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KMS affordances perceived as most useful by knowledge workers

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Résumé

Des recherches antérieures ont démontré qu'une implantation réussie d’un système de gestion des connaissances (KMS) peut considérablement accroître la capacité d'une organisation à générer de la valeur et lui procurer un avantage concurrentiel. Cependant, ces systèmes sont généralement sous-utilisés par les employés. L’utilisation d’un KMS est largement influencée par la perception qu'ont les utilisateurs de ses affordances, définies comme la capacité du KMS d’offrir une action appropriée à la situation. Cela nous mène à la question suivante: quelles affordances des KMS sont perçues par les travailleurs du savoir comme étant les plus utiles ou ayant l'impact le plus positif sur leur productivité?

Ce mémoire tente de répondre à cette question en faisant appel à un panel de dix travailleurs du savoir dans le cadre d’une étude Delphi de type ranking. Cela a permis de générer une liste de 22 affordances ordonnées selon leur importance perçue par le panel. Cette liste peut servir de base pour améliorer l’utilisation des KMS en organisation en priorisant le développement et l’implantation des capacités que ces systèmes procurent selon leur importance perçue par les utilisateurs. Elle permet également d’évaluer la satisfaction des utilisateurs sur chacune des 22 affordances afin d’identifier de possibles faiblesses du KMS qui seraient à améliorer.

Mots-clés: Système de gestion de la connaissance, Travailleurs du savoir, Design, Affordances, classement Delphi

Abstract

Prior research has found that a successful Knowledge Management System (KMS) implementation can drastically increase an organization's ability to generate value and provide a competitive advantage. However, these systems are typically underused by employees. Prior literature showed that the use of KMS is largely influenced by users' perception of its affordances, defined as the actions rendered possible by a technology to a user or group of users. This leads to the following question: what KMS affordances are perceived by knowledge workers as being the most useful or having the most positive impact on their productivity?

This thesis attempts to answer the previous question by eliciting from a panel of ten expert knowledge workers a list of KMS affordances using the Ranking-type Delphi method. A list of 22 affordances ranked by their perceived importance by the panel was produced with this method. This list provides solid grounds for improving the use of KMS in organizations by prioritizing the development and implantation of KMS capabilities that are perceived as most important by the users. It can also be used to assess user satisfaction on each of the 22 affordances and identify potential weaknesses.

Keywords: KMS, Knowledge workers, Design, Affordances, Ranking-type Delphi

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Foreword

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Acknowledgments

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Chapter 1: Introduction

1.1 Research Motivation

Designing artifacts has become a core activity in modern organizations, especially in those who regularly create new and innovative products to improve their performance. Google, Amazon and Samsung for example, are continuously designing new or improved versions of their products, internal systems and processes in order to create value for their customers and shareholders in the most effective way possible. If an organization keeps using the same working recipe for years or decades, therefore involving little to no design, it becomes less agile and unable to adapt when a change occurs in its environment (Tallon & Pinsonneault, 2011). However, designing an artifact is not easy; it requires knowledge (Hevner, March, Park, & Ram, 2004), which is one of the most valuable assets of an organization (Beck, Pahlke, & Seebach, 2014) and is seen as "the capacity for effective action" (Senge et al., 1999; Quoted in Call, 2005, p. 20). Thus, employees, in their role of designers, need to acquire relevant knowledge by seeking existing sources or creating new knowledge (Hevner et al., 2004). Designing and acquiring knowledge are two interconnected knowledge-processing activities that lead to the creation of organizational assets, valuable artifacts and knowledge. Moreover, knowledge processing activities can be characterized by their level of interdependence and complexity. Highly interdependent activities require more collaboration; complex activities are unstructured and involve more knowledge processing than structured activities (Davenport, 2008). Most modern artifacts have a high level of complexity and interdependence and therefore, they need to be designed collaboratively by a multidisciplinary team (Kuhn, Dusch, Ghodous, & Collet, 2012). Given that the ability to process knowledge and collaborate efficiently directly impacts the capacity of the organization to generate value (Nunamaker Jr, Romano Jr, & Briggs, 2002), the motivation to improve performance in those areas is warranted.

Knowledge management tools (commonly referred to as KMS or Collaboration Systems) have functionalities that support the knowledge processing and collaboration capabilities (Qureshi, Briggs, & Hlupic, 2006) necessary for design. Prior research has found that a successful KMS implementation can drastically increase an organization's ability to generate value and provide a competitive advantage (Brown, Dennis, & Venkatesh, 2010). However, such expected benefits are attained if, and only if, the system is used. System use is one of the main success criteria in any IS implementation project (Nelson, 2005; Thomas & Fernández, 2008) and is a suitable measure for IS implementation success in most cases if the nature of the system, its extent, its quality and its appropriateness are taken into account (DeLone & McLean, 2003). It seems clear from the IS literature that system use is a major concern in implementing any information system (Brown et al., 2010; Venkatesh & Davis, 2000; Venkatesh, Morris, Davis, & Davis, 2003).

This is where the problem addressed in this thesis lies: "Firms enthusiastically implement costly KMS that languish from underuse by individual users" (Tiwana & Bush, 2005). Although this problem was identified more than 10 years ago, more recent studies still confirmed its existence. The Dachis Group published a study in 2012 which found that only 10 to 20 percent of workers whose employers implemented a KMS actively used it (the countries represented in the survey include primarily the US (62.7%), the Netherlands (9.8%), France (7.8%), Germany (5.9%) and others) (Dachis Group, 2012). In 2014, Neuralytix research evaluates that number at 12 to 15 percent (All, 2014). Moreover, Loebbecke and Myers (2017) have found that sufficient user participation (implying system use) is still one of the major challenges for Knowledge Portals, a type of KMS.

Many studies have investigated the factors influencing KMS use. Dixon (2008) identified how the physical and relational characteristics of the social networks, such as the number of relationships drawn between people or whether a relationship is face to face or at a distance, differed for those who chose to use a KMS and those who didn't. Tiwana and Bush (2005) showed that individual users' perception of reputation among peer users and system-mediated relationships with other users increased their continued use while investments in personalization of a system initially diminish it. Wint (2016) presented a comprehensive framework of socio-technical factors, related to people, processes and technology, influencing KMS usage. Brown et al. (2010) suggest that technology characteristics such as social presence, immediacy of communications and concurrency have an influence on the perceived usefulness of KMS, which partly predicts users' intention to use a system, and by extension the actual system use (Venkatesh & Davis, 2000). Wang and Lai (2014) investigated the KMS adoption factors, taking into consideration its technological, individual and organizational dimensions. Their results concluded that higher knowledge quality, system quality, top management support and organizational rewards are associated with greater user intention to continue using a KMS.

In a different vein, some researchers approach KMS use from the perspective of their affordances, defined as “the possibilities for goal-oriented action afforded to specified user groups by technical objects” (Markus & Silver, 2008, p. 622). Affordances emerge from the properties of an object combined with the goals and expertise of a user (Bernhard, Recker, & Burton-Jones, 2013). For example, the activity of flying an aircraft is possible because of its physical characteristics, the expertise of the pilot and their desire to do so. In the context of KMS, Dulipovici and Vieru (2015) show that the use of a KMS is largely influenced by users’ perceptions of its affordances. Affordances may not be intentionally created by the developers of the KMS and users may not perceive all of the affordances or may perceive some that do not exist in reality (Pozzi, Pigni, & Vitari, 2014). The implications are that while the features of the KMS are an important determinant of its perceived usefulness and therefore use, perceived affordances have a more direct influence.

Several researchers have studied KMS affordances. Terrenghi, Fritsche, and Butz (2006) focus on the design of affordances for collaboration on table top display. Faraj et al. (2011) propose the affordances of the technology used by online communities as a generative response “that views technology, action, and roles as emergent, inseparable and coevolving”. Lami and Franco (2016) explore how the features of collaborative problem-solving technology support stakeholder interactions from an affordance perspective. While these studies make very interesting contributions, they don’t give insight on the specific affordances that are most desired by users (here, knowledge workers), from the users’ perspective, which would provide useful guidance for developing and implementing KMS that are more likely to be used.

In summary, design is the precursor of value creation in organizations and necessitates effective collaboration and knowledge processing capacity. KMS support these activities but are typically not implemented successfully due to lack of adoption by their targeted users, knowledge workers. One explanation for the underuse of KMS lies in their perceived affordances. Many studies have investigated KMS from an affordance perspective, but little is known about the actual affordances that knowledge workers perceive as most useful.

1.2 Research Objectives and Research Questions

This research aims to bridge this gap by identifying the KMS affordances that are perceived as being most useful by knowledge workers or having the most positive impact on their productivity. While there is no single definition of “knowledge work” that has reached consensus in the literature (Maruta, 2012), design is clearly a type of knowledge work, because it requires the ability to assimilate, use and create knowledge. Design is the process by which useful artifacts are elaborated and created. It is therefore one of the main drivers of innovation and value creation in organizations. For these reasons, this research will focus on knowledge workers who are involved in design activities regarding the development of various artifacts, such as engineers, software developers and architects. For the remainder of this text, the term knowledge worker will refer to this specific type of knowledge workers.

This research aims to answer the following question: what KMS affordances are perceived by knowledge workers as the most useful? In order to answer this question, the goals of this research are as follows:

1. Determine what KMS affordances are commonly perceived as being useful by knowledge workers when designing various artifacts.
2. Determine the ranking in importance of those affordances.

A Ranking-Type Delphi will be used in order to reach those goals. This methodology is specifically designed for eliciting a ranked list of items (here, KMS affordances without taking into account their feasibility) from a panel of experts and building consensus among them (Paré, Cameron, Poba-Nzaou, & Templier, 2013).

1.3 Research Contribution

This research’s contribution is to provide guidance for the KMS developers and the practitioners implementing these systems. With the knowledge provided in this research, KMS developers are able to better chose and prioritize which affordances to include in their systems. The KMS implementation projects champions and change management specialists can better communicate system features to the users in order to align their perception of the systems' affordances with the actual features. A list of 22 most useful KMS affordances was identified and can be used by organizations who heavily rely on design activities to ensure they provide the necessary IT capabilities to their employees.

1.4 Thesis Structure

The next chapter of this thesis will assess the state of the literature on the theory of affordances and KMS affordances. The third chapter will detail the methodology and the fourth chapter will address the procedure, data analysis and results for each phase of the Delphi method used to elicit the affordances perceived as the most useful by knowledge workers. Finally, the fifth chapter will discuss the result and conclude the thesis.

