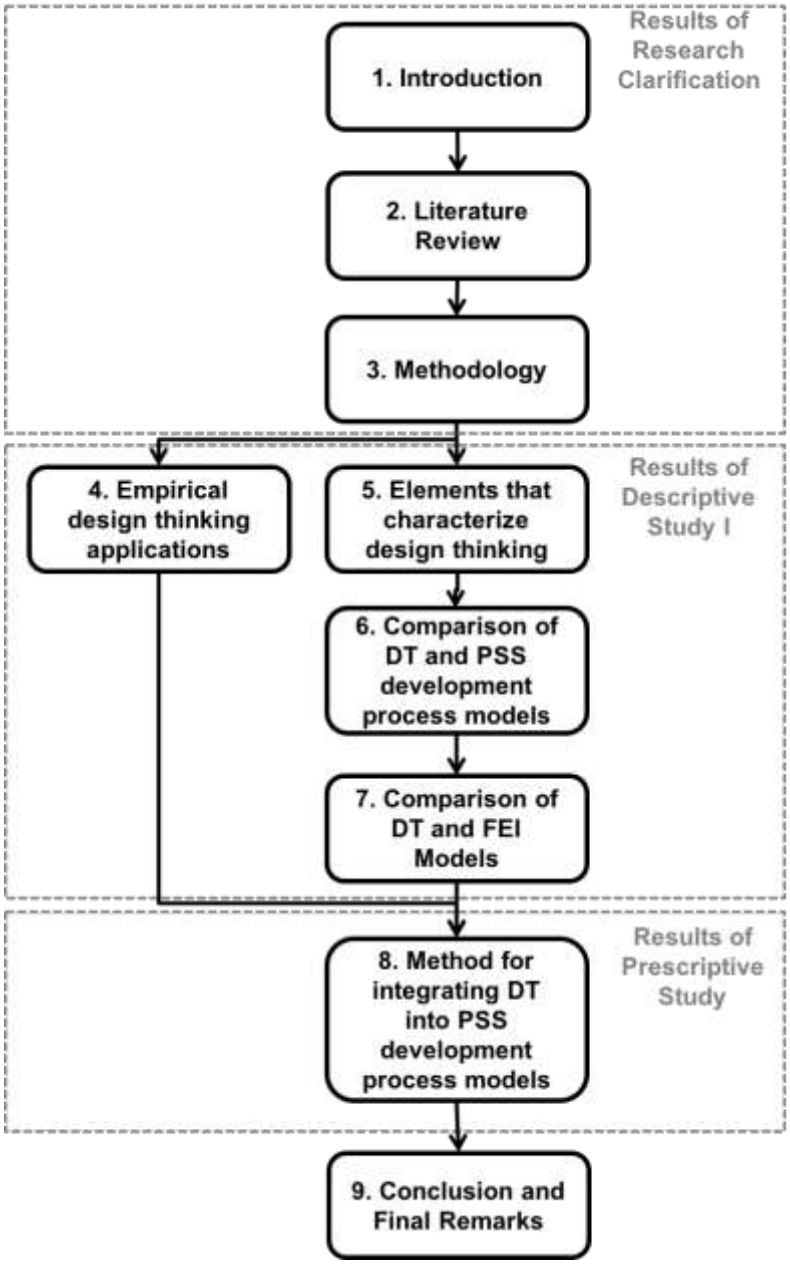
Chapters 4, 5, 6, and 7 are results of the Descriptive Study I stage (for more information, please see chapter 4). Chapter 4 describes the empirical studies performed to better understand the research theme, including two case studies. Chapter 5 describes the most recurrent activities that characterize DT, as well as their division in clusters, and generic and specific guidelines. It also provides the relevant activities from DT. Chapter 6 provides the comparison of DT activities and PSS development process activities, establishing its similarity with the PSS development phases in order to identify how much of the PSS development process is similar to DT activities.

Chapter 7 goes deeper in the analysis, comparing DT activities with product and PSS and product development FEI models in order to better understand how those approaches can be integrated.

Chapter 8 provides the results of the Prescriptive Study stage (for more information, please see chapter 4), retrieving the necessary information and proposing a method for integrating DT into PSS development process models.

This document ends with Chapter 9, which concludes this work with an overview of the results obtained, besides providing limitations and future research opportunities.

Figure 1 - Document structure

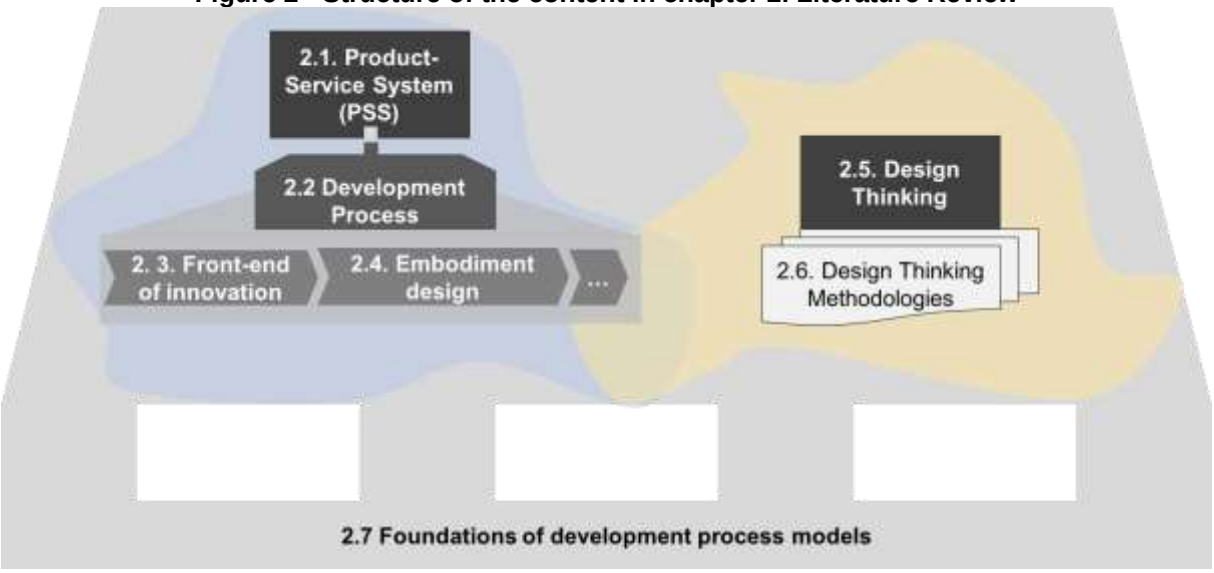


Source: Elaborated by the author

2. Literature Review

The content of this chapter is structured as illustrated in Figure 2.

Figure 2 - Structure of the content in chapter 2. Literature Review



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2.1 Product-Service System

This section presents definitions, typologies, benefits and barriers of product-service systems (PSS), introducing concepts and principles used in this research.

2.1.1 Definitions Related to Product-Service Systems

In a very simple perspective, product is anything that an enterprise can sell to its customers (ULRICH; EPPINGER, 2012, p. 2), what may characterize a product as a physical good (tangible product) or a service (intangible product). In the new product development (NPD) literature, the term product is commonly interchangeable between those two meanings (JOHNE; STOREY, 1998, p. 184).

However, some authors differentiate tangible and intangible products in literature. The first one keeps the label of “product”, being defined as a “tangible commodity manufactured to be sold” (GOEDKOOP et al., 1999, p. 17). The second one is referred to as service, being defined as “an activity (work) done for others with an economic value and often done on a commercial basis” (GOEDKOOP et al., 1999, p. 17). This taxonomy, which is also reinforced by other authors (BOEHM; THOMAS,

2013, p. 245; SHIMOMURA; AKASAKA, 2013, p. 27), will be used in this work, discriminating products and services by different labels.

This differentiation is coherent with the considerable distinct characteristics between products and services. The main differences between them are clarified in Table 1 based on the work of Alonso-Rasgado and Thompson (2006, p. 514-515); De Brentani (1991, p. 35-58); Johne and Storey (1998, p. 187-188); and Jong and Vermeulen (2003, p. 845)). In fact, dealing with such contrasting components with the same approach and mindset may mislead development.

Table 1 - Differences between product and service

Characteristics	Product	Service
Tangibility	Tangible (things)	Intangible (processes)
Heterogeneity	Homogeneous – Quality is not variable	Heterogeneous – Quality varies every time
Simultaneity	Non-simultaneous – First, it is produced, then is consumed	Simultaneous – Is produced and consumed at the same time
Perishability	It can be produced previously and be stored	It cannot be produced previously and be stored
Separability	Separable in parts (modules)	Inseparable
Patentability	Passible of patent	Impassible of patent

Source: Elaborated by the author

Literature has noticed that combining products and services into a system[4] as an unique offer could lead to perceived value increment and could fulfill unsolved customers' demands (BAINES et al., 2007, p. 6; MANZINI; VEZZOLI, 2003, p. 851; MONT, 2002, p. 237; TUKKER; TISCHNER, 2006, p. 1552). This combination is treated in literature as PSS, term proposed by Goedkoop et al. (1999, p. 17) and strongly diffused among the sustainability journals, such as *Journal of Cleaner Production* (BAINES et al., 2007). Mont (2002, p. 239) defines PSS as "a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models". Reim, Parida and Örtqvist (2015, p. 61) also propose

[4] System is defined as "a collection of elements including their relations" (GOEDKOOP et al., 1999, p. 17).

PSS as a business model towards “economic prosperity and sustainable resource management”. However, Manzini and Vezzoli (2002, p. 4) contest the statement that PSS is always interrelated with lower environmental impact, proposing a more generic definition that characterizes PSS as the following:

> *“The result of an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands” (MANZINI; VEZZOLI, 2002, p. 4).*

Many other labels in literature also refer to PSS, usually differentiating its scenarios. Integrated Product and Service Offering (IPSO) is the PSS concept conceived based on the lifecycle and development process theory (CAVALIERI; PEZZOTTA, 2012, p. 281). Functional product, or total care product, is a term used to refer to the combination of hardware, software, service and management of the operation, what delivers performance instead of a product (ALONSO-RASGADO; THOMPSON; ELFSTRÖM, 2004, p. 515-516; LINDSTRÖM; SAS; LIDESKOG, 2015, p. 6; MARKESET; KUMAR, 2005, p. 54-55). Industrial Product-Service System (IPS^2) is used for offers with a customer-enterprise relationship of the business-to-business (B2B) type, aiming to deliver value in the entire product lifecycle (MEIER; ROY; SELIGER, 2010, p. 607; MEIER; VÖLKER; FUNKE, 2011, p. 1176). Within the IPS^2, a PSS may yet be characterized under the label Technical Product-Service Systems (t-PSS), which is mainly used when the product and service represent high investments, emphasizing the physical core of the system with a product of high monetary value, also with a B2B relationship (AURICH; FUCHS; WAGENKNECHT, 2006 p. 1481; AZARENKO et al., 2009, p. 701). There are still many other terms used in literature to refer to PSS or to the process of developing a PSS, such as functional sales, servitization, servicising, service engineering, full service, system selling, integrated solutions, installed base service and extended products (LINDSTRÖM; SAS; LIDESKOG, 2015).

