Integrating Tacit Knowledge in Product Lifecycle Management: A Holistic View of the Innovation Process

by

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L’intégration des connaissances tacites dans la gestion du cycle de vie du produit : une vision holistique du processus d’innovation

Daniela OLIVEIRA

RÉSUMÉ

La gestion du cycle de vie du produit vise à augmenter la réutilisation des extrants de la conception, développement, ventes et soutien à l’utilisation pour réduire le temps de mise au marché et faciliter la création de produits qui répondent mieux aux besoins des clients. Les organisations qui veulent implémenter la gestion du cycle de vie du produit pour en retirer les bénéfices ont également le besoin de maintenir, voire accroître le niveau d’innovation. L’implémentation de la gestion du cycle de vie du produit ne devrait pas se faire en détriment du potentiel d’innovation de l’organisation. La gestion du cycle de vie du produit demande l’intégration des connaissances tacites, soit les différentes courantes de pensée qui coexistent dans l’organisation. L’intégration des connaissances tacites découle du fait que la plupart des pratiques sont sommairement documentées ou nullement documentées. De plus, les connections entre départements avant l’implémentation du paradigme de la gestion du cycle de vie du produit sont, dans leur majorité, informelles. À date, les efforts d’intégration des connaissances tacites dans la gestion du cycle de vie du produit se sont concentrés sur les connaissances tacites individuelles et sur la conversion des connaissances tacites en connaissances explicites. Théoriciens et praticiens sont en accord sur le besoin d’inclure l’expertise et la vision des employées dans la gestion du cycle de vie du produit. En revanche, pour les gestionnaires de connaissance ou les experts en technologie de l’information, c’est un défi de prioriser ou créer une approche équilibrée parmi des perspectives et intérêts multiples qui sont à la fois différents mais également importants. Le besoin d’intégration des connaissances tacites a été discuté dans le domaine de la gestion du cycle de vie du produit, mais aucune recherche n’a profondément exploré la nature des connaissances tacites, les défis entourant leur gestion, leur relation avec l’innovation, la gestion de données ou la conception de systèmes d’information et la relation de ces thèmes avec la gestion de cycle de vie du produit. Cette recherche explore un cadre en Gestion de Connaissances, le Capital Intellectuel. Ce cadre est élargi pour clairement abriter la créativité et l’innovation. Ce cadre est utilisé pour dévoiler la nature multiforme des connaissances tacites, leur relation avec le langage et l’importance de l’interaction sociale pour leur validation et application. Une exploration empirique vient complémenter l’exploration théorique. L’intégration des connaissances tacites demande des techniques d’identification et d’outils de représentation. Ces techniques et outils doivent être informatifs sans toutefois alourdir le processus de conception. Il y existe une longue tradition d’utilisation de classifications en tant qu’outils porteurs de signification sur des domaines de connaissances. De ce fait, les ontologies sont de plus en plus fréquentes dans des environnements organisationnels. Les ontologies sont aussi reconnues en tant qu'outils de choix pour connecter des départements dans des systèmes de gestion de cycle de vie du produit. Il serait donc intéressant que les résultats des techniques et outils d'identification et représentation des connaissances tacites puissent être absorbés par des ontologies. D'autres domaines ont développé des techniques et outils pour intégrer les connaissances tacites. Parmi ces techniques, les groupes de discussion permettent à ses participants le partage de contexte et la quête de consensus. Parmi ces outils, les cartes conceptuelles permettent la représentation du contenu avec un bon niveau d'abstraction. Les cartes conceptuelles peuvent aussi prendre la place de représentation graphique d'une ontologie. Cette recherche explore le potentiel des cartes conceptuelles en tant qu'outil de représentation et leur création collaborative en tant que technique pour identifier les connaissances tacites dans un environnement de gestion de cycle de vie du produit.

Mots-clés: gestion du cycle de vie du produit, gestion de connaissances, connaissances tacites, création collaborative de cartes conceptuelles, conception de systèmes d'information

Integrating Tacit Knowledge in Product Lifecycle Management: A Holistic View of the Innovation Process

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ABSTRACT

Product Lifecycle Management (PLM) aims to increase the reuse of work outputs of the design, development, sales and support of a product in order to reduce time to launch and to facilitate the creation of a product that is more suited to clients' needs. Organizations aiming to benefit from PLM equally need to maintain or increase innovation levels. PLM implementation should therefore not be detrimental to the innovation potential of an organization. PLM requires the integration of tacit knowledge, the different ways of thinking that coexist in the organization. The need to integrate tacit knowledge comes from the fact that most practices are poorly documented or not documented at all. In addition, connections between departments before the implementation of the PLM paradigm are mostly informal. Previous initiatives of integration of tacit knowledge in PLM have focused on individual tacit knowledge and the conversion of tacit to explicit knowledge. Theorists and practitioners agree on the need to include individual employees' expertise and vision in PLM. However, multiple perspectives and needs that are different but equally valid make it challenging for the Knowledge Management (KM) or Information Technology (IT) expert to prioritize them or to create a balanced approach on their own. Although the need for integration of tacit knowledge has been argued in the PLM field, no research has explored in depth the nature of tacit knowledge, the challenges concerning its management, its relationship to innovation, data management and the design of information systems and the relationship of these issues with PLM. This research explores a Knowledge Management (KM) framework, the Intellectual Capital Model (ICM). It expands this framework to clearly consider creativity and innovation. The framework is used to reveal the multifaceted nature of tacit knowledge, its relationship with language and the importance of social interaction for its validation and application. An empirical exploration complements the theoretical one. Tacit knowledge integration requires identification techniques and representation tools. These techniques and tools must be informative without burdening the design process. Classifications have long been used as tools to make sense of knowledge domains. As a consequence, ontologies are more and more frequent in organizational environments. Ontologies have also been acknowledged as important tools to connect departments through PLM systems. Therefore, it would be desirable that the results of tacit knowledge techniques and tools of identification and representation are absorbed by ontologies. Knowledge domains other than PLM have developed techniques and tools to integrate tacit knowledge. Among those techniques, the focus group allows participants to share context and find consensus. Among those tools, concept maps allow groups to represent context in a conceptual level. A concept map may also function as the graphical representation of an ontology. This research explores the potential of concept maps as a representation tool and their collaborative creation as a technique to identify tacit knowledge in an PLM environment.

Keywords: Product Lifecycle Management, Knowledge Management, Tacit knowledge, Concept map collaborative creation, Information systems design

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LIST OF ABREVIATIONS

AEC	Architecture, Engineering and Construction
BIM	Building Information Modeling
IDM	Information Delivery Manuals
IT	Information Technology
IC	Intellectual Capital
ICM	Intellectual Capital Model
KM	Knowledge Management
PLM	Product Lifecycle Management
R&D	Research and Development
SME	Subject Matter Expert

INTRODUCTION

0.1 Motivation

This thesis answers Hennessey and Amabile's (2010) call for research on creativity encompassing the individual and group perspectives, recognizing a system of interrelated forces operating at multiple levels and using interdisciplinary investigation; Lev and Zambon's (2003) demand for different communication and interpretation tools around intellectual capital; Kärkkäinen et al.'s (2012) expressed need that future product lifecycle management software be able to "capture, enhance and deploy also unstructured, tacit and future-oriented customer knowledge" (Kärkkäinen et al., 2012, p. 633). It addresses the gap identified by Jokinen and Leino (2019) on how knowledge management and collaboration should be organized in practice, in complex industrial settings, taking into account whole product lifecycle issues.

Technological innovation is a great driver of economic development (Nelson et al., 2002). Technological innovation is, simply put, an innovation applied to a technological problem. Innovation is performed by humans, however using all the knowledge and infrastructure at their disposal. A straightforward definition of innovation is the implementation of a solution to a problem not previously addressed. In this definition, two crucial elements can be identified: the isolation of a solution – the creative process - and its implementation. In breaking down the creative process, according to Fisher and Amabile (2008), three elements surface: the ability to scrutinize the problem from different angles, the knowledge of the particularities of the field where the problem manifests itself – a branch of technology, for example - and the motivation to go through this process.

The conception of the implementation of a solution requires a deep understanding of the market where it could be commercialized, of the resources needed to scale the production, distribution and support of the solution, of the potential risks, internal and external, of commercializing the solution and of the value the solution could bring. The implementation of a technological solution requires of an organization the ability to consider different modi operandi, or changes in their business model, which falls into the definition of strategic innovation.

If we consider implementation an essential factor of technological innovation, or any innovation for that matter, it follows that technological innovation is only possible if joined by strategic innovation, or the ability to idealize and implement changes in business models. Those two kinds of innovation are complementary, as it is desirable that strategic innovation relies only on what is technically possible, or the boundaries of technological innovation, and technological innovation should focus on what is strategically possible.

Strategic innovation is however performed by administrators, whereas technological innovation is the product of the work of engineers and designers. There is a need for a process supporting the mutual influence between these two kinds of innovation. In fact, if scalability is to be taken into account, technological innovation is at one extreme point of a process and strategic innovation is at the other extreme point. In between lies the product or service lifecycle to be idealized, carrying specific challenges in materials used, in transformation methods employed, in packaging, in distribution, marketing and support networks. If strategic innovation is to be informed of the resources needed to scale the production, distribution and support of the solution, all phases of the product lifecycle need vigorous and yet realistic consideration of the challenges to implement the potential innovation. Vigorous consideration means a large exploration of the knowledge of what can be done, knowledge that is very often only marginally documented – the tacit knowledge. Realistic consideration means the exploration of potential obstacles and of the capacity of the department to overcome those obstacles, often reflecting on past experiences, on how the knowledge of what can be done was developed, diffused, adopted, put to action in the past and how this process could be repeated in the future. Realistic consideration depends on knowledge about how knowledge spreads in the organization – the metaknowledge.

Vigorous and realistic consideration has to be spread out in every department of the organization. As challenges in the implementation of technological innovation are considered throughout the product lifecycle, a creative process to find local solutions to those challenges has to follow. In this process, every department of the organization has to continuously keep alignment with not only the two extreme points of the product lifecycle, but also with all departments that have an influence on the outcome of this given department. A large-scale process supporting innovation, encompassing the whole organization, is needed.

This innovation-support process would be, ideally, flexible enough to be quickly applied from one extreme point of the product lifecycle to the other and to quickly absorb new iterations as the understanding of the problem and the possible solutions evolve throughout the product lifecycle. They would be simple enough to be mastered by anyone involved in the process and yet capable of carrying great cognitive load, necessary to convey complex concepts.

Ideally, once the potential innovation has been approved and the initial product lifecycle is launched, real and specific actions could be derived from this innovation-support process. Once the potential innovation becomes an actual innovation, reaching the market, lessons learned could also be derived from this innovation-support process, enhancing the ability of the organization to perform a similar process in the future, with another potential innovation.

This thesis explores the foundations and characteristics of a promising tool, concept maps, to support a large scale innovation process, their collaborative creation, with the aim of producing robust ideas that incorporate both the talent and the capability of the organization to innovate in a given point in time.

0.2 Document structure

The theoretical constructs explored in this research are present in Figure 0.1. The approaches used, showing the relationship between the theoretical and empirical aspects, are depicted in Figure 0.2.

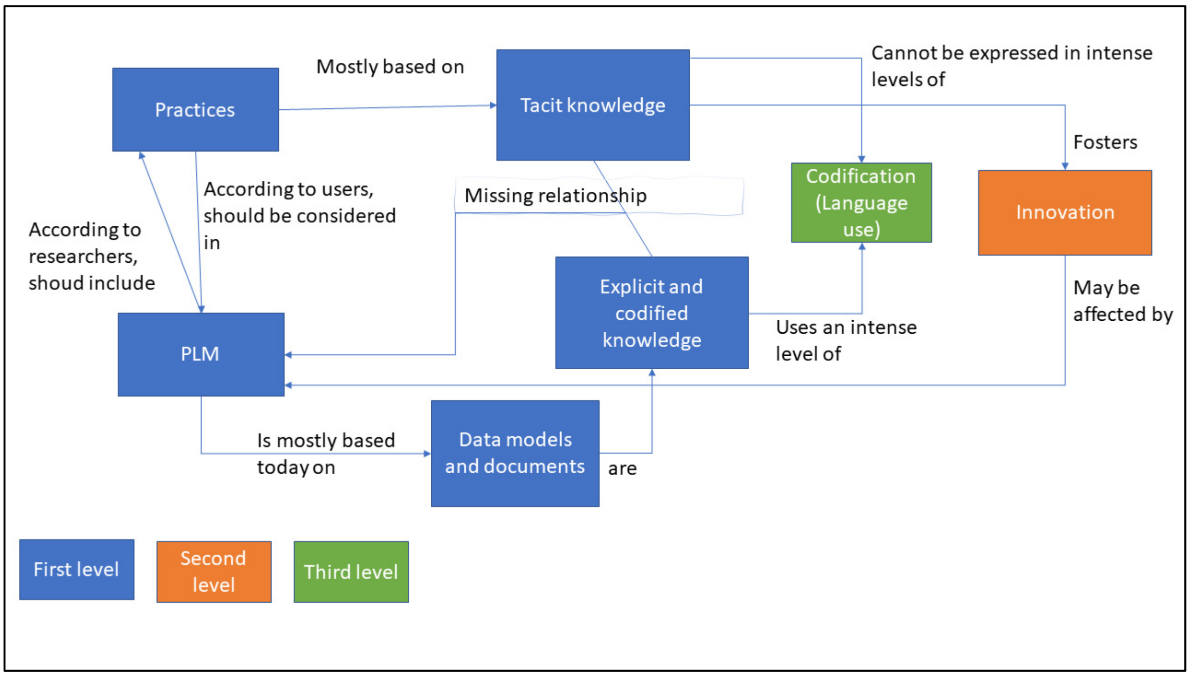

Figure 0.1 Theoretical constructs of the present work

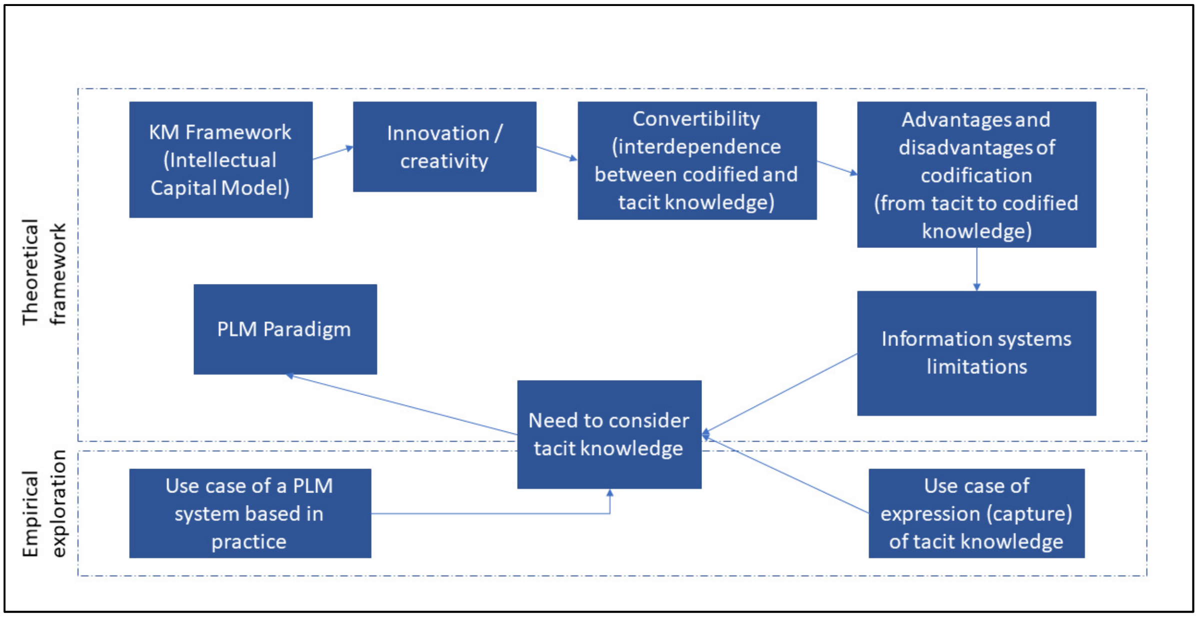

Figure 0.2 Approaches used in the present work

The methodology used in this research is explained in Chapter 1 – Methodology.

This research integrates theoretical frameworks from Knowledge Management and Creativity and Innovation management. The focus is on the nature, the impact and management principles surrounding tacit knowledge. This theoretical exploration is carried out in Chapter 2 – Literature review and theoretical frameworks integration.

Tacit knowledge differentiates itself from explicit knowledge through its relationship towards language. The theoretical exploration of this relationship is made in Chapter 2 – Literature review and theoretical frameworks integration.

As a practical application of the resulting understanding of tacit knowledge is envisioned, a tool that employs language in a way that is suitable for the expression and exploitation of tacit knowledge is analyzed. The theoretical implications of the tool, concept maps, is explored in Chapter 2 – Literature review and theoretical frameworks integration.

A domain of application, Product lifecycle management, was selected. The theoretical exploration of the domain is made in Chapter 2 – Literature review and theoretical frameworks integration.

To guide and support the analyzed intervention, the articulation of tacit knowledge through concept maps to foster product lifecycle management implementations, interviews with domain specialists were made. An experiment was also carried out with a domain specialist. Both initiatives are described in Chapter 3 – Empirical exploration.

The results of the empirical exploration are described and interpreted in Chapter 4 – Discussion.

Finally, general considerations are made in Conclusion and recommendations.

This research has generated some publications during the timeframe it was carried out. Each publication has focused on a specific portion of this research.

0.3 Publications

Oliveira, D., Nascimento, D., & Dalkir, K. (2016). The evolution of the intellectual capital concept and measurement. *Ciencia da Informacao*, *45*(3), 136-155. https://doi.org/10.18225/ci.inf.v45i3.4054

This paper presents two dimensions of intellectual capital (IC): the concept itself and the measurement of IC. In the conceptual section, the importance of IC for competitive advantage and its evolution from practice to academia is discussed. The number and diversity of IC models is considered and their points in common are drawn out: namely, three categories, representing the individual, the collectivity and the relationship perspectives. The importance of social capital for the organization's survival in the current economic environment is explained, a related bibliometric analysis is reported and an IC model acknowledging this component is suggested. The advent of new kinds of capital is explored and a perspective for their integration with the IC model is proposed. In the measurement section, the foundations of IC measurement and different metrics are discussed. A list of factors to be considered for the choice of the ideal set of metrics is presented. The Results-Based Management and Accountability Framework is explained and the evaluation of the Canadian Chemical, Biological, Radiological and Nuclear Research and Technology knowledge management initiative is given as an example. Recommendations to the reader on how to build their own assessment strategy are made and, in conclusion, future research venues are suggested.

Oliveira, D., Gardoni, M., & Dalkir, K. (2018a). Environmental Factors on Concept Maps Design. In P. Chiabert, A. Bouras, F. Noël, & J. Ríos (Eds.), *Product Lifecycle Management to Support Industry 4.0* (p. 25-34). Springer International Publishing. 10.1007/978-3-030-01614-2_3

Building Information Modeling (BIM) environments have a lot of potential to facilitate communication and support collective work, speeding construction times and increasing the overall quality of the project. A few ontology creation efforts have been made by both academia and practitioners to foster the transmission of knowledge in BIM environments. This paper aims to add to the discussion by analyzing the notes of users of concept maps, knowledge structures similar to ontologies, and comparing them to the notes of BIM environment researchers.

Oliveira, D., Gardoni, M., & Dalkir, K. (2018b). Assessing the integration of new types of capital in the three-pillar intellectual capital model. *Proceedings of the European Conference on Knowledge Management, ECKM*, *2*, 633-641.

This paper presents the first step towards the objective of assessing to what point emergent kinds of capital (such as participatory, innovation and entrepreneurial, to mention some) relate to the traditional intellectual capital framework consisting of individual, social and organizational capital. Ways in which the traditional framework should be updated were also investigated. Content analysis on literature of new kinds of capital was performed and analyzed in conjunction with bibliometric methods applied to the intellectual capital field. The study shows that the new kinds of capital are often still based on the traditional pillars of the intellectual capital knowledge domain. Participatory capital publications were found to have the strongest adherence to the traditional framework and entrepreneurial capital, to present the lowest. The study findings suggest that the traditional Intellectual capital framework can and should be updated with notions and elements important for the understanding of the new kinds of capital.

Oliveira, D., Gardoni, M., & Dalkir, K. (2019a). La création participative de cartes conceptuelles dans la gestion de cycle de vie du produit. *Proceedings of CIGI Qualita 2019: 13e Congrès International de Génie Industriel et Qualita*. CIGI Qualita 2019: 13e Congrès International de Génie Industriel et Qualita.

Product Lifecycle Management (PLM) aims to increase the reuse of work outputs of the design, development, sales and support of a product in order to reduce time to launch and to facilitate the creation of a product that is more suited to clients' needs. PLM requires the integration of tacit knowledge, the different ways of thinking that coexist in the organization. Tacit knowledge integration requires identification techniques and representation tools. These techniques and tools must be informative without burdening the design process. In addition, ontologies have been acknowledged as important tools to connect departments in PLM systems. Therefore, it would be desirable that the results of tacit knowledge techniques and tools of identification and representation are easily absorbed by ontologies. Knowledge domains other than PLM have developed techniques and tools to integrate tacit knowledge. Among those techniques, the focus group allows many participants to share a context. Among those tools, concept maps allow groups to represent context in a conceptual level. A concept map may also function as the graphical representation of an ontology. Few efforts have been employed to adapt these technique and tool to PLM. To fill this gap, this study explores the potential of concept maps as a representation tool and their collaborative creation as a technique to identify tacit knowledge in an PLM environment.

Oliveira, D., Gardoni, M., & Dalkir, K. (2019b). Tracking the Capture of Tacit Knowledge in Product Lifecycle Management Implementation. In C. Fortin, L. Rivest, A. Bernard, & A. Bouras (Eds.), *Product Lifecycle Management in the Digital Twin Era* (Vol. 565, p. 146-155). Springer International Publishing. https://doi.org/10.1007/978-3-030-42250-9_14

This study outlines the importance of tacit knowledge for engineering organizations, especially engineer-to-order organizations, and its impact on Product Lifecycle Management (PLM) implementations. The use of maturity models as roadmaps and its functions in PLM and knowledge management (KM) are explored. Difficulties of managing knowledge to prepare an organization for PLM implementation, and how PLM maturity models lack the granularity to support KM for PLM implementations were also explored. To support KM for PLM implementations, a tacit knowledge codification scale was developed from KM and PLM maturity models. The scale intends to help knowledge managers better prepare the organization for a PLM implementation and better support the implementation effort.

Oliveira, D., Gardoni, M., & Dalkir, K. (2021a). Concept Maps Collaborative Creation in Product Lifecycle Management. *Proceedings of the Design Society, 1*, 721-730. https://doi.org/10.1017/pds.2021.72

One of the greatest challenges of large organizations is to promote seamless connections of operations between departments, the Product Lifecycle Management paradigm. Product Lifecycle Management aims to integrate information systems that have been developed with a specific department's culture in mind. Employees' tacit knowledge integration has been recognized as an element that can leverage the integration of information systems. This article presents a potential tool to integrate employees' tacit knowledge into Product Lifecycle Management initiatives.

Oliveira, D., Gardoni, M., & Dalkir, K. (2021b). A Closer Look at Concept Maps Collaborative Creation in Product Lifecycle Management. In D. Tessier (Ed.), *Handbook of Research on*

Organizational Culture Strategies for Effective Knowledge Management and Performance. IGI Global.

One of the greatest challenges of effectively managing knowledge in an organization is promoting seamless connections of operations between departments. The concerns about these connections are explored in the Product Lifecycle Management paradigm, one that concentrates on the suitability of inputs and outputs of a department, on the re-use of sub-products and on the maximization of resources. It is also a paradigm that fosters organizational adaptability and quick changes in production. Historically, information systems supporting operations have been developed with a specific department's culture in background. Due to this legacy, connecting data, information systems and people across the product lifecycle is an ongoing puzzle for organizations, especially long-lived ones. Theorists and practitioners agree on the need to include employees' expertise and vision in this process. However, multiple perspectives and needs that are different but equally valid make it challenging for the knowledge management (KM) or information technology (IT) expert to prioritize them or to create a balanced approach on their own. This chapter explores a tacit knowledge capture tool and a methodology to use it as a means to voice the interaction and negotiation among employees, a process to support KM and IT strategy and development choices. Through its influence on ontologies, concept maps collaborative creation can provide a usability tool focused on meaning throughout the product lifecycle. A literature review of the challenges involved and of the proposed tool is presented, followed by a use case and the methodology for the concept map collaborative creation session, concluded with recommendations drawn from theory and practice

CHAPTER 1

METHODOLOGY

1.1 Integration of theoretical frameworks

The research work documented in this manuscript had two main objectives: a theoretical one and an applied one. The theoretical objective is to identify the role of tacit knowledge in PLM. The applied objective is, given that the theoretical objective is reached, identify practical ways of including tacit knowledge into PLM. The inclusion of an applied objective aims to facilitate the conversion of the theoretical research into measures to be adapted in practice. In other words, it aims to reduce the gap between theory and practice in what concerns this research.

During the timespan this research was developed, the quest for innovation was an important element of management throughout the globe. It was a particularly important element in the culture of the educational institution where this research was developed, the École de technologie supérieure. The importance of the theme motivated the attempt to integrate innovation management into the theoretical objective.

To pursue the theoretical objective, common points of three theoretical frameworks were investigated. Each theoretical framework covered one knowledge domain to be integrated into the research: Knowledge Management, PLM and Innovation management.

The research questions to be answered by the literature review and integration of theoretical frameworks are:

1) Is there a need for inclusion of tacit knowledge in PLM?
2) Is there a need for increasing creativity/innovation potential in PLM?
3) Is the current strategy to include tacit knowledge in PLM is suitable to PLM needs?

4) Can a tool address PLM tacit knowledge capture?

Whereas research questions one to three address the theoretical objective of this research, the fourth research question addresses a possible application of the theoretical portion of the research. In increasing levels of complexity, the first question addresses the motivation for this research; the second question relates the theoretical framework of creativity and innovation to the theoretical framework of PLM; the third question explores the literature on knowledge management and PLM and the impact of creativity and innovation in PLM. It considers whether current approaches to integrate tacit knowledge into PLM tend to convert the most of tacit knowledge potential into benefits in PLM. The fourth question addresses how the theoretical portion of this research can be turned into a practical application.
Concept analysis was employed throughout the efforts to integrate the theoretical frameworks to help the identification of points of contact among the different corpus of literature.

1.2 Empirical exploration

The empirical exploration consisted of two interviews and one concept map exercise. They involved four specialists of the same organization. The aim of the empirical exploration was to verify if the perspectives of the scientific literature on the explored topics was similar to those of subject matter experts in practice.

The empirical exploration collected specialists' impressions on the development of a PLM solution and on the needs that could motivate a PLM approach. The empirical exploration was granted the École de technologie supérieure ethics approval H20190401.

PLM solutions were sought before the identification of specialists. A request for suggestions of solutions somehow connecting two or more departments was made in the professional network of this researcher in 2019. Users of the selected solution were enthused about it. To this researcher, the solution seemed particularly interesting due to its long lifespan (the solution was implemented in 2006 and was fully functional and in place). Publications about the solution were sought and one conference paper from 2007 was retrieved. The two authors of the paper were contacted, one answered. The aim of the interview was explained, and the specialist accepted to participate. An additional ethics approval, from the organization itself, had to be sought as well. The specialist suggested interviews with two other specialists. As the travel time to meet participants was important, the first specialist arranged for all specialists to be present at the same occasion. Before and after the interview, the administrative support of the first specialist provided this researcher with current documentation related to the solution.