Chapter 2: Literature Review

This chapter assesses the state of knowledge on fields related to the research question and contains two main sections plus a conclusion. Intellectual bandwidth is a theory about the capacity of organizations to create value. Since the main utility of KMS is to increase that capacity, the first section will be devoted to this theory. The second section will explore the concept of affordances in IS and the main affordances of KMS that are known in the literature. Finally, the conclusion will close the circle by exploring how each KMS affordance fit in the Intellectual Bandwidth model. The goal of this chapter is to be able to compare the KMS affordances that are known in the literature with the ones that will emerge from the panel of experts in the Delphi.

2.1 Intellectual Bandwidth

The purpose of any organization is to create value for their stakeholders. Value is the property of a tangible or intangible thing that is desirable to its holder. Money for example, is valuable because it can be exchanged for practically anything and it often serves as a measure of value. There is often confusion between value creation and value capture (Priem, 2007). Value capture is about getting the biggest part of the pie, while value creation is about increasing the size of the pie (Johannessen & Olsen, 2010). The Intellectual Bandwidth model, proposed by Nunamaker (2002), aims to be useful for designing IT solutions that reduce the cognitive load of creating value from external domain knowledge and intellectual capital. It is the product of a hierarchy of understanding and a hierarchy of collaboration. The capacity of an organization to transform knowledge along the hierarchy of understanding and to collaborate is what determines its capacity to create value. The purpose of KMS, on an abstract level, is to increase organizations' efficiency on those two dimensions (Qureshi et al., 2006). For this reason, the Intellectual Bandwidth model will serve as the basis for the conceptual framework of KMS affordances that will be presented at the end of this chapter.

Domain knowledge is knowledge that belongs to a specific area or discipline. External domain knowledge is knowledge that resides outside of an organization, in the mind of individuals, on documents or information systems, and that is not directly valuable to it but may become so. The value of external domain knowledge remains unknown until it can be accessed and understood by members of the organization and applied in the current or expected future situation of the organization. Intellectual capital is defined as knowledge that is captured by an organization and made available to its members within its boundaries. Applied knowledge is that which is being used in mission-critical tasks and actually creates value to the organization. “An organization's Intellectual Bandwidth (IB) is its capacity to transform External Domain Knowledge (EDK) into Intellectual Capital (IC), and to convert IC into Applied Knowledge (AK), from which a task team can create value” (Nunamaker Jr et al., 2002).

Six concepts are fundamental for understanding Intellectual Bandwidth:

- Access: the ability to get at something
- Relevant: is related to the matter at hand
- Context: situation, or surroundings of an object that clarifies its meaning
- Understand: to comprehend the meaning of something
- Reason: using logic and argumentation in order to draw conclusions
- Communicate: to exchange concepts and ideas among individuals

The intellectual bandwidth of an organization depends on the capacity of its members to access data, information and knowledge relevant for understanding the causes and consequences of the problems they are trying to solve in their context. The members must reason and communicate possible solutions with each other and with outside stakeholders in order to reach their goal.

2.1.1 The Hierarchy of Understanding

The hierarchy of data, information, knowledge and wisdom is the first dimension of the Intellectual bandwidth model. Most authors suggest that data is at the bottom of the hierarchy, and it can be converted into information with some work. Information can in its turn be converted into knowledge and knowledge into wisdom. Some authors propose the opposite: the hierarchy begins with knowledge and ends with data. The adopted view in the Intellectual Bandwidth model is that both are true, and it is possible to move in either direction in this hierarchy of understanding. Some kind of work is always required to transform knowledge into a more or less abstract level of the hierarchy (Nunamaker Jr et al., 2002).

Data is meaningless without the context in which it was collected. It is just a stream of symbols that could be interpreted in many ways. When put into context, data becomes information. For example, the set of numbers [12, 14, 12, 11, 15] means nothing, unless it is known that these symbols represent the temperature in Celsius at midnight in Montreal at five given dates, then it becomes information. Knowledge represents patterns that emerge in information. For example, with the information about the temperature at midnight in Montreal for every day during a few years, it is possible to observe the seasonal patterns and make prediction about the temperature in Montreal for future dates with some margin of error. Wisdom implies understanding the causes and consequences of known patterns and what knowledge applies to a given context. For example, with a sense of how the earth rotates around the sun, one can explain the difference in seasonal temperatures at any location with the angle at which the light from the sun hits the earth. When sunlight hits the earth at close to a perpendicular angle, more light covers the same surface than when it hits the earth with a smaller angle. Additionally, one can explain the latency of the expected change in temperature at a given location based on this explanation with the presence of water in the area, knowing that water takes more time to change temperature than air and that the wind coming from over water can cool down or warm up the air in surrounding ground locations. A wise person understands that knowledge about geometry, the planetary movements, the heat absorption rates of air and water and the wind is applicable for explaining observed patterns in the temperature at any location on earth and knows how to apply it.

“As entropy is to the physical universe, so noise is to understanding. [...] Just as work is required to maintain order in the universe, so work is required to extract understanding from noise” (Nunamaker Jr et al., 2002, p. 77). Noise and relevance are diametrically opposed and they can both be found at any level of the hierarchy of understanding. Noise is data, information, knowledge or wisdom that is either erroneous or does not apply to the matter at hand and is irrelevant. The closer to the level of wisdom in the hierarchy of understanding, the harder it is to distinguish noise from the rest. Similarly, the higher up in the hierarchy of understanding, the less knowledge is tied to a specific context, or the more general it becomes. This is very noticeable in the example given in the previous paragraph about the surface temperature of the earth. The data is tied to a very specific context, namely the temperatures in Montreal at given times, and the wisdom is applicable anywhere, even probably on other planets.

2.1.2 A Hierarchy of Collaboration

The hierarchy of collaboration is the second dimension of the Intellectual Bandwidth model. There are at least three modes of collaboration that can be situated in a hierarchy: collected work, coordinated work and concerted work. Collected work occurs when each member of a team works individually and no coordination is required for them to be productive. The productivity of the team is an aggregate of the productivity of each member. A team of sprinters is an example of collected work. This kind of collaboration requires minimal communications. In coordinated work, members still work individually, but their success may depend on receiving in time the deliverables of others. The team’s ability to coordinate has a greater impact on its success. A team of relay runners is a good analogy in this case. Activities are typically interdependent in this kind of collaboration, processes are integrated between members and communication is required. Concerted work involves all team members’ efforts to contribute in concert to the group’s performance. The analogy here would be a rowing team. Individuals must synchronize in order to yield the desired results. The process structure is much higher than in coordinated work and requires even more communication among team members.

2.1.3 A Model of Intellectual Bandwidth

The model states that intellectual bandwidth is a function of an organization’s ability to collaborate and transform knowledge. More precisely, intellectual bandwidth equals the multiplication of the levels of collaboration and knowledge transformation. In a graph, it is represented by the surface area of a rectangle which as a height corresponding to the level of ability to transform knowledge and a width corresponding to the level of collaboration. This model can also be used to assess the potential contribution of Information Technologies to the intellectual bandwidth of organizations.

2.1.4 Conclusion

The Intellectual Bandwidth model provides solid grounds to base our framework of KMS affordances. According to this model, there are two main characteristics that can improve an organization's capacity to create value: its ability to process knowledge and its ability to collaborate efficiently. Processing knowledge includes activities that transform knowledge across the hierarchy of data, information, knowledge and wisdom, such as making deductions or inferences, making calculations, reasoning, etc.

It requires cognitive capacities and the ability to distinguish relevant knowledge from noise. A decision support system is a good example of a type of KMS that supports this kind of activity by extending knowledge workers' cognitive abilities. Collaboration, on the other hand, implies communication and coordination between workers and therefore require social and organizational skills. Tools such as project management software or social networks are good examples of KMS that support collaboration. Each KMS affordance should therefore contribute to increasing the intellectual bandwidth of the organization by increasing its capacity to process knowledge, collaborate efficiently or both.

2.2 Affordances

The theory of affordances came to light in the ecological psychology field, when Gibson published "*The Theory of Affordances, Perceiving, acting and Knowing*" in 1977. He defined the concept as the possibility of an action available to an actor in their environment (Pozzi et al., 2014). The actor is an organism that perceives and interacts with its environment. This interaction is enabled by characteristics of both the actor and the environment. According to Pozzi et al. (2014), Hutchby (2001) was the first author to shift the focus of affordance from the environment of the actor to a specific artifact, meaning a man-made object, within the environment. This change made the concept of affordance more suitable for analyzing IT artifacts, and the concept of functional affordance was introduced in the IS field by Markus and Silver (2008) to describe them. It also spiked interest in the engineering field with the notion of affordance based design (Ciavola & Gershenson, 2016; Cormier & Lewis, 2015; Cormier, Olewnik, & Lewis, 2014; Maier & Fadel, 2009).

A literature review was conducted using the keyword "affordance" in the databases ACM Digital Library, ABI/INFORM Collection, Business Source Complete and Computers & Applied Sciences Complete. Two main themes emerged from the search as relevant for this study and are reflected in the following sections. The first one is affordances in general as a concept in the IS discipline and the second one regards the specific affordances of KMS, their categorization and outcomes. The table 2.1 below details the search parameters in each database, the resulting number of articles and the number of articles that seemed relevant for this study base on their title.

<table>
<tr><th>Search</th><th>Database</th><th>Results</th><th>Titles of interest</th><th>Refinement parameters</th></tr>
<tr><td>A</td><td>ACM Digital Library</td><td>103</td><td>1</td><td>Published since: 2008
ACM Publications: Journal</td></tr>
<tr><td>B</td><td>ABI/INFORM Collection</td><td>155</td><td>6</td><td>Full text
Peer reviewed
Scholarly Journals
Published since 2008</td></tr>
<tr><td>C</td><td>Business Source Complete</td><td>88</td><td>8</td><td rowspan="2">Scholarly (Peer Reviewed) Journals
Academic Journals
Published since 2008

Subjects:
-information technology
-information storage & retrieval systems
-knowledge management
-social networks
-technology
-information resources management
-information processing
-information sharing</td></tr>
<tr><td>D</td><td>Computers & Applied Sciences Complete</td><td>169</td><td>5</td></tr>
</table>

Table 2.1: Affordances Literature Review Search Parameters

For each search, the researcher read the titles of all resulting articles and filtered out the ones that seemed irrelevant to the subject at hand. The abstract of the remaining articles was read for further filtering of those that were out of scope and on some occasions articles were eliminated after being read. As a criterion, only articles that were about the subject of affordance as a theoretical concept were kept in the sample for the first theme and those that used affordances as an analytical lens for other purposes were not. For the second theme regarding specifically KMS affordances, only articles that proposed a categorization of KMS affordances and their positive outcomes were selected. The next table (2.2) contains the list of articles that ended up in the final sample for each theme and the searches in which they appeared, corresponding to the letters from A to D in the previous table.