On the servitization terminology, which is also used in this work due to the context of one of the empirical applications described on section **Erro! Fonte de referência não encontrada.**, it is important to highlight one strong difference from PSS. Even though PSS and servitization are commonly used as synonyms in literature, they may not be considered this way (BEUREN; FERREIRA; MIGUEL, 2013, p. 224).

Baines et al. (2009, p. 547) defines servitization as “the process of creating value by adding services to products”, i.e., while PSS is the development object, servitization is “the innovation of an organization’s capabilities and processes to shift from setting products to selling integrated products and services that deliver value in use” (BAINES et al., 2009, p. 563). However, Baines et al. (2009, p. 547) highlight that servitization and PSS have a “striking ovelap” of concepts.

2.1.2 Product-Service System Typology

By considering the outspread of the PSS nomenclature due to its peculiarities, it is clear that PSS may be divided in many different typologies depending on many factors.

One typology that considers a wide range of dimensions of PSS is the one proposed by Rese et al. (2013, p. 193), taking into consideration value, organization, risk distribution, revenue streams and property rights. There are still other more restrict classifications in literature (ADRODEGARI et al., 2015; BREZET et al., 2001; VAN OSTAEYEN et al., 2013).

However, according to Beuren, Ferreira and Miguel (2013, p. 225), certain authors in literature have chosen the typology proposed by Tukker (2004) as the current most appropriate one. Thus, it was used in this work just for classification purposes. Tukker (2004, p. 248-249) classifies PSS in the following categories:

- Product-oriented services: In this macro-category, the sales object is the product. Thus, the ownership belongs to the customer. It is discretized in two categories: Product-related service, and advice and consultancy.
    - Product-related service: The business model covers mainly the product sales, offering also extra necessary services for the use phase of the product lifecycle.
    - Advice and consultancy: Usually used in the software industry, this PSS is focused on product sales and offers advice and consultancy to improve the product use by the consumer.

- Use-oriented services: This macro-category is applicable whenever what is being sold is the use of a given product. Thus, ownership is not necessarily transferred. However, the customers are able to use the product according to their needs.
    - Product lease: The product provider keeps the product ownership and is responsible to keep it generating value to the customer with essential services, such as maintenance and repair. The customer pays a predefined fee in order to have access to the product and the services and she/he keeps unlimited and individual access to the product.
    - Product renting and sharing: It is similar to the product lease. However, in this PSS the product is sequentially rented to other customers and the rent is not unlimited.
    - Product pooling: Similar to product renting. However, instead of a sequential use of the product by different customers, the use is simultaneous.
- Result-oriented services: This macro-category involves offering a complete result, transforming a product as a simple vehicle that offers a much more complete solution that matches the customers' needs.
    - Activity management/outsourcing: This PSS is related to the outsourcing of one enterprise's activity to a second enterprise by making use of a given product.
    - Pay per service unit: Paying per service unit completely shifts the core from the product to the outcomes. A customer does not pay for the product, but for each unit of value that it generates.
    - Functional result: Instead of offering a product, this PSS offers a functional result that solves one or more needs of the customer, such as offering clean water rather than offering a water purifier.

2.1.3 Benefits and Barriers

Depending on the PSS type that shall be implemented, many stakeholders may be impacted, such as market, environment, society and government, among others. Many benefits can be generated from a good PSS implementation. According to Mont (2002, p. 239), a “paramount goal of product-service systems should be to minimize the environmental impact of consumption”, since the product returns to the provider enterprise or remains in the enterprise possession, avoiding the unconscious discard. As already stated before, it should be pointed out that this perspective is not shared by Manzini and Vezzoli (2003, p. 851), who highlight that without a proper strategic approach PSS may not necessarily become a sustainable offer, possibly even generating unwanted rebound effects that increase the PSS environmental impact.

For industry, the consequent benefits of PSS are many. PSS enlarges the company’s field of vision on market opportunities, leading to innovation in a greater level than just the usual incremental one and increasing the likelihood of economic benefits, what is beneficial in the financial point of view (MEIER; ROY; SELIGER, 2010, p. 614; MONT, 2002, p. 239-240). The financial uncertainty is also reduced due to recurrent incomes instead of punctual sales (ALONSO-RASGADO; THOMPSON; ELFSTRÖM, 2004, p. 518). However, it is necessary to pay careful attention to this benefit, since statistical data show a tendency in PSS implementation of increasing revenues, but reducing net profit (NEELY, 2008, p. 110). Yet, in the company’s perspective, customers may keep related to the enterprise for a longer period than just a punctual sale, improving the chances to build customer loyalty (VANDERMERWE; RADA, 1988 apud NEELY, 2008, p. 104).

Specifically for manufacturing companies, PSS directly adds value to the product, both by increasing the perceived value by the customer and by improving the lifecycle time and characteristics of the product, since it will become an enterprise’s good and should last as long as possible (MONT, 2002, p. 240; XING; WANG; QIAN, 2013, p. 5908–5909). This increase of lifecycle time also reduces the impact of environmental legislation on the enterprise (MONT, 2002, p. 240; REIM; PARIDA; ÖRTQVIST, 2015, p. 61). The need of contact with the customers is intensified, bringing the enterprise to a closer attitude towards the customer (MONT, 2002, p. 240; XING; WANG; QIAN, 2013, p. 5908–5909).

For society, PSS dissemination may shift the consumerism culture to more “sustainable patterns of consumption” (MEIER; ROY; SELIGER, 2010, p. 623; MONT, 2002, p. 240). Globally, PSS could be seen as a path to technology access equality, since the price would be lower and low-resource customers could start affording those offers (MEIER; ROY; SELIGER, 2010, p. 623). However, Manzini and Vezzoli (2003, p. 851) state that this benefit is not brought by every PSS, being restricted to PSS developments that are carefully performed with sustainable goals.

The environment also benefits from a new sustainable consumption pattern, which may decrease the waste generation due to product replacement by the customer (MEIER; ROY; SELIGER, 2010, p. 623; MONT, 2002, p. 240). Besides, remanufacturing and reuse will make product and materials last longer (MEIER; ROY; SELIGER, 2010, p. 623; MONT, 2002, p. 240). Additionally, the trend is that enterprises dematerialize their products, reducing resources use since the customer does not pay for materials anymore, but for value (MEIER; ROY; SELIGER, 2010, p. 623; MONT, 2002, p. 240).

In the government perspective, new jobs can be created in order to perform the services that compose each PSS offer, since new skills and more workload may be required (MEIER; ROY; SELIGER, 2010, p. 623; MONT, 2002, p. 240). However, it should be considered that jobs that perform repetitive processes may be automated in long term (MONT, 2002, p. 240).

Finally, the benefits for consumers due to PSS offerings are directly related to a wider range of options in market and to benefits that the associated services bring, such as ease of maintenance and repair, payment and suitability (MONT, 2002, p. 240). Additionally, PSS offers increase perceived value to the customer in stable or changing needs, since the services associated to a product are flexible to be changed (MONT, 2002, p. 240). Furthermore, the customer responsibility over the product is shared with the provider, who keeps the product ownership and guarantees the product’s good functioning (MEIER; ROY; SELIGER, 2010, p. 623; MONT, 2002, p. 240).

Whenever something changes a paradigm, barriers come aside. PSS is not yet a well-established concept and its value is abstract until PSS is effectively concretized,

since it stays between the production and consumption baselines and involves many stakeholders. Those factors complicate the development of a new product or a new business model (MONT, 2002, p. 243). PSS may also require infrastructure completely different from what is already settled in a company, making the implementation costly and risky (MONT, 2002, p. 243).

Even one of the main goals of PSS, reducing the environment impact, may be compromised if the development is not adequately performed. If PSS is not built with the right mindset, environmental impact may not just linger, but also grow due to careless consumption (MONT, 2002, p. 243; TUKKER, 2004, p. 255-256). The company may be impacted also in the cultural aspect. PSS requests many cultural changes. In PSS, profit should be seen as a long-term income, differently from punctual sales (MONT, 2002, p. 243). The cooperation with stakeholders must be closer and more intense, and a shift in culture and marketing concepts must be overcome (MONT, 2002, p. 243).

Customers also may need time to get used to the PSS approach, although Neely (2008, p. 104) makes reference to the intense growth on new demands not on physical product, but on the value generated by it, such as the new services provided by Rolls Royce[5]. However, ownerless consumption is a strong barrier, since people may still be more pleased by owning something than having access to its benefits (MONT, 2002, p. 244).

There are still procedural barriers. It may be hard to trace the benefits of PSS, since it is a completely different paradigm, and the time to market may be delayed to consider environmental impacts (MONT, 2002, p. 244). Finally, long-term PSS's may be faced as a hard challenge, involving a long-term relationship with specific customers and high risks (NEELY, 2008, p. 114).

[5] Rolls Royce has shifted its core from selling aeronautic turbines and engines to selling flight hours, assuming the responsibility about risks and maintenance (NEELY, 2008, p. 104).

2.2 Product-Service System Development Process

2.2.1 Overview

The PSS development process is derived from the already well-established product development process (PDP) field and the service development process (SDP) field (ERICSON; LARSSON, 2009, p. 231-232). However, the final results of PSS development process is more complex than a single product or service, composing a complex system (see Section 2.1). Thus, it is necessary to change the development strategy in order to develop PSS offerings. When a PSS is to be developed, the company must integrate business models, products and services, which must generate value in the economic, environmental and social aspects to stakeholders (VIJAYKUMAR et al., 2015, p. 434).

It becomes clear that the PSS development is a deeply human-centric process. Indeed, according to Ericson and Larsson (2009, p. 232), innovation on PSS development must arise based on an intense investigation of the customers' needs and desires, avoiding the typical technology push development approach. Yet, according to the authors, involving the customers in the early phases of the development and establishing creative project activities that promote communication and collaboration are good practices to be applied in the PSS development process (ERICSON; LARSSON, 2009, p. 233).

Vasantha et al. (2012, p. 26) conclude by means of a literature review that the PSS development field is yet to be developed, finding itself in an initial stage. Barczak (2012, p. 355) also proposes that further research needs to be done yet in order to answer what practices effectively support identifying, creating and developing PSS innovation.

The PSS development process is commonly represented by process models, which contain more detail and information about how to develop a PSS. The PSS development process models are further discussed on subsection 2.2.2.

2.2.2 Product-Service System Development Process Models

There are many PSS development process models in literature. However, they usually don't reach the detail level of most product development process (PDP) models. This difference is mainly because usually the PSS development process models are presented through articles, what limit the available space and, consequently, the amount of information; while the PDP models are commonly presented in books, what allows the author to include every important piece of information, sometimes including even unimportant details.

An analysis of the typical PSS development models in literature was made by Clayton, Backhouse and Dani (2012, p. 277), who conclude that the PSS design process models are usually divided in seven phases: Project initiation, analysis, idea generation and selection, detailed design, prototype the service, implementation, evaluation. However, parts of the work that must be performed in the design process seem to be missing or not sufficiently discretized. Since PSS development process models are commonly based on the PDP models, as already stated in section 2.2 (ERICSON; LARSSON, 2009, p. 231-232), it is possible to see a correlation among the PSS development process models phases and the PDP models phases. Costa et al. (2015, p. 4) identify the generic phases that are commonly present in PDP models. They are the following: product planning; requirement definition; conceptual design; embodiment design; detailed design; production preparation; commercialization; use; and end-of-life (COSTA et al., 2015, p. 4). Both generic sets of phases seem to propose the same development scope, i.e., there is an equivalence of the phases' scope as shown in Table 2.