The fourth specialist expressed to this researcher their interest in solutions somehow connecting two or more departments. They did not have specific knowledge about an existing solution connecting two or more departments, but they had a lot of knowledge about the needs for such a solution. The fourth specialist worked at the same organization as the first three specialists.

The participants were not compensated for their participation. The interviews were conducted in French and translated to English in this manuscript.

The approach to the interviews was Contextual Inquiry (Berndt et al., 2015; Getto, 2020; Martin & Hanington, 2012), which involved:

1) Informing the participant about the research topic in the invitation to participate: tacit knowledge integration in product lifecycle management;
2) Sharing the questionnaire with participants ahead of time – interview questions can be found in appendices I and II;
3) Meeting specialists in their work environment, as they were asked to talk about their work experience;
4) During the interview:
    a) Asking questions to uncover unarticulated aspects of specialists' work;

b) Asking additional (probing) questions to increase the depth with which what seemed to be important issues were covered;
c) Asking questions to validate the interviewer's understanding of the interviewee(s)' points.

In one of the interviews, a concept map was created to help the specialist articulate the connection points between departments.

The four specialists have different roles. One champions a technological solution, one is a manager of a large department, one manages a team and the last one is a project manager. Considering a product lifecycle consisting of research, design, construction and maintenance, one specialist works in the research portion, while the other three were involved in the implementation or support of a technological solution on the other end of the product lifecycle, maintenance. Two specialists identified as women and two identified as men. All specialists have been in the organization for more than a decade.

1.3 Other methodological explorations

Some methodological explorations were made during this research. They were all incorporated into the publications this research generated.

1.3.1 Critical reflection

Fuller (2012) argues that the academic literacy levels of people involved in business has increased over the years. Complementing that idea, Gibbons et al (2010) state that the quantity and quality of knowledge production in industry will be comparable to the one produced in academia in some years. The increasing level of employment of a workforce with doctoral training in the industry and the increasing complexity of the business environment are some of the reasons mentioned for the phenomenon. How can the wealth of the knowledge of the increasingly qualified workforce inform academic research?

Qualified workers can integrate into academic research as informants. If a member of this qualified workforce was to draw on their own experience to produce academic research, they could be considered to be transgressing the principle of objectivity, which may be “seen as crucial to the process of science” (Hughes, 1995), although this notion has been challenged.

Critical reflection is an approach to the generation of knowledge that values the practice wisdom of practitioners and seeks to generate theory from practice experience inductively (Fook, 1999). The approach guides the expression of knowledge derived from experience. In a setting where the researcher draws from their own experience, the approach limits and identifies the knowledge put into discussion according to its origins. In this sense, the credibility of the study is maintained without incurring in the opportunity cost of not integrating the researcher’s own experience into their academic research. Researchers and practitioners are increasingly looking at critical reflection as a research method (e.g. Fook, 2011):

> Critical reflection is normally used in professional learning settings to assist practitioners to improve practice. I have worked for some time using critical reflection in this way with many different types of professionals. Over time, however, I have been impressed by the deeper and more complex understanding of practice experience which the process enables, and which practitioners themselves often cannot initially express. And so I have begun to speculate about the research potential of the critical reflection process, and whether it might be developed as a research method to allow better formulations of practice experience, and therefore, ultimately, better practice (p.55).

Critical reflection was used in Oliveira et al., (2018a), a study that identifies opportunities for transdisciplinary collaboration among the Architecture, Engineering and Construction (AEC) fields and the Education domains, as displayed in Figure 1.1.

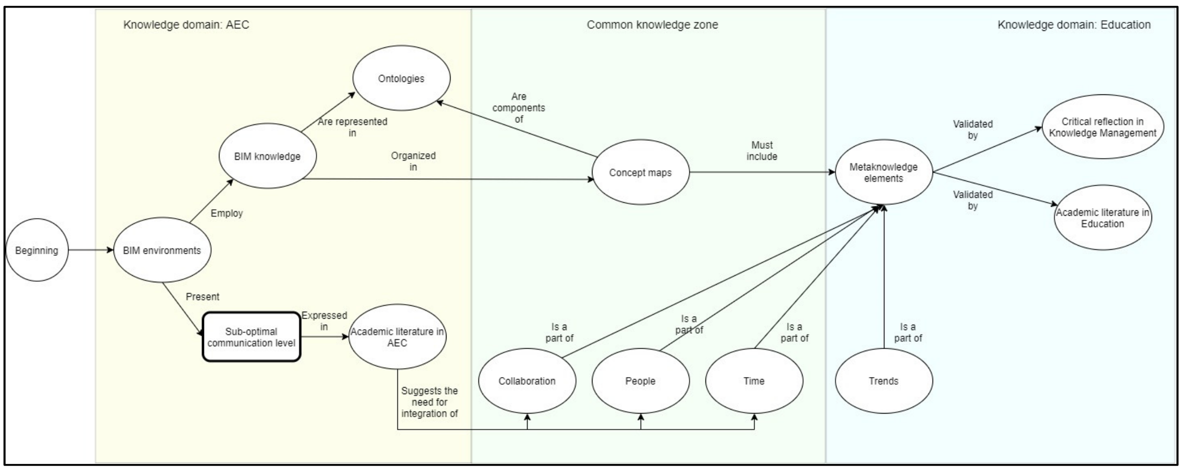

Figure 1.1 Environmental Factors on Concept Maps Design study outline

Using critical reflection, the researcher expressed the elements that involved concept maps creation. The elements that were also mentioned in the literature review were further used to identify a common knowledge zone between the AEC and Education fields.

1.3.2 Research query analysis

Including users in the information architecture design of an application allows the analysis of users' information research trails. In Oliveira et al., (2016) research queries were used to infer users' interest in a topic. GoogleTrends© (https://trends.google.com/trends) was used. As an example, Figure 1.2 shows the incidence of research queries for "concept map" worldwide, from 2004 to 2021.

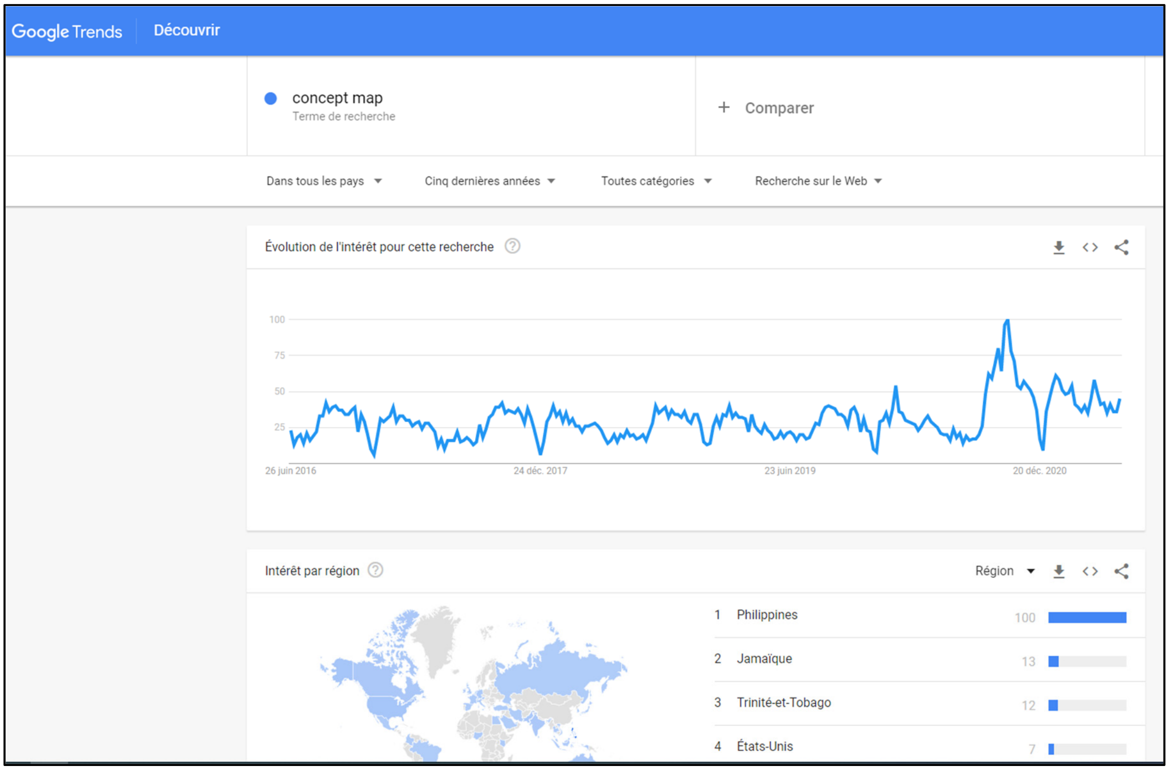

Figure 1.2 GoogleTrends© « concept map » queries worldwide from 2004 to 2021
Taken from GoogleTrends©
https://trends.google.com/trends/explore?date=all&q=concept%20map

In this study, the number of queries on "intellectual capital" over the five years preceding the writing of the study was compared to the number of published papers on the topic in the same period. The concept of "intellectual capital" was decomposed into "human capital" "social capital" and "organizational capital". The number of research queries for these topics was also assessed using GoogleTrends©, revealing that:

> While human capital is most searched in North America, Australia, India and South Africa, social capital is most searched in Mexico and Brazil (Google, 2017b). Indeed, if the report is narrowed to Brazil only, the number of searches for social capital in Google is so high that searches on organizational and human capital become negligible (Google, 2017c), possibly

> indicating a local need or potential felt by Brazilian practitioners. (Oliveira et al., 2016, p. 144)

1.3.3 Citation reports

Two of the main bibliographic databases, Scopus (https://www.scopus.com) and Web of Science (https://login.webofknowledge.com) offer citation reports. Citation reports usually present the number of documents published on a specific topic distributed by date of publication. As an example, Figure 1.3 shows the distribution of documents mentioning "concept map" or "concept maps" in the title, abstract or keywords for Scopus, while Figure 1.4 shows the Web of Science's citation report for the same concept.

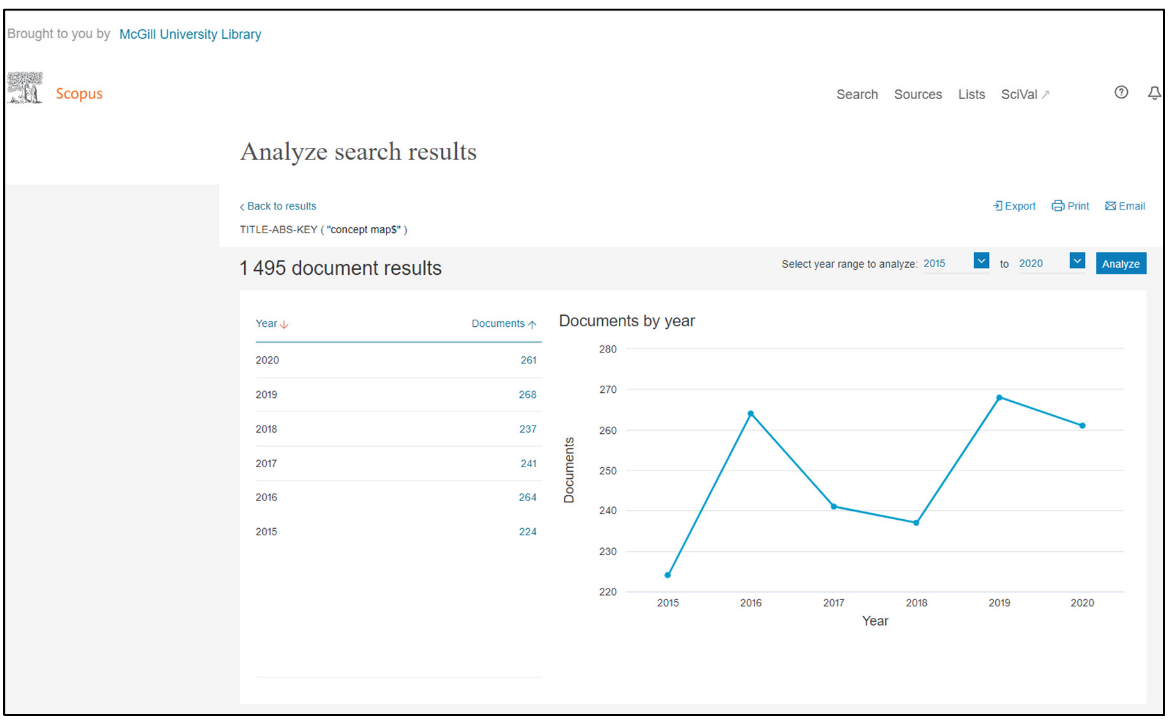

Figure 1.3 Scopus's citation report by year of the query TITLE-ABS-KEY("concept map$") from 2015 to 2020
Taken from https://www-scopus-com

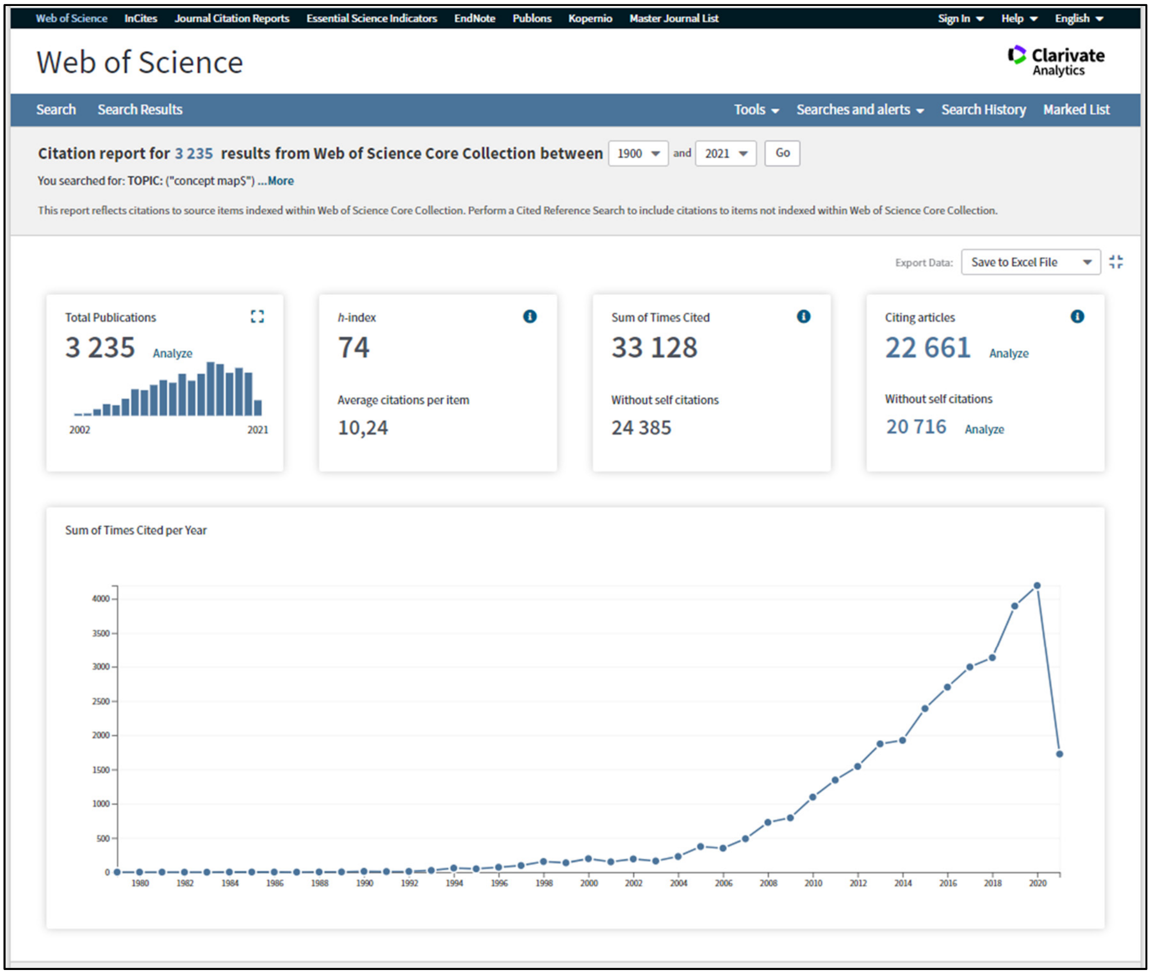

Figure 1.4 Web of Science's citation report by year of the query TOPIC ("concept map$") from 1900 to 2021
Taken from https://login.webofknowledge.com

Scopus also offers the distribution of publication by source, author, affiliation, country or territory, type, subject area and funding sponsor, as exemplified by Figure 1.5.

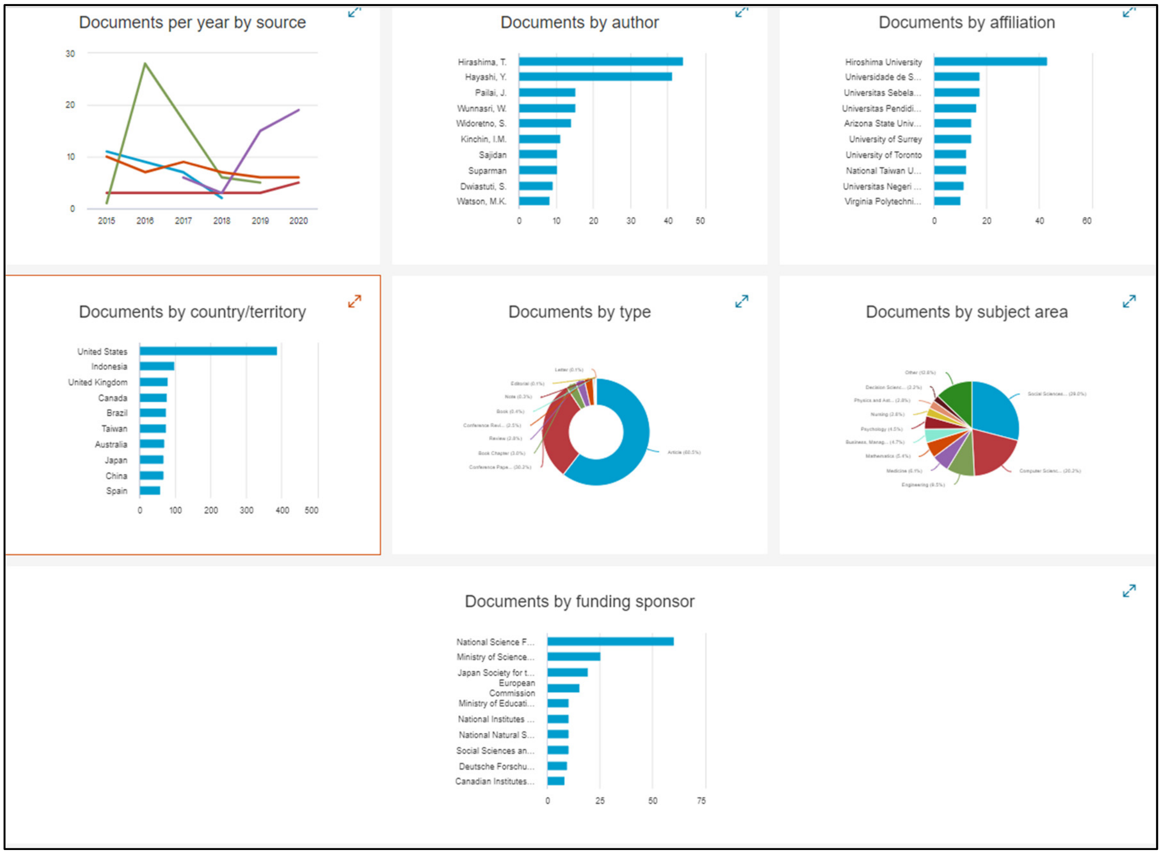

Figure 1.5 Other citation reports from Scopus on the query TITLE-ABS-KEY(“concept map$”) from 2015 to 2020
Taken from https://www-scopus-com

Citation reports were used to convey the effervescence of a field, “2163 documents were retrieved with the query “product lifecycle management” applied in title, abstracts and keywords fields or in any of them” (Oliveira et al., 2019, p. 148) or the number of documents using a specific term “three search queries were applied to the whole Web of Science bibliographic database (Clarivate Analytics, 2018b, 2018a, 2018c) to yield works on the selected new kinds of capital” (Oliveira et al., 2018b).

1.3.4 Bibliographic scans

Bibliometric data assessment is crucial for modern research evaluation processes (Bornmann, 2017). For example, Bornmann et al. (2018) explored the works of Eugene Garfield through the exploration of words mentioned around specific terms. This study inspired the exploration of the possibility of combining research queries offered by Scopus and Web of Science, as displayed in Figure 1.6 and Figure 1.7.

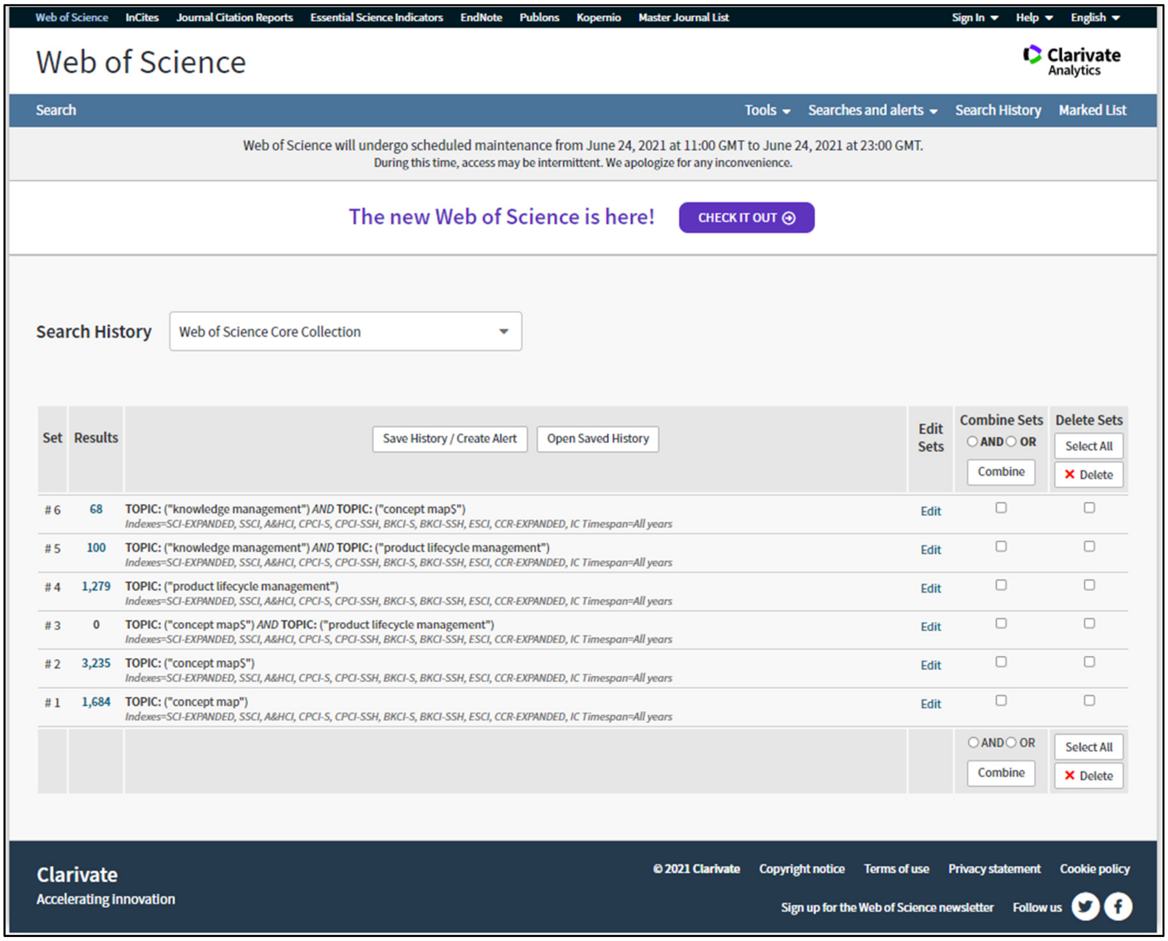

Figure 1.6 Web of Science's search query manipulation interface
Taken from https://login.webofknowledge.com

Figure 1.7 Scopus's search query manipulation interface
Taken from https://www-scopus-com

These bibliographic databases allow for queries in specific fields, queries considering different plural forms and controlling the number of words that can appear in text between two terms, among other features. These features make of the research query process a very informative one. It is possible to evaluate if documents answering one research query also answer a different one. For instance, in Oliveira et al. (2016), only 35% of the documents retrieved after a query on terms related to social capital: (TS=("intellectual capital") and TS=("social capital" or "relational capital" or "customer capital" or reputation or "relationship capital")) actually mentioned the term "social capital", evaluated through the query (TS=("intellectual capital") and TS=("social capital")), "reaffirming the notion that the concept of social capital is often discussed without the actual use of the term (Farr, 2004)" (Oliveira et al., 2016, p. 144).

This technique allowed to verify the incidence of a term in a field:

> Of this body of published literature, little more than a quarter (25.16%) also mentioned the term "knowledge". Only a little less than 7% (6.85%) of the articles mentioned "tacit knowledge", "know-how" or "experience" [3], terms that would suggest some reflection on the knowledge employed by workers

> in the accomplishment of their tasks. The term “tacit knowledge” itself, largely established in the knowledge management (KM) field, accounts for little more than 0% (0.32%, or seven documents) of the works on PLM [4] (Oliveira et al., 2019, p. 148).

By exploring new methodological venues, innovation was sought not only in theory but also in practice in research.

CHAPTER 2

LITERATURE REVIEW AND INTEGRATION OF THEORETICAL FRAMEWORKS

2.1 Knowledge Management: the Intellectual Capital approach

The traditional model of the firm, based solely in standard economic theory, uses economic variables as indicator for variations in economic outcomes. This model does not acknowledge social and cultural factors on economic development. This theory is not enough to explain development outcomes or economic growth (Bhandari & Yasunobu, 2009*)*.

An alternative model of the firm is the one that acknowledges the importance of knowledge for the success of organizations and touches all kinds of organizations (Lev & Zambon, 2003). This model is relatively new if compared to the 500 years in which the traditional model was the one that prevailed (Bontis, 2001).

In the knowledge-based model of the firm, the "ability to attain and keep profitable market positions depends on its ability to gain and defend advantageous positions in underlying resources important to production and distribution" (Conner, 1991, p. 121). Organizations are shaped by knowledge (Conner & Prahalad, 1996). By their existence and actions, organizations also shape knowledge (Conner & Prahalad, 1996).

In this perspective, the creation, production, commercialization and support of sales of a given product at any point depends on how the organization employs the knowledge it holds and determines the success of this organization.

The knowledge-based theory of the firm seems to have evolved from a resource-based perspective (Barney, 1996), although some authors affirm the contrary: that the knowledge-based theory originated the resource-based perspective (Conner & Prahalad, 1996). This theory considers the organization as an organism, capable of recombining and applying knowledge (Sveiby, 2001). This theory considers that learning is a process that can be attributed to organizations (Kogut & Zander, 1992). Organizations develop resources and secure advantageous positions regarding these resources in comparison to competitors (Conner, 1991, p. 121). These resources are developed through the organizations' actions and knowledge application (Conner & Prahalad, 1996). The knowledge of an organization is continuously modelled by its application (Conner & Prahalad, 1996). In this perspective, organizations are seen as organisms capable of solving operations problems. They are also capable of evaluating their own actions and understanding the conditions underlying the origins of those problems, conditions related to how the organization evolves and acts. The organization is then capable of learning how to change the way it acts, a process named double-loop learning (Argyris, 1976, 1977, 2002). This perspective fosters the understanding the different interactions an organization might have with its agents and with external agents, be they individuals or other organizations.