Theme	Reference	Title	Search			
			A	B	C	D
Affordance in IS	(Markus & Silver, 2008)	A Foundation for the Study of IT Effects: A New Look at DeSanctis and Poole's Concepts of Structural Features and Spirit		X	X	
	(Strong et al., 2014)	A Theory of Organization-EHR Affordance Actualization		X	X	X
	(Grgecic, Holten, & Rosenkranz, 2015)	The Impact of Functional Affordances and Symbolic Expressions on the Formation of Beliefs		X	X	X
	(Fayard & Weeks, 2014)	Affordances for practice			X	X
KMS Affordances	(Malhotra & Majchrzak, 2012)	How Virtual Teams Use Their Virtual Workspace to Coordinate Knowledge	X			
	(Abhari, Davidson, & Xiao, 2017)	Co-innovation platform affordances		X	X	
	(Wagner, Vollmar, & Wagner, 2014)	The impact of information technology on knowledge creation: An affordance approach to social media		X	X	
	(Zhao, Liu, Tang, & Zhu, 2013)	Conceptualizing perceived affordances in social media interaction design		X		
	(Hahn & Wang, 2009)	Knowledge management systems and organizational knowledge processing challenges: A field experiment			X	X
	(Rice et al., 2017)	Organizational Media Affordances: Operationalization and Associations with Media Use.			X	
	(Leidner, Gonzalez, & Koch, 2018)	An affordance perspective of enterprise social media and organizational socialization				X

Table 2.2: Articles Retained for the Literature Review on Affordances

2.2.1 Affordances in IS

Markus and Silver (2008) proposed the concepts of technical objects, functional affordances and symbolic expressions as a revision and extension of the structural features and spirit concepts of DeSanctis and Poole’s (1994) Adaptive Structuration Theory (AST). AST is the result of DeSanctis and Poole’s effort to explain the variation across groups of the effect of system use that cannot be explained by technology alone. The structural features and spirit constructs are two ways of describing the social structure provided by an advanced information technology. The structural features are the capabilities offered by a system while the spirit is the intent of a system’s designers with regard to how it should be used and how to interpret its features (DeSanctis & Poole, 1994).

Markus and Silver (2008) identified three main contributions of DesSanctis and Poole. First of all, the concepts of spirit and structural features offer an alternative to designers’ intentions, users’ perception and feature lists for characterizing IT artifacts. While designers’ intentions may not be faithfully executed in the final artifact and users’ perceptions may be limited, structural features and spirit allow researchers to pose hypotheses based on their own interpretation for design research related to the effects of a system's capabilities. Secondly, feature lists are problematic because the presentation of features varies from one system to another, which hinders comparability. Finally, the concept of spirit takes into account the human values that are promoted in a system from a holistic perspective.

Despite these advantages, Markus and Silver also identified three concerns facing DeSanctis and Poole's concepts of spirit and structural features. The first one is that they rely on the philosophically controversial assumption that IT has "embedded social structures", or intrinsic causal properties. The second concern regards the failure to solve the "repeating decomposition problem", or the fact that features can be nested indefinitely within each other. DeSanctis and Poole address this problem by making a distinction between core and optional features and by scaling technologies across relevant dimensions, such as restrictiveness or level of sophistication. These approaches are unsatisfactory according to Markus and Silver, because the relevance of features also depends on how they are implemented and the scaling method "does not address functionality at a level that relates clearly to users' appropriations of technology" (Markus & Silver, 2008, p. 618). The third issue, and the most problematic according to Markus and Silver, is the fact that the spirit is conceptualized as the property of technology but the attributes of goals, intent and values that characterize it are inherently human.

Markus and Silver aimed to address the criticism faced by the structural features and spirit concepts while keeping intact their core insights, namely to avoid the limitations of feature lists, designers' intentions, and users' perceptions and permit a holistic analysis of technology on value dimensions in addition to the functional ones. They did so by proposing the concepts of technical objects, symbolic expression and functional affordances. Technical objects are IT artifacts and their components, including their user interfaces and outputs, such as documents or drawings. Functional affordances and symbolic expressions are relational concepts between a technical object and a user or user group. Functional affordances are what a user or group of users may be able to do with a technical object, given their abilities and goals. Symbolic expressions are the ways in which a technical object communicates to its users how they can interact with it. Both symbolic expressions and functional affordances can exist without being intended by the designers or perceived by the users. Similarly, they can be intended without being perceived or perceived without being intended.

Grgecic, Holten, and Rosenkranz (2015) further extended Markus and Silver's model by decomposing the concept of symbolic expression into communication of values and communication of meaning, allowing quantitative studies on the effect of each sub-dimension. Communication of meaning refers to the conveyance of an underlying real-world phenomenon through the use of a symbol that can be interpreted by the users. Communication of values implies the promotion of standards governing the goals and behaviours of the users, such as control or freedom. Furthermore, Grgecic et al. also show that communication of value and meaning are antecedent to the perception of functional affordances. Together, these three constructs influence how users interact with a system and evaluate its overall quality and the quality of the information it provides. Actions and beliefs about a technical object at a given time also have an influence on the communication of values and meaning, creating a feedback loop of perception of the object and formation of belief. Strong et al. (2014) also contributed to the theory by proposing a process of actualization, by which affordances are acted out by users and produce an outcome intended to be aligned with their goals. They identified three factors that have an influence on whether or not an affordance will be actualized: (1) individual abilities and preferences, (2) characteristics of the technical object and (3) characteristics of the work environment.

In conclusion, affordance is a relational concept borrowed from ecological psychology that represents the set of actions rendered possible to a user or group of users by an artifact. Existing affordances may differ from the ones that are perceived by the user or intended by the designers. Designers use communication of values and communication of meaning techniques in order to help users perceive the intended affordances. Designers may or may not succeed in implementing the affordances as they intend or communicating them to the users, who may or may not actualize them, hence the difference between perceived, existing, intended and actualized affordances. Designers communicate intended values and meaning about a technical object through its characteristics using symbols and features. The materiality of the object combined with the user or users' goals and abilities give rise to the existence of affordances that were or were not intended by the designers. Users can perceive affordances based on their own interpretation of the characteristics of a technical object or the perception of an affordance can be socially shared. Finally, users may choose to actualize perceived affordances in which case an outcome is produced. Only existing affordances that are also perceived by the users can be actualized, regardless of whether or not they are intended. The following Venn diagram illustrates the relationship between the four kinds of affordances.

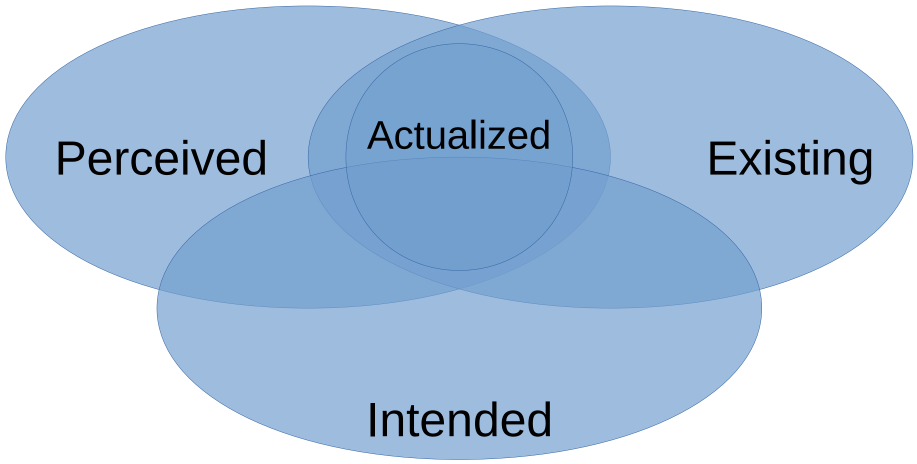

Illustration 1: Affordances Venn Diagram

2.2.2 KMS Affordances

KMS is an umbrella term for many different kinds of systems. Their main characteristic is that they support knowledge processing and collaboration (Qureshi et al., 2006), some of them with an emphasis on either one of those activities. The authors of the articles that were retained for this literature review used different terminology for referring to these systems, ranging from Enterprise Social Media (Leidner et al., 2018) to virtual workspace (Malhotra & Majchrzak, 2012) and others. Table 2.3 synthesizes the main findings of these articles by putting forward the way in which they propose to categorize KMS affordances and the mechanisms through which they can produce a desirable outcome. For reference, the exact definitions of the affordance categories used in the articles can be found in Appendix A: Definitions of KMS Affordance Categories from the Literature. A summary of each article will be presented in the next paragraphs followed by a consolidation of the conceptualization of KMS categories.

Article	KMS type	Affordance categories	Mechanism / Second-order construct / Intermediary Variable	Desirable outcome
(Leidner et al., 2018)	Enterprise social media (ESM)	Networking Organizational visibility Information gathering/sharing Innovation	Executive Perspective Personal Development Bureaucracy Circumvention Name Recognition Morale Booster	Socialization
(Abhari et al., 2017)	Co-innovation platform	Ideation Collaboration Communication	Co-innovation platform affordances	Intention to contribute
(Zhao et al., 2013)	Social media	Physical Cognitive Affective Control	Interaction design	Usability Sociability
(Malhotra & Majchrzak, 2012)	Virtual Workspace	Monitoring of knowledge evolution Virtual co-presence creation	Situational awareness	Knowledge coordination
(Hahn & Wang, 2009)	Knowledge management systems (KMS)	Generate	Iterative brainstorming and idea generation	Solving divergent type knowledge problems (ambiguity and equivocality)
		Choose	Clarify and analyze different alternatives	Solving convergent type knowledge challenges (uncertainty and complexity)
(Rice et al., 2017)	Organizational media	Visibility Editability Self-presentation Awareness Pervasiveness Searchability	Perception of affordances	Technology use
(Wagner et al., 2014)	Social Media	Association Reviewability	Socialization	Knowledge creation
		Reviewability Experimentation	Internalization	
		Authoring Editability	Externalization	
		Editability Recombinability	Combination	

Table 2.3: KMS Affordances and Their Desirable Outcomes

Leidner et al. (2018) identified organizational socialization as a desirable outcome that KMS affordances can help produce. They defined it as “the process whereby newly hired employees learn the beliefs, values, orientations, behaviours, social knowledge, and workplace skills necessary to successfully fulfill their new organizational roles and responsibilities” (Leidner et al., 2018, p. 118). They proposed four KMS affordance categories: networking (the ability to build relationships and interact with peers), organizational visibility (the ability to participate in organizational events and demonstrate leadership skills), innovation (broadening perspective, acquiring new technology skills and acquiring insight on new processes, products and services) and information gathering and sharing. When leveraged by users, these four types of affordance interact and increase socialization by allowing employees to see things through the perspective of executives, circumvent bureaucracy, increase personal development, establish a reputation (name recognition) and boost their morale.