Table 2 - Phases scope equivalence

Phases	Clayton, Backhouse and Dani (2012, p. 277)	Costa et al. (2015, p. 4)
Front-End of Innovation [process]	Project initiation	Product Planning
	Analysis	
	-	Requirement definition
	Idea generation and selection	Conceptual design
Embodiment Design	Detailed design + Prototype the service	Embodiment design
Detailed Design		Detailed design
Implementation	Implementation	Production preparation

Use	Evaluation	Use
End-of-life	-	End-of-life

Source: Elaborated by the author

The generic phases proposed by Costa et al. (2015, p. 4) were used as a reference to this work. They were adapted according to Table 2. The upstream phases were combined into a process called by many authors as Front-end of innovation (FEI) (KHURANA; ROSENTHAL, 1998, p. 59; KOEN et al., 2001, p. 46). More about this process is explained in section 2.3. The production preparation phase was also modified to implementation, since it deals with product production and service implementation.

Aiming to provide an overview of the PSS development process models, fourteen PSS process models were selected (ALONSO-RASGADO; THOMPSON, 2006; AURICH; FUCHS; WAGENKNECHT, 2006; BREZET et al., 2001; KAR, 2010; KIM et al., 2015; LUITEN; KNOT; VAN DER HORST, 2001; MARQUES et al., 2013; MORELLI, 2003; MOSER et al., 2015; NGUYEN et al., 2014; SAKAO; SHIMOMURA, 2007; SUTANTO et al., 2015; TRAN; PARK, 2014; VAN HALEN; MANZINI; WIMMER, 2005). They were extracted from a systematic bibliographic review on PSS process models performed by one of the researchers of the Integrated Engineering Group[6], Caio Nunes[7].

First of all, those models have different characteristics, such as how they call PSS, how they describe their models in level of detail based on what is the information provided, and if it provided methods and tools for supporting the process. In order to provide an overview of this information about the PSS development process models, Table 3 is presented.

Some models present interesting particularities. Luiten, Knot and Van der Horst (2001, p. 192) bring a different approach. Besides dividing the process in phases, they also divide them in tracks, i.e., in parallel, during all stages of the process, there are

[6] The author of this dissertation is a researcher of the Integrated Engineering Group. To know more about this research group, please access: http://www2.eesc.usp.br/grupoei

[7] The identification of DT recurrent activities executed in this work was performed in parallel and in collaboration with the research under progress of the PhD candidate Caio Nunes, where the PSS development activities were extracted from process models of literature.

five areas to be considered: The development of the PSS per se, sustainability, partners and organization, the user, and economical feasibility.

Aurich, Fuchs and Wagenknecht (2006, p. 1481) deal with technical PSS (t-PSS), where product and service represent high investments, emphasizing the physical core of the system with a product of high monetary value, also with a B2B relationship. Thus, differently from other models, it deals with the development of products and services aligned, but not completely integrated. For integrating them, Aurich, Fuchs and Wagenknecht (2006, p. 1487) propose a whole approach involving design information, process modularization, modular design, process libraries, and process compilation.

Table 3 - Characteristics of PSS development process models in literature

PSS development process models	How do they name or specify the PSS?	Information Provided										
		Phases	Description of Phases	Gates	Activities	Description of activities	Activities objectives	Activities inputs	Activities outputs	Actors involved	Methods and Tools	Application case
Alonso-Rasgado and Thompson (2006)	Total Care Products; Functional Products	x	x								x	
Nguyen et al. (2014)	Industrial Product Service Systems (IPS2)	x	x		x							x
Brezet et al. (2001)	Eco-Efficient Services (ES)	x	x		x				x		x	x
Aurich et al. (2006)	Technical Product-Service System (tPSS)	x	x									x
Luiten et al. (2001)	Sustainable Product-Service-Systems (SPSS)	x	x									x
Morelli (2003)	Product-Service System (PSS)	x	x									x
Kar (2010)	Service System	x			x	x			x		x	
Sakao and Shimomura (2007)	Service (here, product is also considered as a service)	x			x	x		x	x		x	x
Van Halen et al. (2005)	Product-Service System (PSS)	x	x	x	x	x	x	x	x	x	x	
Marques et al. (2013)	Product-Service System (PSS)	x	x		x							x
Moser et al. (2015)	Product-Service System (PSS)	x	x						x			x

Tran and Park (2014)	Product-Service System (PSS)	x		x	x					x		
Kim et al. (2015)	Service-oriented Product-Service System (PSS)	x	x		x					x	x	x
Sutanto et al. (2015)	Product-Service System (PSS)	x	x		x							x

Source: Elaborated by the author

Sakao and Shimomura (2007, p. 592) use a different definition for service. They consider service as “an activity that a provider causes, usually with consideration, a receiver to change from an existing state to a new state that the receiver desires, where both a content and a channel are means to realize the service”. The authors consider the sales of physical products also as a service, since the product may be the content or the channel of the desired service. This fact gives evidence that their development model would also be applicable to product development.

Finally, one particularity of the model proposed by Tran and Park (2014, p. 41) is the explicit statement of on which activities stakeholders should be involved, such as idea generation and evaluation, test and feedback, among others. Stakeholders’ involvement is not so explicit in other models. Also, it considers the whole life-cycle, and not just the beginning of life.

Those models, in general, derive from existing product and service development process models. Thus, since they have similar origins, the phases with which they are commonly divided have similar scopes. This equivalence of phases is also illustrated in Table 4. Those models provide an overview of the PSS development process models composition and they shall be used for the future steps of this work for the comparison of the recurrent elements and for the prescriptive proposition of DT integration with PSS development processes.

Due to the scope of this work, not all PSS development phases are going to be approached in detail in this work. As already established before, the primary objective of this work is to identify how the DT approach can be applied in the PSS development process. Thus, it is important to better understand the development process phases with greatest opportunities for innovation, i.e., the front-end of innovation and the embodiment design. They are explained in the following sections.

Table 4 - Phases from PSS development process models and their equivalence with generic phases

PSS Development Process Models	Front end of innovation				Embodiment Design		Detailed Design					Implementation		Use	End of Life
Alonso-Rasgado and Thompson (2006)	Stage 1: Business Ambition of the Client	Stage 2: Potential Business Solutions	Stage 3: core definition of Total Care Product plus Total Care Product options		Stage 4: Enhanced definition of the potential Total Care Product			Stage 5(i): Business case risk analysis of options		Stage 5(ii): Business case validation and evaluation of alternatives		Contract			
Nguyen et al. (2014)	IPS² planning		IPS² concept modeling				IPS² detailed design			IPS² prototyping		IPS² implementation			
Brezet et al. (2001)	Exploration	Policy formulation	Idea finding				Strict development (design)					Realisation		Evaluation	
Aurich et al. (2006)	Idea finding (product)	Demands identification (service)	Feasibility analysis (service)		Concept development (product)	Concept Development (service)	Product construction (product)	Product detailing (product)	Prototype development (product)	Service modelling (service)	Service testing (service)	Manufacturing preparation (product)	Realization Planning (service)		
Luiten et al. (2001)	Future Exploration		System design				Product/Service Specification		Drawing in detail and testing			Implementation			
Morelli (2003)	Value proposition		Market analysis		Product/ service definition	Use-case analysis	Tentative architecture		Test	Final definition					
Kar (2010)	Analysis				Preparation		Synthesis					Implementation	Test		
Sakao and Shimomura (2007)	Making a preliminary flow model		Describing the target receiver	Describing the value	Generating a realization structure		Modifying the flow model								
Van Halen et al. (2005)	Startegic analysis	Exploring opportunities	PSS Idea Development				PSS Development					Preparing for Implementation			
Marques et al. (2013)	Phase 0 Organisation preparedness	Phase 1 Planning	Phase 2 Design									Phase 3 Post-processing			
Moser et al. (2015)	Planning				Development				Preparation			Market Performance			Replacement
Tran and Park (2014)	PSS Idea Development	PSS Planning	Requirement Analysis	Design and Integration...			...Design and Integration		Test and Refinement			Implementation			Retirement and Recycling
Kim et al. (2015)	Strategic Planning		Idea Generation and Selection				Service Design		Product Development						
Sutanto et al. (2015)	Identify design requirements	Determine design requirements rating	Integrating product and service												

Source: Elaborated by the author

2.3 Front-End of Innovation

This section discusses the Front-end of innovation and it is divided into three parts. The first one (2.3.1) provides an introduction to the front-end of innovation, highlighting its main characteristics. The second one (2.3.2) describes a generic model for the front-end of innovation, as well as a more detailed description of the usual parts that compose it and of the models on which it was based. Finally, the third one (2.3.3) explores the customer involvement in the front-end of innovation and its consequences.

2.3.1 Introduction to the Front-End of Innovation

The Front-end of innovation (FEI), also know and Fuzzy front-end (FFE) or front-end in literature, is the set of the initial phases that precede the technical development, i.e., all phases that precede specification and design (KHURANA; ROSENTHAL, 1997, p. 105), covering up to the point where concept is defined and architecture will start to be developed.

There is a great discussion about this terminology in literature. Koen et al. (2001, p. 46), for example, criticizes the use of the term “Fuzzy front-end”, which is commonly used due to the experimental nature of this stage, possibly becoming even chaotic. The criticism done by Koen et al. (2001, p. 46) is justified by the statement that the term “Fuzzy” may lead people to understand that the FEI is unmanageable and unpredictable. Thus, henceforth this work will use the terminology “Front-end of innovation” (FEI).

The FEI terminology is commonly used in the new product development (NPD) research line, which is composed mainly by business related researchers. The typical product development process (PDP) researchers compose their process with the upstream phases, but seldom refer to them as front-end. There is a difference in those research lines also in the way they propose a development project to begin. NPD authors believe that the project effectively begins only after the front-end phases (KHURANA; ROSENTHAL, 1998, p. 59; KOEN et al., 2001, p. 51). PDP authors, instead, propose that the project may begin before concept definition, defining the concept after its start (PAHL; BEITZ, 1988, p. 19; ULRICH; EPPINGER, 2012, p. 14).

In this work, although we call the upstream phases under the label of FEI, we believe that the project must begin according to the company strategy. Based on the generic phases proposed by Costa et al. (2015, p. 4) in section 2.2.2, the FEI would cover the phases of product planning, requirement definition and conceptual design.

The FEI is seen as an opportunity for the improvement of the innovation process[8] (KOEN et al., 2001, p. 46) and as a root for success whenever the product innovation follows a discontinuous strategy (REID; DE BRENTANI, 2004, p. 170).

In the FEI phases, many important and complex decisions about the product are taken, such as who is the target market, the cost, and functionalities of the product. According to Markham (2013, p. 89), FEI success is “the strongest independent predictor for all of the new product development performance variables”, being strongly related to the development success. being responsible for a great impact in the development success. Thus, it is risky not to perform the FEI accordingly. Even with this risk, methods are frequently replaced by a guess on the FEI (JETTER, 2003, p. 261).

Many aspects and challenges characterize the front-end of innovation (FEI). Some of the challenges that must be overcome in the FEI are uncertainty about the market, technology, environment and resource allocation; and the interdependencies among the front-end activities (JETTER, 2003, p. 262-264).