Intellectual Capital (IC) is a framework on Knowledge Management that is concerned with the value of knowledge. The first IC publications were in the 1980s and investigated the phenomenon of companies being traded for more than their book value (Sullivan, 1998). Book values are the empirical representation of the financial perspective of the firm. They describe the company in question through financial figures in investments, options and obligations. It also describes the company in terms of tangible assets, meaning buildings, machinery and stocks. The discrepancy in book values and the actual figures involved in company transactions disclosed that the financial aspects of a firm were not a reliable measure of its value. This discrepancy increased over time (Lev, 2005). A good example is Microsoft, whose shares were sold for ten times more than its book value (Sveiby, 1997). Overall, some industry sectors presented more discrepancy from book values than others, but this discrepancy could be six times higher from a company to another in the same industry sector (Sveiby, 1997).

The first description of the elements that motivated the money figure discrepancy was made by a team led by K. E. Sveiby in Sweden in 1986 (Sullivan, 1998). These elements, that included patents, processes, management skills, technologies, information about customers and suppliers and experience, were named intangible or invisible assets (Stewart, 1991) or intellectual assets (Bontis, 1998). Intellectual assets were considered the Intellectual Capital of an organization (Sullivan, 1998).

Intellectual capital fosters the overall knowledge, capabilities and competitive advantage of an organization (Nahapiet, 2009). Intellectual assets could be considered intermediate products of knowledge: intangible elements that have crucial importance in an organization's performance, such as employee competence, brand names, relationship with customers and suppliers and the company's reputation (Sveiby, 1997), patents, processes, management skills, technologies and experience (Stewart, 1991), among others.

The Intellectual Capital movement had as its core the commitment to acknowledge that elements that could be neither visible nor measurable could have value and that this value could exceed the one of physical assets.

The literature on Intellectual Capital divided assets into categories. For Sveiby (1997), those categories should be external structure, internal structure and employee competence. External structure would consist in the trademarks, brand names, relationships with customer and suppliers and in the company's reputation. Internal structure would consist in patents, models, and administrative systems and the organizational culture. The human resources that both used and produced the assets of the external and internal structure would be employee competence. For Bontis (1998), intellectual assets should be divided into human capital, containing the intellectual assets of individuals, the structural capital, containing assets that were owned by the organization and customer capital, containing all assets pertaining to the relationship of the organization with its customers.

Following these two Intellectual Capital models, most models presented three kinds of intellectual assets. One would englobe the assets that are clearly owned by the organization or that are simply more connected with the collectivity that constitutes the organization. This category can be named (Roos & Roos, 1997) structural (Bontis, 1998) or corporate (Al-Ali, 2003) and is comparable to Sveiby's internal structure. In this category, one would find proprietary software systems and distribution networks (Petty & Guthrie, 2000) in addition to administrative systems, organizational culture, models and manuals. Most of these intellectual assets are well formalized, codified in documents and, overall, less volatile (Andriessen, 2004). Of all the intellectual assets surrounding an organization, these would be the most difficult to change.

Although Sveiby (1997) stressed that all assets and structures in an organization are the result of human actions, most Intellectual Capital models would present a category with intellectual assets of individuals such as formal training, experience, expertise (Edvinsson & Sullivan, 1996), creative potential and commitment of employees. This category of intellectual assets would be named Human Capital (Edvinsson & Sullivan, 1996) or Individual Capital (Nahas, 2016; Sveiby, 1997). Although exploited by the organization, this kind of intellectual capital is not owned by the organization (Roos et al., 1997). On the contrary, these intellectual assets walk "out the door at the end of the day" (Edvinsson & Sullivan, 1996, p. 356).

The remaining of intellectual assets that would add to the value of the organization would be the one encompassing the relationships of individuals that are part of the organization and the organization itself with the exterior, be these relationships with other individuals or other organizations. This category of intellectual assets was named external (Sveiby, 1997), customer (Bontis, 1998); relational (Seleim & Bontis, 2013) or social (Nahapiet & Ghoshal, 1998) capital. The table 2.1 summarizes the distribution of intellectual assets according to different authors.

Table 2.1 Distribution of assets across components according to different IC models

Author \ Intellectual Assets Categories	**Collectivity Level**	**Individual Level**	**Relational Perspective**
Bontis (1998, 2001)	Hardware Software Databases Organizational structure Patents Trademarks Relationships developed with key customers	Knowledge Skills Innovativeness Ability to meet the task at hand Company's values Organizational culture and philosophy	Knowledge of marketing channels and customer relationships Knowledge of customer desires
Edvinsson	Information systems Software Work procedures Marketing plans Company know-how Costing structures Supplier relationships	Collective experience Skills General know-how	Not present
Sveiby	Patents Concepts Models Computer and administrative systems	Capacity to act and create tangible and intangible assets	Relationships with customers and suppliers Brand names Trademarks Company's reputation

These models shed light to how the level of "tacitness", the quality of the knowledge that that resides only in the mind of an individual (Nonaka & Takeuchi, 1995), touches the knowledge in the organization.

The intellectual capital of an organization is then composed of an organizational portion, the one that is most often codified in documents in technological tools, the individual portion, that is mostly not codified, and the social portion, that is also mostly not codified. There is, however, difficulty in "isolating capital in its various forms due to the convertibility and overlapping nature of different types of capital" (Stringfellow & Shaw, 2009, p. 137). The actions of the organization and its very existence are indeed due to human actions (Sveiby 1997), which employs intellectual assets of all the three kinds, explores the overlaps between those three kinds and converts intellectual assets from one kind to another (for example, a manager would use their own experience - individual capital - and the experience of other managers - obtained through social capital - to create a policy - organizational capital).

The concept of convertibility touches all kinds of capital. Any form of capital can be converted into another (Bourdieu, 1986). More specifically, the three kinds of intellectual capital described above: organizational, individual and social, do overlap among themselves and can be converted in all three ways (Sveiby, 2001; Seleim & Bontis, 2013).

In an economy based in knowledge, intellectual capital assets are the foundation for the success of companies (Nahapiet, 2009). All kinds of companies are touched by the importance of their intellectual capital to their success (Lev & Zambon, 2003). What differentiates one organization to another is the ability to create and extract value of intellectual capital assets. For this reason, since the beginning of the field, much attention has been consecrated to explore the creation and extraction of value of intellectual assets, as well as the measurement of the intellectual capital of an organization and its subsequent report (Sullivan, 1998).

The use of the term "capital" evolves from the needs that are at the origin of the conception of metaphors (Eco, 1984). It aims to convey the idea that accumulation is possible (Bourdieu 1986). Accumulation of different sorts of intangible elements is part of the structure and functioning of the social world (Bourdieu 1986).

The phenomena surrounding intellectual assets: the multiple forms they can take, their possible accumulation and conversion and the overlap among different kinds of intellectual capital demanded the breakdown of traditional disciplinary boundaries (Lev & Zambon, 2003). Standard economic theory only does not explain nor base all possibilities of value creation or extraction of intellectual capital. As a result, the framework of Intellectual Capital has been used in a variety of fields, such as sociology, psychology and economics, and studies from many different disciplines have been used to explain the role of intellectual assets (Guthrie et al., 2012).

In addition to great interdisciplinarity in the field of Intellectual Capital and its application in different disciplines, research on intellectual capital has greatly benefited from the collaboration between academia and practitioners (Larsen et al., 1999; Roos & Roos, 1997).

One of the concentrations of the field is the identification of characteristics of intellectual assets, their role and impact in the company (Bontis, 2001). Understanding the characteristics, role and impact of intellectual assets allow for better investment in those assets (Lev, 2005). Lack of understanding of intellectual assets or lack of information on intellectual assets identified in an organization can result in a lack of investment in important assets, leading to considerable social cost (Lev, 2005).

Understanding characteristics of intellectual assets, their role and impact, however, demand measurements, communication, interpretation tools and methods that are not widely employed in organizations (Lev & Zambon, 2003).

A more holistic, macro view on the intellectual capital model has been advocated by Davidsson and Wiklund (2007). Does the current model cover the relationship of intellectual assets and creativity, innovation or attitudes that may facilitate creativity and innovation?

Many different kinds of intellectual capital were identified as the field evolved in the effort of understanding characteristics of intellectual assets, their role and impact. Innovation, entrepreneurial, participatory and competitive capital are some of them, among many others.

Three of the new kinds of intellectual capital were analysed for their close connection to creativity and innovation: innovation, entrepreneurial and participatory capital (Oliveira et al., 2018b). These three new kinds of intellectual capital stemmed from the analysis of organizational processes and of the overlapping and conversion phenomena in which the three original kinds of capital (organizational, individual and social) take part. The description of the new kinds of capital (innovation, entrepreneurial and participatory) in the literature tends to reflect how intellectual capital assets impact the performance of an organization through its processes, whereas the traditional kinds of capital that compose the model of Intellectual Capital were developed according to a static perspective of the organization. They intended to promote a portrait of the intellectual wealth of the organization at a certain point in time. In this tripartite model, there was no consideration to movement in the organization's intentions or actions.

Considering these aspects, we have named the three original kinds of capital Descriptive kinds of capital (Oliveira et al., 2018b). The new kinds of capital studied, innovation, entrepreneurial and participatory, were named Process capital, to outline the differences in the analysis used to create the terms in comparison to the analysis used to create the original concepts of organizational, individual and social capital.

In the effort of understanding the relationship between innovation, entrepreneurial and participatory capital and organizational, individual and social capital, a study was designed to outline the relationships established in the literature among the new and the traditional kinds of capital. The study aimed to establish if there was overlap in the concepts of the traditional and the selected new kinds of capital. Content analysis strategies were designed to identify how much of the concepts of the traditional kinds of capital were present in the definition of the new kinds of capital. The intended result should reflect the collective view of the authors in the field. For such, content analysis was used to confirm or reject three hypothesis:

- H1: The majority of the participatory capital works recognizes at least one of the traditional pillars of intellectual capital

- H2: The majority of the innovation capital works recognizes at least one of the traditional pillars of intellectual capital.
- H3: The majority of the entrepreneurial capital works recognizes at least one of the traditional pillars of intellectual capital.

Data collection was based in search queries, designed for the application on the whole Web of Science bibliographic database. The first three search queries (Clarivate Analytics, 2018b, 2018a, 2018d) intended to recall works on the three new kinds of capital. A first exploration of the literature mentioning the new three kinds of capital was performed to inform the design of the search queries in regard to their breadth. The query for the first exploration, as it was intended to have the most possible recall on each one of the topics, consisted in our preferred term for the kind of capital, “participatory capital”, for example, applied to all possible fields of the bibliographic database. This first literature exploration led to query designs that considered small variances in the labelling of the terms while still addressing the same concept. For instance, the query design for participatory capital included the terms “participation”, “participatory” and “participant”, as long as those terms were followed by the term “capital”. All queries focused on the title field. This strategy was also informed by the first exploration of the literature. Articles discussing the concept of each of the new kinds of capital tended to mention the corresponding term in their title, whereas articles that only peripherally touched the concept would mention the term in other fields. These latter articles mentioned the new kind of capital as part of a larger discussion, without deeper attention to the definition of the new kind of capital or to mention of examples of intellectual assets composing the kind of capital. An additional query was designed to verify if any of the works recalled in the first queries actually answered more than one of them (Clarivate Analytics, 2018c). This query was designed to inform the subsequent data treatment. Sixty-eight documents were retrieved: two on participatory capital, nineteen on innovation capital and forty-seven on entrepreneurial capital.

The translation of the aim of the study, the understanding of the relationship between innovation, entrepreneurial and participatory capital and organizational, individual and social capital, into content analysis inclusion criteria showed that two levels of criteria were needed: a practical and a theoretical one. The practical criteria considered the way the bibliographic database decomposed search queries and applied its elements to articles in the database. Web of Science does respect the distance between terms used in a query – by joining the main term of the kind of capital with the term “capital” itself, the query ensured that the main term and the term “capital” would have no other words in between. However, the bibliographic database disregards the presence of commas in the articles scanned to answer a query. For instance, it does not differentiate between the mention “innovation capital” in a phrase and the mention “innovation, capital”, yielding articles containing both phrases such as “what is innovation capital” and “incentivizing innovation, capital needs of companies”. This behavior played a considerable important role in the study, since the former phrase did answer the aim of the study, whereas the second one did not because it used the term “capital” in a different context. Therefore, titles were scanned for commas. All identified documents were intellectually analyzed to confirm the use of the term “capital” in a different context. All identified documents were excluded. As further steps of the study required the analysis of the full text of documents, those that were not written in English were excluded. One document was found to be a reprint of another document and was also excluded.

The theoretical criteria involved the analysis of the kind of documents. Book chapters and journal articles are means of academic communication that privilege ideas that have possibly been previously diffused and discussed through other means of academic communication, such as conference proceedings. As the study aims to identify solid positions and discussions about the new kinds of capital, the only document from conference proceedings was excluded. For the same reason, the only document published before 2000, in 1979, was excluded. The study also aimed to represent a variety of perspectives in the field. Furthermore, as subsequent steps of the study involved quantitative analysis to represent those perspectives, it was important that authors were not overrepresented. Therefore, only documents of authors not previously represented or, if previously represented, that discussed different concepts from the ones already retained, were considered. One document was excluded. Of the remaining documents, nine referred to the term “capital” in physical or financial context and were also excluded. Thirty-four documents representing an accepted and diversified discourse on the conceptualization of participatory, innovation and entrepreneurial capital were retained.

Discourse analysis (Neuendorf, 2017) was then performed in the title, abstract and full text of the documents to assess mention to organizational, individual or social capital. A document was considered to connect a new kind of capital to a traditional one if:

- An explicit mention to one of the traditional pillars was made. Terms accepted were, for individual capital, ‘individual capital’ and ‘human capital’; for organizational capital, ‘organizational capital’ and ‘structural capital’ and for social capital, ‘social capital’, ‘relational capital’ and ‘client capital’;
- An explicit mention to an element covered by the scope of the traditional pillars was made. Mentions to formal training, education, experience, expertise, creative potential and commitment of employees were accepted for individual capital; to proprietary software systems, distribution networks, administrative systems, in-house developed software, patents, trademarks, policies, procedures, models and manuals, for organizational capital; and relations, networks and reputation of both individuals and organizations, for social capital. (Oliveira et al., 2018b).

All documents discussing the concept of participatory capital mentioned the three traditional kinds of capital. All documents discussing the concept of innovation capital mentioned two of the traditional kinds of capital: organizational and social, while half of these documents also mentioned individual capital. Documents discussing entrepreneurial capital were the ones expressing less adherence to the intellectual assets composing the traditional kinds of capital, with fifty percent mentioning organizational capital, seventy percent mentioning social capital and seventy-three mentioning individual capital. Twenty-three percent of the documents discussing entrepreneurial capital mentioned all three traditional kinds of capital, with fifty-four documents mentioning both individual and social capital.

Participatory capital is the power one has to have people and organizations acknowledge, assess and recommend one's statements and actions. In the study, participatory capital was more connected to governmental organizations. In that sense, participatory capital refers to the engagement of the surrounding community in helping identify problems and build solutions to address them. It is accumulated when individuals and collectivities get involved in political and voluntary organizations and activities. It can help governmental organizations to acquire awareness and address the needs and concerns of the population they represent (Oliveira et al., 2018b). There is however no doubt that companies are progressively considering customers' feedback. Online and mobile applications and specific features in companies' websites, in addition to social media platforms, are progressively providing features to help people and organizations express their acknowledgement and recommendations. Participatory capital is then connected to organizational capital, in the sense that organizational infrastructure is developed to harness and express the organizational participatory capital.

Entrepreneurial capital is heavily based on individual capital (Albort-Morant et al., 2015; D. B. Audretsch & Keilhach, 2007; D. Audretsch & Monsen, 2007; Buenechea-Elberdin et al., 2017; Cabrita et al., 2015; Jaen & Linan, 2013; Laborda Castillo et al., 2011; Mendonca & Grimpe, 2016a; Shaw et al., 2008, 2010; Stringfellow & Shaw, 2009; Venter, 2012). Entrepreneurial success is also related to social capital in the sense that those who possess vast social capital may benefit from more opportunities than others (Burt, 1997). A portion of the literature on entrepreneurial capital highlights the importance of policies at an organizational, regional or national level (D. B. Audretsch et al., 2008; D. B. Audretsch & Keilbach, 2004; Cabrita et al., 2015; Laborda Castillo et al., 2011; Mendonca & Grimpe, 2016b; Shaw et al., 2009; Urbano & Aparicio, 2016).

Innovation is the process of implementation of a new idea (Evan, 1966). Implementing a new idea requires a process of interpretation, application and evaluation in an organization (Weick, 1995). This process results in a concrete service or product deriving from an abstract idea (Oliveira & Dalkir, 2013). Ideas are produced by individuals through their expertise, creativity and motivation (Amabile, 1998), sometimes shaped by training (De Bono, 1992) and, more often than not, in groups (Carrier & Gélinas, 2011; Fisher & Amabile, 2008). Human capital originates the potential for innovation (Bontis, 1998), whereas the social capital of the organization determines its potential for innovation (McElroy, 2002). Innovation pipelines, however, are a matter of company or unit management (Cooper, 1990), organizational capital. As argued by Amabile (1998), innovation capital is closely connected to creativity. Innovation capital is also connected to elements of individual capital (Bontis, 1998), such as expertise and motivation (Conti & Amabile, 2011). If considered that an individual's motivation to innovate inside an organization can be intentionally nurtured and influenced by this organization (Amabile & Kramer, 2011; Kofman & Senge, 1993; Thomas, 2000; Ulrich, 1998), elements of organizational capital, such as organizational culture, programs, policies and procedures would be involved in this nurturing effort. Innovation depends on the ability of the creative individual or group to convince and mobilize others, implying the use of their social capital (Oliveira et al., 2018b). The most accurate picture of innovation capital is therefore portrayed by those that place it in the crossroads of the descriptive Intellectual Capital model components, such as Chen et al. (2004).

Innovation capital can be expressed as the ability of an individual or an organization to create a concrete expression of an idea. It also refers to structures in place to foster future innovations. Innovation capital can also be seen as the track of past innovations of an organization, in the sense that it might be an indicator of the innovation potential of that organization.

The discourse analysis performed on the selected innovation, entrepreneurial and participatory capital publications convey a wide representation of the field. Research on participatory, innovation and entrepreneurial capital generally acknowledges and refers to the intellectual capital model, composed of individual, organizational and social capital. Indeed, social capital is both the field and the moving force of participatory capital, as individuals and organizations involvement requires the creation of relationships. It is not to be neglected, however, that the sharing of clients' and citizens' opinions and ideas is and will be more often facilitated by technological platforms, assets whose development is ensured by investments in organizational capital and in which they are included (Oliveira et al., 2018b). Innovation capital is profoundly connected to creativity (Amabile, 1998) and other individual traits, or elements of individual capital (Bontis, 1998), such as expertise and motivation (Conti & Amabile, 2011). It is to be considered that an individual's motivation to innovate inside an organization, specifically, can be intentionally nurtured and influenced by this organization (Amabile & Kramer, 2011; Kofman & Senge, 1993; Thomas, 2000; Ulrich, 1998) and is generally affected by elements of organizational capital.

According to the studied works, the importance of social capital is undeniable. It is an important component of intellectual capital and also adds value or amplifies the existing value of the other types of intellectual capital. The future of intellectual capital seems to lie in the increasing awareness of the importance of social capital. In addition, the reading of the traditional Intellectual Capital model would gain in recognizing new forms of intellectual capital such as entrepreneurial capital, which is connected to innovation and creativity, as well as participatory capital, where citizens are empowered to play a greater role in government policy and decision making.

The results of the study confirmed the three formulated hypotheses. Additionally, it pointed to one intellectual asset not mentioned in the fundamental literature basing the three-pillar intellectual capital model: humor. Humor, identified by Aggestam (2014), is characterized as a personality trait, therefore, part of individual capital. It is to be noted that many intellectual assets have been recognized as individual capital when they are first introduced in the literature. Creativity is itself a good example. Before the intellectual asset gained attention from academicians, it was believed to be an innate personality trait and, as a consequence, some people had it and some people did not. The more an intellectual asset is understood, the more it becomes something that can be taught or at least somehow transmitted. Aggestam argues that humor is a “door opener” (Aggestam, 2014, p. 166), suggesting impact in social capital and maybe in the way other kinds of capital can be converted.

The notion of convertibility seems to partially address the more holistic, macro view of the intellectual capital model that has been advocated by Davidsson and Wiklund (2007). According to this principle, intellectual assets of one kinds of capital can be “converted” into intellectual assets of different kinds of capital. “Conversion” here means that, although a new intellectual asset is created, the motivation and context for its creation and possibly maintenance was originated in another intellectual capital. Although most of the early literature on intellectual capital promotes the notion that intellectual assets can motivate the creation of other intellectual assets, it is a recent claim that those new assets can be of a different kind. Convertibility clarifies the mutual influence of intellectual assets. As an example, project teams’ composition (organizational capital) data could be treated and become the foundation of an organizational directory of internal experts (organizational capital asset, same kind as the original asset) was generally accepted. The notion of convertibility explains that, in addition, an organizational directory of internal experts (as seen, organizational capital) could lead to more connections between employees (a social capital asset) and possibly enhancing confidence in individuals (an individual capital asset).

Another element addressing a holistic view of the intellectual model is “symbolic capital” (Bourdieu, 1986). Further studies are necessary to assess if, according to the intellectual capital model, this element is an intellectual asset or a kind of capital encompassing many intellectual assets. This element is undoubtedly related to tacit knowledge, maybe in the form of organizational culture. It is possibly connected to organizational policies and even procedures.

An example of symbolic capital is how two individuals having comparable individual capital can yield different perceptions of competence. Indeed, female entrepreneurs might be perceived as having less competence to lead a business than their male counterparts because of the symbolic capital attached to “being a woman” (Shaw et al., 2008). Further studies on symbolic capital may explain the creation and legitimization of ideas and their inclusion in organizational culture. In the study (Oliveira et al., 2018b), the association of symbolic capital with social capital was formulated, introducing the concept of social capital effectiveness. Social capital effectiveness is an intellectual asset of social capital that explains why a social interaction or relationship can be effective for some actors and not for others.

The descriptive kinds of capital, named individual, social and organizational capital interact among themselves, sometimes in a way that converts intellectual assets from one kind of capital into intellectual assets of another kind of capital. The new kinds of capital that were studied shed light on the interaction among the descriptive kinds of capital, but they do not present intellectual assets that are not covered by the descriptive kinds of capital. Innovation, entrepreneurial and participatory capital illustrate how individual, social and organizational capital interact in different processes. They were therefore named Process Capital. The consideration that intellectual assets grouped in Process Capital originally stem from the Descriptive kinds of capital helps to understand how each component of the Intellectual Capital model contributes to organizational performance. This consideration also indicates that the Intellectual Capital framework is suitable to support analysis of creativity and innovation phenomena in an organization.

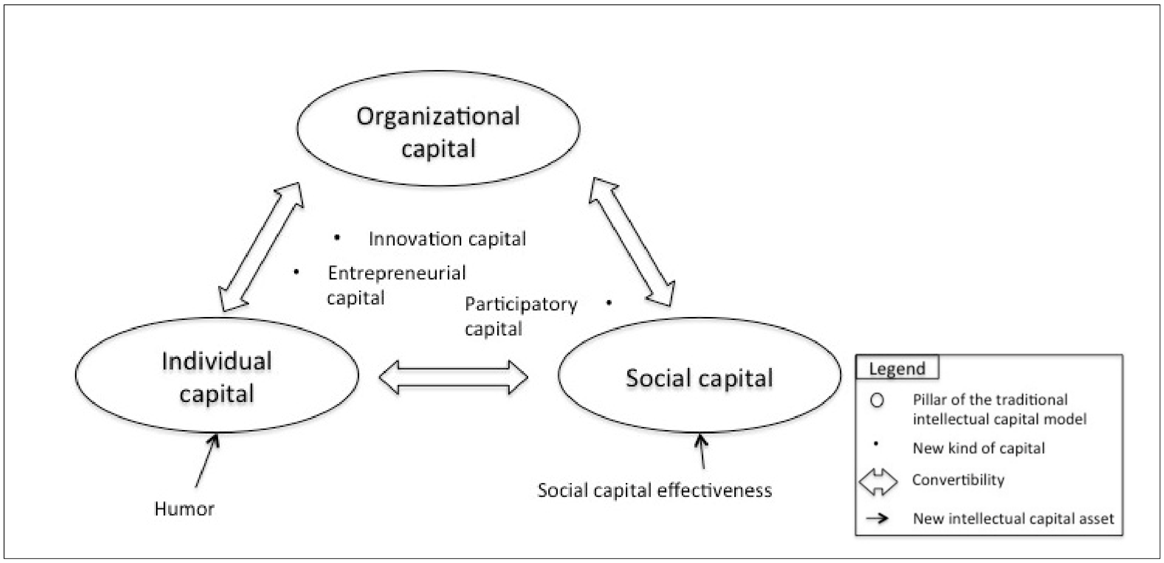

Figure 2.1 An inclusive Intellectual Capital model
Taken from Oliveira et al. (2018b)

The study mentioned (Oliveira et al., 2018b) respected the core premise of Intellectual Capital research, which is to be open and able to recognize value in new types of business endeavors as research focusing on organizations evolves. It made clear that management of intellectual capital can have an impact in innovation and creativity through the influence it has on creation, development and use of intellectual assets considered to contribute to innovation and creativity. The different kinds of intellectual capital have among themselves a relationship that allows for more than the sum of their impact in the life of the organization. They can also engage in a kind of synergy that allows for value to be better sustained over time (Oliveira et al., 2018b).

The Intellectual Capital model as depicted in Figure 2.1 offers a comprehensive outlook of knowledge assets and knowledge management that groups the current perspective of the scientific literature. As such, it is a suitable theoretical framework to represent knowledge characteristics and dynamics in the organizational environment when compared to other dimensions of the organization.

2.2 Social capital

Special attention should be given to the social capital element of the Intellectual Capital model, as this concept sheds light on the dynamics between individuals and the organization.

The traditional model of the firm portrayed very well how a company would thrive in the industrial era. The model of the firm reflected how competitive advantage could be obtained: the company that secured more financial capital ended up having larger production numbers, themselves a result of more production lines, more machinery. Markets were rather regional and consumers rather open to products, their financial capacity being their main obstacle towards consumption of the goods the firm might produce.

Markets have changed and so have consumer's buying decisions. Deregulation, environmental concerns, technological discontinuities, political uncertainties, changing demographics and turbulence in financial markets are some of the elements that Nahapiet (2009) uses to explain the changes in the competitive environments of the United States, Europe and Japan. Janine Nahapiet was one of the first researchers to recognize the importance of social capital, if not the first.

Competitive advantage is not seen the same way (Nahapiet, 2009) as it was before. Access to financial capital is maybe not as restricted as it once was. More machinery does not necessarily mean greater production numbers. Consumers are not necessarily open and willing to buy whatever companies produce. For Nahapiet (2009), the way competitive advantage is seen in the knowledge era "puts connectedness, interdependence and collaborative advantage centre stage" (Nahapiet, 2009, p. 207). The consideration of the organization as an organism, one that is capable of creating, developing and maintaining relationships is essential to understand the new competitive dynamics worldwide. As Drucker (2001) predicted, different kinds of alliances between organizations are the new normal, sometimes ranging from collaboration and competition with the same other organizations, a relationship referred to as coopetition. In addition to being able to forge and maintain relationships with other organizations, there is a need to foster an environment for human-to-human interaction that is conducive to meeting the organization's goals.

The management of social capital becomes a differential for organizations to thrive. Relationships are at the center of social capital. An enormous number of variables influence relationships, which makes the reliance on them a rather risky endeavour. To add to these risks, businesses have a long tradition of securing, cultivating, managing, and drawing value from ownership and labor exploration while securing, cultivating, managing, and drawing value from relationships as a means of obtaining competitive advantage is a new phenomenon.