Abhari et al. (2017) propose a different set of KMS affordances. In their paper, they identify communication, ideation and collaboration as the main components of co-innovation platforms, a type of KMS. In their view, ideation is the first possible action in such platforms and allows proposing a new idea for a product or service. Collaboration differs from ideation, because it consists of improving or commenting on someone else's idea rather than proposing a new one. Finally, communication affordances allow for the exchange of knowledge or information. Although it can lead to collaboration, it is different in that the main goal is not necessarily to improve on an idea but rather to learn, network, self-promote or share understanding. Those three affordances are important factors influencing KMS users' intention to contribute.

Malhotra and Majchrzak (2012) point to knowledge coordination as a desirable outcome and identified the affordances of virtual co-presence and knowledge evolution monitoring as factors that can increase it. Knowledge coordination is defined as "a temporally unfolding and contextualized process of input regulation and interaction regulation to realize a collective performance" (Faraj & Xiao, 2006). In other words, it consists of the degree to which members of a team working towards a given goal unfold their actions and communications over the duration of their project in a contextually harmonious and efficient way. In the context of virtual teams, knowledge coordination can be particularly challenging because of the lack of opportunity for collocation, or physical interactions between coworkers. Even when collocation is possible, a large portion of the communication is done via electronic means in most modern teams. A major consequence of this is the loss of non-verbal cues, context knowledge and common ground about how to communicate (Malhotra & Majchrzak, 2012). The affordance of virtual co-presence can mitigate the negative impact on knowledge coordination by allowing members to feel as if others are in the same room. Similarly, the affordance of monitoring knowledge evolution can improve knowledge coordination by giving members the opportunity to observe the progression of their peer's knowledge about the shared task.

Hahn and Wang (2009) make the distinction between two different types of knowledge problems and propose categories of KMS affordances that are appropriate for each of them. Convergent and divergent knowledge problems differ in that the former tend to be solvable by a single acceptable solution while the latter have no unique answer. Finding a solution to convergent problems involve reducing its complexity and uncertainty by acquiring facts and analyzing the situation. Complexity problems are characterized by a high quantity and diversity of situational elements and their relationships. Organizations facing complexity problems need to either increase their information processing capacity or ignore some aspects of the situation in order to simplify the problem. Uncertainty “represents a lack of information, or factual "knowledge about" current and future states, preferences and appropriate actions” (Michael H. Zack, 2001, p. 21). Organizations can manage uncertainty by acquiring more facts or increasing their capacity to predict, infer or estimate. Divergent problems, on the other hand, consist of dealing with equivocality and ambiguity. Ambiguity is the impossibility to make sense of a situation, while equivocality means that there is more than one way to interpret a situation. Ambiguity and equivocality problems require multiple rounds of interpretation, explanation and negotiation where hypotheses are iteratively generated until a satisfying one emerges. Drawing from the theory of task-technology fit (TTF), Hahn and Wang (2009) conclude that the KMS affordance of choosing between alternatives is better suited for solving convergent problems and the affordance of generating ideas is more appropriate for tackling divergent problems.

Rice et al. (2017) elicited a list of six organizational media affordances from a survey with 461 participants: pervasiveness, self-presentation, searchability, awareness, visibility and editability. Pervasiveness is the ability to communicate while being on the move and to get responses from others quickly. Self-presentation is the ability to manage your virtual identity. Searchability is the capacity to look for information or people by using tags, keywords or following links. Awareness is the capacity to know what others are up to in terms of their progress on a project, their opinion and their knowledge. Visibility is the capacity to view other people’s contributions. Finally, editability is the capacity to update information posted previously. They conclude that the perception of those affordances by users can improve technology use of the system.

Wagner et al. (2014) explore the impact of social media affordances on the four knowledge creation processes known as externalization, socialization, internalization and combination, illustrated in table 2.4. According to Nonaka (1994), the four modes of knowledge creation describe how knowledge can be transformed from tacit to tacit, tacit to explicit, explicit to tacit and explicit to explicit. Explicit knowledge can be expressed in a formal language and be encoded and stored into a medium for transmission and dissemination. Tacit knowledge on the other end, represents the hidden part of the iceberg, or the knowledge that we have without being able to clearly and easily communicate it.

	To		
		Tacit	Explicit
From	Tacit	Socialization	Externalization
	Explicit	Internalization	Combination

Table 2.4: The four modes of knowledge creation (Nonaka, 1994)

Socialization is the mode of knowledge conversion that transforms tacit knowledge through the social interaction of individuals. Oral communication (language), observation and imitation are types of interactions that allow tacit knowledge to be transferred from one individual to another. Shared experiences, which allow people to share their thinking process embodied within emotions and nuanced context, is the key to acquiring tacit knowledge. Combination involves individuals exchanging information through social processes or interactions and reconfiguring existing explicit knowledge. This reconfiguration consists of sorting, adding, recategorizing and recontextualizing information in order to create new explicit knowledge. Tacit and explicit knowledge complement each other and can be transformed from one form to the other. Their mutual interaction allows them to expand over time and generate new knowledge. Externalization is the conversion of tacit into explicit knowledge and internalization is the inverse. Socialization, combination and internalization overlap with concepts from organizational theory. Socialization is connected to organizational culture, combination refers to information processing and internalization is similar to organizational learning. Wagner et al. (2014) identified six affordances in total having a role to play with the four knowledge creation processes.

Specifically, association, the ability to create and view connections or links between individuals and content (individuals and other individuals, individuals and content or content with other content), is correlated with socialization. Experimentation, the ability to try out novel ideas, is associated with internalization. Authoring, the capacity to generate content, is linked to externalization. Recombinability, the capacity to merge and build on other people's contributions, corresponds to combination. Reviewability, the ability to view content evolution over time and the contributions of others, relates to both socialization and internalization. Finally, editability, the ability to make modifications and revisions on existing content, is associated with combination and externalization.

Zhao et al. (2013) offer a different perspective on KMS affordances classification. They made the distinction between physical, cognitive, affective and control affordances. Physical affordances include all the ways in which users can interact with the palpable interface of the system, like being able to draw on a screen with a pen, for example. Cognitive affordances support information and knowledge acquisition and processing by the users. Affective affordances allow users to share their emotional reactions to something, such as the "like" button on Facebook. Finally, control affordances provide users with the ability to customize their experience and manage access permissions to resources on the system by allowing them to modify settings.

The seven articles presented above provide a rich breath of KMS affordance conceptualizations, but several overlaps exist among the different categories. With the goal of producing a coherent conceptual framework of KMS affordance categories, the following table (2.5) puts forward the similarities between them. In this table, the overlapping concepts from each article are presented on the same line and the column on the right contains a consolidating term that encompasses them all and captures their essence. This term was formulated as an action that users can perform with a KMS, in order to fit the definition of affordance. The methodology used to generate this table was simple. The affordance categories of the first article were listed in the first column, and the those from the other articles were listed in the following columns one after the other with the similar ones on the same line based on their definitions.

Abhari, Davidson, & Xiao, 2017	Hahn & Wang, 2009	Leidner, Gonzalez, & Koch, 2018	Malhotra & Majchrzak, 2012	Rice et al., 2017	Wagner, Vollmar, & Wagner, 2014	Zhao et al., 2013	Consolidation
Communication		Networking	Virtual co-presence	Pervasiveness			Communicate
Ideation		Information sharing			Authoring		Create new contributions
Collaboration	Generate	Innovation					Collaborate and brainstorm in iterations
	Choose						Clarify and analyze different alternatives
		Organizational visibility		Self-presentation		Affective	Manage virtual profile
		Information gathering		Searchability	Association		Gather information
			Monitoring of knowledge evolution	Visibility	Reviewability		Review historical contributions and their evolution
				Editability	Editability		Edit existing contributions
						Cognitive	Process information and knowledge
					Experimentation		Experiment
					Recombinability		Merge existing contributions
						Control	-
				Awareness			-
						Physical	-

Table 2.5: Consolidation of KMS Affordance Categories From the Literature

Some of the categories were left out of the consolidation intentionally for different reasons. The first one is awareness, it was not consolidated because it is not an action and therefore it doesn't fit the definition of affordance. Furthermore, Malhotra & Majchrzak (2012) base their findings on situational awareness theory and conclude that virtual co-presence and monitoring of knowledge evolution both contribute to knowledge coordination by increasing awareness. Although awareness is very important, it was excluded because it is considered as a benefit resulting from the existence of some affordance categories rather than an affordance category in itself. Physical affordances were also excluded because they address how users can use the system rather than what they can do with it. This is not to say that the way in which users physically interact with a system is not important. On the contrary, whether a conventional keyboard or an electronic pen is used can have a significant impact on the cognitive load of ideation, problem solving and reasoning (Oviatt, Cohen, Miller, Hodge, & Mann, 2012). However, this area of research belongs to the human computer interaction field and is considered out of the scope of this thesis. Finally, control was also excluded for similar reasons. Affordances are defined as goal-oriented actions that users are able to perform with a system. For the purposes of this thesis, it is considered that the goal must be external to the system. Drivers use their car because they want to get from point A to point B, not because they can change the position of their seats. Similarly, designers may use a KMS because it facilitates their work, but the ability to customize the system is secondary. This being said, control is still an important aspect of a KMS that may significantly influence the behaviour of its users (Zhao et al., 2013).

The result is a list of 11 items that represent the main high-level affordances of KMS reflecting the scientific literature on the subject (see table 2.6) A definition was derived for each of them from the original definitions of the affordances that compose them.