The FEI has very unique characteristics that differ this specific set of phases from the development process as a whole. These characteristics are highlighted in Table 5.

Due to its specific characteristics, the FEI is a complex and uncertain process. Also, the FEI management is an arduous challenge, since it is unstructured, dynamic and hard to formalize (KIM; WILEMON, 2002, p. 269). In fact, literature offers FEI frameworks usually based in high-level activities and many works have been trying to structure the FEI.

[8] The innovation process is understood in this work as a sequence of “all scientific, technological, organizational, financial and commercial steps which actually, or are intended to, lead to the implementation of innovations” (OECD, 2005, p. 47).

Table 5 - Differences between FEI and other phases of product development process

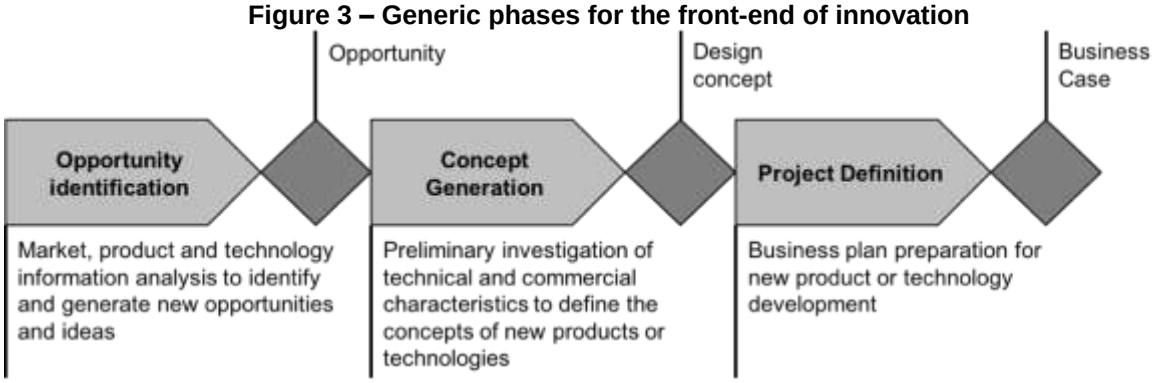
	Front-end of Innovation (FEI)	Development process
Nature of Work	Experimental, often chaotic. Difficult to plan Eureka moments.	Structured, disciplined and goal-oriented with a project plan.
Commercialization date	Unpredictable.	Definable.
Funding	Variable. In the beginning phases, many projects may be "bootlegged", while other will need funding to proceed.	Budgeted.
Revenue expectations	Often uncertain. Sometimes done with great deal of speculation.	Believable and with increasing certainty, analysis and documentation as the product release date gets closer.
Activity	Both individual and team in areas to minimize risk and optimize potential.	Multi-functional product and/or process development team.

Source: Koen et al. (2001, p. 47)

2.3.2 Generic Model for the Front-End of Innovation

In order to provide an overview of a generic framework of the FEI, this subsection will use the work of Oliveira et al. (2011). Oliveira et al. (2011, p. 316) identifies FEI models in literature by means of a systematic review and selects the 7 of them due to their characteristics. They are the engineering design pre-development model (PAHL; BEITZ, 1988), the development process framework front-end (WHEELWRIGHT; CLARK, 1992), the front-end model (KHURANA; ROSENTHAL, 1998), the new concept development model (KOEN et al., 2001a), the Stage-Gate® pre-development (COOPER, 2001), the new products management pre-development (CRAWFORD; DI BENEDETTO, 2011), and the integrative front-end process model (SANDMEIER et al., 2004). Based on those selected models, he reaches three generic phases for the FEI. Those phases, as well as their main deliverables and a small description, are illustrated in Figure 3.

Figure 3 – Generic phases for the front-end of innovation



Source: adapted from Cunha (2011, p. 38) and Oliveira et al. (2011, p. 318)

Although the process refers directly to product and technology, the description of each one of the phases in this process is generic enough to cover PSS development. In fact, Oliveira et al. (2011, p. 318) state in their work that the generic FEI synthesis proposed by them may generate new businesses, new products, new services, and new technologies. If products and services can be generated, the composition of them should also be possible. This variety of possible outcomes was also cited by Koen et al. (2001, p. 50), who propose in their model that the opportunity identification may lead to product improvement or a complete business approach, such as “a new product platform, a new manufacturing process, a new service offering, or a new marketing or sales approach”. Thus, the generic phases represented synthesized in Figure 3 are shown to represent the front-end of innovation for any of the following outcomes: Business, product, service, technology and, most importantly in this work, PSS.

Figure 3 is self-explanatory, giving a short overview of what each phase comprises. However, there is much more to understand about each phase and about the FEI as a whole. Oliveira et al. (2011, p. 316) characterize the FEI as providing three outcomes: opportunity, product concept and business case. Oliveira et al. (2011, p. 316) describe those outcomes as the following:

- Opportunity: “marketing or technology gap capable of providing competitiveness and improving business performance” (OLIVEIRA et al., 2011, p. 316);
- Product concept: the “written or visual description” of the concept, composed by “its primary technical features, customer benefits and required technology” (OLIVEIRA et al., 2011, p. 316);

- Business case: it covers the financial analyses that are used in to support decision-making (OLIVEIRA et al., 2011, p. 316).

As illustrated in Figure 3, the first phase covers identifying opportunities and generating ideas. According to Murphy and Kumar (1997, p. 8-10), idea generation may be done by three main means: direct contact with customers and users, marketplace analysis, and internal ideas provided by employees. More about making direct contact with customers and users in analyzed in more detail in the next subsection (2.3.3).

The second phase covers defining the concept. As explained before, although Oliveira et al. (2011, p. 316) refer to a tangible product concept, the outcome proposed by FEI models may not be a product. Authors from the FEI models used, such as Koen et al. (2001, p. 50), propose that the model may lead from product improvement to complete business approach, such as “a new product platform, a new manufacturing process, a new service offering, or a new marketing or sales approach”. Those models may be compatible, thus, with PSS and service development too. It is important to establish what are the differences among the concept of a product, a service and a PSS, since they are composed by different components. The definition of each concept is given in Table 6.

The specific concepts of each development object have their own peculiarities. Thus, the concept definition used in this work will be the generic one provided by Andreasen, Hansen and Cash (2015, p. 26), who define concept as “a design proposal that is detailed enough to justify if it is a good answer to the task or intention, and show a high probability of realization and success”.

In the second phase of the FEI process, the ideas and opportunities that were identified in the first phase are analyzed and selected, and the concepts are created. Then, the best concepts are selected by means of a preliminary commercial and technical evaluation (CUNHA, 2011, p. 38).

Table 6 - Definition of product, service and PSS concept

Concept	Source	Definition

Product	Andreasen, Hansen and Cash (2015, p. 31)	“A concept is a proposal for a product’s composition and issues that is detailed enough to justify it as a good answer to the task and intention. Further, the task and intention are justified with respect to the conceptual need satisfaction and the knowledge required, i.e. the probability of successful realization, need satisfaction, and success in the widest sense.”
Service	Clark, Johnston and Shulver (2000, p. 73).	The concept of a service is composed by four smaller subcomponents: value, form and function, experience, and outcomes (or provided benefits).
PSS	Komoto and Tomiyama (2009)	The concept of a PSS must include information about the products and services that compose it, i.e., the concept of each product and service that compose the offer, as well as support and interface information, in a detail level that is enough to justify a decision whether it is a good solution to the goals of the development process.

Source: Elaborated by the author

The concept definition phase impacts on the greatest part of a product, service, or PSS costs, mainly if the development object brings innovation or novelty (WANG et al., 2002, p. 981). Due to its importance and high complexity, many methods in literature support the concept definition. For software development, the most common methods and tools used in concept definition are problem solving strategies, genetic algorithms, case-based reasoning, agent technology, functional analysis systematic technique (FAST), functional flow-charts, and functional logic diagrams (WANG et al., 2002, p. 983). Rozenfeld et al. (2006, p. 247-251) also recommend the use of the methods of functional modeling, brainstorming, the 635 method, lateral thinking, synetics, gallery, morphological matrix, systematical analogy, value analysis, checklists and surveys, and the theory of inventive problem solving (TRIZ). Finally, Morelli (2003, p. 86) suggests the use of blueprints to describe the services and the PSS, storyboards, and other graphical representation methods in literature. We believe that the concept definition should be performed for the whole PSS offer. Thus, all proper tools and methods to develop the concept of a product or a service may be useful in the concept definition for a PSS.

Finally, the third phase is where the business case is developed. Although the best concepts were already selected in the second stage, the third stage is responsible by defining which concepts will become a development project based on the analysis

of risks, resources, finance, among others, that shall provide information for the business plan (CUNHA, 2011, p. 39).

It is important to point out that the front-end of innovation seems to strongly require creativity, mainly in the first phase, where ideas are effectively created, and in the second phase, where the concepts are composed. The FEI synthesis that was used as a basis for this work (OLIVEIRA et al., 2011, p. 322) also describes user involvement as a longitudinal practice that may be considered in FEI. It shows an opportunity for using user-centered approaches, such as DT.

The models used in the generic synthesis proposed by Oliveira et al. (2011, p. 316) are used in this work for comparison purposes in chapter **Erro! Fonte de referência não encontrada.**. For a better understanding on how those models are structured, see Table 7.

Table 7 - Phases for front-end of innovation models used in this work

Model	Opportunity	Product Concept	Business Case
Wheelwright and Clark (1992)	Technology assessment and forecasting + market assessment and forecasting	Development goals and objectives	Aggregated project plan
Khurana and Rosenthal (1997)	Preliminary opportunity identification	Product concept and definition	Product definition and project planning
Cooper (2001)	Discovery + Idea screen	Scoping + Second screen	Build business case + go to development gate
Koen et al. (2001)	Opportunity identification + Opportunity analysis	Idea genesis + Idea selection	Concept and technology development
Sandmeier et al. (2004)	Market and technology opportunities	Product and business ideas	Draft concept of product and business plan
Crawford and Benedetto (2006)	Opportunity identification and selection	Concept generation	Concept/ project evaluation + full screen
Pahl and Beitz (2007)	Analyze the situation + Formulate search strategies	Find product ideas	Select product ideas + define products

Source: Oliveira et al. (2011, p. 316)

2.3.3 User Involvement in the Front-End of Innovation

There are many methods in literature that have been used to integrate users in the FEI process, such as market orientation, voice of the customer, virtual customer, customer-driven innovation and consumers as co-developers (SANDMEIER, 2009, p. 3).

Research made involving users and customers to generate innovation on the FEI show that, in general, their involvement is benefic (LÜTHJE; HERSTATT, 2004, p. 565-566; WADELL et al., 2013, p. 305). Lüthje and Herstatt (2004, p. 556) highlight the involvement of lead users, who, according to the authors, are capable to foresee new needs earlier than ordinary users and state that those specific users are more motivated to work on new solutions. Extreme users, i.e., users that use a specific offer more intensely or in an unusual way, were also studied, stressing out problems more effectively and in a wider range than normal users (LÜTHJE; HERSTATT, 2004, p. 556). Wadell et al. (2013, p. 295) empirically study ordinary users. They emphasize that the incorporated user acts as a change agent and encourage the change of mindset in the development team. They also refer to the user as a representative member, bringing the user needs and perspectives, as well as the user experience. According to Wadell et al. (2013, p. 296), the incorporated users also collaborate with ideas in an active way, being called by them as “innovation champions”. Finally, one main role of the users who are incorporated to the process is a communication channel. They are the network that connects company to other target users.