Relationships can have great influence in how other kinds of intellectual capital evolve. Social capital is extremely situational: what is effective in one context might not be in another; it can have detrimental as well as positive implications for knowledge, learning and ultimately performance (Nahapiet, 2009). Early publications on social capital implied that drawing value from it was just a matter of management directing the effort of their teams outwards (Sveiby, 2001). Training and small changes in the organizational environment would make organizations obtain the best of social capital. Indeed, social capital is very often connected to organizational culture. However, as the literature corpus on social capital evolved, its power and the subtleties of managing it became more clear. For Nahapiet (2009), harnessing the power of social capital implies a change in the way strategy is conceived and put to practice.

Social capital allows for the validation of new knowledge and new ideas, a necessary step before knowledge and new ideas are acted upon and championed by an individual or a group of individuals in the organization, before they become more broadly accepted and integrated in a small or large part of the organizational culture.

2.3 Individuals and the organization

The knowledge-based theory of the firm, resulting from a resource-based perspective (Barney, 1996) or at its essence (Conner & Prahalad, 1996) sees the organization as an organism that, as such, can recombine and apply knowledge (Sveiby, 2001), and learn (Kogut & Zander, 1992). Although somewhat recent, the theory hosts concepts that are four decades old and originated from organizational learning, such as the double-loop learning (Argyris, 1976, 1977, 2002). In this theory, organizations' "ability to attain and keep profitable market positions depends on its ability to gain and defend advantageous positions in underlying resources important to production and distribution" (Conner, 1991, p. 121) and are not only shaped by knowledge, but also shape knowledge and its application by their existence and actions (Conner & Prahalad, 1996). These perspectives and theories lay grounds to understand different ways in which the organization interacts with its own and exterior agents.

Although all assets in an organization are the result of human actions (Sveiby, 1997), the motivating power for the creation of these assets, the individual intellectual capital, is not owned by the organization (Edvinsson & Sullivan, 1996; Roos et al., 1997). A lot of the organizational assets owned by the organization, such as patents, procedures and technology, depend on the exteriorization process described by Nonaka and Takeuchi (1995) and their subsequent codification.

As mentioned in one study,

> When knowledge is codified, written, explained, be it in policies, procedures, detailed estimates, patents or any other kind of document, it can be said to be "explicit". Explicit knowledge is visible, can be regrouped and analyzed without interaction with the people who hold that knowledge. There is however a great amount of knowledge that has never gone

> through the codification process. It is, for instance, the knowledge of which policies apply in a specific case, which procedures interact in a process, what is the consequence of including an information in a detailed estimate and so on. This kind of knowledge is recognized by the term “tacit knowledge”, which covers all knowledge that is not codified. Tacit knowledge may have never been articulated, discussed or exposed to management. (Oliveira et al., 2019b, p. 146)

Individuals are the first to integrate new knowledge, before any new knowledge is embedded in procedures, reports, patents or technology. “The integration of knowledge is a personal skill. It cannot be disposed of or transferred; each person must build it up individually” (K. E. Sveiby, 1997, p. 32). Individuals have to choose which piece of knowledge to acquire, since they cannot acquire the totality of knowledge available. Individuals then make a choice, conscious or not, about what kind of knowledge or expertise to develop. That choice can be influenced by a group or by the organization. Hence the importance of social capital and organizational culture.

Social capital can help disclose and develop the potential of individual capital. In the absence of social capital, individual capital incurs the risk of remaining encapsulated and incapable of generating value. Social capital allows knowledge to be diffused. Therefore, social capital may reduce the risk of knowledge loss.

On the other hand, organizational culture, to positively reinforce the individual’s choice of knowledge to acquire or develop, should include translations of the organizational strategy into operational values that can guide knowledge choice or development.

Knowledge is “the individual's complete set of response possibilities from which a new response is to be synthesized and information against which the new response is to be judged” (Ruscio et al., 1998, p. 257). This image suggests:

- A private, intellectual landscape composed of facts;
- The complexity of this intellectual landscape, composed of successive intricate informational layers of information received, drawn from facts or from other information;
- The knower’s ability to navigate this intellectual landscape and to identify actionable elements that would correspond to an external challenge and, finally;
- The knower’s ability to question these actionable elements against the same intellectual landscape that generated them.

When applying knowledge to practice, individuals read the organizational informational environment, considering both tacit and explicit dimensions of knowledge. Individuals also take into account the informational environment outside the organization, functioning as points of entrance of external knowledge (Shoham & Hasgall, 2005). These processes may however be a part of the individual’s tacit knowledge, possibly difficult to express.

The development of knowledge can be achieved through formal training. The ability to apply that knowledge to practice is however achieved through the development of tacit knowledge. An individual’s tacit knowledge can be built through diversified experience, interaction with other knowers, observation, on-the-job training, mentorship, and other activities with high level of interaction between participants. Individuals develop tacit knowledge through their exposition to learning opportunities that can be diverse in their form and content.

2.4 Tacit and explicit knowledge

2.4.1 Definitions

Knowledge, as per Nonaka and Takeuchi’s SECI model (Nonaka & Takeuchi, 1995), reaches a great milestone when it is expressed in some kind of language. At that point, knowledge can be said to be explicit. Given a knowledge portion, the relationships between its elements and its underlying structure can be externalized in such a level that it can be codified in documents. A good amount of knowledge spends a lot of its existence in people's heads before going through the codification process, while a great amount never goes through that process. For instance, the knowledge of which policies should apply in a specific case, which procedures interact in a process, what is the consequence of including an information in a detailed estimate are examples of knowledge that is only rarely codified, if ever. This kind of knowledge is recognized by the term "tacit knowledge". Knowledge that has been codified in documents was necessarily expressed in some kind of language and is therefore considered explicit. However, through the use of language, the same document might activate different portions and levels of tacit knowledge in the reader.

Knowledge that has never been codified might have been eventually externalized. Knowledge eventually externalized but never codified can be considered explicit as per Nonaka and Takeuchi's SECI model. The ephemerality of the expression of this knowledge, however, envelopes this knowledge in the characteristics of tacit knowledge: difficult to identify, to index or model. Therefore, knowledge eventually externalized but never codified is usually addressed by the term tacit knowledge. Never codified explicit knowledge can however be shared and promote the validation of this knowledge. When different individuals can reach the same conclusions together or expect the conclusions the other individual will reach, it can be said that these individuals can collectively produce tacit knowledge. These individuals understand a common set of norms and interpretation paths, although maybe never externalized.

It is more suitable to think of knowledge externalization as a continuum. On one end, knowledge that has never been externalized, the tacit knowledge, can be found; on the other, knowledge that was codified. In the middle, knowledge that has faced different levels of exteriorization and with variable frequency. The perennity of this knowledge can somewhat be ensured through different levels of language use. It is the case of drawings, presentations, concept maps, data models and interface mock-ups, to name only some examples. The language use and the externalization level of this knowledge does not justify the employment of the term “codified knowledge”. This knowledge is better addressed by the term “captured tacit knowledge”.

2.4.2 Tacit knowledge

The exteriorization process allows tacit knowledge to be articulated (Nonaka & Takeuchi, 1995). At the end of this process, the piece of knowledge in question becomes more easily shareable, explored and subsequently acquired by others. In Nonaka and Takeuchi’s (1995) terms, the knowledge becomes “explicit” without, however, suppressing the tacit knowledge at its origins.

Tacit knowledge exists in people’s heads but might be common to a certain group. For example, professionals in the same function might develop a common understanding of which policies should apply to a specific case. Although those professionals might not come to the exact same list of policies covering a specific case, a core understanding might still be observed. That core understanding may have been developed individually, through the exposition of individuals with similar background to similar experiences. It might also have been developed through the interaction between individuals, sharing their perceptions, their reasoning behind decisions made and experiences. That core understanding might be achieved through exposition of individuals to similar experiences or through a group effort.

A group of individuals interacting in a knowledge development effort will develop a common understanding of reality, even if that common understanding can be limited. Even if individuals of the group do not agree in many points, making consensus difficult, they share the understanding of the underlying structure of the tacit knowledge that is particular to that group. Each learner that is part of that group is potentially closer to understanding the reasoning of any other individual of that group than is any other individual that is not a part of that group.

Considering that tacit knowledge has as its medium people's minds, it cannot be exposed, transferred or in any case put to application without interaction with the people who hold it. Tacit knowledge has limited visibility if compared to codified knowledge, which can be easily diffused to a great number of people. Tacit knowledge may be less visible but is still the doorway for the application of the organizational knowledge to the operational environment (Shoham & Hasgall, 2005). Apart from ensuring codified or explicit knowledge to be suitably applied to the operational environment, it is tacit knowledge that enables flexibility, out-of-the-box thinking and innovation.

It should also be argued that literacy levels of people involved in business is not the same as thirty years ago. The increase in literacy levels of people involved in business has reduced the distance between academia and business (Fuller, 2012). Knowledge production in the industry with a rigor comparable to the one employed in academia has increased (Gibbons et al., 2010). The high level of knowledge production suggests a prominent presence of tacit knowledge.

For an individual to translate a piece of knowledge into action, this knowledge has to have been validated (Mokyr, 2000). Validation occurs through rhetorical conventions that are recognizable by knowers as accepted by the group to which the knowledge is submitted (Mokyr, 2000). As a consequence, knowledge validation depends on the existence of a language that supports the expression of that knowledge, a group of individuals able to understand that knowledge and on the existence of rhetorical conventions established by the group to validate new knowledge.

The validation process might be influenced by the notion of symbolic capital even before its beginning. Symbolic capital is portrayed by Bourdieu (1986) as a reading of facts and information that is somehow suggested by culture. The exploration of the concept in the study on the application of the Intellectual Capital model to creativity and innovation (Oliveira et al., 2018b) suggested that symbolic capital is also present in organizational culture. Symbolic capital being applicable to the reading of information and facts, it might also be applicable to knowledge. In practice, symbolic capital applied to knowledge development would mean that employees consider the potential of acceptance of a specific kind of knowledge before choosing to acquire or develop that kind of knowledge. Employees might also identify ways to approach knowledge that are potentially more acceptable by the organization than others.

A practical example would be a data analyst that sees a need for enhancement of data visualization at work and takes the initiative to explore data visualization tools. This analyst might choose to learn how to use open-source data visualization tools if they are in an organization that has a historical track of approving open-source tools for internal use, as opposed to an organization having most of its technological application tools in use built in proprietary code. Although there might not be an explicit reinforcement of the choice of open-source versus proprietary code in the organization, employees might identify in the company history and *modus operandi* an indication of the potential of the acceptance of the knowledge to be acquired. In that sense, a knowledge selection would be performed even before the validation process. That selection would be reinforced by the results of the validation process of new knowledge, solidifying organizational history employees' perception of the company's *modus operandi* in what involves knowledge acquisition.

The knowledge validation process might therefore be the way in which intellectual capital assets such as organizational culture, policies and procedures influence the choice of knowledge to be acquired, validated and ultimately, put to practice. That premise indicates that information technology tools and implementation are influenced by knowledge validation processes or, at least, by organizational culture.

Although symbolic capital might suggest readings of data and information and influence knowledge acquisition and development, it does not suppress the potential for ambiguity in language. Variance of meaning, or semiotics, is a natural element of human communication, and a consequence of the existence of different backgrounds, beliefs and experience. Different backgrounds, beliefs and experience means the assignment of different meanings to the same words and symbols. Language is, therefore, a medium that is subject to different interpretations. Language is the medium that allows for the exteriorization of knowledge, or the transformation of tacit knowledge into explicit knowledge. For knowledge to be discussed and validated, it has to be exteriorized. Knowledge validation processes depend on the exteriorization of knowledge in some kind of language. That language is prone to semiotics. Semiotics account for the cultural richness in society, but in a performance-intensive environment, it can be a source of misunderstandings, frustrations, and barriers to collective work. Even in environments meant to support the work of professionals of different backgrounds, such as *Building Information Modeling* environments, misconceptions and misunderstandings might happen as a result of lack of support of communication and knowledge-related processes among professionals (Oliveira et al., 2018a). The knowledge validation process is one that involves many challenges on its own.

In the knowledge economy, any employee has an informational environment inside the organization to navigate in order to assess acceptable courses of action in their roles. The employee's understanding of the organizational environment and the surrounding environment – their tacit knowledge – is crucial when selecting informational sources.

The way individuals develop and apply their expertise seems particularly influenced by the context surrounding the individual. In a historical analysis of knowledge, technology, and economic growth in the Industrial Revolution, Mokyr (2000) points out two ways in which the context influences the development of knowledge – a term employed with sensibly the same meanings as the term "expertise" in creativity studies. First, individuals have to choose which piece of knowledge to acquire, since they cannot acquire the totality of knowledge available. Second, for an individual to translate a piece of knowledge into action, this knowledge has to have been validated through rhetorical conventions accepted in society. It is to note that the validation of knowledge that Mokyr (2000) refers to is a function of a more or less large group of individuals.

2.4.3 Tacit knowledge and language

In the exteriorization process, knowers create a mental model (Cowan & Foray, 1997; Nonaka & Takeuchi, 1995) and translate that mental model into some kind of language (Brannen, 2004; Cowan & Foray, 1997; Eco, 1976; Gibbons et al., 2010; Mokyr, 2000; Nonaka & Takeuchi, 1995; Redman et al., 2017). The clarity among informational layers in the knowledge made explicit seems to be a result of both processes: the creation of mental models and their translation into language.

Considering the exteriorization process as a continuum, “tacit” and “explicit” knowledge are terms that represent more or less the point in the exteriorization continuum a certain piece of knowledge has reached. This continuum can be analyzed in the individual dimension: a piece of knowledge that an individual has never articulated is “tacit”, whereas the reports this individual creates convey “explicit” knowledge. This continuum can also be analyzed in the group dimension: “tacit” knowledge can represent knowledge that has rarely been externalized, but that is common to a certain group. The tacit knowledge of an individual will influence how this individual internalizes explicit knowledge. In the same lines, the tacit knowledge of a group will influence how this group internalizes explicit knowledge.

The creation of a language-sharing community entails the creation of a local, specific culture (Brannen, 2004; Mokyr, 2000). The creation of a local culture fosters a common understanding of knowledge (Florida, 1995) and, particularly, of codified knowledge (Brannen, 2004; Mokyr, 2000). However, beyond natural languages such as English and French, communities with a common interest may develop a specific vocabulary (Barley, 1983; Cowan & Foray, 1997). A particular vocabulary, jargon, terminology or even notation increases the cost for accessing knowledge (Cowan & Foray, 1997; Mokyr, 2000) or, in other words, restrain the entrance to a community employing particular language. In addition, the difficulty to enter a community may be increased by exclusionary practices, be them intended or not (Mokyr, 2000).

In a natural language, many meanings can be associated with a word (Eco, 1976). A local, specific culture creates context, a content plane in which the possible meanings are reduced (Eco, 1976) and to which mental models are somewhat related (Cowan & Foray, 1997). The number of possible intended meanings of a word is greatly reduced when that word is used in a specific culture. For example, something "transparent", in natural language, is "translucid", "diaphanous", "see-through". The word suggests something that one forgets that is there, something that does not block the view, that allows one to see everything else, something that is itself difficult to see. In Information Technology, "transparent" is said of a procedure that does not disturb the user in any way, or that the user is not aware of. In Law studies, "transparent" means that a specific portion of information is disclosed.

The variance of meaning is often addressed by the term "semiotics". Semiotics are a natural phenomenon in human communication. Different backgrounds, beliefs and experience, of individuals and groups result in naturally different assigned meanings to the same words and symbols. Some level of ambiguity is always present in any kind of document. The same idea can be expressed in knowledge terms: the interiorization of explicit knowledge depends on the tacit knowledge existing in the individual. In other words, expressing knowledge through language does not eradicate ambiguity. Codified knowledge is not immune to misinterpretations.

Arduin et al. (2015) portray documents and information systems as a valid channel to both help provide structure to knowledge and diffuse it, suggesting that documents and information systems play the same role as a language in the translation of a mental model.

For example, to represent a real object in an information system, the user must identify its corresponding conceptual object. The matching conceptual object is categorized in a certain way in the system, is related to other conceptual objects and, most probably, its creation must respect a number of mandatory fields. Even if the conceptual object in question, among all other conceptual objects available in the system, is the most suitable for representation of the real object, its categorization, the relationships and the mandatory data might not correspond to the real object in question. Whereas information systems can provide ample means of codification and diffusion to real objects that were considered in their design, it is not the case for real objects that were not considered. In the described situation, users are faced with the decision of abandoning the representation process, creating noise in the data by entering fictitious values – reducing the system's reliability - or opt to less restrictive ways of codification, such as spreadsheets and text documents. Comparing to the information system designed and supported by the organization, however, ad hoc spreadsheets and text documents have much less visibility to other potential users, limiting the diffusion of the knowledge they contain.

The creation of an information system and other technological solutions implies the translation of a mental model through a choice of how to express the knowledge in question, similarly as the process described by Cowan and Foray (1997) above. This choice is also made from a rather large, if not unlimited, number of possible meanings offered by the programming language, design and data manipulation techniques, similarly to the process described by Barley (1983) and Eco (1976) above. Regarding natural language, the translation of a mental model consists in choosing the words conveying the meanings that knowers see fit to describe the knowledge in question (Cowan & Foray, 1997) from an unlimited number of possible meanings offered by the chosen language (Barley, 1983; Eco, 1976).

The existence of the same labels to describe different content, and sometimes different labels for the same content, is a manifestation of a phenomenon known as "semantic heterogeneity" (Kadiri & Kiritsis, 2015; Kermanshahani, 2009). While there is a technological aspect to heterogeneity in multiple databases, such as one field versus multiple fields for the same information; object-oriented supported databases or not; different constraints in query languages and in system aspects (Sheth, 1999), semantic heterogeneity results from the fact that the knowledge originating each database is sensibly different.

To promote the transmission of the intended meaning from the sender to the addressee through a message, explains Eco (1976), both sender and addressee are supposed to know the entities and events around the meaning, be them mentioned or not in the message. Where the addressee is not aware of the related entities and events, they might interpret from the text something that is different from the sender's intent. If the addressee refers to a content plane that is different from which the sender used, the message may make perfect sense to the addressee, although it does not convey what the sender meant (Eco, 1976). The addressee may have misunderstood the message as it was intended by the sender by far and yet have the confidence that the message was well understood.

Semiotics account for the cultural richness in society. However, in a performance-intensive environment, it can be a source of misunderstandings, frustrations, and barriers to collective work.

2.4.4 Codification efforts

When knowledge is codified, written, explained, be it in policies, procedures, detailed estimates, patents or any other kind of document, it can be said to be "explicit". Explicit knowledge is visible, can be regrouped and analyzed without interaction with the people who hold that knowledge. It could thus be argued that the access cost to knowledge is reduced once this knowledge is codified and made accessible. Similarly, explicit knowledge also reduces the risk of knowledge loss. Tacit knowledge residing on people's minds, access to this kind of knowledge is suppressed when the individual that holds that knowledge leaves the organization.

Whereas the access to tacit knowledge is limited to the level of interactions with the individual holding that knowledge, codified knowledge can be stored and shared without interaction with the knower and can survive their departure from an organization or even death. Codified documents produced in the organizational environment are very often considered property of those organizations. It is then understandable that the codification of knowledge became central to modern processes of dissemination, transfer and retention (Cowan & Foray, 1997).

The properties of explicit knowledge are sometimes argued as properties of information, perhaps because the informational layers that compose knowledge are more easily navigable when the knowledge is made explicit. In the exteriorization process, knowers create a mental model (Cowan & Foray, 1997; Nonaka & Takeuchi, 1995) and translate that mental model into some kind of language (Brannen, 2004; Cowan & Foray, 1997; Eco, 1976; Gibbons et al., 2010; Mokyr, 2000; Nonaka & Takeuchi, 1995; Redman et al., 2017).

A community of agents that can understand the language in which a piece of knowledge is codified is a requirement for knowledge codification (Cowan & Foray, 1997). The distance between learner and knower, however, is much shorter than in the process of tacit knowledge sharing. As explored above, learner and knower might need to share experiences or background for the first to grasp tacit knowledge from the latter. However, the level of explicitness necessary for codification makes much of the content explicit, drastically reducing the need for interaction between learner and knower. The reduction of need for interaction between learner and knower explains the quest for codification of knowledge and its extensive use in knowledge diffusion. Explicit knowledge was instrumental in department integration, data production and software implementation. It was, therefore, also instrumental for the first implementations of product lifecycle management.

The development of the Knowledge Management (KM) field reflected the importance given to codified knowledge. It is also understandable that early Knowledge Management initiatives, based in the Intellectual Capital approach before the emergence of new kinds of intellectual capital, stress the importance of knowledge codification. The incorporation of knowledge that was once only tacit, therefore individual intellectual capital, into organizational intellectual capital through the process of exteriorization and codification served as a basis for the phenomenon acknowledged by Nelson et al., (2002), that some organizations strongly enforce knowledge dissemination through its codification. Once documents, technological solutions or other kinds of artifacts containing codified explicit knowledge are created, their ownership can be assessed, conveyed and protected. Codified explicit knowledge in an organization is usually considered property of the organization and is legally protected (e.g. through patents, copyright or non-disclosure clauses).

Dalkir (2017) argues that the first generation of Knowledge Management was more focused on the development of technological solutions to support knowledge management; it preceded two other generations, one more focused on connecting and managing tacit knowledge and the current phase, more focused on content management.

The focus on codification of the first generation of the Knowledge Management field shifted to studies mostly identifying and mapping tacit knowledge, produced in its second-generation phase, and is now turning into a phase more focused on content (Dalkir, 2017). The current Knowledge Management phase is exploring the processes of tacit knowledge identification, exteriorization and codification with more regard to the impact of the knowledge in question. Knowledge Management is shifting from the strategy of codifying all knowledge (first generation), through identifying all existing knowledge that has not been codified (second generation) to specific strategies according to the specific knowledge pocket in question (third generation).

The exteriorization and codification of knowledge reduces the risk of knowledge loss. Many initiatives in Knowledge Management focus on codifying tacit knowledge – creating documents out of the existing tacit knowledge. This process can be costly as expressing tacit knowledge requires time from the knower. If a person holds tacit knowledge that is recognized as valuable enough to be documented, chances are this person has many responsibilities in the organization. Allowing time for documentation of tacit knowledge often means a difficult trade-off with time spent on operational or managing activities.

Codification allows for continuity and better diffusion of knowledge. It helps prepare new employees for the practice. Also, through the management of organizational memory, codification helps organizations foster incremental innovation and better adapt for disruptive innovation. A balance between the exploitation of tacit knowledge and codification efforts has to be achieved, however. Codification efforts prepare for the future, whereas the exploitation of tacit knowledge allows for its value extraction in the present.

There is also a balance to be achieved between the reliance on codified knowledge and the reliance on tacit knowledge. The codification process implies a process of validation of the knowledge. The knowledge that has been codified in an organization is knowledge that has been culturally vetted and is accepted to be valid, suitable, correct. However, tacit knowledge allows for the application of codified knowledge. When an employee strictly follows codified knowledge, they incur less risks of having their actions criticized or reproached. It is nevertheless the application of tacit knowledge that increases the adaptability levels of an organization, for their connection with creativity and innovation. It can be said then that organizations that strongly enforce knowledge dissemination through its codification (Nelson et al., 2002), be it in documents or information systems, might face the undesired effect of organizational rigidity (Arrow, 1974) and incur "unfortunate consequences for creativity and radical change" (Cowan & Foray, 1997, p. 616). According to Daiyun and Pichon (2004), however, there is a silver lining: mental models' transfer may sometimes still be successful in limiting languages if an "intentional effort" or a "poetic presence" is employed by the agents involved (p. 32). How to integrate "intentional effort" or "poetic presence" into information systems design is yet to be explored. Placing employees in the position of informants about how things actually work in the organization and promoting conditions for dialogue between departments has nevertheless demonstrated to be a good technique to reduce conflict (Schein, 2013).

Access to codified knowledge can be granted to a great number of individuals, whereas access to the individuals possessing the tacit knowledge that originated its codified version is limited

(Dalkir, 2017). The cost of accessing knowledge is not negligible in terms of time and often other resources as well (Mokyr, 2000). It could thus be argued that the access cost to knowledge is reduced once this knowledge is codified and made accessible. Declining access costs are instrumental in the rapid diffusion of new useful knowledge (Nelson et al., 2002). It is then understandable that the codification of knowledge became central to modern processes of dissemination, transfer and retention (Cowan & Foray, 1997).

2.4.5 Tacit knowledge collective production

Joint production of tacit knowledge demands a shared context and some closeness between teams. Each of the employees would contribute to a changing blend of experience, values, contextual information and insights of experts, which would make the knowledge of the organization (Davenport & Prusak, 1998). The collective production of tacit knowledge is achieved when knowledge is diffused and socially validated.

2.4.6 Tacit knowledge capture

Tacit knowledge capture was explored in Oliveira et al. (2021b):

> The term "tacit knowledge" refers to knowledge that has not been expressed in any kind of language (Nonaka & Takeuchi, 1995). "Explicit knowledge" addresses the knowledge that has been articulated to the extent that it can be understood without needing direct access to the holder of that knowledge. Consider a continuum of media that hold knowledge. Human minds would be on one extreme whereas documents would be on the other. The knowledge that resides in human minds is named tacit knowledge. To be codified, knowledge has to be exteriorized (made explicit) to some level, one that makes it possible to use of natural language. The knowledge that was exteriorized to the

> level needed for codification allows for a more or less complete understanding of the topic without the need to talk to the original holder of the tacit knowledge. This study explores a medium that is between human minds and documents, a medium that requires a less difficult exteriorization process. This medium offers a range of possible meanings but depends on the original holder of the tacit knowledge to be fully understood. The somewhat exteriorized knowledge cannot be said to be explicit, as it is not independent from the tacit knowledge at its origins. It is therefore named "captured" tacit knowledge, to convey the meaning of an incomplete exteriorization process. Captured tacit knowledge differs from explicit knowledge in the sense that it keeps most of the multifaceted nature of tacit knowledge, requiring reconstitution of context in order to be accurately conveyed and understood. (Oliveira et al., 2021b):

2.4.7 Capture of different perspectives

In Building Information Modeling environments, technical interoperability has been addressed by the development of standards and long-term use of BIM tools (Howard & Björk, 2008). However, business interoperability is yet to be fully supported in order to expand collaboration (Liu et al., 2017). The multidisciplinary perspectives the same object can take in Architecture/Engineering/Construction (AEC) and the lack of tools that can support them seem to be in cause (Lee & Jeong, 2012).

Very few studies addressed different context or environmental elements in the interpretation process of ontologies (Santos et al., 2017). As observed by Cerovsek's (2011), there is little attention paid to the different meanings and interpretations the same object or object characteristics may take – the semiotics - of communication in AEC.

The Information Delivery Manuals (IDM), guiding BIM implementations, represent the effort to connect and describe the context (Laakso & Kiviniemi, 2012). They are intended to provide directives to represent what is the place of a process, what is its relevance, the actors around the information represented, the information itself and how it should be supported by applications (Wix & Karlshoej, 2010). However, as Eastman, one of the most prominent scholars studying BIM (Zhao, 2017), argues, the use of IDM is only a first step towards answering the need for full interoperability in BIM tools (Eastman et al., 2010).

AEC work is a good example of the limitations that specific cultures may impose. A lack of interoperability may be a consequence of the multidisciplinary perspectives the same object can take and the lack of tools that can support them (Lee & Jeong, 2012).

2.4.8 Context

For Lee and Jeong (2012), the people involved and the purpose of the information are the key elements to identify context in BIM projects.