Affordance	Definition
Communicate	The ability to exchange information or knowledge at any time with other people who may be at a remote location.
Create new contributions	The ability to generate ideas and externalize knowledge.
Collaborate and brainstorm in iterations	The ability to generate ideas in teams and improve them over time in multiple iteration cycles.
Clarify and analyze different alternatives	The ability analyses and compare multiple alternatives in order to make the right choice
Manage virtual profile	The ability to share information about oneself and show one’s interest or affection towards content or other people
Gather information	The ability to obtain, search for or browse knowledge or information
Review historical contributions and their evolution	The ability to view past contributions made by others and their evolution through time
Edit existing contributions	The ability to make changes to existing contributions
Process information and knowledge	The ability to transform knowledge or information, reason and make deductions or inferences
Experiment	The ability to try novel ideas and evaluate their performance
Merge existing contributions	The ability to create new contributions by combining existing ones

Table 2.6: Definition of the Main KMS Affordances

All articles that were retained in this literature review correlated the affordances with the beneficial outcomes that their existence can create for organizations. Those benefits, as illustrated in table 2.3, can now be generalized to the consolidated list of high-level affordances of KMS. As a reminder, the list of benefits analyzed by the different articles is presented here:

A) Socialization (Leidner et al., 2018) (or sociability (Zhao et al., 2013))
B) Intention to contribute (Abhari et al., 2017)
C) Usability (Zhao et al., 2013)
D) Knowledge coordination (Malhotra & Majchrzak, 2012)
E) Solving divergent type knowledge problems (Hahn & Wang, 2009)
F) Solving convergent type knowledge challenges (Hahn & Wang, 2009)
G) Technology use (Rice et al., 2017)
H) Knowledge creation (Wagner et al., 2014)

Leidner et al. define socialization as the "process whereby newly hired employees learn the beliefs, values, orientations, behaviours, social knowledge, and workplace skills necessary to successfully fulfill their new organizational roles and responsibilities" (Leidner et al., 2018, p. 118). Zhao et al., on the other hand, state that sociability is "concerned with how users interact with each other via the supporting technologies and artifacts, and the focus is human-human interaction which embedded with more social elements" (Preece, 2000 in Zhao et al., 2013, p. 294). The beliefs, values and other elements that constitute Leidner et al.'s definition of socialization are all tacit forms of knowledge, indicating that they also correspond to Nonaka's definition of socialization which is the transfer or transformation of tacit knowledge, as seen earlier. Socialization, according to Nonaka, is done through the interaction of people. Therefore, it can be said that sociability as defined by Zhao et al. is the process, while socialization as defined by Leidner et al. is the result. Because they are closely related, they were combined together in the previous list.

The following table (2.7) illustrates the association between each consolidated affordance and their corresponding beneficial outcomes from the previous list. Those benefits are likely not exhaustive, but they reflect the conclusions that were drawn in the various articles retained for this literature review. The letters correspond to the list above.

	Beneficial outcomes							
	A)	B)	C)	D)	E)	F)	G)	H)
Communicate	X	X		X			X	
Create new contributions	X	X						X
Collaborate and brainstorm in iterations	X	X			X			
Clarify and analyze different alternatives						X		
Manage virtual profile	X		X				X	
Gather information	X						X	X
Review historical contributions and their evolution				X			X	X
Edit existing contributions							X	X
Process information and knowledge	X		X					
Experiment								X
Merge existing contributions								X

Table 2.7: Generalizing the Desirable Outcomes of Affordances to the Consolidated List

In conclusion, 11 high level KMS affordances were extracted from the relevant literature on the subject and are each associated with a subset of 8 main benefits. Those 11 affordances are the primary types of actions that KMS make possible to their users according to the literature on the subject. This list could potentially be further reduced by nesting the affordances in one another. For example, it could be argued that in order to be able to collaborate and brainstorm in iterations, one must also be able to experiment, merge existing contributions and gather information. However, there could be more than one way to nest them. Since this is the level of granularity that is found in the literature, it will be kept in this thesis.

2.3 Conclusion

The first section of this chapter was dedicated to the model of Intellectual Bandwidth, a conceptual framework that illustrates the two dimensions characterizing the ability of organizations to generate value. KMS have features that support both of these dimensions to different degrees (Qureshi et al., 2006). Organizations can therefore improve their value output by increasing their knowledge processing and collaboration capacity using a KMS. The second section of this chapter was dedicated to understanding the concept of affordance and determining what the main affordances of KMS are.

This final section will put the two together by exploring how each of the 11 main KMS affordances fit in the Intellectual bandwidth model.

Knowledge processing and collaboration are integrated rather than orthogonal concepts (Qureshi et al., 2006). The implication is that the two are not independent from each other and technologies that support one generally also support the other to a certain degree. The same is true for technology affordances, as each one generally supports both dimensions of the Intellectual Bandwidth model. However, they can usually be classified as mostly relate to one, as was done in the following table (2.8) with the 11 main KMS affordances. Collaboration affordances are mostly related to the exchange of information and coordination between users, while knowledge processing affordances are more related to the transformation of knowledge.

Mostly collaboration KMS affordances	**Mostly knowledge processing KMS affordances**
Communicate	Create new contributions
Manage virtual profile	Collaborate and brainstorm in iterations
	Clarify and analyze different alternatives
	Gather information
	Review historical contributions and their evolution
	Edit existing contributions
	Process information and knowledge
	Experiment
	Merge existing contributions

Table 2.8: Classification of the Main KMS Affordances in the Intellectual Bandwidth Model

This table will be useful to analyze the results of the Delphi. It will be interesting to compare the affordances elicited from the panel of experts to the ones that are known in the literature and see if there are differences or similarities. The differences could indicate gaps in the literature while the similarities could confirm the importance of already known KMS affordances.

Chapter 3: Delphi Methodology

The goal of this research is to discern what KMS affordances are useful to knowledge workers or have the most positive impact on their productivity when designing various artifacts and in what order of importance.

The ranking type Delphi methodology is perfectly suited for this purpose, because it's used to build consensus among a panel of experts on a list of items and their relative importance (Paré et al., 2013). It consists of selecting a panel of experts and administering them a series of questionnaires designed to converge their opinions toward a consensus. After each questionnaire, the participants receive a feedback of their own answers compared to the panel as a whole. There are three main phases to the process, after having selected the panel. The first one is brainstorming, where the goal is to elicit the greatest number of items. It is then followed by a filtering phase, after which only the most important items remain. Finally, the third phase is for ranking the items in order of importance. Each phase contains at least one questionnaire, or more if necessary to reach consensus.

The principal advantage of this methodology, often used in the IS field, is to make accessible the implicit knowledge embedded in the minds of experts with years of experience (Paré et al., 2013). It is particularly relevant for the purposes of this study because its main goal regards the perception of knowledge workers.

The HEC Montreal Research Ethic Board has ruled that the data collection related to this study meets ethical standards in research involving humans. All questionnaires were available in French and in English and the participants could choose their preferred language. They were first written in English and then translated into French by the main researcher, and they were proofread by another person to make sure the translation was equivalent.

3.1 Panel Selection

If this study was interested in the objective needs of knowledge workers, a good approach for creating the panel would be to recruit experts on knowledge work, like scholars or consultants who specialize in this field. However, because the question of this research regards the perception of knowledge workers using KMS to design various artifacts, it follows that the expert panel should be composed of such workers. This may include many professions, such as architects, engineers, software developers and others. While a large breath of perspectives is desirable for this kind of study (Paré et al., 2013), a panel that is excessively heterogeneous may not reach consensus. For this reason, it has been decided to select experts who are members of the same profession but are involved in designing different kinds of artifacts.

The engineering profession was selected for multiple reasons. The first one is the large pool of qualified engineers available in Quebec, the province where this research is conducted, which facilitates recruiting participants. Secondly, this profession is regulated by a professional order, ensuring that their work title is not misleading, since using the title of engineer without being a member of the order is illegal in Quebec[1]. Additionally, the fact that there are multiple specialization fields in engineering, such as electrical, mechanical, civil, molecular and many others, increases the diversity of possible perspectives within the same profession.

Another concern for the selection criteria of experts is the number of years of experience. Junior and senior engineers may have very different perspectives, and both should be included in the results of this research. However, engineers with too little experience may not yet fully grasp the intricacies of the job and therefore a minimum should be required. The minimum doesn’t have to be too restrictive because students in engineering have to do many internships before graduation and therefore are already quite familiar with the job when they start working. In Quebec, there is a period of up to 36 months after graduation where junior engineers have to work under the supervision of a more experienced engineer. For all these reasons, the bar was set to at least one year of experience as a junior engineer.

The initial recruiting strategy was to contact the engineering professional order of Quebec (l’Ordre des Ingénieurs du Québec or OIQ) and associations of graduated students in engineering and ask them to forward an invitation to participate in the study to their members. However, every single request was denied, because these organizations have strict requirements for transmitting messages to their

1 Pourquoi être membre de l’Ordre ? (n.d.). Retrieved June 8, 2018, from http://www.oiq.qc.ca/fr/jeSuis/candidat/pourquoiEtreMembre/Pages/default.aspx

members and this research didn’t qualify. The snowball sampling method was used instead as a fallback. A recruiting questionnaire was created with Qualtrics, an online survey tool, and distributed to the engineers in the contact network of the researcher and four out of five of them signed up. The researcher also asked other people in his contact network to invite the engineers they knew to participate by filling out the online questionnaire, which generated eight more participants for a total of twelve. Of those twelve, only ten completed the brainstorming phase and nine completed the two remaining phases. The target number of participants was between 15 and 20 but it wasn’t reached because of the encountered difficulties in recruiting. Because of the limited resources of this study the decision was made to continue despite the small size of the panel and we understand that this may impact the validity of the results.

The identity of each participant is known to the researcher, but not to each other. The anonymity of participants is a crucial aspect of the Delphi method, because it prevents the domination of participants based on their authority or reputation (Paré et al., 2013). For this reason, the name of the participants has been replaced with the letter “P” followed by a number from one to ten in the feedback that was sent to them after each questionnaire. No identifying information was ever transmitted to the participants about each other.

The following table (3.1) contains the portrait of the ten participants who completed the first phase. The final panel contained 5 senior engineers and 5 junior engineers. There was also a good variety of engineering backgrounds: one industrial engineer, three electrical engineers, three software engineers, two mechanical engineers and one chemical engineer. They are all regularly involved in the design of artifacts related to their respective fields and all of them completed the whole process except for P9 who did not respond in the filtering phase and P2 who did not respond in the brainstorming phase.

	Specialization	Year of graduation	Years of experience (including jr. years)	Level of experience
P1	Industrial (Transport)	2012	5	Senior
P2	Electrical	2013	3	Senior
P3	Software	2010	7	Senior
P4	Electrical	2013	4	Junior
P5	Software	2012	5	Senior
P6	Software	2015	2	Junior
P7	Mechanical	2013	4	Junior
P8	Chemical	2007	10	Senior
P9	Mechanical	2015	2	Junior
P10	Electrical	2016	2	Junior

Table 3.1: Participant Profiles

Chapter 4: Procedure, Analysis and Results

Due to the iterative nature of the Delphi methodology, the procedure, analysis and results of each phase will be presented together in this chapter. The following sections will respectively address the brainstorming, filtering and ranking phases of the ranking type Delphi method.

4.1 Brainstorming Phase

The goal of this first phase is to elicit as many items as possible from each participant and consolidate the list by merging similar items. Two rounds of questionnaires were necessary in this phase, the first one for generating and consolidating the list and the second one for validating the interpretation of the researcher with the participants in regard to the consolidation of the list.