Many cases of user involvement in literature show successful results in diverse areas, such as sports (LÜTHJE; HERSTATT; VON HIPPEL, 2005, p.954-955), medicine (LÜTHJE et al., 2003, p. 565-566), hardware systems (HERSTATT; VON HIPPEL, 1992, p. 215-220), software systems (MORRISON; ROBERTS; VON HIPPEL, 2000, p. 1514), among others. However, it is important to highlight that there are also negative side effects. Gassmann, Kausch and Enkel (2010, p. 57-58) investigate the possible side effects presented in literature. Through practical investigation, they find out some of them to be true.

First of all, the participation of few customers with similar profiles or of customers with specific interests may bias the development, possibly leading to a solution that

misses other points of view and that may require rework (GASSMANN; KAUSCH; ENKEL, 2010, p. 53). Focusing on customers' individual wishes may also lead to a very limited market niche (GASSMANN; KAUSCH; ENKEL, 2010, p. 54). Another problem is related to the customers' behaviors and mindset. If the customer is involved in co-creation and does not behave properly, she/he might lead to a product increment rather than a radical new solution (GASSMANN; KAUSCH; ENKEL, 2010, p. 55). There is also the possibility of an exclusivity requirement from the customer. Exclusivity only makes sense when few customers are expected and the customer involved in the process has a great potential of buying. Otherwise, it may limit severely the sales range solution (GASSMANN; KAUSCH; ENKEL, 2010, p. 55). The personality of the involved customers may also bring negative side effects. It is not interesting to involve only conservative customers, nor only visionaries. Those extremes might lead to solutions that are distant to a radical innovation. It may be too conservative or too innovative, ignoring details that are important to the solution solution (GASSMANN; KAUSCH; ENKEL, 2010, p. 55). Finally, the confidentiality problems must also be considered. When a customer is involved, he will acquire important information about a company. It may be strategic depending on the project that she/he is involved. Information may leak if the proper measures are not taken (GASSMANN; KAUSCH; ENKEL, 2010, p. 56).

Magnusson (2003, p. 78), in a contrary position to a general excitement about involving users in the FEI, identifies that simply involving the user without providing adequate information about the technology being applied leads to a lack of feasible ideas, generating what the author calls "suggestions". However, those suggestions may inspire for more feasible ideas generated by the team.

Gassmann, Kausch and Enkel (2010, p. 59-60) explain that making the proper arrangements can prevent all the side effects. Thus, when the customer is involved in the front-end of innovation, it is probable that the results shall be better than if they are not, if every care is taken.

Finally, it is important that the involved customers have some qualities. Wadell et al. (2013, p. 305) propose that they must show "flexibility, self-awareness, and ability to appreciate others' perspectives in order to function well".

The guidelines of user-involvement in FEI literature could improve user-involvement in other phases of the development process as well. It seems to reduce the failure risk of innovation, and we believe that this involvement could be extended to other phases of the development process. However, the proper measures should be taken to avoid the common risks that user-involvement may bring.

2.4 Embodiment Design

Pahl and Beitz (1988, p. 227) define the embodiment design phase as “a part of the design process in which, starting from the principle solution or concept of a technical product, the design is developed in accordance with technical and economical criteria and in the light of further information, to the point where subsequent detail design can lead directly to production”.

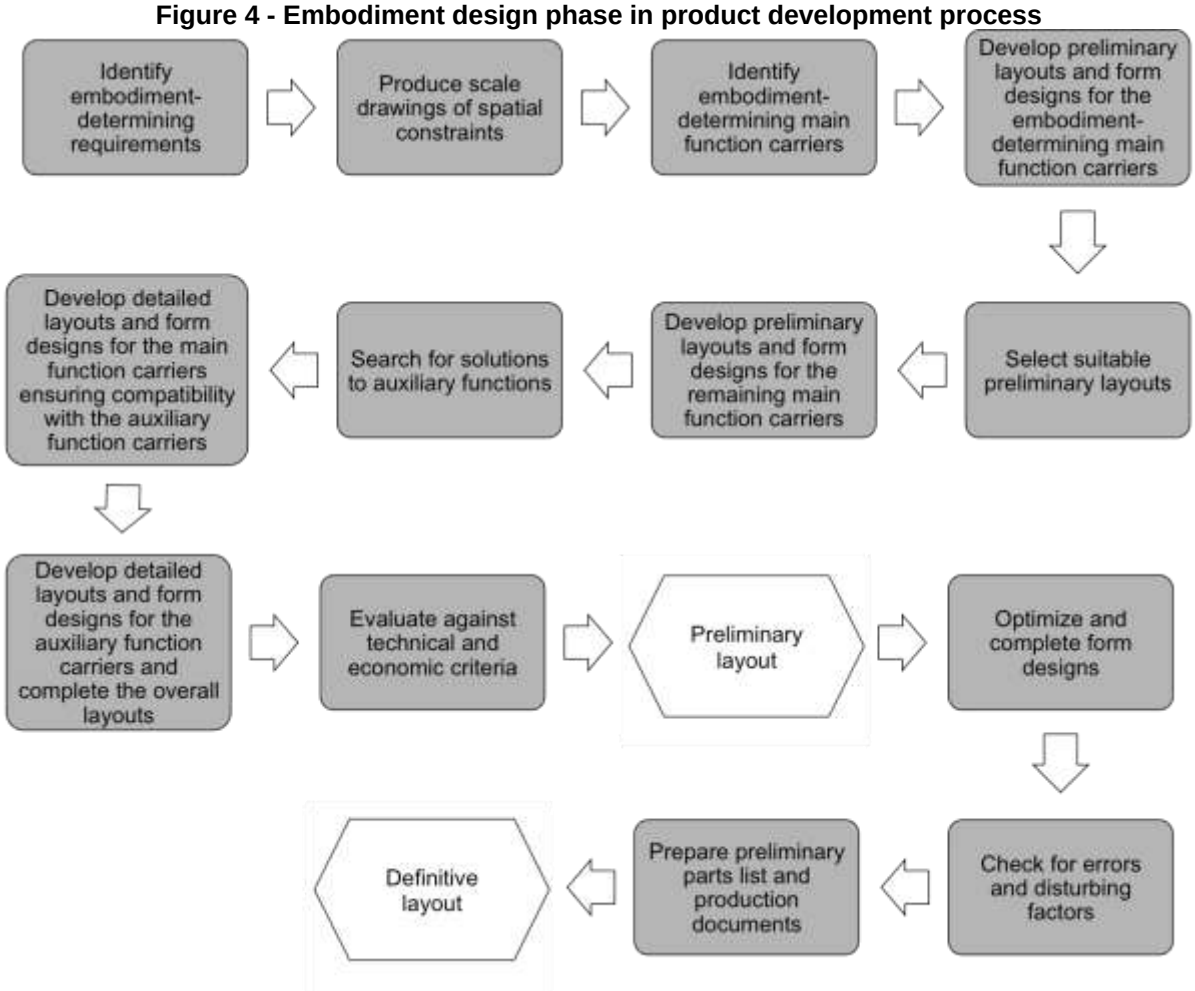
Basically, the embodiment design is a concretization of the initial concept, reaching a final architecture (ULRICH; EPPINGER, 2012, p. 9). Ulrich and Eppinger (2012, p. 185) define the product architecture as the scheme that establishes what are the components that compose the products, what are the physical arrangements and how each arrangement interacts with the others. In the service area, this definition is still true. However, services are intangible. Thus, the architecture is the scheme representing the subfunctions of a service and their interactions. Finally, for a PSS, the architecture may be established as the composition of the products and services architectures and the relationship among the specific architectures (VOSS; HSUAN, 2009, p. 543).

In some development process models, the embodiment design is not separated as a single phase, being embodied by other phases. For example, in the product development model proposed by Rozenfeld et al. (2006, p. 44), the authors name the second phase as “conceptual design”. However, its scope covers from concept definition until architecture definition, i.e., the conceptual design phase and the embodiment design phase.

The sequence of activities proposed by Pahl and Beitz (1988, p. 229) to perform the embodiment design is illustrated in Figure 4. It is important to notice that the activities prescribed in the process model of Pahl and Beitz (1988, p. 229) are

specifically applied for the product development process. The activities used in the service or PSS development process must be adapted to the reality of those instances.

Figure 4 - Embodiment design phase in product development process



Source: Adapted from Pahl and Beitz (1988, p. 229)

It is possible to notice that the embodiment design phase requires creativity and problem solution, since it is where main and auxiliary functions are established. It allows space for innovation, although in a lower level than the phases of the front-end of innovation (FEI).

2.5 Design Thinking

Design thinking as referred in this work is a user-centric methodology with the objective of achieving innovation. Meinel and Leifer (2011, p. xiv) define it as the following:

> *"[Design thinking] integrates expertise from design, social sciences, engineering, and business. It blends an end-user focus*

> *with multidisciplinary collaboration and iterative improvement to produce innovative products, systems, and services. Design thinking creates a vibrant interactive environment that promotes learning through rapid conceptual prototyping."* - (MEINEL; LEIFER, 2011, p. xiv)

The core concept of DT is its reasoning pattern, firstly referred to in literature by Simon (1969) in his well-known book "The Science of the Artificial", long before the term "design thinking" even was born. Simon (1969, p. 111) approaches the design process reasoning pattern, which, he says, is the core reasoning for professions in fields that deal with problem solving, such as engineering, architecture, business, and medicine, not being limited to designers. This reasoning pattern that aims to reach "how things ought to be" is what differs those problem-dealing professions from natural sciences, which lead towards "what things are" (SIMON, 1969, p. 114). The theme continued to be discussed by many authors, such as Cross (1982) and Schön (1983). A few years later, Rowe (1987) names this reasoning pattern under the label "design thinking" in his book entitled after it.

The evolution of DT research led it to three different research lines (KIMBELL, 2011a, p. 297), which are explained below: The first research line kept the concept of DT as a cognitive process, performed by individual designers and focused on problems resolution. The second research line is the "design thinking as a general theory of design", bringing a macro perspective of design as a field that deals with "wicked problems". Finally, the third research line is the "design thinking as an organizational resource", which is covered by the definition provided so far for DT as approached in this work. The key concepts of the three research lines referred until now and the nature of their design problems, as well as some key texts, are provided in Table 8, adapted from the work of Kimbell (2011a, p. 297).

Table 8 - Characteristics of the three DT research lines

	Design thinking as a cognitive process	Design thinking as a general theory of design	Design thinking as an organizational resource
Key texts	Simon (1969); Cross (1982); Schön (1983); Rowe (1987); Lawson (2005); Cross (2006); Dorst (2006)	Buchanan (1992)	Dunne and Martin (2006); Bauer and Eagen (2008); Brown (2008); Brown (2009); Martin (2009)
Key concepts	Design ability as a form of intelligence; reflection-in-action; abductive thinking	Design has no special subject matter of its own	Visualization, prototyping, empathy, integrative thinking, abductive thinking
Nature of design problems	Design problems are ill-structured, problem and solution co-evolve	Design problems are wicked problems	Organizational problems are design problems

Source: Adapted from Kimbell (2011a, p. 297).