In a professional data integration initiative to provide faster and more convivial access to an organization's client-related data, three databases had a field labelled "partner", intended to codify the name of a client's life partner. One department considered that a client's partner was the last one that the client verbally declared in any communication with the organization. Another, the last one mentioned in a written statement with a recognized signature. Another yet, the person the client requested to be included in the client's product. Unaware that different departments had different definitions for the term "partner", the data analysis team was faced with a good proportion of clients having two or sometimes three different "partners" for the same period of time. The mental models behind the labelling of each field in each database were different, as were the ways data were collected. It was not a problem while each database was only used by the department that originated the mental model, but it became one when data integration was aimed.

The effort needed to translate an idea to a different content plane might shed light on the kind of misunderstanding that might happen when this effort is not present. When translating one idea to a different content plane, a different term might be needed (Eco, 1976). Sometimes, adding other terms, or even an explanation, are needed to express the original idea (Bin, 2004). In the example above, the first label could have been “partner - marketing”, the second, “partner - documented”. Sometimes the idea itself has no correlation in another content plane; an analysis of the roots of the idea has to be made in order to find possible similar ideas that can be expressed in another content plane (Brannen, 2004). In the example above, the third label could be “joint - client” and bear an explanation: only common-law partners and spouses were admissible until 2010.

Somehow representing the organizational culture context when analyzing data can be particularly important in machine-learning projects. For example, during the COVID-19 pandemic, important social movements made organizations implement changes. For instance, the gender-gap recognition and the Black Lives Matter movement made organizations implement policies or procedures intended to extend or adapt the analysis of job applications of persons identifying as women or members of Black and Brown communities. It was expected that the recruiting behavior of these organizations would change from the moment those policies or procedures were adopted. Machine-learning projects associate the outcomes of a process with data surrounding that process. Datasets are used to create algorithms that produce similar outcomes for the same process. The organizational changes mentioned, however, intended to alter the outcomes of the job application analysis. In that sense, the datasets intended for machine-learning projects involving job application analysis would have to be limited to the data produced after the implementations of more inclusive policies and procedures in the organization in order to reflect the new outcomes. Alternatively, other measures to limit the influence of the data generated before the change should be adopted. In this example, identifying the data as pre or post policies and procedures implementations would have an impact in the acceptability of machine-learning projects.

2.4.9 Ontologies

Classification schemes aimed to serve the whole organization might lack the needed flexibility for use in specific departments, even when it respects acclaimed principles of records management. Indeed, in the study involving the experience of a subject matter expert (SME) with the organizational classification scheme (Oliveira et al., 2019a), a high level of frustration was expressed. Following the organizational classification scheme rules, the work of the SME's team would be scattered across five different categories, which turned the information retrieval process cumbersome and more prone to errors. The SME's team also had difficulty satisfying the need of long-term analysis over a specific problem, as their work would be classified according to the year of production of each analysis report.

Ontologies present concepts and their relationships as they are perceived by an individual or a group of people (Gruber, 1993) in a machine-readable format.

In Building Information Modeling, ontologies have been developed and implemented to help increase knowledge flow and business interoperability. Ontologies have been considered as a means to foster collaboration in AEC environments exchanging BIM, but very few studies addressed different context or environmental elements in the interpretation process of ontologies (Santos et al., 2017). Not much have been said about communication in BIM projects and its relation to ontology use (Cerovsek, 2011; Santos et al., 2017).

2.4.10 Tacit knowledge capture and organizational learning

The cost of knowledge access should be considered in the development of a learning organization. The cost of accessing knowledge is not negligible in terms of time and often other resources as well (Mokyr, 2000). Declining access costs are instrumental in the rapid diffusion of new useful knowledge (Nelson et al., 2002). Social capital allows for the reduction of knowledge access cost. In this sense, social capital contributes to the development of a learning organization.

Another factor of the development of a learning organization, the development of the organizational memory, is also facilitated by social capital. Social capital is the fabric that allows knowledge to be consistently diffused, therefore reducing the risk of knowledge loss.

Tacit knowledge is multifaceted, not articulated in language, expresses context and is dependent on social validation to be applied by a group. Organizations intending to promote access to this kind of knowledge must integrate its ambiguity and promote a culture that enables social capital.

2.5 Creativity, innovation and knowledge

2.5.1 A creativity-enabling environment

Creativity requires three main elements to express itself: motivation, expertise and creative skills (Amabile, 1998). Creativity studies tend to situate the role of expertise in creativity as a highly individualistic asset. The creative spark is a rather private, human event (Amabile, 1998; Xu et al., 2010), although it can be influenced by the environment surrounding the individual. The conditions surrounding creativity manifestation can and should be managed (Amabile, 1998). This individualistic view contrasts with trends in creativity studies. Creativity Management literature, as the “theorizing and research surrounding the creative process” has mostly targeted groups (Hennessey & Amabile, 2010, p. 579). Group work scores higher in many creativity measures than individual work and in most organizational settings collaborative work is expected (Hennessey & Amabile, 2010).

2.5.2 An innovation-enabling environment

Ideas in business environments are required to be, in addition to original, “appropriate, useful and actionable” (Amabile, 1998, p. 79). Once the creative spark is generated, it has to find its way in the organizational structure in order to be transformed in innovation, commercialized or otherwise implemented in or by the organization. Creativity is analyzing a new problem or an old problem in a different way. Cultivating knowledge allows the collection of potential problems and the creation of a setting where different ways to approach them are possible. Innovation is the implementation of the solution that results from that analysis.

As competitive advantage is more and more defined as the ability to drive innovation, the organizational ability to transform creative ideas into innovation becomes the key objective for an organization to thrive in the market. Continuous innovation may be the only chance of the organization to survive. In addition, the organization’s internal knowledge may be not enough to foster innovation in a level that makes the organization achieve its objectives. In those cases, the organizational internal ability to transform creativity in innovation has to be enhanced by an opening to external input. Social capital can provide access to resources that are essential to the organization but are outside its boundaries (Nahapiet, 2009). In other words, organizations lacking knowledge to implement innovations, if effectively capable of managing their social capital, may thrive with the help of other organizations.

2.5.3 Knowledge, creativity and innovation

Knowledge is often mentioned in creativity studies as “expertise”, an umbrella term that involves both tacit and explicit knowledge. Tacit knowledge allows for application of explicit knowledge and also enables flexibility, out-of-the-box thinking and innovation.

Codification of knowledge requires language (Brannen, 2004; Cowan & Foray, 1997; Eco, 1976; Gibbons et al., 2010; Mokyr, 2000; Nonaka & Takeuchi, 1995). As a consequence, it might be difficult or even impossible to express concepts for which there are no viable representations in the language in question. The absence of a viable representation may result from the increasing specification of a language (Cowan & Foray, 1997) and does not spare organizations (Zellmer-Bruhn & Gibson, 2006).

Considering that creativity requires expertise to come to light, persons that hold a high level of tacit knowledge around their practice might be the ones that can more easily conceive new ideas or more effectively help existing ideas turn to a feasible and profitable form. These persons might also hold important operational or managerial responsibilities, or both. Dedicating these persons' time to codify tacit knowledge means reducing these persons' time to engage in social capital activities, sharing and collectively creating tacit knowledge. In that sense, the trade-off implied in the codification of tacit knowledge might not only impact operational and managerial activities, but also limit the collaboration of the individual in question in the innovation process of the organization.

In the intellectual capital framework, knowledge is not considered an object that can be managed in its essence (Craven, 2020), but an asset that can be influenced, just like creativity is considered in creativity research. K.-E. Sveiby, owner of a publishing company and a manager himself (Gurteen, 2020) asserted the influence of the individual's environment on knowledge using sensibly the same notions evoked by Ruscio et al. (1998) mentioned, in regard to expertise in creativity studies: "we make sense of reality by categorizing it into theories, methods, feelings, values, and skills that we can use in a fashion that tradition judges to be valid" (Sveiby, 1997, p. 32).

Daiyun and Pichon (2004) mention that the strong use of technology may hinder the transfer of mental models. The development of radically new knowledge is then compromised because it cannot be expressed (Cowan & Foray, 1997; Zellmer-Bruhn & Gibson, 2006). It is possible that the effects seen by Daiyun and Pichon (2004) do not stem from the strong use of technology itself, but from the way this technology is developed and integrated into human's actions with the environment and with other humans. Maybe the strong use of technology does not necessarily imply less possibility for human intervention, less human interaction, less human realization of its inherent potential. There are possibly ways to conceive, design, develop and implement technology that consider creativity, through different uses of language and the multiplication of occasions for employees to express tacit knowledge. One such approach is the use of concept maps.

2.6 Research questions

This research aims to identify whether recommendations relative to knowledge management (KM), specifically tacit knowledge management, and creativity and innovation management apply to product lifecycle management (PLM). It also aims to identify if the practice in product lifecycle management already takes those recommendations, if needed, into account. The results of this research should help designers of specialist systems to design the informational environment behind those systems. In other words, the results of this research should help designers create the mental model behind interfaces aimed at supporting knowledge intensive tasks.

To achieve this objective, a number of research questions apply:

1) Research question one: Is there a need for inclusion of tacit knowledge in PLM?
2) Research question two: Is there a need for increasing creativity or innovation potential in PLM?
3) Research question three: Is the current strategy to include tacit knowledge in PLM suitable to PLM needs?
4) Research question four: Can a tool address tacit knowledge capture?

These questions will be answered through both theoretical and empirical exploration.

2.7 Concept maps

Concept maps represent concepts through one or two-word terms consisting of the "subject matter of the phrases (nouns or adjectives)" (Rovira, 2016, p. 61) inside forms, the "nodes" (Lambiotte et al., 1989, p. 333). Nodes are connected with lines, representing the relationship between concepts. Two nodes and a line stand for a proposition, or the combination of two concepts with the relationship that connects them (Ruiz-Primo & Shavelson, 1996).

Concept maps have been the object of sustained interest from internet users over the past five years (Google, 2021). Convergently, the scientific literature review has conferred increased space to the topic, with the number of published articles increasing exponentially in the past five years: while 66 articles were published on the topic in 2015, in 2020 2005 articles explored the topic (Clarivate Analytics, 2021).

Technological solutions to support of the production of concept maps are numerous in the market (Koblentz & Kattau, 2017). While some of these solutions try to mimic human behaviour in concept mapping (Nunez-Mir et al., 2016), other target a more integrated approach with other tasks of the user population. For these applications, a deeper understanding of the diversity with which concepts maps can be designed may be helpful. Understanding this diversity can inform the development of technology specific for representing collective knowledge or rather adapt existing technology for this purpose.

Concept maps were originally developed to increase learning capabilities of students in elementary school (Novak & Cañas, 2009), but were soon employed in undergraduate and graduate learning (Markham et al., 1994), solidifying their usefulness in science education (Novak, 1990). In the educational environment, concept maps have been used in testing (Jamieson, 2012; Ruiz-Primo & Shavelson, 1996; Srinivasan et al., 2008), instructional design (Daley et al., 2016; Daley & Torre, 2010) and curriculum development (Markham et al., 1994).

Corporations have also benefited from the use of concept maps. Zopounidis and Doumpos (2002), for example, identified seven major fields where such concept maps were used to help increase performance:

1) Medicine;
2) Pattern recognition;
3) Human resources management;
4) Production systems management and technical diagnosis;
5) Marketing;
6) Environmental and energy management or ecology and,
7) Financial management and economics.

The magnitude of the usefulness of concept maps justifies the research for ways to automate or support their production process (Zopounidis & Doumpos, 2002).

Generally speaking, in educational settings, the process of creating a concept map helps students relate different concepts of the domain explored (Dansereau, 2005). Once the concept map is ready, it serves as a tangible representation of the domain and helps the student recall the propositions of the domain (Lambiotte et al., 1989). In knowledge management, concept maps are used to produce "visual representations of complex knowledge domains that meet social scientists' standards for rigor and reliability, while being easily interpretable to practitioners" (Petrucci & Quinlan, 2007, p. 27). The collaborative design process of the concept map may be itself a team-building activity involving a lot of articulation and negotiation skills (Freeman & Jessup, 2004; Stoyanova & Kommers, 2002).

2.7.1 Concept maps and knowledge

Concept maps are “an effective and efficient way to represent knowledge” (Lambiotte et al., 1989, p. 331). Simply put, concept maps are graphical tools for organizing and representing knowledge (Novak & Cañas, 2009).

Stoyanova and Kommers (2002), stating that while information can be transmitted using only verbal structures, knowledge "needs to be constructed as a web of meaningful connections" (p.112), suggest that concept maps might one of the few ways to portray a knowledge field.

Humans process information better if it is presented in manageable chunks (Miller, 1956). Concept maps can convey a simplified portrait of a knowledge field because they compartmentalize similar elements under the same topic, offering less elements for analysis at a time. This illusion of reduced complexity facilitates the absorption and understanding of a knowledge domain.

Concept maps' potential in transmitting knowledge has reserved them a variety of uses both in academia and industry. Concept maps also contribute to knowledge sharing, an activity strategically important to organizations (Navimipour & Charband, 2016). Among other uses in organizational settings are knowledge field explorations (Freeman, 2004; Vincent & Ross, 2001), communicating a vision (Trochim, 1989; Weber & Manning, 2001), knowledge mapping activities (ConceptDraw, 2017), creating a common understanding (Eppler, 2006; Trochim et al., 1994) and engaging in participatory research (Windsor, 2013).

A concept map design exercise entails multi-dimensional work (Lambe, 2002; Nesbit & Adesope, 2006; Pike & Gahegan, 2007). Collaborative creation of concept maps has been mentioned in the literature under the terms “participatory diagramming” (Kesby, 2000) and “diagrammatic elicitation” (Umoquit et al., 2013). They allow for the identification of common knowledge zones (Hughes & DuMont, 2002) between one or more groups. The same exercise helps identify the knowledge zones that are particular to one specific group. If the inclusion of data pockets, information systems, documents and processes descriptions and the representation of their connection to knowledge zones are incentivized, collaborative creation of concept maps can help identify possible connections among information systems and among processes of different groups. Collaborative concept maps creation might also be a valuable tool for assessing data semantic heterogeneity. Concept maps' capacity to promote the construction of shared meaning assured the tool the recognition as a feminist research method (Campbell & Salem, 1999).

Concept maps have been used to help physicians better express the reasons why they did not always follow directives in drug prescription (Steinman et al., 2010) or in their practice in general (Steinman et al., 2010; Stuit et al., 2011; Ting et al., 2011); to help teams involved with knowledge management systems development (Andreasik, 2007; Baracskai & Velencei, 2004); in software development (Jabar et al., 2010) and support (Mohamed, 2010); in multimedia development (Freyens & Martin, 2007); in urban development (Hall & Virrantaus, 2016) and in construction (Barrett & Sutrisna, 2009), to mention only some. Kothari et al. (2011) suggested that the graphical layout of concept maps was the element that inspired the expression of action and skills. In other words, concept maps help the expression of the connections between an individual's behavior (their actions) and their tacit knowledge (their skills).

2.7.2 Tacit knowledge and concept maps

Integrating tacit knowledge into any initiative requires tools to support the identification and articulation of this knowledge. Concept maps are one type of tool that can help. They have been used in the expression of tacit knowledge possibly because they are situated somewhere between drawings and language, as explained by Umoquit et al. (2013), who made use of the studies produced by Banks (2001).

2.7.3 Reuse of concept maps

Conceptual maps are often the first step for classification products, such as ontologies, controlled vocabularies and taxonomies. Classifications, taxonomies and ontologies are sometimes differentiated based on the kind of concepts represented as nodes and the kind of relationships between nodes represented. “Concept map” is the term used to address a specific visual display that classifications, taxonomies and ontologies might take (Garshol, 2004). The graphical portion of ontologies is often referred to as conceptual maps (Sowa, 1992). Slightly different visual presentations have motivated the creation of the term “mind map” (Davies, 2011).

Concept maps are the first step for the creation of ontologies (Brilhante et al., 2006; Castro et al., 2006; Starr & Oliveira, 2013; Yao & Gu, 2013). Ontologies provide a set of standards to which concept maps have to conform in order to become machine-readable.

2.8 Product Lifecycle Management

Stark (2015) defines Product lifecycle management (PLM) as “the business activity of managing, in the most effective way, a company’s products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of” (p. 1). PLM aims to increase the reuse of work done in design, development, commercialization and sales support of a product in order to increase the speed in the product launching or delivery. Part of its objectives is also to facilitate the design of products that are more adapted to client’s needs.

Potential benefits of applying PLM include faster and less faulty distribution of change information, the anchoring of products to its related certificates, records and test results, and easier diffusion and maintenance of standards (Sääksvuori & Immonen, 2008).

The implementation of the PLM approach requires the identification of points of contact among existing departments. It requires the analysis of the impact of deliverables of a team in the work of others. It also demands the knowledge of data collection, treatment and use of each department, in addition to the mapping of information systems employed by the organization.

Connections between departments might exist before the implementation of the PLM approach. They are, however, of informal nature and not directly supported by information systems serving more than one department. They might also be poorly documented in policies and procedures.

Informal collaboration exists because of tacit knowledge. The tacit knowledge involved would be the knowledge of common practices or procedures among departments; of points of contact among departments; of the organizational culture and its particularities in each team. The problem-solving ability of an individual and their personal contacts in other teams can also be added to the tacit knowledge involved, which is certainly not restricted to the mentioned elements.

In other terms, even before the implementation of the product lifecycle management paradigm, a certain level of connectivity among departments might exist, or at least the knowledge of what is needed to create that connectivity might be held by some employees, even if not documented. As long as this knowledge remains in the realms of tacit knowledge, however, this connectivity, as well as its related obstacles and enablers, is lost once the individuals holding that knowledge leave the organization. If available, this knowledge has the potential to facilitate the transition towards the product lifecycle management paradigm, adapting the process to the organizational reality and culture.

The challenges in the adoption of the product lifecycle management paradigm are not to be neglected. PLM impacts working processes and activities, which includes people's roles, responsibilities and authorities (Wognum & Kerssens-Van Drongelen, 2005). The PLM paradigm might also require new types of skills and capabilities and even large-scale cultural and strategic changes (Kärkkäinen & Silventoinen, 2016a). The challenges might even not be restrained to the organizational boundaries. PLM affects a wide range of processes inside and outside the company, often involves changes to existing business processes and working practices (Batenburg et al., 2006).

2.8.1 The department-oriented culture

The design, development, commercialization and sales or implementation support of a product have been traditionally led by different departments in the organization, each one specialized in their function. This domain specialization led to the creation of knowledge silos and specific cultures. Specific cultures in the organizational environment have been credited with different ways of perceiving reality, doing things and interpreting the organization mission and values (Schein, 2016; Schein & Schein, 2017). Specific cultures in the organizational environment were precisely the reason for the development of the Product Lifecycle Management (PLM) field. There was a traditional department-oriented paradigm: demand was detected by Marketing, products were designed by Engineering, produced by Manufacturing and supported by Sales (Kale, 2016). Different systems, supporting very different views of the same reality were put in place. Understanding of those systems and sometimes even access to each one of those systems depended on the understanding of each underlying specific culture. Even when the management of a product stage was satisfactory and well supported by an information system, there was the need for an overview of the product development process as a whole. The need to improve the capability to manage products across departments was present (Kale, 2016).

2.8.2 The role of tacit knowledge in Product Lifecycle Management

Batenburg et al. (2006) credited most of the challenges related to the implementation of product lifecycle management support systems to problems that are “more of organizational nature rather than technical” (p. 335).

Many knowledge-related processes may be involved in the organizational issues that surround PLM implementation. The validation process of the knowledge embedded in PLM might not have been fulfilled by the organization. The incompletion of the validation process would have implied that the tacit knowledge involved would not yet have been codified in the level that is needed for the development and implementation of product lifecycle management support systems that heavily rely on codified knowledge. The whole dimension of knowledge-related processes being still barely overlooked in PLM implementations, the tacit knowledge involved might not even have been identified, let alone supported by PLM tools. Tacit knowledge being closely related to creativity and knowledge application in settings different from the ones initially considered in knowledge development, PLM tools would lack the balance between information management and tacit knowledge support that maintain the flexibility needed for knowledge workers to perform well.

Understanding the importance of tacit knowledge and knowledge-related processes allows, for instance, the prioritization of initiatives covering these processes. Codification initiatives could be prioritized where they would have the most impact. Codification of tacit knowledge could be performed to the optimal extent, the point where an acceptable compromise is reached between standardization and flexibility. In a study of Knowledge Management and PLM maturity models, stages of tacit knowledge codification were identified, and a scale of tacit knowledge codification was proposed (Oliveira et al., 2019b).

2.8.3 Knowledge integration in PLM

In the traditional model of the firm, each department has its mission, that is accomplished with little or no interaction with other departments. The Product Lifecycle Management paradigm focuses on the integration of steps in the lifecycle of a product across different departments. Early initiatives focused on the integration of document references and information systems across departments. The field evolved to solutions to better integrate data and information across different systems and departments. The field's main objective was to integrate the management of product-related information through the entire product lifecycle (Sääksvuori & Immonen, 2008). The introduction of tacit knowledge as an important factor in the product lifecycle has only recently happened. Traditionally, the Product Lifecycle Management paradigm has mostly addressed codified knowledge. Focusing on data treatment follows a scientific mindset, but leaves the perception of managers and employees outside of the process (Schein, 2016).

The codification of knowledge requires language (Brannen, 2004; Cowan & Foray, 1997; Eco, 1976; Gibbons et al., 2010; Mokyr, 2000; Nonaka & Takeuchi, 1995). Agents identify and combine elements of the language to express their message. If a language becomes more specific, general concepts or concepts far from the focus of the field the language bases itself on might lack a viable representation in that language. As a consequence, it might be difficult or even impossible to express concepts for which there are no viable representations in the language in question. The process of specification of a language is therefore a process that affects knowledge expression (Cowan & Foray, 1997) and does not spare organizations (Zellmer-Bruhn & Gibson, 2006).

Language possibilities and development depend on the agents that understand and use that language. In fact, language does not exist disembodied of the interaction between different agents (Eco, 1976).

In the traditional model of the firm, departments were the representation of a domain inside the company. Professionals in that department were formed in that domain. This architecture helped to evolve the influence of the domain on the company. Members of the department, having a domain in common, had the tendency of developing specific terminology and to consolidate practices of the domain in the organization. Specialized departments meant specific terminologies.

Language has a close relationship with culture (Barley, 1983; Brannen, 2004; Eco, 1976). It is difficult to assess if the creation of a language-sharing community entails the creation of a local, specific culture, as argued by Brannen (2004) and Mokyr (2000), or the opposite. The establishment of a specific culture reinforces the specificities of the shared language. As such, considering that professionals of the domain were mainly concentrated in the same department, terminology and practices had little chances of being shared with other departments, reinforcing the creation of silos.

The creation of specific terminology reinforced by the consolidation of cultural silos is reflected in the information systems developed to support the work of each department built according to the traditional model of the firm. The specific language provided a frame through which knowledge was externalized and the specific culture, how this knowledge was connected to the department tacit knowledge. The creation of an information system and other technological solutions implies the translation of a mental model through a choice of how to express the knowledge in question, similarly as the process described by Cowan and Foray (1997): agents identify, in the existing language, ways of expressing their tacit knowledge. Once expressed, becoming explicit knowledge, it can be codified in information systems and other technological solutions. The idea that explicit knowledge is codified in technological solutions is largely supported (Arduin et al., 2015; Bontis, 1998; Cowan & Foray, 1997; Edvinsson & Sullivan, 1996; Gardoni et al., 2000; Gibbons et al., 2010; Kärkkäinen et al., 2012; Redman et al., 2017; Wiig, 2007; Xu et al., 2010, 2011).

Information systems and other technological solutions make use of words, to a certain extent, to express the knowledge in question. Mostly, however, knowledge is expressed in data scope and presentation, in the actions available to the user and in the relationships between the available actions. The information system determines how the knowledge on a specific case can be expressed. It vests itself with the possibilities made available by the specific culture and it operationalizes the limitations of the language that is part of that culture. In other words, the information system becomes the language to express knowledge on a specific case, constraining that expression to the mental model that was used to create the system, which can be, in turn, very restricted to the departmental culture. The same way that language can be a limitation for the expression of radically new knowledge, Daiyun and Pichon (2004) explain that the strong use of technology may hinder the transfer of mental models. The development of radically new knowledge is then compromised because it cannot be expressed (Cowan & Foray, 1997; Zellmer-Bruhn & Gibson, 2006).

Efforts have been made to expand the possibilities offered by information systems developed to support operations of a specific department, such as greater representation of context. For instance, in Building Information Modeling applications, directives guide the representation of the place of a process, what is its relevance, the actors around the information represented, the information itself and how it should be supported by applications (Wix & Karlshoej, 2010). This representation would be supported by ontologies, which would connect the representation in one department with that of other departments, providing a first step for the creation of building interoperability. The same need for representation of different perspectives over the same objects exists in PLM.

2.8.4 Codification efforts and PLM

In both KM and PLM maturity models, tacit knowledge codification precedes the sharing and collective production of tacit knowledge (Oliveira et al., 2019b), which suggests that initial efforts of tacit knowledge codification are necessary for the collective production of tacit knowledge.

Engineer-to-order organizations make a larger use of tacit knowledge. Conversely, the implementation of PLM in those organizations is particularly difficult (Kärkkäinen & Silventoinen, 2016b). Tacit knowledge enables flexibility. It is the expertise that is one of the pillars of creativity and, in that sense, enables innovation and reasoning that goes beyond the usual solutions. These elements are crucial in engineer-to-order organizations, where the end result depends on teams' ability to adapt to new challenges.

Engineer-to-order organizations are defined by Schönsleben (2016) as industries where "at least some design or engineering work occurs during delivery lead time, according to customer specifications" (p. V). In engineer-to-order organizations, the interventions must be adapted to the order requirements.

The joint creation of products or sub-products by more than one team indicates a certain level of collaboration between those teams. However, the comparison between different collaboration endeavours remains difficult to assess. How many products or sub-products jointly produced can indicate a specific state of easiness in collective production of tacit knowledge? Elements to take into consideration when exploring this question should be the complexity of the tasks involved and the staff movement in teams involved in the collaboration effort. Jointly producing products or sub-products involving complex tasks imply greater knowledge exchange in comparison to products or sub-products with less complex tasks. Tacit knowledge exchange or collective production requires contact with the knower. In the case of tacit knowledge exchange, the knower holding the tacit knowledge in question has to be present for the exchange to take place. In the case of the collective production of tacit knowledge, knowers achieve together incremental levels of tacit knowledge production. When knowers leave the collaboration effort, teams lose access to the tacit knowledge already absorbed by the knowers that left the collaboration effort and to the social capital level already achieved with those knowers. New members to the collaboration effort will have to be introduced to previous efforts of collective tacit knowledge production. The social capital level with the new knower has to be nurtured by the team in order to find the same level of synergy that existed with the knower that left the collaboration effort.

2.8.5 Tacit knowledge and PLM

PLM has been defined as "the ability to manage the knowledge and capabilities of an organization to respond effectively to specific customer needs, at any point in time" (Kale, 2016), where "knowledge" refers to codified knowledge and capabilities refer to tacit knowledge.

Kärkkäinen and Silventoinen (2016b) identified nine maturity models specifically conceived for PLM. As organizations have different PLM needs, the authors analyzed the focus of these maturity models along three dimensions: (1) from Functional, Organizational to Inter-organizational; (2) from Data / Information to Knowledge / People and (3) from Process automation to Ad-hoc process integration. Engineer-to-order organizations need more flexibility in adapting tasks to the product requirements at hand, meaning they need a strong Ad-hoc process integration. Of the nine PLM maturity models analyzed by Kärkkäinen and Silventoinen (2016b), the Sharma (Sharma, 2005) model had the strongest ad-hoc process integration. In addition to that, it allowed for a balanced description of needs in the Data / Information to Knowledge / People spectrum. Still according to Kärkkäinen and Silventoinen (2016b), the Sharma (2005) model also focuses on process automation.