4.1.1 Procedure

It was decided not to constrain the participants on the nature of the KMS affordances that they could list in the questionnaire. In other words, the instructions were formulated in a way that asked participants to list affordances of information systems in general rather than KMS specifically. The main reason for this is the fact that participants may not know what a KMS is. Explaining what they are could make the instructions overly complicated in addition to bias the participants towards affordances that fit the explanation. Additionally, KMS is an umbrella term for any information system that supports knowledge workers in their knowledge processing and collaboration activities, such as email, decision support tools, calendars, social networks, and many others (Butler & Murphy, 2007). Because of this, there is an underlying assumption that any information system affordance perceived as useful by knowledge workers, as long as it is realistic, could potentially be embedded in a KMS.

An important challenge at this point was to formulate the brainstorming instructions in a way that would generate items that fit the definition of affordance, but without using the word “affordance”, because participants may not understand it. Furthermore, the items should not be limited to affordances that the participants already have at work and should also include affordance that they would like to have. These issues were addressed by asking the participants to “draw up a list of actions made possible by technology that are or could be useful for an engineer". This formulation is in line with the definition of affordance and implies that the items could be affordances that they already have or not.

Another concern was the fact that engineers may be in charge of a team or have administrative tasks in addition to their design-oriented tasks. This kind of activity may also qualify as knowledge work, but since this study is specifically interested in knowledge work that revolves around design, participants were specifically instructed not to include actions related to administrative or personnel management responsibilities. Furthermore, the instructions included directions to write a description of each action as well as examples of technologies that can afford these actions in order to facilitate interpretation by the researcher.

A pretest was carried out prior to distributing the final questionnaire in order to validate the formulation of the instructions. It was conducted in French with two students who were recruited on the campus of our institution. Although they were not engineers, they were asked to answer the questions as though their job was to be a student. Students use many different tools on a daily basis that can be considered as KMS including email, online collaboration tools, social networks and learning management systems. Students are also regularly involved in team projects where they have to collaborate with their peers to work on assignments. The goal of the pretest was to verify the face validity of the questionnaire (whether the items generated fit the definition of affordance) and if the participants understood the instructions correctly.

After the pretest, two changes were made to the formulation of the questions. The first one was to impose a minimum of 10 items rather than ask participants to list as many as they could. Both participants in the pretest asked for what the minimum should be and they seemed more comfortable after a target of 10 was given to them. They both had difficulties coming up with the last few items, but they put in an extra effort in order to hit the target. Asking for a minimum is therefore warranted in order to generate more items and incite the participants to think a little harder.

The second change made after the pretest was to ask the participants to complete this sentence for each item: "It is / would be useful for an engineer to have technological tools that allow him / her to ...".

This change was introduced because some of the items generated in the pretest were formulated like system features, despite the instructions that were given. Asking participants to complete a phrase increases the probability that the items will be formulated as affordances.

The final questionnaire was distributed to the panel with the online survey tool Qualtrics. All members of the panel were located in Montreal, Canada and the exact instructions that they received can be found in Appendix B: Questionnaire Instructions p.56.

4.1.2 Analysis

The goal of the consolidation process is to merge redundant items together and clarify the confusing ones (Paré et al., 2013). The first round generated a total of 104 items, as all participants submitted the requested minimum of ten except P10 who exceeded it by four. The complete list can be found in Appendix C: Brainstorming Data p.58. P5 visibly did not understand the instructions correctly, as he submitted the same items multiple times with a different technology example each time. In total, six of the ten items submitted by P5 were repetitions that had to be eliminated. Additionally, two items submitted by P8 were also eliminated because they were hardware related. The first one was the capability to print 3D models of plans and the second one was the ability to use electronic devices on construction sites without damaging them.

The remaining 96 items were consolidated using a spreadsheet software. They were all listed vertically in the first column on the left-hand side of the spreadsheet, leaving blank the first two lines on top. The new consolidated items were listed horizontally on these two top lines in French and in English, starting from the second column. For each item in the vertical list, the researcher checked if a corresponding consolidated item existed in the horizontal list. If not, a new consolidated item was created either by copy and pasting the original item or by reformulating it when necessary. The value “1” was inserted in the cell at the intersection of the row of the original item and the column of the corresponding consolidated item in order to keep track of the relation. On two separate occasions, the researcher had difficulty understanding an item and the participant who wrote it was contacted for clarification.

Consolidated items were often reformulated in order to generalize from the type of design objects (or artifacts) specific to each engineering specialization. For example, mechanical engineers create 3D models of the objects that they want to create while electrical engineers create circuit diagrams. Both of these activities can be understood as creating a virtual representation of the design object or “Modelling”. In some cases, this generalization caused items from the same participant to be grouped together. For example, the items “technical drawing” and “3D modelling” (translated from French) from P4 were grouped under the term “Modelling”, because they both consist of creating a graphical representation of a design object.

In other cases, the same item could be associated with multiple consolidations. For example, P3 created the item “consult legal resources” (translated from French) and explained in the description that it was important to make sure that development projects conform to the rules. This item was classified under “Requirement management and elicitation” because it is related to legal requirements and “Search for information quickly and efficiently in all available internal and external documentation” because it requires the capability to find external information.

After the consolidation process was completed, the list was reduced from 96 to 39 items. The result was sent to the participants for validation of the researcher’s interpretation. They received the consolidated list of items with all the original items that were associated with each of them. Every participant received a personalized document where their own original items were highlighted in green in order to facilitate the validation process. They were instructed to read the entire list of 39 consolidated items and to confirm whether their own original items were correctly categorized. Only one participant pointed out a minor mistake that resulted in the reformulation of one item and no other modification were made to the list after that. P5 was informed of their mistake and was invited to amend their initial answer, but after reading the consolidated list of items, they didn’t have anything to add. The whole panel was also invited to add any items they could think of that were missing, but none of them did which marked the end of the brainstorming phase.

4.1.3 Results

The following table (4.1) contains the whole consolidated list of 39 items in the left column with the number of original items associated with each of them in the right column. As a reminder, those items correspond to affordances from any type of information system, not only KMS.

Affordances	**Nb of corresponding item submitted by participants**
Create model of design object	18
Simulate design object in its environment	12
Store data	7
Participate remotely in meetings	6
Calculate	6
Plan resources (tools, materials, product orders, etc.)	6
Search for information quickly and efficiently in all available internal and external documentation	6
Analyze data	5
Manage Projects	3
Manage and elicit requirements	3
Code (programming)	3
Transfer and share files (securely)	3
Track issues	3
Communicate by writing	3
Manage file versioning	3
Automate tedious or repetitive tasks	3
Create data visualizations	2
Edit text	2
Control quality of design object	2
Know who to ask for questions about any given task/document/process	2
Collect data from measuring devices	1
Create business application forms	1
Edit images	1
Program microcontrollers	1
Manage virtual machines	1
Manage tools inventory	1
Detect differences between two large text files	1
Convert different file types	1
Manage document retention calendar to comply with regulations	1
Quickly grasp your mind around a subject	1
Automatically generate documentation elements from CAD files	1
Annotate digital files of different formats	1
Make complex data operations on data in spreadsheets with a programming language	1
Program API interactions with any data storage files	1
Use outdated file formats with backward compatibility	1
Convert measure units seamlessly	1
Import web form data into spreadsheet	1
Be aware of tasks automatically performed in the background by software	1
Edit very large text files	1

Table 4.1: Results of the Brainstorming Phase

4.2 Filtering Phase

4.2.1 Procedure

The main goal of this phase is to narrow down the consolidated list from the previous phase to a manageable number containing only the most useful items. Because of the advanced functionalities of Qualtrics, it was possible to also rank the items with a single questionnaire. This questionnaire contained the list of 39 consolidated items displayed in both French and English in a random order that was different for each participant. The panel was asked to drag and drop the 20 most useful items into a box and to rank them from most useful on top to least useful in the bottom. The exact instructions that they received can be viewed in Appendix B: Questionnaire Instructions p.56.

An individual score was attributed to each item based on their average ranking. For each participant, an item could either be ranked from 1 (most useful) to 20 (least useful) or not selected, in which case they were attributed a rank of 30. The reason behind this is that if the items that were not selected had been ranked, their rank would be from 21 to 39 and therefore 30 on average. On this scale, the best possible individual score is 1 and the worst is 30. A complete overview of the individual scores from this phase and the average score attributed to each item is available in Appendix D: Filtering Data p.59.

4.2.2 Analysis

Two different selection rules were applied in order to narrow down the list. The first one was based on the number of participants who selected the item. All items that were not selected by more than half of the participants were eliminated, as recommended by Schmidt (1997). Since P9 did not answer the filtering questionnaire, more than half is equivalent to at least five. The following table (4.2) shows the number of items that were selected by N participants, where N is an integer from 0 to 9. 23 items remained after applying this first rule.

N	Number of items	Cumulative sum of items
9	2	2
8	4	6
7	4	10
6	4	14
5	9	23
4	1	24
3	4	28
2	7	35
1	3	38
0	1	39

Table 4.2: Number of Items that Were Selected by N Participants Where N = 0, 1, …, 9

The second selection rule was that no remaining item should have a score that is worse (higher) than the best score of the items that were eliminated by the first rule. In other words, the second rule sets the maximum score at the level of the minimum score of all the items that were eliminated by the first rule. In the present case, this maximum (lower) score is 21.33 (see table 4.3), which eliminates one more item from the list for a total of 22 items remaining. This rule was designed to eliminate items that may have been selected by many participants but were ranked poorly by most of them.

It was not necessary to carry out another round of filtering because our number of remaining items was close to twenty, which is the recommended number for ending this phase (Paré et al., 2013). In addition to being used for the second filtering rule, the aforementioned score was used as a second ranking parameter for the items that were selected by the same number of participants. For example, “Issue tracking” and “Data analysis” have both been selected by nine participants, but “issue tracking” has a better (or lower) score of 7.44 and therefore it is ranked first. This ranking is not by any means intended to be final, but it served as the order in which the items were presented to the participants in the next phase. This is common practice, as 19% of the studies analyzed by Paré et al. (2013) presented the items to the participants during the first round of the ranking phase in the order obtained from the filtering phase, compared to 10% who used a random order, 2% who grouped the items by themes and 69% who did not specify the order they used. Schmidt (1997) recommends using a random order for the first round of the ranking phase but doesn’t provide any justification for not using an order derived from the filtering phase. He does provide a good argument for not combining the filtering and ranking phase into one by using the mean rank as the main filtering rule. However, simply presenting the items during the first round of the ranking phase in an order derived from the filtering phase is not discussed. Modern tools like Qualtrics, the survey instrument that was used in this study, didn't exist when Schmidt published his paper. Such tools allow participants to select a number of items in a list and to rank them visually in one simple step. Given the limited resources of this study and with the goal of minimizing the time required from the participants, it was decided to take advantage of this feature. It is assumed that the order in which the participants ranked the items in this phase is a good approximation of how they would rank them in the next phase if they were presented randomly.