The concept of DT as an organizational resource was popularized after Brown (2008), CEO of the American design company IDEO, first published an article about DT in the Harvard Business Review. Brown (2008, p. 2) refers to DT as an approach to balance users' needs with technical and business feasibility, generating customer value and market opportunity. His perspective at that time was strongly related to the product innovation, matching customers' needs and desires. However, DT now permeates all levels of organizational innovation: operational, product/service, strategic and management (LEAVY, 2010, p. 6). In fact, DT objectives evolved from products to user experience, then to corporate strategy, reaching even intangible complex systems and business models (BROWN; MARTIN, 2015, p. 2).

Some conflict has been generated among those research lines. Some authors criticize the emerging of the last two research lines and coin the term "designerly thinking" to differ the first line of research. Some authors, though, believe that there is not a differentiation in those research lines, but a strong connection. Johansson-Sköldberg, Woodilla and Çetinkaya (2013, p. 132) and Dorst (2011, p. 522), for example, believe that DT as an organizational resource is actually a translation of the cognitive style (which they call "designerly thinking") to a more popularized version. In fact, all those research lines are intertwined, even if researchers of the first one usually try to avoid the connection. DT as an organizational resource is a more comprehensive way of design reasoning, associating methods and tools to support the process for

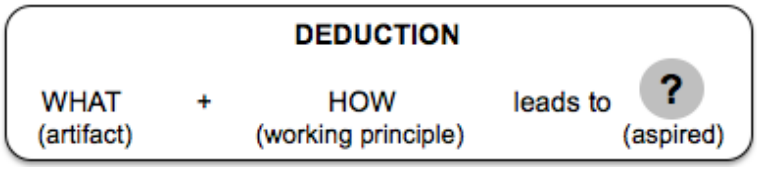
people who are not yet used to this procedure in order to solve design, wicked and organizational problems. In short, DT can be seen as a human-centered design approach connected to the design reasoning patterns.

2.5.1 Reasoning Patterns of Design Thinking

One important aspect of the DT approach are the reasoning patterns that permeates the design process (DORST, 2011, p. 522). Dorst (2011, p. 525) explains that human reasoning in problem solving uses four basic reasoning patterns, which are explained below:

- Deductive thinking: Deduction is the reasoning pattern equivalent to the AND function in Boolean logic (DORST, 2011, p. 523). It happens whenever an artifact is provided and a working principle is related to it, allowing a consequence of this combination to be deducted. This reasoning pattern is grounded in natural sciences, such as mechanical physics, in areas with already established laws and principles. For example, if there is an object in continuous movement and a force with given amplitude is applied to it; it is possible to deduct how the object displacement will be due to the force.

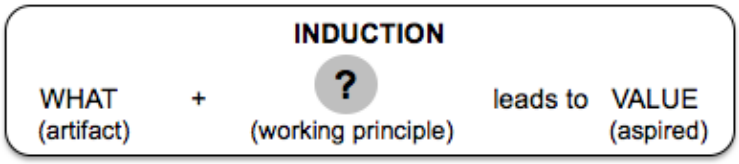
Figure 5 – Deductive thinking



Source: Adapted from Dorst (2011, p. 523)

- Inductive thinking: Induction is the “discovery” and “hypotheses”-reasoning pattern (DORST, 2011, p. 523). It is the logic that infers a working principle based on a given phenomenon that is observed and a given artifact. It is the logic pattern in Isaac Newton’s gravity discovery. There is an apple and it falls. Thus, there is a working principle, which is gravity.

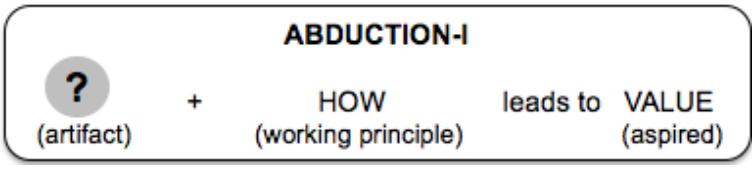
Figure 6 – Inductive thinking



Source: Adapted from Dorst (2011, p. 523)

- Abductive thinking – I: Abduction-I is the first logic pattern that guides the creation process. In this logic pattern, the person knows what value should be created and knows the working principles. Then, with those two elements, the person creates the artifact (DORST, 2011, p. 523). This is the typical reasoning pattern of engineers and designers.

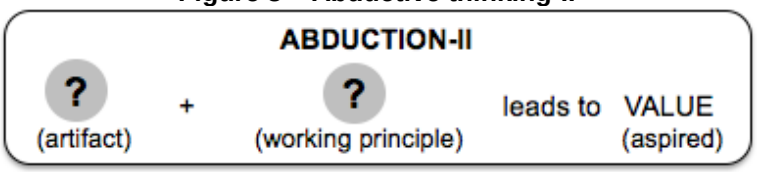
Figure 7 – Abductive thinking-I



Source: Adapted from Dorst (2011, p. 523)

- Abductive thinking – II: Abduction-II is very similar to abduction-I, however this time the person does know neither the artifact nor the working principle (DORST, 2011, p. 524).

Figure 8 – Abductive thinking-II



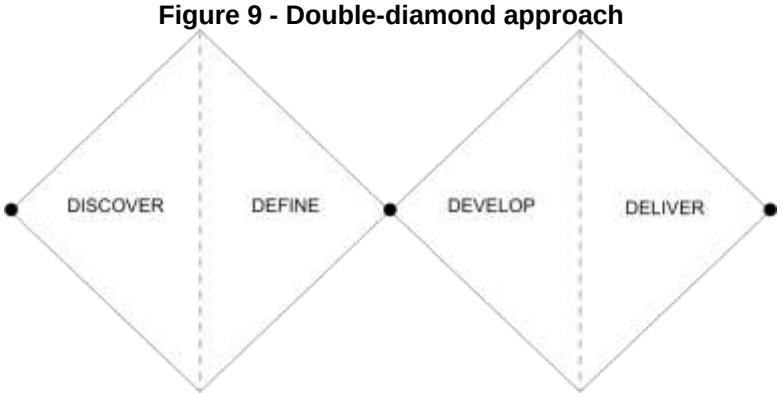
Source: Adapted from Dorst (2011, p. 524)

According to Dorst (2011, p. 525), all those reasoning patterns are involved in the DT process. In order to achieve a final value, they are combined in thinking processes.

2.5.2 Design Thinking Generic Characteristics

The DT process may be compared to the traditional double-diamond approach, described by the British Design Council (STICKDORN; SCHNEIDER, 2011, p. 118). The double-diamond is illustrated in Figure 9.

Figure 9 - Double-diamond approach

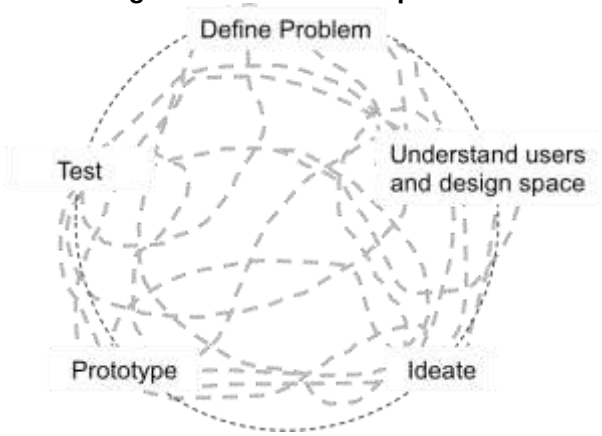


Source: Stickdorn and Schneider (2011, p. 119)

This approach deals with a process that goes through divergent and convergent moments. The discovery part is divergent and explores the design space, identifying opportunities. Then, there is a convergence, defining a problem to be solved and worked on. For this problem, many solutions are developed, leading the process to a new divergence. Finally, there is a convergence towards the best solution, delivering the final result. Although nor DT neither the double-diamond process is linear, they are illustrated this way to ease understanding. A schematic form of the DT process is provided by many methodologies provided in literature. Those methodologies will be discussed in more detail in subsection 2.6.

Meinel and Leifer (2011, p. xiv) propose that the process illustrated in Figure 10 is a good representation for a generic DT process. It is being shown for didactic purposes and will not be further used, since it does not represent all possible stages of a DT process. There are stages in certain methodologies that are not forecasted in this model. However, it allows a clear comprehension of the main stages.

Figure 10 - Generic DT process



Source: Adapted from Meinel and Leifer (2011, p. xiv)

The methodologies usually lead the process through five stages: Define problem, Understand users and design space, Ideate, Prototype, and Test (MEINEL; LEIFER, 2011, p. xiv). Figure 10 shows that those stages are cyclical. It happens because design should not end after the test. The artifact can always be improved and other problems will be waiting to be solved. Also, the stages are not necessarily sequential. While DT is being performed, people involved in the process may go back to the problem definition stage if the problem was weakly defined or more information about users may be required. Thus, the process may seem fuzzy or chaotic and leads to each stage whenever it is necessary. A short explanation of the purposes of each stage is written below:

- Define Problem: This stage covers the challenge definition: What is the macro-problem that must be solved? This is the starting point where a team will be composed in order to find the solution.

- Understand users and design space: In his stage, empathy is generated with users by observing them, engaging with them and immersing in their lives (PLATTNER, 2010, p. 1). After users are understood, it is easier to define what specific needs relate to the challenge, identifying a more specific challenge to solve.

- Ideate: In this stage, the team members generate ideas to solve the more specific challenge and the most promising ideas are selected.

- Prototype: DT proposes that everything must be communicated in a tangible way. Thus, the selected ideas are built in low-resolution[9] prototypes with the goal of testing specific variables. Prototypes in DT are not the typical engineering prototypes. They may be done with raw materials, such as paper and paint; with storyboards; sketches; or in any other way that may represent the ideas hypotheses that need to be tested.

- Test: In this stage, the users test the prototypes in order to validate, refuse or improve the specific variables being tested.

[9] The design thinking approach suggests that the best way to develop a new concept is by materializing it. Thus, methods are proposed to obtain low-resolution prototypes, also known as rapid prototypes. Those prototypes do not depict the whole concept in a realistic way. They aim to materialize few aspects to test specific variables in order to identify if the concept meets specific requirements of the users.

It is important to highlight that this process results in a concept, and not in a detailed specification of the product nor in a set of information and resources that allow the value chain of the company to produce the final result, such as the product development process.

Some guidelines are essential to the DT process and, thus, must be followed in order to achieve proper results. Meinel and Leifer (2011, p. xv) point out the following four rules as the most important guidelines to perform DT. More specific guidelines are provided in the description of the most important methodologies in subsection 2.6.

1. Human-centric approach[10]: Everything in every stage during the DT process must be focused on the human being.

2. Ambiguity must be preserved: This guideline recommends not selecting one concept to work on, but to make a comprehensive range of choices to be excluded by the users through the process.

3. Re-design: Even after finding the ideal concept to a problem solution, it is not perfect yet. Other problems may need solution too and future needs should be foreseen. Thus, the process should never end.

4. Visual thinking and communication: Authors usually highlight the importance of prototyping in order to think. When ideas, concepts, ideals and thoughts are made tangible, the team communication is enhanced. It is easier to understand what another person wants to communicate by visual means.