The management of knowledge, especially its tacit dimension, has been noticeably left out of PLM (Kärkkäinen et al., 2012).

Dalkir (2017) argues that the first generation of Knowledge Management was more focused on the development of technological solutions to support knowledge management; it preceded two other generations, one more focused on connecting and managing tacit knowledge and the current phase, more focused on content management. As mentioned before, the notion of managing the essence of knowledge was not present in the first works of Intellectual Capital. The field, however, does consider any unit of development, storage and dissemination of knowledge, be they human or not, as intellectual assets, which are all analysed under notions of investment and value. These concepts served well companies that had always functioned under the paradigm of financial capital. The instrumental approach of the Intellectual Capital field, coupled with the ease of protection of ownership and access cost reduction, may explain the focus on the development of technological solutions to support the creation, storage and diffusion of codified knowledge that characterized the field of Knowledge Management in its inception. A similar focus was applied in the early studies and initiatives from the Product Lifecycle Management (PLM) field. The field's main objective was to integrate the management of product-related information through the entire product lifecycle (Sääksvuori & Immonen, 2008). Whereas the KM field concentrated in the codification of knowledge, the PLM field concentrated on its distribution throughout the departments of the organization involved in the product lifecycle.

In the last two decades, however, the focus of both fields has changed. It has been acknowledged that knowledge development and dissemination is not dependent solely on technology, but also on the ability to create an environment allowing the application of the individual's knowledge and the dissemination of the concepts created by each individual (Wood, 2002). The focus on codification of the first generation of the Knowledge Management field shifted to studies mostly identifying and mapping tacit knowledge, produced in its second-generation phase, and is now turning into a phase more focused on content (Dalkir, 2017).

The PLM field is now attempting to include tacit knowledge (Kärkkäinen et al., 2012).

There is difference between how processes are formally structured and how they are actually carried out in practice (Brown & Duguid, 2000). Different departments in an organization are somehow connected around a product, even if a formal product lifecycle management has not yet been implemented. These connections are informally made, probably not supported by policies, procedures, information systems, datasets or documents touching more than one department. These connections are created, nurtured and maintained by individual or group initiatives. They are fostered by the knowledge involved people have about the convergence points between departments, about the culture of each department and of the organization as a whole, by the contacts individuals have in other departments and by the ability of individuals to solve problems and mobilize other people around objectives. This connectivity is what makes the product lifecycle somehow feasible before a PLM implementation. Workers involved have their own perception about what works and what does not in the integration between departments. Above all, they have expectations regarding the integration among departments. Disregarding this knowledge and these expectations may lead to frustration in the implementation of PLM.

In a bibliometric study regarding tacit knowledge and PLM, the Scopus bibliographic database was used to verify the frequency of mention of terms related to tacit knowledge and product lifecycle management (Oliveira et al., 2019b). The query "product lifecycle management" applied in title, abstracts or keywords fields yielded 2163 documents (Elsevier B.V., 2019c). Little more than a quarter (25.16%) also mentioned the term "knowledge". A little less than 7% (6.85%) of the articles mentioned "tacit knowledge", "know-how" or "experience" (Elsevier B.V., 2019a), terms that would suggest some reflection on tacit knowledge. The term "tacit knowledge" itself, largely established in the knowledge management field, accounted for little more than 0% (0.32%, or seven documents) of the works on PLM (Elsevier B.V., 2019b).

The bibliometric study was updated in 2021 and yielded 13 documents mentioning tacit knowledge and PLM. It is to be noted that Scopus is a major bibliographic database, with over

25.100 titles and around 77.8 million records (Elsevier, 2020). The full text of eight of those were obtained and are discussed here.

Arduin et al. (2015) argue that knowledge and particularly tacit knowledge have to be considered and shared during the whole product lifecycle process. The authors add that considering tacit knowledge may improve collaborative work and acknowledge that different people may interpret differently the same information. Explicit knowledge is needed to carry out processes, but tacit knowledge ensures their efficiency. The authors' examples of tacit knowledge are routines, non-written procedures, skills and crafts, among others. "Design based on PLM systems should integrate the possibility of meaning variance" (p. 509). The authors also acknowledge ontologies as tools that could potentially handle the meaning variance in PLM systems.

The focus of the study is individual tacit knowledge. The authors consider that the transmission of tacit knowledge happens only after its transformation into information and data by the tacit knowledge holder, which will, on their turn, be transformed into tacit knowledge by the knowledge receiver. Following this perspective, the authors present a platform where users can develop ontologies in a collaborative way. Each user has its role codified and may interact with other users depending on their roles. The platform supports the codification of the tacit knowledge held by users that can, according to the authors, be retrieved in the future. The platform was tested on students who expressed enthusiasm towards it.

Brunsmann (2011) reaffirms engineers' use of tacit knowledge to fulfill tasks ranging from idea generation, design, manufacturing and service, up to disposal of a product and emphasize the knowledge loss once these professionals retire or leave a company. Their approach is to support the codification of engineers' tacit knowledge as linked data. That data would be used as annotations for product lifecycle data models and preserved in long-term archives.

Grieves and Tanniru (2008) make a difference between processes and practices. Processes are well-defined routines, with well-defined inputs and operations performed on those inputs to generate a set of outputs. Processes are programmable or structured decisions and have been largely studied in literature. Practices are highly unstructured and "tend to deal with unstructured and even ambiguous information. Over a period of time, some of the practices may be sufficiently routinised to move them to become processes" (p. 5). Practices are goal seeking and different individuals may select different inputs and perform different operations on those inputs to reach the desired output or goal" (p. 5). Which inputs and operations are better "is subject to discussion, argument, and negotiation, etc., and may not be objectively determined" (p. 5). In addition, practices around product development are not a sequential, iterative process of analyse, synthesise, test and repeat. Often this involves dealing with competing ideas, trade-offs, arguments and coalescence" (p. 9). The authors base themselves on the work of Latour (1987) to claim that practices have been largely ignored in the literature in favour of a focus on process. "Structured information supports processes, but practices require unstructured, contextual and tacit knowledge" (p. 3) and when design teams became separated by thousands of miles, they lost the ability "to engage in the practice of design" (p. 9). As a solution, the authors propose Virtual Collaboration Rooms as a solution.

Virtual Collaboration Rooms would have controlling designs, workflows, Gantt charts and other information that would be necessary for development teams to exam and modify. The authors also propose that e-mails, instant messaging and video conferences be captured and used as an information resource.

Another key aspect of the authors' propositions is the codification of knowledge provenance, the connection between the explicit knowledge or shared information and the holder of the tacit knowledge at their origins, joining, to some extent, Arduin et al. (2015).

Grieves and Tanniru (2008) also argue that the tacit knowledge associated with a practice may evolve as the holder of this tacit knowledge interacts with other members of their network.

Jokinen and Leino (2019) acknowledge a gap in the literature on how knowledge management and collaboration should be organized in practice taking into account product lifecycles. Current practice, they argue, only supports the requirements and the final decisions, leaving a great reasoning gap that can be actioned many times throughout the product lifecycle, generating back and forth movements. "Usually, the master design data in PLM systems represents the final state of designs and does not explain how and why the final result became what it is" (p. 743). The authors explore in depth the role of tacit knowledge in the product lifecycle, mentioning designers' thoughts to make a design decision, for instance. Poor documentation plays a great role in product development time. "Because only a limited amount of decisions is self-evident and major portion of the rest is not documented, the knowledge either stays hidden (in a tacit form) or is lost" (p. 743). The loss of links between design decisions and change requirements and the lack of integration between teams are other problems raised by the authors.

Koomen (2020) conducted an empirical study on nine PLM implementation projects in small and medium entreprises. These companies, the author argues, "are 'cutting corners' in the hope that a technical software implementation will fix their business problems" (p. 554). However, it is not entreprise systems or information systems that will bring the change. "It is the way the organization can change its processes and culture that has the most influence on the value of an ES/IS investment" (p. 554). Operational details, claims the author, can only be obtained through access to tacit knowledge.

PLM implementation, affirms the author, is in itself a process that has to be designed. The author also suggests that a visual tool would help in the design process. The author also suggests Set-Based Concurrent Engineering and A3 methods to help the PLM implementation design process.

Liao et al. (2012) propose approach that could be placed between those proposed by Grieves and Tanniru (2008) and Arduin et al. (2015). Semantic annotations would focus more on "carrying out the different views and much less on changing the knowledge expressed by ontologies" (p. 7). Semantic annotations would have an existence of their own but would be connected to the existing ontologies.

Meyer and Marion (2013) stress the need to develop research on the field and argues that this need is a barrier to innovation:

> [M]anagement processes for research and development (R&D) remain firmly planted in traditional developmental paradigms. These paradigms - in which functional areas are managed and controlled through gated decision processes——seek to create and, in many ways, isolate distinct phases and their unique knowledge and information from other points along the innovation process (p. 51)

After accompanying 146 firms in PLM endeavours, the authors identify three main problems surrounding tacit knowledge in PLM. First, translating detailed user insights. Second, the maintenance of connection points between different teams and parties. Third, the maintenance of the knowledge value across different development functions. The latter problem refers to how consultants' knowledge, specifically about new distribution partners' requirements and new types of customers was either brought in too late or de-prioritized in terms of product, package, communication and service design. "Knowledge and information exist not only within a particular step in the innovation process but also across steps" (p. 53).

The authors are particularly critical about how information technology has supported knowledge management needs. "[T]he use of IT is pervasive across companies large and small. Something is not working in the use of IT, and it is hurting firms' ability to compete effectively with new products and services" (p. 53). The problem would not be a consequence of the lack of PLM principles or tools:

> We noted that even firms with full-fledged PLM systems expressed difficulty in both representing tacit knowledge, such as user needs or channel requirements in their databases, and transferring that knowledge between design, engineering, and sales. (p. 56)

The authors went further and validated their perception with a PLM system vendor:

> This sentiment is evident in a statement from an executive of one of the leading PLM software vendors serving industry on a global scale:
>
> "We can't find one company that does this well. Companies are still using the same old examples. We even joined a government project to see how the front-end information could be translated to engineering, but it was no help. This needs to be addressed. There is a tendency for information loss and a lack of systematic thinking throughout the process. But it's hard to get people to move beyond disparate systems. It's easy to use a spreadsheet." (p. 60)

The authors suggest that tacit knowledge lends itself poorly to codification:

> Tacit knowledge is hard to share electronically because of the dimensionalization and codification problem. To obtain information, individuals need to have face-to-face (or at least webcam-to-webcam) interactions in which verbal and nonverbal insights and queues are fundamentally important to share observations, insights, and collaborations on open questions. (p. 54)

The solution, the authors argue, may be IT-independent:

> Enable domain empathy. Place up - or downstream human resources together, face to face, to foster empathetic discovery and tacit knowledge translation. This can be as simple of having an engineer accompany an industrial designer in field research to uncover user insights rather than relying on communication or IT. (p. 57)

The last study on tacit knowledge and PLM, by Reefman and Van Nederveen (2012) emphasizes the lack of studies covering both Knowledge Management and engineering environments: "Both professions do not really know what the mutual position is" (p. 2). In an approach that is similar to other studies covering knowledge management in engineering environments, the authors focused on expressing the needs. "The Know Why is often missing. Therefore capturing knowledge in a design and engineering environment has to focus on Know Why. This is difficult because many hidden unconscious assumptions may play a role" (p. 5). Some challenges are also expressed, such as the need to handle non documented knowledge like product ideas and lessons learned in an environment where "[i]nterviewing during a running project is usually not accepted, not even in a mature Knowledge Management organisation" (p. 5).

To summarize, previous propositions for the inclusion of tacit knowledge into PLM have covered:

- Definition and identification of roles of knowledge workers;
- The cost and other challenges surrounding tacit knowledge codification efforts;
- Tacit knowledge can be expressed in ways that keep its multifaceted nature (video, drawings) or it can be made explicit through verbal language;
- The need to integrate both individual and collective tacit knowledge;
- The need to foster negotiation, consensus and interaction among knowledge workers;
- The need to foster diffusion and validation of tacit knowledge;
- The need to foster collective production of tacit knowledge;

- The need to promote social interaction in PLM;
- The limitations of information technology solutions;
- The challenges to include tacit knowledge exteriorization into the product lifecycle;
- Ontologies as a possible tool for connection between departments.

2.8.6 The role of ontologies in knowledge integration in PLM

Ontologies are recognized as essential elements in management systems integration (Lanzenberger et al., 2008; Pellini & Jones, 2011; Pincher, 2010). In PLM efforts, ontologies have gained popularity as means to operationalize connections and interdependencies among departments (Smirnov & Shilov, 2018), to the point that some authors consider ontologies essential to PLM implementation efforts (Kadiri & Kiritsis, 2015).

Ontologies serve as machine-readable means of representing the context surrounding the knowledge that is represented in specialised systems in product lifecycle management. They help implement connections and represent interdependencies among departments (Smirnov & Shilov, 2018). An ontology aims to represent the perception of concepts and their relationships as per an individual or of a group of people (Gruber, 1993). Their potential to represent context have made them essential in the integration of management systems (Lanzenberger et al., 2008; Pellini & Jones, 2011; Pincher, 2010). Their potential on to represent context in specialized systems, as those used in product lifecycle management, is also recognized (Kadiri & Kiritsis, 2015). The representation of knowledge that ontologies carry aid the management of data pockets holding semantic heterogeneity. Semantic heterogeneity refers to data pockets that may be perceived in different ways by different departments and treated and used in different ways, even though they may have similar labelling or seem to belong to a similar data model (Kadiri & Kiritsis, 2015; Kermanshahani, 2009; Sheth, 1999; Sheth & Kashyap, 1993).

Ontologies are commonly developed through the analysis of organizational documents such as policies and procedures, as documented by Joseph and Lourdusamy (2018) or Lim et al.

(2011). The inherent logic behind the management and use of data or, in other words, the context of data modelling, is extracted from those documents.

Through the lenses of the expanded SECI model (Nonaka & Konno, 1998; Nonaka & Takeuchi, 1995), policies, procedures and other organizational documents hold explicit knowledge. In Oliveira et al. (2021a), it was argued that

> Ontologies being the codification of knowledge themselves, they are also explicit knowledge. Or, explicit knowledge cannot be generated from explicit knowledge. It must first be interiorized, transformed into tacit knowledge, and subsequently exteriorized. In the process of interiorization and exteriorization, humans create mental models to absorb explicit knowledge or to transform tacit knowledge into explicit. Ontologies being developed mostly by information technology experts, their mental model is used in the creation of those ontologies. (Oliveira et al., 2021a, p. 726)

This reasoning was further explored in Oliveira et al. (2021b):

> Documents convey codified knowledge, knowledge that went through the exteriorization process, which is a lengthy and costly process. Knowledge regarding data management and use might never have gone through that process, while still being vividly present in employees' minds. Ignoring that knowledge creates the risk of not adequately representing data, information and document sources, work flows or the interactions among different departments or key actors in a project. For instance, data meaning might be inferred by field labels, what would motivate the grouping of different data erroneously; information and document sources such as ad-hoc controls and accessible

> legacy information systems might be ignored, motivating future users to create workaround solutions for their information needs; work flows and interactions among different departments might be ignored or implemented in a linear fashion while interactions actually happen in several points of the work flow, motivating users to reduce the use of the support system. (Oliveira et al., 2021b):

Most ontologies do not portray the mental model of the intended users of the systems where those ontologies are implemented, causing a disconnect with the organizational reality and having the understandable potential to lead to user resistance and frustration (Wognum & Kerssens-van Drongelen, 2000; Wognum & Kerssens-Van Drongelen, 2005).

A first usability challenge results from the knowledge-intensive environment where these ontologies are deployed. In these environments, some of the tasks involve knowledge representation in a system for subsequent use. The second usability challenge lies in the kind of source used for ontology development: explicit knowledge. Arduin et al. (2018) argue that the knowledge residing in an organization cannot be reduced to what has been codified. When performing their work, employees navigate a complex environment of explicit and tacit knowledge, tacit knowledge being the kind of knowledge that informs action. The very kind of knowledge that is overlooked by current processes of ontology creation (Oliveira et al., 2021a).

Ontology creation begins with its graphical portion (Brilhante et al., 2006; Castro et al., 2006; Starr & Oliveira, 2013; Yao & Gu, 2013). The graphical portion of ontologies is often referred to as conceptual maps (Garshol, 2004; Sowa, 1992). "Concept map" is a term that has been extensively used in education literature to refer to "an effective and efficient way to represent knowledge" (Lambiotte et al., 1989, p. 331), a visual representation of abstract ideas (Novak & Cañas, 2009). While the graphical portion of ontologies respect the content-focused definition of graphical tools for organizing and representing knowledge (Novak & Cañas, 2009) and the visually-focused definition of a structural representation made of nodes and labelled lines, each node representing a concept and each one of the lines connecting nodes, a relationship between the concepts it connects (Ruiz-Primo & Shavelson, 1996), the term "concept" takes the encyclopaedia format of metaphor (Eco, 1984), as it represents the knowledge surrounding the data, information, knowledge, process or task codified rather than abstract ideas, becoming knowledge structures that codify objects and their relation to each other (Oliveira et al., 2018a).

The aim of Product Lifecycle Management (PLM) is to connect all the steps of creation, development and commercialization of a product. To foster connectivity, implementation of the PLM paradigm must consider:

> - The contact points among existing departments;
> - The impact of the deliverables generated by a team on the work of other teams;
> - The knowledge of the data and information systems serving and used by each department (Oliveira et al., 2021, p. 727)

Classifications based on each one of the developmental steps might already exist within the organization.

> Each classification, however, might reflect the thought paradigm that is particular to the department it serves, with no overlap or contact point between classifications. In an organization that has not somehow adopted PLM principles, if connections among departments exist, happen in an informal way. They are not supported by information systems. They may poorly documented in policies or procedures or even not documented at all (Oliveira et al., 2021, p. 727)

However, if informal collaboration exists, it implies different manifestations of tacit knowledge, for example:

- Knowledge about the common points and areas among departments;
- Knowledge about the organizational culture;
- Personal contacts in other teams;
- Problem resolution capacity.

If informal collaboration exists, a certain knowledge of what is missing to create that connectivity already exists before the implementation of the product lifecycle management paradigm, be it documented or not.

> This knowledge resides mostly in employees and is lost when those employees leave the organization. On the other hand, the conversion of all this tacit knowledge into explicit knowledge is expensive, sometimes not possible and may not yield the intended results, as explicit knowledge requires the use of language and logic, which invariably leads to the reduction of the multifaceted nature of tacit knowledge (Oliveira et al., 2021, p. 727)

It is however possible to represent tacit knowledge in a fashion that is clear enough for some uses without actually converting all of it into explicit knowledge.

> In this process, named tacit knowledge capture, the exteriorization level sought is lower than the one necessary for creation of discursive documents. Captured tacit knowledge is different from explicit knowledge as it keeps most of its multifaceted nature.
>
> Whereas product lifecycles may be based on theoretical logic and leave the task of adapting ongoing practices to employees, using captured tacit knowledge has the advantage of adapting

> product lifecycle to the organization's reality, taking into account the ongoing practices and making it easier for employees to adopt changes. (Oliveira et al., 2021, p. 727)

The literature review and integration of theoretical frameworks aimed at providing a theoretical construct for tacit knowledge in PLM to foster innovation. The empirical exploration will verify how much of these theoretical frameworks is expressed by specialists holding tacit knowledge in organizations dealing with product lifecycle challenges and intending to innovate.

CHAPTER 3

EMPIRICAL EXPLORATION

3.1 First interview – Specialists B, C and D

3.1.1 Organizational context

The organization has a central unit, responsible for the strategic and executive decisions. Maintenance work is carried out by branches distributed across the province. Considering a product lifecycle consisting of research, design, construction and maintenance, the products/services performed in the maintenance phase of the product lifecycle are maintenance interventions on the products/services of the organization. The products/services of the maintenance phase have a lifecycle of their own. Needs must be identified and prioritized; the suitable materials to answer the needs must be established and then sought; a decision about performing interventions with internal or outsourced resources must be made; the resulting intervention must be surveyed and afterwards, verified. Finally, there is a time constraint as most of those processes can only be made during about eight months of the year.

The organization has four categories of workers: technicians, professionals, managers, and executives. A technical degree is required for technicians, while a university degree is required for professional roles.

The branches across the province that are responsible for maintenance count mostly on technicians, with very few professionals on support (about one for every group of ten technicians) and one branch manager.

All three specialists worked in the central unit, with one specialist having spent ten years in a branch. Specialists B and C were involved in the implementation of a technological solution, whereas specialist D is involved in the support of this technological solution. All specialists have more than ten years of experience in the department they represent.

3.1.2 Technological solution description

The technological solution was launched in 2005 and was still in use at the time of the interview, 2019, with no plans for decommissioning. The aim of the technological solution is to support budgetary planning and compliance, but also, project and task planning and realization. The technological solution supports all processes in the maintenance phase, although some sub-processes and some activities are more supported than others.

The technological solution costs amounted to six million dollars by the time of deployment, which, according to one specialist, would amount to about ten million dollars in 2019 values.

The technological solution was a part of a greater endeavour, the establishment and implementation of somehow standardized processes. The resulting system was seen as an "administrative and technological solution", as stated by one specialist. There was an executive vision for the design and development of this kind of systems, one that accounted, on one hand, for standardization of administrative practices and, on the other, for integrated technological solutions that would support those administrative practices. Not all technological solution developments of the organization fell into the "administrative and technological solution" category.

"Knowledge management" is not mentioned in the historical background presented in the technological solution documentation. Many of the interventions performed before or during the technological solution development had the character, the objectives and the form preconized by knowledge management initiatives today. The focus on the tacit knowledge from workers of the field was demonstrated in many points of the interview.

3.1.3 Tacit knowledge and usual software development in the organization

The organization had a certain level of consideration of operational employee's tacit knowledge. As explained by one specialist, whenever the organization engaged in software development, at least two committees of employees would be created to work on or influence software design. The steering committee, was the one responsible for identifying all the user needs in the whole organization, prioritizing those needs and translating them into functionalities. Members of the steering committee would be potential users of the software themselves. In addition, it was expected that members expressed the opinion of the potential users of the geographical region they represented. The terms "opinion" and "idea" were used to express the tacit knowledge of potential users, indicating that some kind of consultation to potential users was performed, probably by the members of the steering committee. More than once it was expressed that the information technology team should not "work by themselves" and that it should be "told what to do", denotating that needs identification was an exercise done mostly by the steering committee with the potential users. The alternative, that the information technology team identified needs according to a logical analysis of processes and the data and other resources used in the process, was deemed by the interviewed specialists "illogical" and destined to produce a "solution that is not adapted to the field", as mentioned one specialist. "Consulting people", explained another specialist, "is important to make the right choices. Choices from which the whole organization can benefit". This specialist returned to the idea in another point of the interview: "it is impossible to develop any framework without the vast experience of the people from the branches".

The steering committee creation is one of the first efforts made to implement a technological solution. It accompanies the design, development, and implementation of the software in question. After the solution launch, the steering committee continuously evaluates the success of the technological solution, while identifying opportunities for further developments or corrections.

The second committee is composed by managers. This committee's role is to select and approve which portions of the software to develop. This committee also commits financial resources to the software development.

3.1.4 Existing solutions

There were some technological solutions already in place when the need for the studied solution was identified. The studied solution was to replace some of the existing solutions and create a connection with others.

One of the existing technological solutions offered the possibility of logging expenses. This solution was to be replaced by the studied technological solution, at least in what concerned the departments involved in the maintenance phase of the organizational product/service. A list of products/services of the maintenance phase was employed by the existing solution. With the concern of reusing existing informational resources, the steering committee decided to use the existing list of product/services as a departure point for the creation of a taxonomy of product/services for the studied solution.

The existing list contained around 1800 products/services related to the maintenance phase. This list was reduced to around 100 main terms in the new taxonomy. The process of reorganization of terms was done with the collaboration of a large number of workers "from the field", as the specialists named employees from branches. Terms would be discussed in meetings of the Maintenance Mentorship Roundtable, a community of practice of workers involved with the maintenance phase. The efforts to reorganize existing terms were of the first employed.

3.1.5 Context and solution description

The specialists' perception of the studied technological solution seemed to consider it very different from usual software development. "It was really very different from everything else we had done", stated one specialist.

In different points of the interview, specialists mentioned different reasons to foster a system that would support the maintenance activities from beginning to end. The need for standardization and the need to clearly include and reinforce organizational guidelines in the targeted activities were some of the points argued. Consistently throughout the interview, however, specialists mentioned the need to identify best practices, diffuse them and sponsor the application of those practices.

It is to be noted that the maintenance phase of the product/service of the organization, targeted by the envisioned system, is ensured by a large number of branches geographically distributed. In 2021, 52 branches had that responsibility. Branches might have different structures of resources and different levels of homogeneity of product/services under their responsibility. Before the system implementation, "each branch was free to work as they saw fit", as stated by one specialist. The studied initiative was the first one to consider all processes related to product/service maintenance in the organization and their integration. The organization is a long-lived one. It is therefore to be expected that many different ways to handle those processes had been developed by each branch before the system implementation.

The system aimed to support all maintenance processes, from planning to planning. Maintenance needs can be identified through many processes: through the ongoing maintenance schedule of the branch; through the surveillance activities of the branch; through the product/service aging analysis performed by another unit; through a scheduled maintenance after launch planned by the design and construction unit, and through communication of any employee from the branch, involved in needs collection or not. Once the maintenance need is identified, a needs assessment process is initiated, that might result in different levels of urgency. The intervention can be deemed necessary in a wide timeframe, covering from “before the following day” to “during the current year”. A real-time and future evaluation of resources is made and the consequent decision to use internal resources or to outsource the maintenance intervention. Budget must be allotted to maintenance interventions. Planning of duration and resources for the intervention is made. A verification of the intervention is done during and after its conclusion. Verification of compliance, reporting and subsequent follow-up planning should also be supported. Different groups of employees must intervene at the right moment and be freed as soon as possible. Employees must also have the right information at their disposal. The aim of the steering committee was to harmonize the processes of about 52 branches geographically distributed and design and implement a technological solution. The technological solution would support the standardized result and would actually replace or at least complement the local systems and processes developed by branches.

The solution aimed at supporting the standardized approaches on:

- Documentation of maintenance intervention needs;
- Evaluation of resources needed for each maintenance intervention;
- Budget planning and allocation;
- Maintenance intervention phases;
- Outsourcing maintenance interventions.

Before the technological solution was developed, the standardized approaches had to be defined. “The system puts in place the maintenance flowchart. We had to define the processes first”, explained one specialist. “We have created the flowchart, it was not trendy at that time”, cherished another. It was also mentioned that an organizational process had to be defined before the development of the technological solution.

3.1.6 User-centered focus and tacit knowledge acknowledgement

The tacit knowledge around the studied solution was particularly recognized by the specialists. "There is someone in a branch that has 40 years of experience. They know absolutely everything about how to fix any problem that may arise in the field. We do not have tools for everything yet", explained one specialist.

"It all began with a book written by someone in the field", mentioned one specialist, referring to an employee working in a local branch. "That was the first look" at a comprehensive approach to maintenance processes, explained the specialist.

"We have to consult the users, those who are actually going to use the system every day. Managers are present, too, not all needs are acted upon", mentioned one specialist. Another specialist added: "When a tool, a guide, a training session is developed, it is never done from the office. We start with a version 1 and will end up with a version 10, with all the changes and comments from the field". The third specialist intervened: "Process improvement and ideas about how to perform a task come from the field". "We create a storyboard and put together a task force", mentioned one specialist. "If not, the system would not be fit to the field", added another. The approach was the same to locally developed solutions and helped to harmonize current practices into one solution: "Some branches had their own system. But then, there is a branch that has one system, another that has another system. There is a change to manage also".