4.2.3 Results

The following table (4.3) contains the definitive list of 22 affordances that are most useful to knowledge workers according to the panel of experts recruited in this study. The ranked order in which they are presented here is derived from the number of participants who selected each item and their score in this phase, but this order remains likely to change in the next ranking phase.

Item	N	score	Rank
Track issues	9	7.44	1
Analyze data	9	10.22	2
Create model of design object	8	7.33	3
Manage Projects	8	10.44	4
Search for information quickly and efficiently in all available internal and external documentation	8	10.78	5
Code (programming)	8	11.22	6
Manage and elicit requirements	7	11.89	7
Simulate design object in its environment	7	13.78	8
Plan resources (tools, materials, product orders, etc.)	7	16	9
Automate tedious or repetitive tasks	7	16.78	10
Quickly grasp your mind around a subject	6	14.44	11
Calculate	6	15	12
Manage file versioning	6	17.78	13
Make complex data operations on data in spreadsheets with a programming language	6	19.78	14
Communicate by writing	5	18.78	15
Know who to ask for questions about any given task/document/process	5	19.44	16
Transfer and share files (securely)	5	20	17
Create data visualizations	5	20.11	18
Control quality of design object	5	20.11	19
Store data	5	20.22	20
Participate remotely in meetings	5	20.44	21
Collect data from measuring devices	5	20.56	22

Table 4.3: Results of the Filtering Phase

Kendall's coefficient of concordance (W) is commonly used in ranking Delphi studies in order to assess the agreement among the experts on the ranking of items. W is a value between 0 and 1 that represents the strength of the consensus in the panel on the order in which the items should be ranked. A value of 1 indicates that all experts gave the same ranking to each item while a value of 0 corresponds to a perfectly random ranking. W is based on the sum of the experts' rankings for each item, the number of items and the number of experts. It is usually most relevant during the ranking phase, but since a first ranking was established during the filtering phase, W was calculated for this phase as well in order to observe its progression throughout the whole process.

Calculating W for the filtering phase involved some extra steps, since the participants had to choose only 20 items out of 39 and 22 remained after the filtering rules were applied. Therefore, for each participant, some of the 22 remaining items were not ranked and some of the items that were ranked have been filtered out of the final list. For this reason, some manipulation of the data had to be done in order to calculate the W of the filtering phase. These manipulations were only done in order to calculate W and didn't affect the final result of the filtering phase.

The first one was to shift the rankings of each participant in order to fill in the holes left by items that were filtered out while preserving the original order. For example, if the item that was ranked first by a participant didn't end up in the final list, then the item that was ranked second took its place.

Secondly, the items of the final list that were not ranked by a participant were listed as tied on the last position in that participant's ranking. For example, if only 18 of the 20 items that were selected by a participant made it to the final list of 22, then the 4 remaining items that the participant didn't select were all assigned to the last rank. In order to calculate W when ties are present, tied items must be given the average rank that they would have if there was no tie (Kendall, 1945). To continue with the previous example, the last 4 items would have been ranked 19, 20, 21 and 22. Therefore, they must be assigned the rank 20,5 instead of simply 19 because it is the average. The result of these manipulations can be found in Appendix E: Calculating W in the Filtering Phase p. 60.

There are two formulas for calculating W (Kendall & Smith, 1939; Kendall, 1945):

(1) $$W = \frac{12\sum_{i=1}^{n}(R_i^2) - 3m^2 n(n+1)^2}{m^2 n(n^2-1) - m\sum_{j=1}^{m} T_j} \quad \text{Or} \quad W = \frac{12\sum_{i=1}^{n}(R_i - \overline{R})^2}{m^2(n^3-n)}$$

- Where:
  - n = the number of items
  - m = the number of experts
  - R = the sum of the rankings for item *i* from all participants
  - T_j = correction factor for the expert *j*

These two formulas are equivalent, but the one on the left must be used when there are ties in the rankings. *T* is a correction factor used to compensate the negative effects of ties in the ranking on the value of W. It is calculated for each expert *j* with this formula (Kendall, 1945):

(1) $$T_j = \sum_{i=1}^{g_j}(t_i^3 - t_i)$$

- Where:
  - t_i = number of tied items in the i^{th} group of tied items for expert *j*

This formula for calculating T reflects cases where there are multiple groups of ties. However in the present case, there is only one per expert which simplifies the calculations: $T_j = t^3 - t$. The following table (4.4) contains the number of tied items and the calculated value of T for each participant.

	P1	P2	P3	P4	P5	P6	P7	P8	P10	Sum
Number of tied items	3	5	5	6	5	5	8	9	10	
T	24	120	120	210	120	120	504	720	990	2928

Table 4.4: Calculating the Correction Factor (T) for Tied Items in the Filtering Phase

The resulting value of W for the filtering phase is 0.216. This low W indicates that the participant roughly agree on the ranking of the items but not to a degree that is anywhere close to a consensus. The degree to which it is comparable to the W of the ranking phase is uncertain because of the various data manipulations that were necessary to calculate it.

These manipulations rely on the assumption that the items would have been ranked in the same order by the experts if only those that ended up in the final list were presented to them initially. They also rely on the assumption that treating the items from the final list that were not selected by a participant as ties in last position is a good approximation of the rank they would have if the participant had selected them. These assumptions are reasonable, but they add up to a significant margin of error. If the items that were not selected by a participant had been ranked, they would not be tied because participants didn't have the option to create ties in their ranking. Therefore, it can be argued that the margin of error should be correlated with the average number of items that were not selected by each participant and ended up in the final list. This number is 6.22 or around 28% of the 22 items. It follows that the value of W for the filtering phase should be close to 0.216 ± 14% or between 0.185 and 0.246.

A high value of W at this stage would have rendered unnecessary the next ranking phase. This could only be possible if the participant had all selected roughly the same items and ranked them in almost the same order. However unlikely, this is not impossible and calculating W at this stage warrants completing the ranking phase because it is not sufficiently high to conclude that the participants have a consensus on the order of importance of the items. Furthermore, the W at this stage will provide a point of comparison to view the progression of consensus building in the panel. If the W of the first ranking round is close to 0.216 ± 14%, it will indicate that little progress has been made.

4.3 Ranking Phase

4.3.1 Procedure

The goal of this phase is to finalize the ranking of the items in order of importance. Another questionnaire similar to the previous one was created on Qualtrics. This questionnaire contained the list of the 22 remaining items in the order that was established during the previous phase. The instructions informed the participants of how the list was narrowed down and how the order was determined. The participants were instructed to change the order of the items as they saw fit by dragging them up or down on the screen to reflect their relative importance. The exact phrasing of the instruction in the questionnaire can be found in Appendix B: Questionnaire Instructions p.56 and the resulting data can be found in Appendix F: Ranking Data p.61.

4.3.2 Analysis

From the data collected, the sum of the rankings attributed to each item (sum) was calculated in order to compute the new ranking and W value. This method is equivalent to using the average because the latter involves a simple division of the sum by the number of participants, which doesn't affect the items' relative proportion to each other and therefore doesn't affect the ranking. The percentage of participants who ranked each item in the top half of their list (top half %) was calculated too, because it can also be used for ranking the items and portray a sense of the degree of consensus (Schmidt, 1997). It is interesting to note that there is a high correlation of -0.95 between sum and top half %. This indicates that the two ranking methods have similar results. The top half % method generates many ties while the sum method only generates one (see table 4.5). However, it's not clear that the additional precision using the sum is meaningful. While all ranking methods have their flaws, Schmidt (1997) suggests using Kendall's method based on the sum or the average rank because its drawbacks are mitigated by the iterative nature of the Delphi methodology.

Paré et al. (2013) recommend ending the ranking phase when one of these three conditions is fulfilled: W is above 0.7, W doesn't change significantly between two rounds or three rounds have been completed. Calculating W in the ranking phase is much more straightforward since there is no extra steps necessary as in the previous phase and the simpler formula can be used when there are no ties. For the first ranking round, this value was 0.56. Because it is significantly higher than in the previous phase but lower than 0.7, a second round would be warranted. However, given our limited resources and time, it was established that the current W is deemed acceptable for the purpose of this study.

In order to produce the final list of ranked KMS affordances, a decision had to be made regarding the tied items ("Search for information quickly and efficiently in all available internal and external documentation" and "Plan resources (tools, materials, product orders, etc.)") with a sum of 75. Putting one before the other in the list implies that it is more important, which cannot be concluded based on the collected data. However, grouping them together as ties might suggest that the other items' ranking is precise, which is also misleading due to the relatively low W. Even if there were no other ties, another ranking round could have changed the final result. Furthermore, the top half % method would suggest that there are many other ties. Since only one ranking round was done (not counting the ranking from the filtering phase), Schmidt's argument that the drawbacks of the sum method are mitigated due to the iterative nature of the Delphi method is less applicable. Therefore, it is clear that none of the items' ranking is precise to its exact position, even using the sum method which generates fewer ties than the top half %. Nevertheless, despite the significant increase of W, the difference in ranking position of each item since the previous phase is small, especially for items at the bottom of the list that barely moved at all. On average, each item moved up or down in the ranking by 1.7 positions with only one outlier that had a difference of 6 with its previous rank. This implies that while the degree of consensus (W) is moderate, it is unlikely that another ranking round would change the position of each item by much. Therefore, despite the imprecision of the results, their rough position in the ranking is significant and could be valuable to practitioners.

The imprecision of the results could be mitigated by ranking the affordances in groups corresponding to their quartile or quantile position. This would be more representative of the imprecision, but would also imply a clear distinction between the groups which is also misleading. Considering all those factors, it was decided that the best approach is to keep the rating from Kendall's method and warn the reader that the results should be interpreted by taking the imprecision of the ranking in consideration. The tie was broken by using the top half % as a second ranking parameter but the difference in position between those or any other two items that are right next to each other shouldn't be interpreted as meaningful.

4.3.3 Results

The following table (4.5) presents the final ranking of the KMS affordances that are considered most useful by the panel. The Sum column contains the sum of the rankings of all participants for each item. The Rank (sum) column contains the rank based only on the sum, which is almost identical to the final rank except for the tie on the 7th position. The Previous rank column contains the ranking of each item from the filtering phase. The Rank diff. (sum) column contains the difference of ranking between the rank based on the sum and the previous rank. Finally, the Top Half % column contains the percentage of participants who ranked each item in the top half of their list. The final rank is based on a combination of the rankings based on the sum and the top half %, with priority to the sum.