2.5.3 Design Thinking Application

Literature brings a comprehensive amount of case studies and applications relative to DT in various fields, besides being “a way to improve the process of designing tangible products”, which was first proposed for DT (BROWN; MARTIN, 2015, p. 14).

[10] DT has some limitations on scope applications. Since it is a human-centric approach, it is able to support development of solutions that provide an experience to the final user or stakeholders. For example, the need for new materials may be derived from a solution created by DT, however this approach will not lead to the creation of a new material as the focus. DT is an approach focused on solving people’s problems and improving their experience.

One vast application is in social design, mainly due to IDEO efforts into making what they call “social innovation” with IDEO.org, a non-profit organization that uses design to improve life of people in “poor and vulnerable communities” (IDEO, 2011), and their publication of the “Human-Centered Design Toolkit” in 2009, which evolved to “The Field Guide to Human-Centered Design” (IDEO, 2015). Work associating social and environmental sustainability has been done by Erzurumlu and Erzurumlu (2015, p. 6), applying DT to support sustainable mining development in Central America.

One important publication that brought DT to the business perspective is the work of Dunne and Martin (2006), further detailed and discussed in Martin’s book “The Design of Business” (MARTIN, 2009). Many authors discuss the applicability of DT in this field. Liedtka (2010, p. 9-11) shows how DT was applicable to business strategy problems due to their compatible characteristics. It is important to point out the PSS development may also be seen as a business strategy problem, showing compatibility of DT and PSS development process. Liedtka (2014b, p. 42-43) also provides examples of companies that have been melding DT to their traditional approaches to strategy. Yet, according to Liedtka (2014b, p. 42-43), DT has been used by many enterprises to improve customer-contact centers, align corporate strategy, improve internal processes, create collaborative experiences, improve social networks use, and enhance corporate creativity.

Clune and Lockrey (2014, p. 67) apply DT to support the development of “context-specific environmental sustainability strategies” associated to Life Cycle Assessment. Young (2010, p. 24) also emphasizes the capacity of DT to assist sustainability, complementing the possibility of use of DT to create or adjust new business models, including PSS.

DT also impacted the education field. Noweski et al. (2012) believe that “DT as a constructivist methodology offers teachers the needed support towards a new way of teaching” so students could learn the so-called “Twenty-First Century Skills” (critical thinking, problem solving, collaboration, agility, adaptability, initiative, entrepreneurialism, effective oral and written communication, accessing and analyzing information, curiosity, and imagination).

Kirkland, Parham and Pastores (2009, p. 291-292) use the DT approach for hospital administration purposes in order to joint support from staff and administration, more specifically for buying and managing cooling technology. Norman et al. (2010, p. 1016) deal with a wider problem, applying DT as part of the strategy to handle with complex problems in health care and public health system, developing what they call the “Complex Network Electronic Knowledge Translation Research model” (CoNEKTR). More specifically working with medical devices, Shluzas, Steinert and Riita (2014, p. 135) study the application of DT in the development of intramuscular drug delivery devices, which also are complex mechanical systems.

Lindberg et al. (2012, p. 238) identify that DT is seen in five different ways in the IT field: as a foregoing project, as a service, as a reminding to developers to change their way of working, as a process phase, and as an adaptive tool. However, DT has been strongly applied, even if in different perspectives. The SAP, an enterprise that develops software for data processing in various business fields, was co-founded by Hasso Plattner, a great enthusiast of DT and who openly states and encourages the use of DT in the SAP’s development, having published papers collections and toolkits about DT (PLATTNER, 2010; PLATTNER; MEINEL; LEIFER, 2012, 2014, 2015; PLATTNER; MIENEL; LEIFER, 2012). The DT application is not limited to business software, being also applied for games development (HAYES; GAMES, 2008, p. 2) and in software logic, besides other applications (STEINERT; HIRSCHFELD, 2012).

DT is not necessarily constrained to the fields described in this section, since only the recurrent themes were approached. The application of DT is not limited to one development case either. For example, Brown and Martin (2015, p. 7) describe a case of DT application in the whole corporate strategy of a Peruvian bank, calling the strategy as “Intervention design”. DT was used iteratively and continuously for all smaller and bigger challenges, reaching solutions to keep corporate strategy aligned to the market reality and leading to social transformations in Peru. Thus, the application of DT is very wide and adaptable, leading to a great innovation potential when the stakeholders’ experience is being taken in consideration.

2.5.4 Criticism Around Design Thinking

Although DT has showed itself as a promising approach to generate innovation, criticism has emerged with its popularization. One strong criticism to DT was its weak relationship with new technology in order to provide innovation. Traditional DT authors explicitly say that innovation is not generated with technology, but with value, and criticize the techno-centric perspective of innovation (BROWN, 2009, p. 22). Thus, some authors may become afraid that new technology may be neglected towards user-needs focus. Woudhuysen (2011, p. 5) claims that DT is a force broadly hostile to technological innovation. Even some enthusiasts of DT have been changing their minds, suggesting that technology should come first, and invention last[11] (MCCULLAGH, 2010, p. 39). Perhaps both views were drastic, since, as highlighted in section 1.1, an invention can only become innovation if it provides value. Woudhuysen (2011, p. 10) also points out that DT is a complement and not a substitute for the development process, criticizing enterprises that cut their budget on R&D in order to implement DT.

Other authors, who are more related to user-centered design and participatory design, criticize the constant affirmation that DT is a new revolution, claiming that DT is nothing new. Bjögvinsson, Ehn and Hillgren (2012, p. 101) say that DT is nothing but “good old participatory design”: an approach that abandons the mere development of “things” in order to develop socio-material assemblies, but better articulated. The similarities, Bjögvinsson, Ehn and Hillgren (2012, p. 106) say, are strongly highlighted by the focus on prototyping and role-playing as creative tools.

There is also a strong criticism on the prescription level of DT. Helen Walters (2010) apud Mcculagh (2010, p. 37) says the following about the DT process:

> *“Those looking for a prescribed way to implement design thinking are destined to be disappointed. It’s a messy, opaque process that depends as much on group dynamics as intellect or insight.”* (HELEN WALTERS, 2010 apud MCCULLAGH, 2010, p. 37)

However, this is not effectively a problem. Describing a process in too much detail may stiffen a process that should be creative. Authors, such as Brown (2008, p.

[11] The proposition of McCullagh (2010, p. 39) is based on a technology push or market pull approach. Usually, the greatest inventions in history were achieved by means of a technology push strategy, where technology is developed first and products are derived later.

4), state that “the design process is best described metaphorically as a system of spaces rather than a pre-defined series of orderly steps”. A wider, non-rigid description is required, not a process model.

Another strong criticism is the excessive simplification of DT due to its great popularization. According to Johansson-Sköldberg, Woodilla and Çetinkaya (2013, p. 131), people usually believe that making DT is equal to being creative. Others, still according to the authors, believe that it is simply a toolbox. Dorst (2011, p. 531) also criticizes this aspect, saying that some authors simply put creative tools together and call it DT. This is a great problem. Kimbell (2012, p. 143), for example, reinforces that using the tools and methods that some authors call “design thinking” without the culture of design and the correct mindset shall not generate the desired results.

There is more general criticism about this approach. The more traditional designers, who are usually more related to aesthetics, criticize that DT as an organizational resource neglects completely the style when developing a new product (TONKINWISE, 2011, p. 533). Traditional designers also usually criticize DT as an organizational resource, claiming that the DT discourse will “most probably die if it does not acquire a scholarly base that relates more to designerly thinking”, i.e., DT as a cognitive process (JOHANSSON-SKÖLDBERG; WOODILLA; ÇETINKAYA, 2013, p. 131).

There are other authors that also complain about the lack of systematic studies about DT as an organizational resource, highlighting that most of them are anecdotal, but they also incentive that research should be done to evolve DT in this perspective (LIEDTKA, 2014a, p.1).

Finally, it is possible to identify personal opinions in literature. DT has been a target of constant attacks of people involved in the design field for a longer time, mainly by supporters of DT as a cognitive process. Norman (2010), for example, published in Internet his thoughts about DT, saying it was a false solution or a “useful” myth. However, three years later, Norman (2013) published again about the theme, changing his point of view and saying that DT may be “transformative”.

2.6 Design Thinking Methodologies

This section provides an overview of how methodologies were selected and an overview of DT methodologies that are used in this work.

2.6.1 Introduction and Selection of Design Thinking Methodologies

First of all, it is important to establish the differences between what this work calls DT models and DT methodologies. The DT approach can be found in the shape of models or methodologies. Models are those that propose a given order for DT stages and that can even prescribe in short what should be performed in each stage, but do not propose methods and tools to go through them. The methodologies, on the other hand, are the so-called toolboxes, where the practitioners are provided with methods that support this approach.

Many DT models and methodologies were identified in literature and, mainly, in webpages that claim to support practitioners. The way they refer to DT is not well structured. Some researchers and practitioners, such as those from IDEO and d.School, have been calling it recently as human-centered design (IDEO, 2015). Other authors may refer to it just as a participatory design methodology, a UCD[12] methodology, a UX[13] methodology, service design toolkit, social innovation toolkit, experience design toolkit, among other possibilities. However, even if called under a different name, they were considered DT approaches whenever their characteristics were compatible to those listed in subsection 2.5.2.

Subsection 2.5.3 showed how comprehensive are the DT application fields. Many methodologies arose to support its application. In this research, a search was performed in literature in order to find DT methodologies in the English language. A great number of DT methodologies were identified in books, papers, theses and in websites focused on providing support to practitioners. Eight DT methodologies were selected for in depth analysis. They were selected by analyzing citations, authors and

[12] UCD is a broad term that describes any design approach that actively involves the end-users during the development process, usually composed by methods, procedures, processes, and a specific mindset (ABRAS; MALONEY-KRICHMAR; PREECE, 2004; MAO et al., 2005; MIASKIEWICZ; KOZAR, 2011; SALAH; PAIGE; CAIRNS, 2014).

[13] According to the ISO 9241-110, UX is “a person’s perceptions and responses from the use and/or anticipated use of a product, system or service” (ISO, 2010 apud VERMEEREN et al., 2010).

application context. First of all, the most known and used methodologies were selected. Then, methodologies proposed by known researchers of DT were also included. They were selected focusing on the scope, avoiding methodologies based on the same context.

First, it was verified if the authors were meaningful for the DT theory and literature by identifying the amount of work published by those authors. Secondly, it was seen if the methodology was highly cited in literature and commonly used. Then, the application context was analyzed, in order to obtain varied contexts, avoiding bias from one specific area. Methodologies with qualities that differentiated them from other methodologies, such as extra information or prescription of methods order, were also preferred. Eight methodologies were selected, covering contexts such as business, social, service, and general design. Their overview is provided on the next subsection.

2.6.2 Overview of Design Thinking Methodologies

As explained in the last subsection, eight DT methodologies were selected (FABRICANT et al., 2012; IDEO, 2015; KIMBELL; JULIER, 2012; KUMAR, 2013; LIEDTKA; OGILVIE, 2011; PLATTNER, 2010; RCA, 2010; STICKDORN; SCHNEIDER, 2011). This subsection provides an overview of DT methodologies. Their detailed description may be observed in Appendix A.

Each one of the methodologies was chosen due to citations number, relevance or context.