"Even when training was being provided, we have adjusted the technological solution" to better reflect the challenges of the field. "We had forgotten a portion of it and someone told me in the training 'ma'am, your stuff doesn't work'. I stopped the training and started taking notes", explained one specialist.

The focus on users helped the design team define the depth of the solution. "There is always the need to adapt to regional particularities", explained one specialist. "The system supports the steps, the activities, but each branch has to build their own process, that should be anchored in the organizational one", added another specialist.

In addition to a user-centered view, one of the specialists, that has a managing position, expressed a human-centered view: "It is important to invest in our resources. Acknowledgement, teamwork, communication. If these are our focuses, we are able to recruit all the people we need and keep them".

3.1.7 Measures to integrate tacit knowledge to the studied solution

3.1.7.1 Regular steering and managing committees

As mentioned, the organization had in place a culture that considered needs specifications a matter of regular employees instead of information technology professionals. Regular measures to ensure input from regular workers included the creation of two committees: the steering committee and the managing committee. The steering committee was composed of potential users. In the case of the studied solution, potential users invited to the steering committee were individuals recognized as workers experienced in the practice or workers of the practice that were recognized as tech-savvy. Once the solution was launched, the steering committee composition changed to include the users committee. One of the specialists is a member of the current steering committee. This steering committee has been in place since the launch of the solution, in 2006, and today offers support and considers requests for improvement, the update of the product/service taxonomy and locally-developed solutions. "For example, one branch has developed a connection between three mission systems and the solution. We have asked permission to diffuse their solution to all the other branches". The specialist continued: "One branch has asked to have a daily planning tool. All the other branches were asked to collaborate and to share their current tools for that". Another specialist added: "Good ideas from the field and the organization behind".

The managing committee was composed of some of the managers of the branches and some specialists from the central unit.

One of the specialists mentioned that the solution had cost about ten-million dollars in today's value. This figure "covered only software acquisition, configuration and user training", explained one specialist, leaving untracked the costs of the measures employed to integrate tacit knowledge into the ideation, development, and implementation of the solution.

3.1.7.2 Community of practice

Some of the measures were a part of the organizational culture in relation to software development. The particularities of the studied solution, however, made specialists employ additional measures to ensure input of tacit knowledge from potential users to the studied solution. At the very beginning of the initiative, the Maintenance Mentorship Roundtable was created. The Roundtable was composed of about a hundred members from the whole province. It would meet in person every two months. One of the mandates of the Roundtable was to reorganize the main terms of the taxonomies to be used in the studied solution. One of the taxonomies that benefited from this input was the list of products/services, that had originally about 1800 terms that were finally reduced to about a hundred main terms. "In the Roundtable, there were technicians, engineers, managers, all in one room". "The Roundtable meetings were like conferences. They would take two to three weeks of work" to be prepared, explains one specialist. "If the Roundtable did not exist, the system would not be adapted" to the practice.

Even though the Roundtable had a pivotal role in the ideation and development of the studied solution, its activities ceased. "Many budgetary cuts were put in place and at a certain point, the Roundtable was not viable anymore", mentions one specialist. Another specialist adds: "Five years ago, that was impossible. But at that time, we had an executive leader that believed in change management, in mobilization and knowledge management. This leader gave us free reins". The first specialist notes: "In the past three years knowledge management is being more recognized as a science and we have been able to start communities of practice again".

3.1.7.3 Users committee

A group of potential users was formed. Although the users committee was not explored in depth in the interview, it seems to have addressed practical issues such as moment of information collection and reporting regarding maintenance activities; clarity of interfaces and terms used. After the launch of the solution, the users committee was merged with the steering committee.

3.1.7.4 Co-development with users

Another measure to integrate tacit knowledge from employees of the field was the inclusion of experienced maintenance technicians in the development process. This measure lasted three years. "We took two technicians, ripped them off their branches and they came to work with us full time", explained one specialist. It is to be noted that the initiative meant that technicians had to move to another city during the week. "It was not easy. One of them was in a couple…" Two, sometimes three maintenance technicians were part of the development team full time. In the three years the initiative lasted, five maintenance technicians contributed to the solution development this way.

3.1.7.5 Unique development headquarters

As explained by one specialist, all stakeholders were physically grouped during development. "The technicians worked in the information technology office, instead of having the IT folks developing everything on their own. The people in project management were also with them". This measure helped to constantly shape the solution to the users and organizational needs. It also helped to overcome technical issues in ways that made more sense to the users and the organization. “There was a complete synergy”.

3.1.8 Perceived importance of the department

The three specialists were adamant about how their department is perceived as having a minor importance by the organization. “We never have enough budget. We cannot seem to raise enough awareness among our executives. Everything goes to design and construction. If construction is late, more resources are provided. If it costs too much, more resources to estimate are provided. It never gets to us”, explained one specialist. “But if the maintenance was done as it should, maybe some projects would not have to take place”, added another specialist. “It is not recognized”, cherished the third specialist.

3.1.9 Unexpected positive effect

Beyond satisfying the needs for product/service lifecycle in the maintenance department, the data model developed for the solution seemed to be useful for the community to understand the construction environment over time. “There was a need for historical data, so we developed for that. It is possible to query data since 2005. Many external stakeholders have asked for the data for market studies”.

3.1.10 Readiness of the development team

The innovative character of the approach and solution was possibly reflected in the specialists’ capacity to plan for resources: when one specialist mentioned the implementation team had worked crazy hours, the other specialist involved in the solution implementation nodded.

The innovative character of the approach and solution may also have influenced the capacity of the team to understand their impact. “When we built the system, we were so overwhelmed that we were not capable to make a post-mortem and translate this experience to other systems", mentioned one specialist.

3.1.11 The role of visual support

Did the team make use of diagrams, or do the specialists see any gain in employing drawings or diagrams in the process? "We have created the maintenance flowchart, with all the processes involved, out of the need to easily communicate", said one specialist. "Looking back, other diagrams might have been useful. But it was not trendy as it is now". After a pause, they added "maybe for afterwards". "But when the project finished, we were so overwhelmed that we could not look back and see what could be transferred to other realities. It was really huge", another specialist said.

3.2 Second interview – Specialist A

3.2.1 Organizational context

Specialist A is a team manager. Considering a product lifecycle consisting of research, design, construction and maintenance, the specialist works in the research phase of the product lifecycle, named "Opportunity Study". As explained in Oliveira et al. (2021a),

> The implementation of project-based management happened in 2012 in this organization. It was joined and supported by the creation of a document classification system, implemented in 2016. The classification system offers ways to group documents of a project since the first steps of product design and covers the product lifecycle up to its transfer to the maintenance team. The organization also employs a classification plan that covers all organizational activities, updated in 2018. Document management is supported by a technological solution where both classification systems were implemented. (Oliveira et al. 2021a)

Figure 3.1 represents the role of Opportunity Study in the organization.

> The participant's team mission is to analyse issues stemming from the use of existing products and suggest solutions and new interventions. Different solutions may be proposed. Among them, the creation of new products. The creation of new products is responsibility of this team, whereas their development is assured by other teams. To idealize new products, the Opportunity Study team has to regroup needs expressed by product users and by partner organizations representing those users. Some of these partner organizations manage the territory where products are implemented. The communication with users and partner organizations is assured by other teams. The project management methodology does not apply to the communications initiated by users or by partner organizations. The document management supporting communications follows the classification plan of the organization. In their communication with the organization, partner organizations may refer to products by their commonly known name ("main street", in the case of a municipality, for example) or just generally express concerns. Although these concerns may be generalized to all products managed by the organization, partner organizations voice the best interest of users in their territory, which cover only a portion of the organization's products. The extent of that portion needs not to be explicitly mentioned in the communication with the organization. (Oliveira et al., 2021, p. 725)

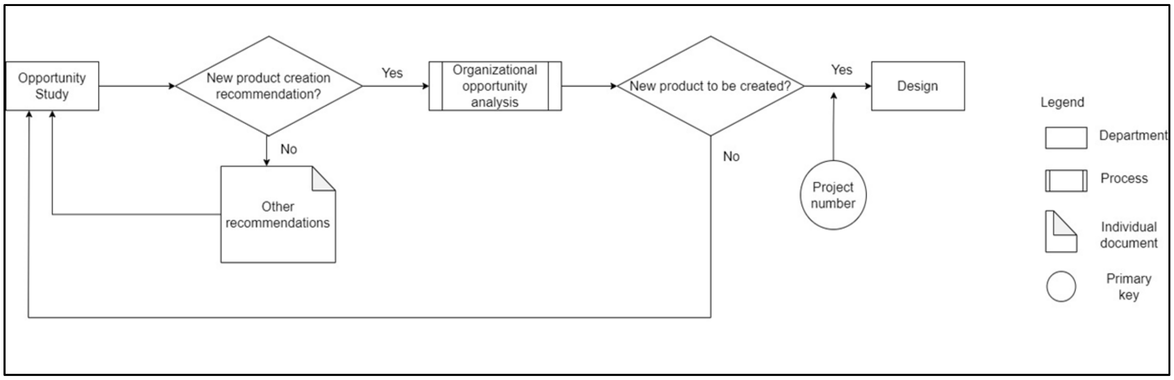

Figure 3.1 Opportunity Study role in project creation
Taken from Oliveira et al. (2021b)

The documents produced by the departments responsible for the communication with users are organized according to the overall classification scheme.

> Documents produced by the departments responsible for communication with users and partner organizations are grouped in chronological order according to the department responsible for their creation. The creator department can also employ a code inserted in the document title to help retrieval through the technological solution used to hold all documents produced by the organization. The code depends on the creator department's context: complaint number, request number and so on. Although this system possibly satisfies the creator departments' needs, it is far from practical for the participant's team. To identify communications regarding a portion of a product, the participant's team has to browse all years and, in each year, browse all partner organizations that manage the territory where that portion lies (and all other organizations represented in the classification plan that could possibly have an interest in the product portion), in addition to consulting each communication piece. (Oliveira et al., 2021, p. 725)

3.2.2 Existing solutions

The focus of specialist A was on the document management portion of the product lifecycle management.

The specialist presented the classification scheme for documents once research reaches the design phase. The project management methodology follows five steps: Opportunity Study, Design, Plans and Specifications Preparation, Construction and Evaluation. One classification system supports the steps from Design to Evaluation. Another, the overall classification plan, covers all organizational activities, including those taking place before or during the Opportunity Study phase.

During the Opportunity Study phase, the project is not yet named a “project”, but a “study”. Once the project is accepted into the Design phase, it is assigned a project number, as represented in Figure 3.2. “Studies do not always end up becoming projects. Studies involve research on the problems surrounding the products”, explained the specialist.

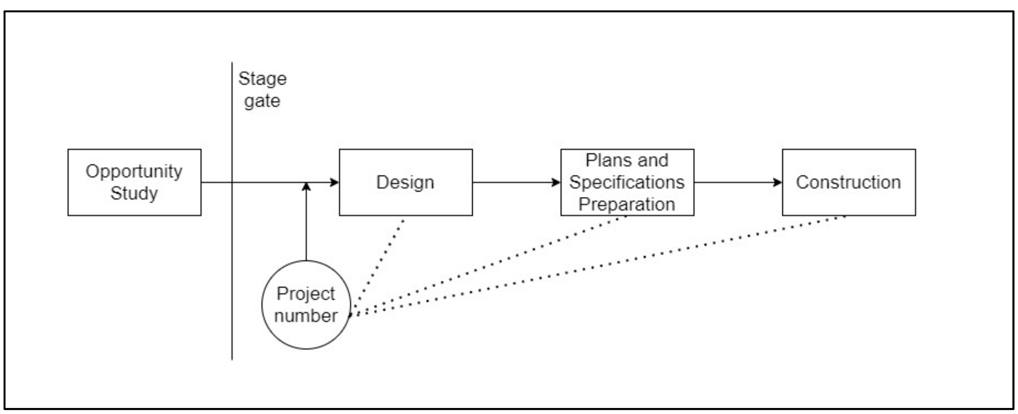

Figure 3.2 Project phases and project number use
Taken from Oliveira et al. (2021b)

When the project is accepted to the Design phase, documents related to the project begin to be organized according to the project-management based classification scheme. The project number also ensures a greater possibility of tracking of the project across different information systems:

> The project number is widely used across different activities throughout the organization and an essential piece of data in a number of databases supporting information systems, either as a primary or external key. In other words, in the human activity dimension, the project number identifies a project both in the departments that are directly involved with the management of the project and in the departments whose activities are more loosely related to project management. Parallelly, in the information systems dimension, the project number's use is also twofold: as a primary key, a main code of reference, in information systems closely related to project development, such as the one holding project deadlines, budget and names of professionals responsible for the project, and as an external key, a liaison code to projects in information systems that are loosely related to project development, such as the one holding information on supplier payments. (Oliveira et al., 2021, p. 724)

Before the project acceptance to the Design phase, documents are identified in many different ways and placed in many different entries of the overall classification scheme. Figure 3.3 outlines the document environment of interest to Opportunity Study.

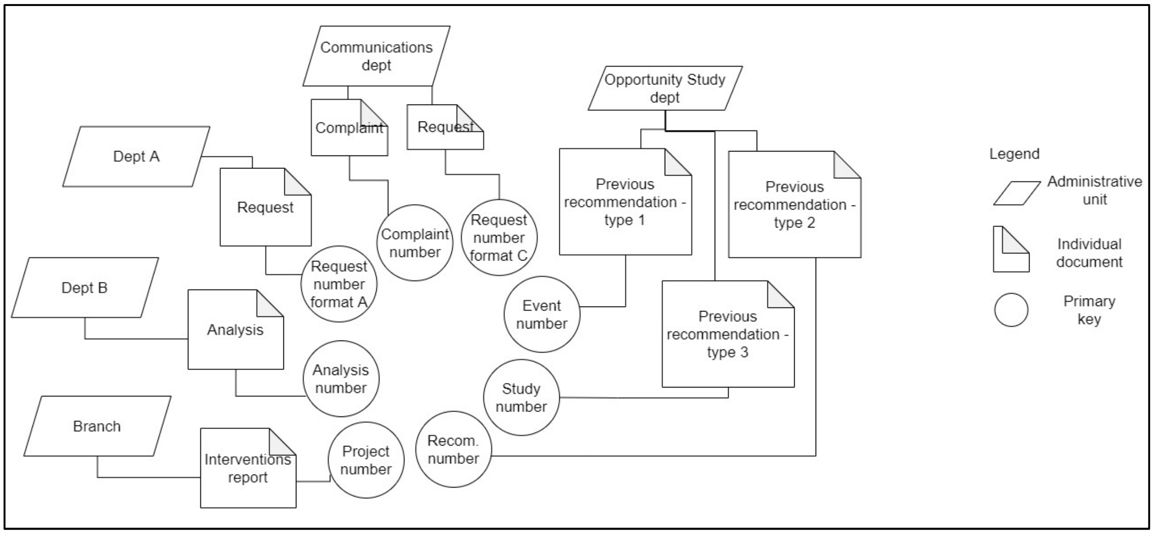

Figure 3.3 Documental environment of interest to Opportunity Study in the creation of new products
Taken from Oliveira et al. (2021b)

Grouping the necessary information to base the decision to submit a project proposition is a challenge for the specialist. Figure 3.4 displays a simulation of this challenge when the chosen strategy for document identification is browsing through the classification scheme implemented in the document management technological solution. Even documents produced by their own team become difficult to locate once they are deposited in the document management system. "It is difficult to check-in documents in the organizational document management system because of how the research activities are covered in the organizational document classification scheme, which is different from the one dedicated to design and construction phases", they stated.

The challenge remains if the strategy for document identification is the search engine. The search engine

> [R]etrieves only documents that mention the exact terms mentioned in the search box. The search engine would miss relevant results when the product portion is referred to by its common name ("main street", in our example) or recall a great

> number of irrelevant results (in a search for a municipality, for example, complaints and requests would be among past projects, new projects, announcements and other documents that are not of interest for the participant's team). (Oliveira et al., 2021b)

"It is also difficult to recall existing data, information or knowledge about a given problem. Knowledge management at the research phase is ill-supported. That harms the transfer of this knowledge to the subsequent phase of the product lifecycle", explained the specialist. "Stakeholders might have mentioned a given problem or the studied product/service in previous communications. It's extremely difficult to find those communications". "What happens is that the stakeholder might get notice of the project only when it is already in the

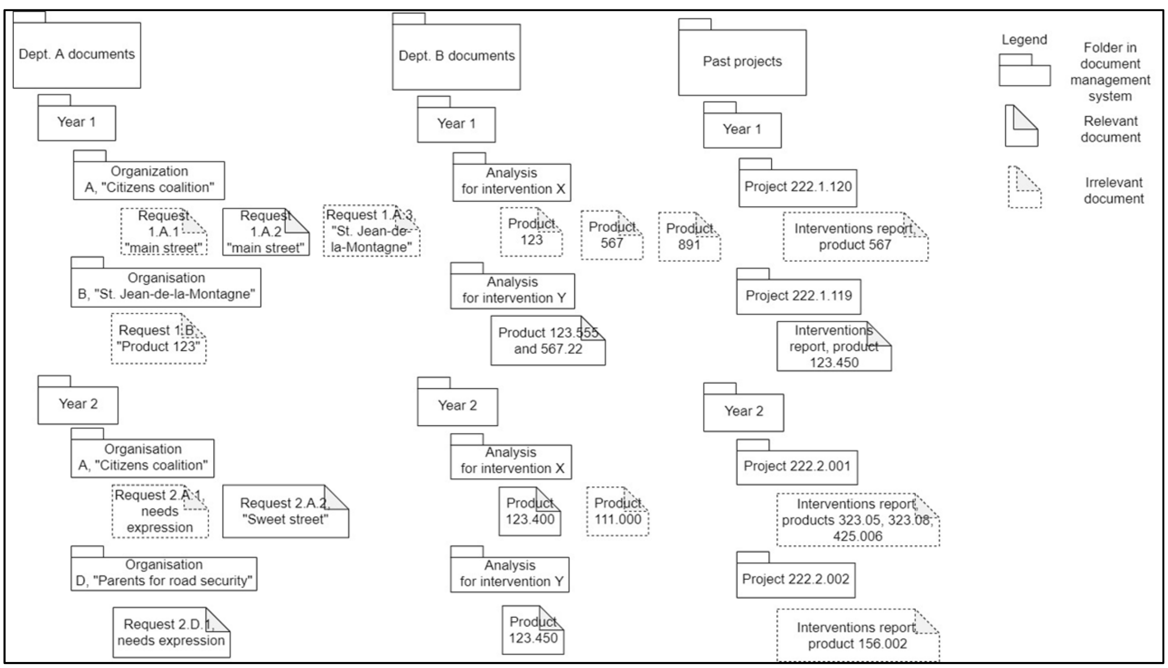

Figure 3.4 Document research through browsing challenge
Taken from Oliveira et al. (2021b)

construction phase. At that point, the stakeholder's requests might not be taken in charge at all. The best-case scenarios are when an additional project is designed, or an extension of the existing project is granted. In both cases, there are additional costs. In all cases, the stakeholder will be frustrated", added the specialist, mentioning that, ultimately, the difficulty in identifying previous communications harms the image of the organization. "I have even tried to ask stakeholders directly. But usually, they are not much better off identifying their communication with us either". "It is not so much that knowledge around a problem or a product/service is not documented, is that the documents produced are not organized, or are poorly organized, what makes them inaccessible".

In addition, the research process is not linear and has to be performed under a time constraint. The specialist summarizes the situation: "To group knowledge around a product, I have to ask the people that might have worked with that product, or with the potential stakeholders. There is a disconnection between the practice and the way knowledge around a product should be organized".

3.2.3 Perceived importance of the department

The specialist perceives the document management challenges as a lack of inclusion of their department into the product lifecycle. "All the focus is given to the design and construction phases, that are very well-covered in the document management system".

3.2.4 Input from users

"When new developments are made, the users should be considered to be the people who are actually going to use the system in their daily tasks". "But we are only briefly consulted by email and the development team doesn't share enough information for us to understand the impact of our contribution", explained the specialist.

To attempt a different form of consultation with users, an exercise was conducted with the participant. Concept maps were explained to the participant. Next, a concept map with concepts used in the current document management strategy for documents produced in the context of a project (Figure 3.5) was presented to the participant.

> The participant recognized the representation of all concepts used in the document management strategy considering documents produced during a project in this concept map. These concepts represented codes, steps in a process, document creators and outcomes. Each one of these elements was represented the same way, by a term inside an elliptical form. The connections between elements serve to illustrate a variety of different relationships. (Oliveira et al., 2021, p. 725)

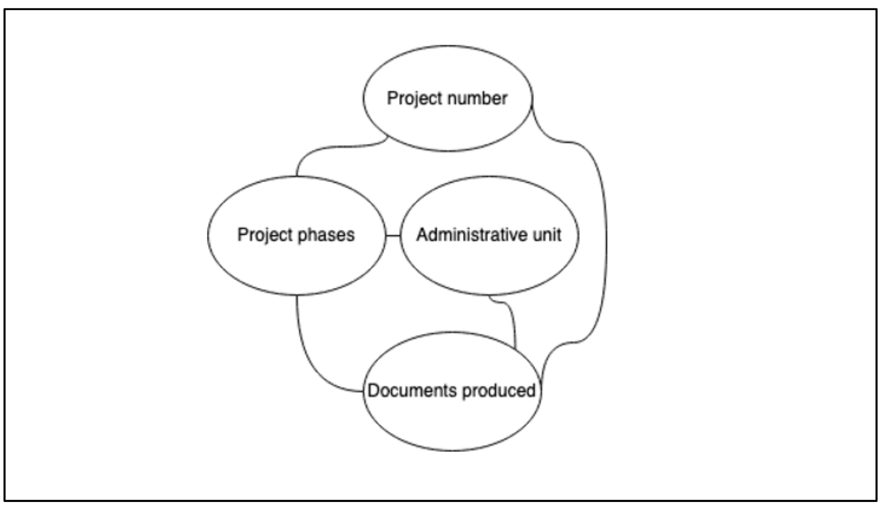

Figure 3.5 Concepts used in the current project management practice
Taken from Oliveira et al. (2021a)

A critical thinking activity based on the grouping of documents produced by other teams followed. In this activity, four additional concepts were added to the diagram, “user”, “partner”, “request” and “complaint”.

> A subsequent critical thinking activity explored the connection between the four new concepts and the existing ones. The participant identified a piece of information known to most departments of the organization that can be a common code among the departments involved. The use of this code could address the challenge of the grouping of documents their team required. During the critical thinking activities, the representation of a complex reality using minimalist elements provided a rich way for articulating the challenges surrounding the pre-project and the project phase and helped to explore possible elements of a solution. The concept map fostered a broad vision of the issues involved. In addition, the concept map became a way of conveying the solution found. (Oliveira et al., 2021, p. 725)

The resulting concept map is presented in Figure 3.6.

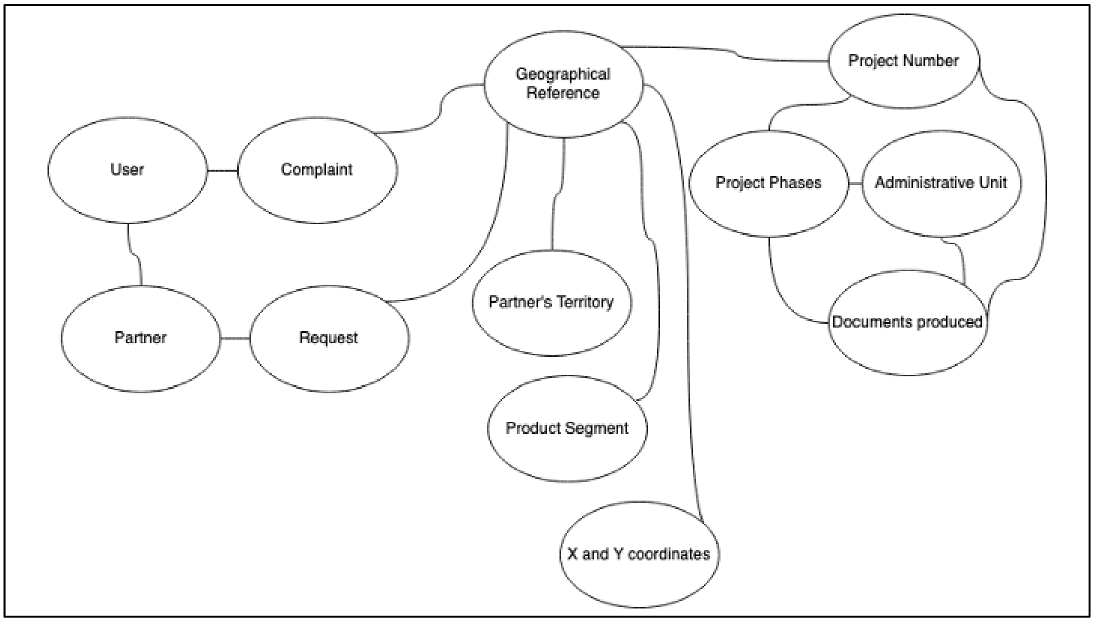

Figure 3.6 Proposed connection link of documents and information in pre-project and project phases
Taken from Oliveira et al. (2021a)

3.3 Conclusion

Many of the points raised in the interviews were observed or at least considered in the scientific literature. These points of convergence, as well as the points of divergence, are discussed in the next chapter.

CHAPTER 4

DISCUSSION

“It all began with a book written by someone in the field”. “That was the first look” at a comprehensive approach to maintenance processes”, explained one specialist in the first interview of the empirical exploration. The book provided a first comprehensive view of the maintenance processes in a branch. It provided a high level workflow of those processes and argued the connections between one activity and another, one process and another, which is close to the definition of product lifecycle management.

The book in question was published in 1999. In Scopus, a major bibliographic database, the article responding to a query on “product lifecycle management” on title, abstract or keywords was published in 1996 (Figure 4.1). No articles on the term were published in the two subsequent years. It was only in 2003 that the term started being used in at least 50 published articles per year (Elsevier B.V., 2018).

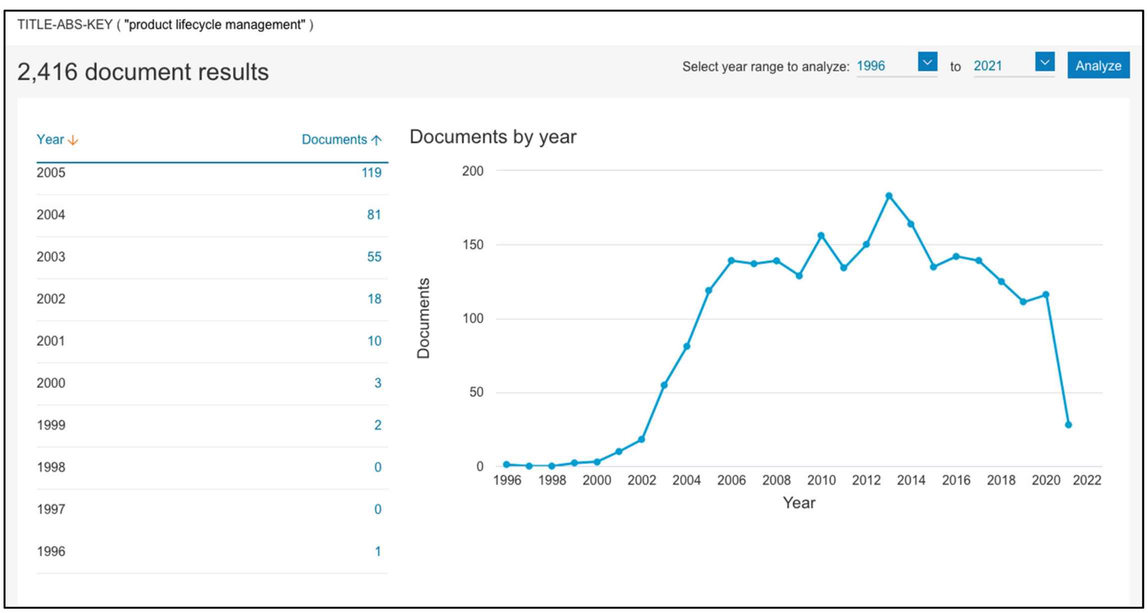

Figure 4.1 Distribution of publication dates of "product lifecycle management" articles. Taken from Elsevier B.V. (2021)

The fact that a book on PLM might have been written by a knowledge worker that was not a part of senior management of an organization a few years before the concept began to spread in academia defies the belief that new knowledge is only created in a top-down direction in organizations or only in academia. Indeed, in the knowledge economy, argues Gibbons et al. (2010), new knowledge may be developed in industry with the same rigor that it is developed in academia. The importance of non-technological innovations is also reinforced. In addition, the idea that workers are points of entrance of external knowledge (Shoham & Hasgall, 2005a) is justified, as well as how the different kinds of intellectual capital overlap (Lev & Zambon, 2003; Stringfellow & Shaw, 2009).

In terms of intellectual capital, both interviews in the empirical exploration, but particularly the second one, show how individual capital is converted into organizational capital, a notion first explored by Bourdieu (1986) and further explained by Stringfellow and Shaw (2009), as explored in the literature review. In other words, knowledge workers navigate the knowledge and informational environment around them to accomplish their tasks, which joins Grieves and Tanniru (2008) statement that practices are highly unstructured and "tend to deal with unstructured and even ambiguous information" (p. 5).

In the first interview of the empirical exploration, an existing taxonomy was used to help structure the application in development. The existing taxonomy was adapted with the input of workers. The use of existing taxonomies with the inclusion of tacit knowledge defies the view that data comprehension should be obtained independently from the existing knowledge and affects the notion that knowledge is necessarily extracted from information, which is necessarily extracted from data. Existing knowledge, particularly in the form of in-house tacit knowledge, can be brought in to benefit the data exploration, manipulation and treatment that precedes their inclusion in applications. These findings may affect data insight beyond PLM systems. Indeed, tacit knowledge of workers about their surrounding data has been used to differentiate reliable from non-reliable data in machine-learning application development (Sexton, 2021).

The relationship of knowledge workers with their surrounding data was also exemplified in the exercise described in the empirical exploration. The exercise showed how employees may be knowledgeable about the data that is involved in their practice. In other words, the exercise showed that humans learn from their interaction with the data involved in their practice. This fact might have repercussions in implementations of artificial intelligence initiatives. Indeed, machine learning initiatives replace the human manipulation of data. Such initiatives should consider ways to maintain the learning opportunities generated by data manipulation once the artificial intelligence application is in place.

The first interview of the empirical exploration outlined how PLM systems implementation may pose a higher challenge level if compared to other technological solutions. This notion has been argued by Batenburg (2006) and Meyer and Marion (2013). The need to tackle organizational change in processes in culture was also exemplified in the same interview and was mentioned by Kärkkäinen and Silventoinen (2016) and Koomen (2020) in the literature review.

The particularities of PLM systems and the integration of tacit knowledge might require additional knowledge management measures, as exemplified in the first interview and mentioned by Meyer and Marion (2013). The need for social interaction to resolve and control semantics was particularly demonstrated in the role of the Roundtable regarding the existing taxonomy, explored in the first interview of the empirical exploration. The need for social interaction was claimed by Grieves and Tanniru (2008). In addition, social interaction might not always be technology-mediated, as exemplified in the same interview and argued by Meyer and Marion (2013).

The need to integrate users in early stages of PLM systems development and was mentioned in both interviews. In the first interview, co-development was exemplified. This need was explored in the literature review chapter in the writings of Meyer and Marion (2013).

The empirical exploration, particularly the second interview, raised the point that users need to understand the context in which their opinion is being requested and what are the outcomes of the consultation. It is to be considered that their understanding might evolve as the project evolves, as mentioned by Meyer and Marion (2013), Jokinen and Leino (2019) and in an earlier publication (Oliveira et al., 2019).

The exercise on the second interview verified the potential of concept maps for needs expression, as argued by Trochim et al. (1994), Stoyanova and Kommers (2002) and Eppler (2006) and previously verified by Ardouin et al. (2015).

The second interview brought to light the magnitude of the document and information retrieval problem, as stated by Jokinen and Leino (2019) and verified by Meyer and Marion (2013), that mentions an affirmation by one aerospace manager "We have so many revision levels that sometimes we do not know what the current part is and why it changed" (p. 56).
The importance of the knowledge of the domain for creativity was explored in the writings of Amabile (1998). Knowledge of the domain is extremely difficult to obtain in the setting of the second interview, as it was already argued by Meyer and Marion (2013) and Jokinen and Leino (2019). Low levels of innovation are to be expected in those settings. In fact, even regular productivity is harmed, as showed in the second interview, which can in turn harm the reputation of the organization, as mentioned by the participant. This situation brings a new perspective into the convertibility of individual capital into organizational capital. In the same way that individual excellence can be converted into organizational success, individual challenges can be converted into organizational challenges.

The existence of a difference between how things are in theory and how things are in practice were verified in both interviews, after being explored in the literature review in the writings of Brown and Duguid (2000) and those of Grieves and Tanniru (2008). In the second interview, the specialist explained that the practice is not linear and that a disconnection between the practice and how the practice is supported by information organization and information technology solutions.

Two points were raised in the empirical exploration and were not present in the literature review. The departments interviewed expressed their feeling of not being given enough resources or organizational attention to their needs. It would be important that these departments feel as integrated and as heard as other departments in a comprehensive PLM initiative. Also, the first interview brought to light challenges of integrating knowledge management into PLM initiatives. Planning for knowledge management initiatives may be challenging, particularly if the organization has a low level of maturity in knowledge management.

4.1 Research questions, theoretical constructs, data source and collection methodology, results and discussion

4.1.1 Is there a need for inclusion of tacit knowledge in PLM?

Following the analysis of the nature of tacit knowledge, the exploration of the need for inclusion of tacit knowledge in PLM can be divided into the exploration of three topics: the need for context representation, the need for social validation and a concern with knowledge silos in PLM.

4.1.1.1 There is a need for context representation in PLM

Context representation is necessary if different perspectives on the same topic need to coexist. Representation of different perspectives relate to the ideas, approaches, information and knowledge to which data, information, knowledge or task is related. Indeed, the literature review outlined that PLM involves different tasks, roles and backgrounds working with the same reality, eventually at the same time and in co-dependent ways. The empirical exploration showed that an organization-broad perspective, at least in what concerns document management, is not enough to foster the particularities of practice in departments.

The representation of different perspectives allows for negotiation on the importance and other particularities of the different perspectives for the construction of a global, comprehensive perspective. It also allows for the identification of differences that may be incompatible with a comprehensive perspective and therefore need to be supported in a complementary way.

It undeniable that the need for representation exists, but the modeling of this representation needs input from the specialist staff.

The theoretical construct of context representation points to the task, the process, the point in time or data to which data, information, knowledge or task is related.

The literature review brought to surface that, as PLM touches different contexts, information and knowledge have to be connected to context representation for better understanding.

The interviews in the empirical exploration indicated that the analysis of existing technological solutions and logical analysis of the workflow was not enough to understand the needs of the field. The experience with the participant showed that connections between contexts are also important.

The need for context representation was therefore verified.

Context representation, however, demands context modeling, which, if dependent on codification of tacit knowledge, might entail longer design periods.

4.1.1.2 There is a for social validation of knowledge in PLM

The role of social validation is to apply a collective endorsement of knowledge. The literature review made it clear that PLM deals with a vast data, documents, information and knowledge inventory. By designing solutions based only in explicit knowledge, PLM systems include knowledge that has been socially validated. However, PLM systems fail to offer mechanisms for the social validation of knowledge that is produced after the systems implementation.

4.1.1.3 Issue of knowledge silos in PLM

Silos are groups of knowledge workers with particular culture and / or terminology that have low level of interaction with other groups. The literature review showed that there is a department-oriented paradigm. This paradigm has influenced the development of information systems, which implement the specific culture, perspective and terminology of the departments they serve. The aim of PLM is exactly to break this paradigm and increase reuse of knowledge, inputs and outputs among departments. The concern with silos is therefore central to PLM. However, joint work between different teams demands mutual understanding. The exercise becomes more and more easier as first attempts are successful.

The exploration of these three questions granted a more general view of the need for inclusion of tacit knowledge in PLM.

The literature review depicted tacit knowledge as a multifaceted, involving and permeating all kinds of intellectual capital of an organization. Its manifestation through language forces a reduction of meaning, justifying its change of nomenclature, from tacit to explicit knowledge or even to information. Tacit knowledge is profoundly anchored in context. The representation of tacit knowledge's context is a challenge when this knowledge is converted into explicit knowledge. This challenge is directly linked to the cost of tacit knowledge exteriorization. The theoretical construct of tacit knowledge also revealed its dependency on social validation if knowledge application is to be sought.

The literature review and theoretical framework integration showed how important it is to increase business interoperability in PLM, even when document and data management and workflow solutions are in place. The importance of breaking silos is crucial for effective PLM.

The empirical explorations exemplified the relationship between tacit knowledge and business interoperability: each division had its own naming conventions and its own workflows. A collective effort of mutual understanding with a strong organizational directive for standardization was necessary to achieve a normalized solution. Even so, a certain degree of flexibility had to be integrated.

Business interoperability can be achieved by the recognition that knowledge produced in different departments and levels of the organization are valid and have to be taken into account. The integration of this knowledge has to consider that information may have to be transferred in a non-linear way and in many directions. Information flows are definitely not only top-down. On the other hand, designing business interoperability without tacit knowledge would be flawed, as business interoperability is created in organizations mostly through practices that are poorly, if ever, documented.

The capture of tacit knowledge has therefore the potential of bringing to light necessary flows of information and situations where greater attention has to be paid to context representation. By doing so, the capture of tacit knowledge can facilitate the creation and scaling of business interoperability.

4.1.2 Is there a need for increasing creativity/innovation potential in PLM?

Creativity is analyzing a new problem or an old problem in a different way. Innovation is implementing the solution resulting from that analysis.

The literature review showed that, for some organizations, creativity and innovation means creating competitive advantage in the market. For others, such as engineering-to-order organizations, creativity is part of the regular business. It was also seen that PLM implementation in engineer-to-order organizations is especially difficult as those organizations have a greater need for flexibility. Strong stress in knowledge codification might generate systems that are too rigid to allow for creativity.

The need for more flexibility on how things are done in the product lifecycle, especially in engineer-to-order organizations, was therefore demonstrated.

It can be argued that the inclusion of tacit knowledge in PLM systems may enhance the flexibility of the system. As greater flexibility in systems may foster greater creativity, the inclusion of tacit knowledge has the potential to increase innovation levels, as has the collective production of tacit knowledge.

4.1.3 Is the current strategy to include tacit knowledge in PLM suitable to PLM needs?

It was observed in the literature review that the main tacit knowledge of interest to PLM is the connection between departments and the different perspectives that can be supported by data, information and knowledge involved in the PL. There are not many implemented attempts to support tacit knowledge in PLM. The proposals from the literature review stress the role identification and the addition of metaknowledge such as purpose of the information or knowledge presented, their connection to project development stage and their provenance.

The strategies proposed to include tacit knowledge in PLM systems yielded in the literature review do not actually include tacit knowledge as they rely on tacit knowledge codification. Instead, they create medium for tacit knowledge to be expressed. Only a portion of tacit knowledge is covered, the one that conforms to the form and language of the system.

It can therefore be stated that the proposed strategies found in the literature review represent a great step in the inclusion of tacit knowledge. However, they do not offer the possibility of including tacit knowledge in the data model or information architecture of the technological solutions supporting PLM themselves.

A related, additional question to be explored is if there is a need for the inclusion of social interaction in PLM. Social interaction means opportunities of friction between the knowledge in individuals. It allows for validation and prioritization of knowledge. As the implementation of innovation is the result of social interaction around and idea, it is impossible without social interaction.

It was verified that there is little social interaction in the design of PLM systems. The inclusion of tacit knowledge in PLM systems design may orient PLM approaches and promote greater social interaction.

4.1.4 Can a tool address tacit knowledge capture?

Tacit knowledge resides in people's minds. The literature review and the integration of theoretical frameworks showed that the expression of tacit knowledge demands the creation of a mental model in the head of the knower. It also brought to light that the process of eliciting tacit knowledge is crucial to its capture. Although a tool may help the process, there is a need of guidance and structure.

A tool alone would help the capture of tacit knowledge, but the creation of a common perspective, born from the collective sharing and creation of tacit knowledge is a human function and would therefore need a methodology to better fulfill the expectations placed on the tool. Therefore, a methodology to employ a tool should be developed to aid the elicitation of useful tacit knowledge.

The exploration of this question generated four correlated questions, involving tacit knowledge validation and expression; social interaction for common tacit knowledge creation and the integration of a potential tool into PLM.

4.1.4.1 A methodology to address tacit knowledge validation

The theoretical construct drawn from the literature review and the integration of theoretical frameworks indicate that tacit knowledge has to be expressed to be validated. Knowledge validation demands social interaction around that knowledge.

The literature review showed that tacit knowledge can be expressed in ways that keep its multifaceted nature, such as recordings or drawings. It can also be made explicit through its exteriorization in verbal language. Validation demands social interaction around the artifacts that somehow convey the tacit knowledge in question. However, the literature review also demonstrated that to promote validation of the tacit knowledge, the social agents involved must be able to understand the language in which the knowledge is expressed.

The resulting observation is that some aspects of the generation, validation and application of tacit knowledge are already known. Some techniques already support these processes. Grouping these techniques, adapting them to the context and applying them with the help of a tool would enhance the potential of capturing tacit knowledge around a specific process, product, service or idea.

A tool to help tacit knowledge capture should be easy to read. The methodology should allow for the sharing of the necessary context to validate knowledge. The focus is then not only on each piece of knowledge expressed, but also in its relation to the whole domain.

4.1.4.2 A methodology to foster tacit knowledge expression

It was seen that tacit knowledge is not articulated in verbal language. The knower might acknowledge the know-how as an ability, a confidence feeling or even not at all. The use of verbal language might be cumbersome and take long time, turning the process rather costly.

The literature review indicated that drawings are alternative ways to express tacit knowledge. On the other hand, concept maps are mid-way between language and drawing, which may provide a good compromise between the need for tacit knowledge exchange and the cost of tacit knowledge exteriorization. Knowledge expressed in drawings or concept maps cannot be said to be explicit as the flexibility they allow in interpretation makes of them rather ambiguous medium of knowledge expression.

Therefore, it cannot be said that tacit knowledge was made explicit in concept maps. It is more suitable to label the process a capture of tacit knowledge, as it keeps its multifaceted nature.

As a counterpart, exteriorizing tacit knowledge in verbal language implies the reduction of the multifaceted nature of tacit knowledge in order to fit the constraints of verbal representation. A methodology coupled with a tool that respects the nature of tacit knowledge has the potential of lowering the effects of meaning reduction in the exteriorization process.

4.1.4.3 A methodology to foster social interaction for common tacit knowledge creation

The social interaction needed for common tacit knowledge creation is the one allowing for modeling of concepts. It demands acceptance of negotiation between participants regarding labeling, importance and coverage of concepts.

The literature review showed that the focus group is the only methodology that focus on the interaction between participants. The interviews in the empirical exploration showed that it is difficult to validate the view of a group with the other. There is a need for synchronous negotiation. As a beneficial secondary effect, the negotiation process itself might inform priorities and other decisions in PLM.

It is therefore reasonable to expect that a methodology aiming to create the necessary elements for knowledge sharing and concentrating on the interaction between participants may facilitate common tacit knowledge creation.

Using focus groups to produce concept maps might address the need for social interaction to elicit tacit knowledge in the design phases of PLM.

A methodology supporting the use of concept maps in PLM efforts should cover the design of the collaborative creation of concept maps. As such, participant selection, introductory activities, the actual map-building activities and the absorption of the resulting concept map in one or more ontologies are discussed in Oliveira et. al (2021b). Participant selection should consider participants that are knowledgeable and vocal about the informational environment surrounding their work. To promote free expression, hierarchical relationships should be absent in each concept map collaborative creation session. Introductory activities aim to create an environment of trust and complicity and have to consider the relationships among participants, that are previous to the concept map collaborative creation session. The creation of the concept map must be an activity with a clear objective, being that the validation of an existing concept map or the creation of one having only previously prepared statements or discussions around the process or practice that the activity aims to portray. Recording of the session, in addition to notes taken by a person that is not directly involved in the activity might help capture the context that will be suggested in the concept map. The translation of the concept map into an actual ontology or its absorption in an existing ontology might require further validation of the concepts portrayed and their relationship.

4.1.4.4 A tacit knowledge tool integrated into PLM

Ontologies have been used to connect different departments' information in solutions supporting PLM and in administrative solutions in general. The literature review also showed that concept maps are the first step to ontologies and that concept maps can be translated into ontologies.

However, due to the circumstantial nature of collaborative creation of concept maps, validation of concepts and their coverage in terms of data, information and knowledge might be needed before they can be assertively transformed in ontologies.

Table 4.1 groups the main research questions this work covered.

Table 4.1. Research questions covered by the present work

Research question #	Research question	Theoretical construct	Data source / Collection methodology	Results	Discussion
1	Is there a need for inclusion of tacit knowledge in PLM?	Tacit knowledge is multifaceted, not articulated in language, expresses context and is dependent on social validation to be applied by a group	Literature: PLM needs to increase business interoperability. Silos are the main concern of PLM. Expert interviews: Each division had its own naming conventions and workflows. Internal SMEs had to be consulted	Business interoperability requires multiple flows of information and presentation of context. Considering only explicit knowledge would miss out important connections that are not codified anywhere	Capture of tacit knowledge can elucidate effective flows of information and situations where context has to be represented to facilitate business interoperability
2	Is there a need for increasing creativity/ innovation potential in PLM?	Creativity is analyzing a new problem or an old problem in a different way. Innovation is the implementation of the result of that analysis	Literature: PLM in engineer-to-order organizations is particularly difficult. Systems might be too rigid for creativity, that needs flexibility. Creativity and innovation are needed in all organizations	There is a need for more flexibility on how things are done in the PL, especially in engineer-to-order organizations	Inclusion of tacit knowledge in PLM systems may enhance the flexibility of the system. Greater flexibility in systems may foster greater creativity. Collective production of tacit knowledge may increase innovation levels

Research question #	Research question	Theoretical construct	Data source / Collection methodology	Results	Discussion
3	The current strategy to include tacit knowledge in PLM is suitable to PLM needs	The main tacit knowledge of interest to PLM is the connection between departments and the different perspectives that can be supported by data, information and knowledge involved in the PL	Literature: previous attempts: identifying roles and adding metaknowledge such as purpose of information presented	The current strategies to include tacit knowledge do not actually include tacit knowledge but create medium for tacit knowledge to be expressed. Only a portion of tacit knowledge is covered.	The current strategies represent a great step in including tacit knowledge. However, they do not offer the possibility of including tacit knowledge in the data model or information architecture of the technological solutions supporting PLM
4	Can a tool address tacit knowledge capture?	Tacit knowledge resides in people's minds	Literature: the expression of tacit knowledge demands the creation of a mental model in the head of the knower; Eliciting tacit knowledge precedes its capture. A tool may help, but guidance and structure to the process are needed	A tool would help the capture of tacit knowledge; a common view, created from the collective sharing and tacit knowledge is a human function and would need a methodology to fulfill the expectations placed on the tool	A methodology to employ a tool should be developed to aid the elicitation of useful tacit knowledge

CONCLUSION AND RECOMMENDATIONS

The literature review and integration of theoretical frameworks of this research integrated the notion of innovation into the Intellectual Capital model. Intellectual Capital, as a framework to approach Knowledge Management, brings the insight that individual activity of employees, as well as their interaction, are converted into organizational assets in multiple and nonlinear ways. Organizational assets depend on individual and collective knowledge to be applied to practice. Part of this knowledge is codified in documents and information systems. The greatest part of this knowledge, however, resides in the mind of individuals. The knowledge that resides in the mind of individuals, the tacit knowledge, is the one that allows individuals and groups to navigate the knowledge and informational environment of the organization.

The application of the existing knowledge to real problems in an organization may be guided by processes, which may be structured and documented in procedures and policies. These processes are carried out thanks to practices, which are unstructured, nonlinear and that involve collecting, interpreting and producing knowledge and social connections that may never be documented. Processes and practices, as well as codified and tacit knowledge are factors that make employees solve problems in their everyday activities and achieve their intended goals.

Tacit knowledge, a concept much explored by Dalkir (2017), has a close relationship with creativity and innovation. Rigid structures are not favorable to the flourishing of creativity.

PLM intends to assist the whole product lifecycle, particularly the transitions between departments. This bold objective involves almost the whole organization. The need for PLM comes from rigid organizational structures that evolved into segmented and local cultures, reflected in sensibly diverse information systems, processes and practices. PLM endeavours, however, have mostly focused on one single pillar of the Intellectual Capital model, the organizational capital, meaning, data, information systems and codified knowledge. Even though this focus considers the organization through a limited perspective, great expectations have been placed in PLM solutions, including increase in productivity, reduction of leading time to market and greater innovation.

The need for inclusion of tacit knowledge has been argued in many studies explored in the literature review. However, only three studies presented a proposal of solution for this inclusion: Brunsmann (2011), Liao et al. (2012) and Arduin et al. (2015). An additional study, Koomen (2020), recommended approaches for the inclusion of tacit knowledge. Brunsmann (2011), Liao et al. (2012) and Arduin et al. (2015) recommend punctual exteriorization and codification of tacit knowledge, focusing on individual tacit knowledge. Brunsmann (2011) and Liao et al. (2012), through semantic annotations somehow connected to ontologies and Arduin et al. (2015), through changes in existing ontologies mediated by a technological platform. Koomen (2020), on the other hand, recommends the focus on different ways of thinking and organizing PLM implementations, suggesting collective initiatives.

After consideration of the characteristics and impact of tacit knowledge in PLM, both in theory and practice, the approach recommended by this research incorporates or complements the previously recommended approaches. The collaborative creation of concept maps is flexible enough to assist in the creation and modification of ontologies, as well as in knowledge discovery and organization of PLM implementations. It involves collective initiatives, as PLM is, above all, a team effort that must incorporate negotiation and consensus.

The collective creation of concept maps relies on less important codification efforts, enough to consider tacit knowledge "captured" instead of "codified", which brings advantages and disadvantages discussed in the previous chapters, but seems suited to the magnitude and fast pace of PLM implementations. In that sense, the focus is more in eliciting tacit knowledge from workers at the moment the tacit knowledge is needed and immediately integrating that knowledge into artifacts or actions. The focus is less on the codification of knowledge, which entails high costs and might generate a corpus of codified notes difficult to reuse due to their lack of context representation, as verified by Gardoni et al. (2000), and more on the production of common tacit knowledge, knowledge that was negotiated, validated and prioritized by significant members of the community involved. This approach respects the multifaceted nature of tacit knowledge, its need for validation by a social group for application, its anchoring in context and its constantly changing nature. Concept maps collaboratively created may be converted into ontologies or intellectually applied to other uses. The interaction among participants has to be captured with rich media, as the approach also respects the ephemeral nature of tacit knowledge exteriorization when it is not intended for codification.

APPENDIX I

QUESTIONNAIRE – PARTICIPANT A

Projet : L'intégration de connaissances tacites dans la gestion du cycle de vie de produit

Chercheur principal : Mickaël Gardoni

Étudiante : Daniela Oliveira

Profil Expert – utilisation d'outils

Questions d'entrevue

(présenter le feuillet d'information)
(mentionner que la création de l'arborescence se fait automatiquement par SFP/ SIC lors de la création d'un projet)

1. Voici un diagramme représentant les rubriques de l'arborescence de documents destinés à la gestion d'un projet dans votre organisation. Pouvez-vous identifier dans quelle étape votre travail se situe?

2. Voici un diagramme représentant l'arborescence pour la gestion de documents dans votre étape. Qu'est-ce que vous identifiez comme problème dans cette arborescence?

3. Quel est l'impact des problèmes que vous identifiez dans cette arborescence?

4. Quel serait votre suggestion pour l'arborescence?

5. Quel serait le gain de vos suggestions pour l'intégration des étapes de gestion d'un projet?

6. Si un nouvelle façon de gérer les documents pour l'intégration des étapes d'un projet était à concevoir aujourd'hui, dans quel moment croyez-vous qu'il serait intéressant d'obtenir vos suggestions: dans le tout début de la conception, pendant le développement des outils d'intégration ou une fois les outils d'intégration développés?

7. Est-ce que vous avez travaillé avec l'arborescence préconisée par la gestion de projet?

8. Combien de temps après que vous aviez commencé à travailler avec l'arborescence préconisée par la gestion de projet êtes-vous rendu compte que des adaptations étaient nécessaires?

9. À quel point du projet vous vous êtes rendu compte qu'il était nécessaire d'incorporer ces connaissances non documentées?

10. Une carte conceptuelle a pour but identifier les concepts importants dans un projet. Voici une carte conceptuelle de la gestion de documents pour intégrer les étapes d'un projet tel que préconisée dans votre organisation. Est-elle adéquate? Que changeriez-vous dans cette carte conceptuelle?

11. Dans la création hypothétique d'une nouvelle façon de gérer les documents des étapes d'un projet, croyez-vous que l'exercice que nous venons de faire, soit la création d'une carte conceptuelle, aurait aidé à informer cette nouvelle façon de gérer? Pourquoi?

APPENDIX II

QUESTIONNAIRE – PARTICIPANTS B, C ET D

Projet : L'intégration de connaissances tacites dans la gestion du cycle de vie de produit

Chercheur principal : Mickaël Gardoni

Étudiante : Daniela Oliveira

Profil Expert – création de système de gestion de cycle de vie du produit

(Présenter le feuillet d'information)

Questions d'entrevue

1. Quel était le but du système?

2. Quel était le rôle des connaissances dans les têtes des gens dans le contexte de ce projet?

3. À quel point du projet vous vous êtes rendu compte qu'il était nécessaire d'incorporer ces connaissances non documentées?

4. Quand avez-vous commencé à incorporer ces connaissances?

5. Comment avez-vous incorporé les connaissances non documentées?

6. Avez-vous fait usage de diagrammes pour vous aider à incorporer les connaissances non documentées?

7. Est-ce que le système conçu couvre toute la gestion de cycle de vie du produit?

8. Si le système conçu ne couvre pas toute la gestion de cycle de vie du produit :
    a. Est-ce qu'il est nécessaire un système ou d'autres systèmes pour appuyer la gestion de cycle de vie du produit? Pourquoi?
    b. Si un système ou d'autres systèmes de gestion de cycle de vie du produit sont nécessaires, est-ce des connaissances non documentées doivent encore être explorées?

c. Si des connaissances non documentées doivent encore être explorées, dans quoi cette nouvelle démarche serait différente de celle que vous avez entrepris?

9. Combien de temps a pris l'incorporation de ces connaissances dans le projet?

10. Était-il possible de prévoir précisément le temps que l'incorporation de ces connaissances a pris? Pourquoi?

11. Quels ont été les gains d'inclure les connaissances dans les têtes des gens?

12. Quels problèmes auriez-vous rencontré si vous n'aviez pas pris en compte les connaissances dans les têtes des gens?

13. Si c'était à refaire, quels changements feriez-vous dans la démarche que vous avez entamée pour incorporer les connaissances non documentées?

14. Quels conseils donneriez-vous à d'autres créateurs de systèmes qui doivent incorporer des connaissances non documentées?

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