The Bootcamp Bootleg (PLATTNER, 2010) methodology is one of the most recognized DT methodologies, being cited by many works that deal with DT application (MELLES; HOWARD; THOMPSON-WHITESIDE, 2012; RAUTH et al., 2010). The model was established at the d.School, in Stanford, to provide guidance through the DT process for recent graduates and proposes 51 methods.

The “Designing for Growth” methodology (LIEDTKA; OGILVIE, 2011) was proposed in the management context by Jeanne Liedtka, a well-known researcher of the DT area and has much published work about DT, mainly in the context of business application (LIEDTKA, 2010, 2011, 2014a, 2014b). It contains 10 main methods and 4 additional tools.

“Designing with people” (RCA, 2010) is proposed in the web by the Helen Hamlyn Centre for Design at the Royal College of Art, proposing 20 methods and additional information about them, such as expertise, time, staffing and costs.

The “Field Guide to Human-Centered Design” (IDEO, 2015) is a step-by-step guide with 56 methods focused on the social sector practitioners, mainly for what they call “social innovation”. This guide was developed by IDEO, a pioneer design consultancy firm, and IDEO.org, its non-profit institution that work with design to improve poor communities’ quality of life.

The “Collective Action Toolkit” is proposed by FROG (FABRICANT et al., 2012), a global design and strategy firm, and is focused on social design. It brings 25 methods and a suggested sequence for their execution.

“This is Service Design Thinking” (STICKDORN; SCHNEIDER, 2011) is a textbook with 25 methods focused on service development, but also citing possible application in what it calls “product-service hybrids” or PSS (MIETTINEN, 2011, p. 55-56).

“The social design methods menu” (KIMBELL; JULIER, 2012), proposes 11 methods on the social design context, is authored by Lucy Kimbell, who presents much work in literature, both about DT and service development (KIMBELL, 2009, 2011a, 2011b, 2012). One aspect that differs it from all other methodologies is that it offers a set of “recipes”. It means that it provides a species of project typology, proposing what methods should be performed and in which order depending on what type of project. Those “recipes” cover fixing service critiques, developing with agility, improving services or social issues, and innovating.

The “101 design methods” methodology (KUMAR, 2013) is the largest of the DT methodologies selected, providing 101 design methods.

Each one of the methodologies is composed by stages, which are named differently by each author. However, the description of the stages on each methodology shows that they usually have the same core idea. Even though some authors may propose a greater number of stages, such as Plattner (2010, p. 1-5), than others, such as IDEO (2015, p. 11); the stages scope is equivalent. The only aspect

that does not converge in all methodologies when referring to stages is the proposal of an implementation stage by some authors, while others propose to end the process after prototyping and testing. In order to show how the methodologies stages superpose among themselves, they are illustrated in Figure 11, providing the following stages generic labels: empathy generation and problem definition, ideation, prototyping and test, and implementation.

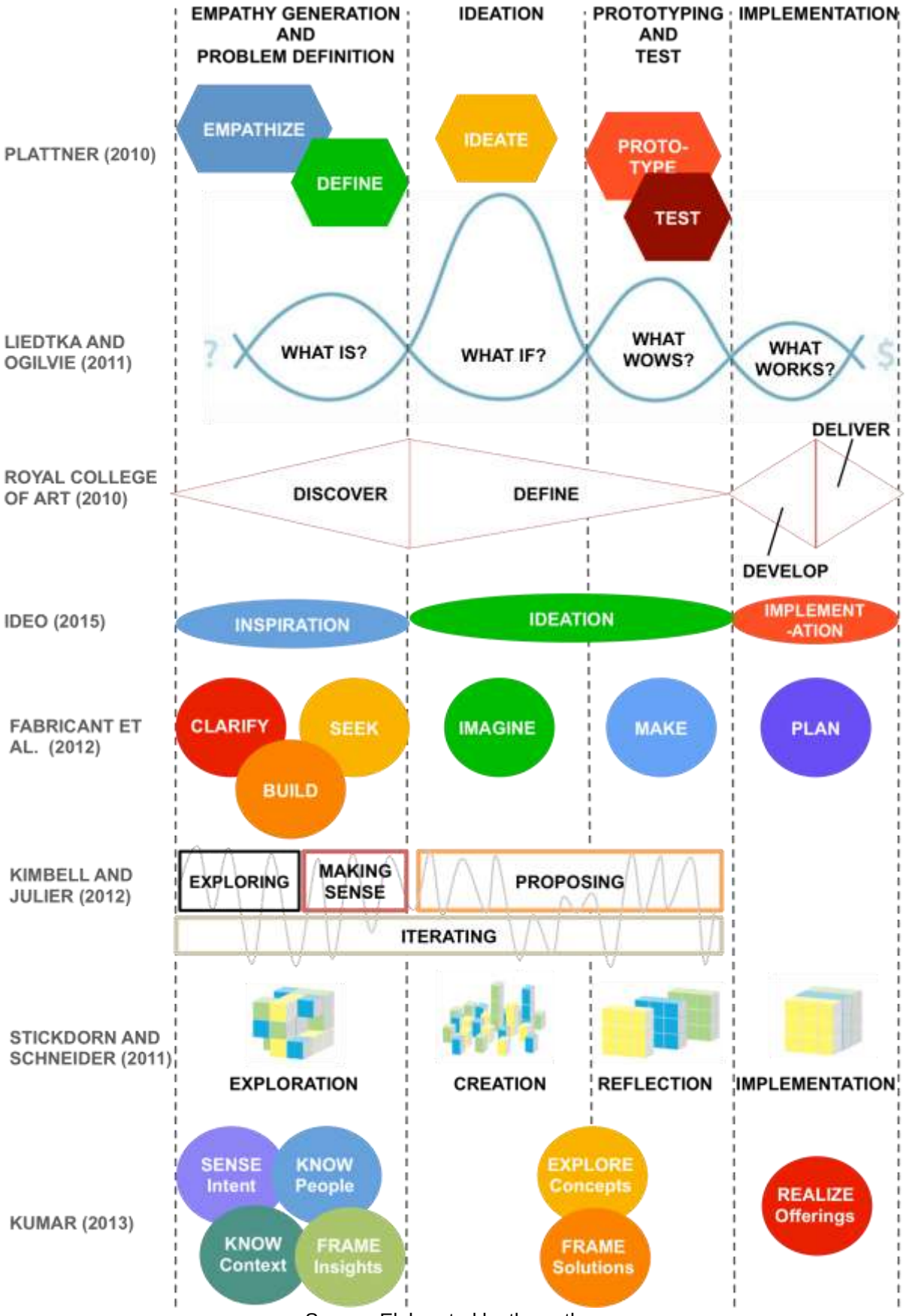
- Empathy generation and problem definition: In this stage, the team members should create empathy with users by observing “users and their behavior in the context of their lives”; engaging with users by interacting and interviewing them “through both scheduled and short ‘intercept’ encounters; and immersing the user reality by experiencing what they feel and what they do (PLATTNER, 2010, p. 4). Additionally, in this stage, an “actionable problem statement”, also called “point of view” (PLATTNER, 2010, p. 5), is established, i.e., a meaningful specific problem to be solved.

- Ideation: After data exploration and its synthesis, the second stage focus on creativity. In this phase, creative ideas arise. The ideation in this stage does not allow constrains, but focus on identifying a whole range of new possibilities. In the end of this stage, the concepts to be tested are proposed (LIEDTKA; OGILVIE, 2011, p. 109-110).

- Prototype and test: This stage covers prototyping selected ideas and testing them with users and stakeholders. The prototypes are simple and may even not represent the solution, but specific hypotheses to be tested. The prototypes may be done for many reasons besides testing hypotheses with users. It can be done to gain empathy, to explore options, and to provide inspiration.

- Implementation: This is the stage with greatest variability among authors. Here, it is considered as the set of activities that prepare the development project to be started, i.e., preparing plans, business model, business case, and performing final tests and strategic planning.

Figure 11 – Stages of the DT methodologies and their connections



Source: Elaborated by the author

It is important to point out that Liedtka (2014a, p. 4) performed a similar analysis with the DT stages. She compared the stages proposed by one methodology and four educational DT models[14] proposed by academic and commercial institutions. She analyzed the stages scope and reached three generic stages: Data gathering about users' needs, idea generation, and testing. The "data gathering about users' needs" stage is equivalent to the "Empathy generation and problem definition" stage proposed in this work. The "idea generation" stage proposed by Liedtka (2014a, p.4) is equivalent to the "ideation" stage of Figure 11. Finally, her proposal of the "testing" stage covers the scope of this work's "prototyping and test" and "implementation" stages conglomerated.

The DT methodologies usually are proposed by a set of methods and tools preceded by a list of recommendations or guidelines (called by them as "mindsets" or "principles").

Each author provides methods with distinct detail levels. One example is the method "Visualization" proposed by Liedtka and Ogilvie (2011, p. 159), which has included in its description procedures that are similar to the methods "Personas", "Storyboards" and "Storytelling" from Stickdorn and Schneider (2011, p. 172, 181, 198). The journey map method proposed by Liedtka and Ogilvie (2011, p. 198) also fits this situation, which, besides journey mapping, covers the scope of methods such as 2x2 matrix[15] and stakeholders maps[16].

Additionally, the methods titles are not common among authors. In fact, some authors may use an identical title to cover completely different scopes, such as co-creation. The definitions of each author for the co-creation method are provided at Table 9 in order to ease the differences understanding.

It is easy to see differences in the co-creation methods. Those differences are mainly on the performed activities in co-creation and the involved people. The co-creation methods proposed by Plattner (2010, p. 38) and IDEO (2015, p. 109) involve customers and users to create new solutions. Stickdorn and Schneider (2011, p. 194) involve all stakeholders and see co-creation as a concept that can be involved with all

[14] Please see the subsection 2.6 to understand the difference between DT models and DT methodologies.
[15] Method proposing the use of four quadrants to organize information, which is based on the range of two variables.
[16] Method that lists down and relates all stakeholders involved in the development project.

activities proposed in their methodology. The co-creation proposed by Liedtka and Ogilvie (2011, p. 453), on the other hand, is more related to testing with users.

Further characterization of these methodologies is part of the scope of this work as one of the secondary research goals. Thus, in chapter **Erro! Fonte de referência não encontrada.** the elements selected in subsection **Erro! Fonte de referência não encontrada.** are characterized.

Table 9 - Co-creation definitions

Authors	Method	Co-creation method definition
Plattner (2010, p. 38)	User-driven prototyping	“The approach to creating a user-driven prototype is to set up a format for your users to create something which leads to your understanding of how they are thinking”
Stickdorn and Schneider (2011, p. 194)	Co-creation	“[Co-creation] can involve anyone from the staff, designers, executives or customers working collaboratively in order to examine and innovate a given service experience.” “Co-creation is a principle that can be used in conjunction with many other tools in the service design toolset.”
Liedtka and Ogilvie (2011, p. 453)	Customer co-creation	“Customer co-creation Is the process of engaging a potential customer in the development of new business offerings. It involves putting some prototypes in front of potential customers, observing their reactions, and using the results to iterate your way to an improved offering.
IDEO (2015, p. 109)	Co-Creation Session	“The purpose of a Co-Creation Session is to convene a group of people from the community you’re serving and then get them to design alongside you.”

Source: Elaborated by the author