Final rank	Item	Sum	Rank (sum)	Previous rank	Rank diff. (sum)	Top half %
1	Create model of design object	39	1	3	2	1.00
2	Manage Projects	43	2	4	2	0.89
3	Track issues	52	3	1	-2	0.89
4	Analyze data	54	4	2	-2	0.78
5	Simulate design object in its environment	65	5	8	3	0.89
6	Calculate	72	6	12	6	0.67
7	Plan resources (tools, materials, product orders, etc.)	75	7	9	2	0.89
8	Search for information quickly and efficiently in all available internal and external documentation	75	7	5	-2	0.67
9	Code (programming)	76	9	6	-3	0.78
10	Manage and elicit requirements	95	10	7	-3	0.44
11	Make complex data operations on data in spreadsheets with a programming language	96	11	14	3	0.44
12	Quickly grasp your mind around a subject	103	12	11	-1	0.56
13	Automate tedious or repetitive tasks	105	13	10	-3	0.56
14	Manage file versioning	107	14	13	-1	0.33
15	Communicate by writing	124	15	15	0	0.33
16	Know who to ask for questions about any given task/document/process	135	16	16	0	0.11
17	Transfer and share files (securely)	141	17	17	0	0.11
18	Create data visualizations	148	18	18	0	0.11
19	Control quality of design object	151	19	19	0	0.22
20	Store data	157	20	20	0	0.22
21	Collect data from measuring devices	177	21	22	1	0.11
22	Participate remotely in meetings	187	22	21	-1	0.00

Table 4.5: Results of the Ranking Phase

Chapter 5: Discussion and conclusion

As a reminder, the intellectual bandwidth model, detailed in Chapter 2, explains how KMS support the two fundamental capabilities that shape organizations' value generation capacity: knowledge processing and collaboration. All of the 11 known main categories of KMS affordances that were identified in the literature fit within principally one of those two dimensions of the Intellectual Bandwidth model. Knowledge processing consists of transforming data, information, knowledge and wisdom into one another by using cognitive abilities such as reasoning and deduction. The collaboration dimension corresponds to the degree to which members of the organization have to exchange information and coordinate in order to accomplish their knowledge processing tasks. Collected, coordinated and concerted work respectively require an increasing level of communication.

A ranking-type Delphi study was conducted with a panel of engineers in order to elicit the affordances that are perceived most useful by knowledge workers. The main results consist of a list of 22 ranked KMS affordances that emerged as most important according to the panel and a list of 11 affordances that were prevalent in the literature. Unsurprisingly, many of the affordances elicited from the panel of experts can be categorized under the main affordance categories extracted from the literature. Additionally, some items from each list don't have any corresponding one in the other. The following table (5.1) puts the two lists side by side and highlights the similarities and differences between them. The items that are in cells with a gray background are the ones that have no relation to the other list.

This table was generated by listing all the affordances elicited from the panel next to a corresponding affordance from the literature if there was any, or next to an empty cell otherwise. The fit between affordances from the literature and the data collection was established based on the researcher's own interpretation of the definition of the affordances. We understand that this method may be biased and constitutes a weakness in the analysis.

Intellectual bandwidth dimensions	KMS affordances from the literature	KMS affordance from the Delphi
Mostly knowledge processing KMS affordances	Create new contributions	Create model of design object
		Code (programming)
	Collaborate and brainstorm in iterations	
	Clarify and analyze different alternatives	Plan resources (tools, materials, product orders, etc.)
	Gather information	Search for information quickly and efficiently in all available internal and external documentation
		Quickly grasp your mind around a subject
		Know who to ask for questions about any given task/document/process
		Collect data from measuring devices
	Review historical contributions and their evolution	Manage file versioning
	Edit existing contributions	
	Process information and knowledge	Analyze data
		Calculate
		Make complex data operations on data in spreadsheets with a programming language
		Create data visualizations
	Experiment	Simulate design object in its environment
	Merge existing contributions	
		Track issues
		Manage and elicit requirements
		Automate tedious or repetitive tasks
		Control quality of design object
Mostly collaboration KMS affordances	Communicate	Communicate by writing
		Transfer and share files (securely)
		Participate remotely in meetings
		Store data
	Manage virtual profile	
		Manage Projects

Table 5.1: Comparison of the KMS Affordances From the Literature With the Elicited Ones

The fact that many affordances elicited from the panel of experts correspond to the ones from the literature is a confirmation of their importance in KMS. However, four of the 11 main affordances from the literature (Collaborate and brainstorm in iterations, Edit existing contributions, Merge existing contributions and Manage virtual profile) were not mentioned by the panel of experts. This raises questions, as there are at least four possible explanations for this discrepancy. The first one is that they are actually less important than the others. The second one is that they are important, but their importance is not perceived by the experts. The third one is that they are so obviously important that the panel didn't think to mention them because they were taken for granted. The fourth possible explanation is that they are only relevant for concerted work and the members of the panel mostly operate at the level of collected or coordinated work. As a reminder, those are the three levels of collaboration from the Intellectual Bandwidth model. The data collected in this research doesn't allow ruling out any of these explanations.

The five affordances that were mentioned by the panel but were not found in the literature on KMS affordances (Track issues, Manage and elicit requirements, Automate tedious or repetitive tasks, Control quality of design object and Manage Projects) indicate potential gaps in the literature. Unless their importance is overrated by the panel, they could point to areas where research is needed. It could also be the case that they are specific to the engineering profession and don't generalize to all knowledge workers.

The list of 22 most important KMS affordance from the perspective of knowledge workers has many potential uses for practitioners. It provides vendors of KMS solutions and their customers with a way to prioritize implementation or implantation of KMS capabilities. It can also be useful for assessing user satisfaction with each of the 22 items. The lack of satisfaction for one item could indicate that it is missing in the system or that it is not perceived by the users. This would be a sign that the system needs to be improved, or the affordance better communicated to the users with clearer documentation, symbolic expression or training.

Practitioners should be advised not to induce false precision in the ranking of the items. The difference in importance between one affordance and the next is not statistically significant, especially given the W obtained in the ranking phase that indicates moderate consensus in the panel. The ranking of the affordances starts to be meaningful with a difference of two or more in position on the list.

The goal of this thesis was to ascertain the affordances of KMS that are perceived as most useful by knowledge workers and their order of importance. In the second chapter of this thesis, a synthesis of the main KMS affordances and their benefits that are present in the literature was established and put in relation with the Intellectual Bandwidth model. In the third chapter, the methodology that was used to elicit the most important KMS affordances from the perspective of knowledge workers who are heavily implicated in design activities was detailed and the results consist of a list of 22 KMS affordances ranked in order of importance. In this fourth chapter, the two sets of affordances will be compared and analyzed in order to draw conclusions and implications for researchers and practitioners.

A major limitation of this research is the small size of the expert panel used for data collection, due to the difficulties encountered in recruiting participants. There is no clear recommendation in the literature on the number of panellists that Delphi studies should have (Jörn Kobus & Markus Westner, 2016), other than it shouldn't be too large and it should be reported (Paré et al., 2013). This being said, the 9 panellists who completed the study is a small number when compared to the sample of Delphi studies analyzed in Paré et al. Only 6% of them had between 7 and 13 experts, compared to 54% that had between 14 and 30 and 29% that had between 31 and 60.

Another important limitation regards the W that is lower than the recommended value of 0.7 for stopping the ranking phase in a Delphi study. This reduces the significance and validity of the ranking.

Finally, this study assumes that the results can be generalized to all knowledge workers who are involved in design activities, but it could very well be the case that they are not since the panel was only composed of engineers.

Despite those limitations, this study sheds light on potential gaps in the literature on KMS affordances and provides practitioners with a useful tool to prioritize the development and implantation of KMS capabilities and assess user satisfaction. It increases out understanding of the perception of knowledge workers in regard to the importance of different KMS affordances. This is crucial for improving the use of these systems and the benefits that they bring to organizations for improving their value creation capacity.

Bibliography

Abhari, K., Davidson, E. J., & Xiao, B. (2017). Co-innovation platform affordances. *Industrial Management & Data Systems*, *117*(5), 873–895.

All, A. (2014, August 8). 5 Ways to Get People to Use Enterprise Social Software. Retrieved June 20, 2017, from http://www.enterpriseappstoday.com/social-media/5-ways-to-get-people-to-use-enterprise-social-software.html

Beck, R., Pahlke, I., & Seebach, C. (2014). Knowledge Exchange and Symbolic Action in Social Media-Enabled Electronic Networks of Practice: A Multilevel Perspective on Knowledge Seekers and Contributors. *MIS QUARTERLY*, *38*(4), 1245–1270.

Bernhard, E., Recker, J. C., & Burton-Jones, A. (2013). Understanding the actualization of affordances: A study in the process modeling context. In *Institute for Future Environments; Science & Engineering Faculty*. Università Bocconi, Milan. Retrieved from http://aisel.aisnet.org/icis2013/proceedings/ResearchInProgress/41/

Brown, S. A., Dennis, A. R., & Venkatesh, V. (2010). Predicting Collaboration Technology Use: Integrating Technology Adoption and Collaboration Research. *Journal of Management Information Systems*, *27*(2), 9–54. https://doi.org/10.2753/MIS0742-1222270201

Butler, T., & Murphy, C. (2007). Understanding the design of information technologies for knowledge management in organizations: a pragmatic perspective. *Information Systems Journal*, *17*(2), 143–163. https://doi.org/10.1111/j.1365-2575.2007.00237.x

Call, D. (2005). Knowledge management – not rocket science. *Journal of Knowledge Management*, *9*(2), 19–30. https://doi.org/10.1108/13673270510590191

Ciavola, B. T., & Gershenson, J. K. (2016). Affordance theory for engineering design. *Research in Engineering Design*, *27*(3), 251–263. https://doi.org/10.1007/s00163-016-0216-5

Cormier, P., & Lewis, K. (2015). An affordance-based approach for generating user-specific design specifications. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing : AI EDAM*, *29*(3), 281–295. https://doi.org/10.1017/S089006041500027X

Cormier, P., Olewnik, A., & Lewis, K. (2014). Toward a formalization of affordance modeling for engineering design.

Research in Engineering Design, *25*(3), 259–277. https://doi.org/10.1007/s00163-014-0179-3

Dachis Group. (2012, August). *Current State of Social Engagement Inside The Large Enterprise | Enga…*. Retrieved from https://www.slideshare.net/dachisgroup/current-state-of-social-engagement-inside-the-large-enterprise-engagement-scale-report

Davenport, T. H. (2008). Improving Knowledge Worker Performance. In D. Pantaleo & N. Pal (Eds.), *From Strategy to Execution: Turning Accelerated Global Change into Opportunity* (pp. 215–235). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-71880-2_11

DeLone, W. H., & McLean, E. R. (2003). The DeLone and McLean Model of Information Systems Success: A Ten-Year Update. *Journal of Management Information Systems*, *19*(4), 9–30.

DeSanctis, G., & Poole, M. S. (1994). Capturing the Complexity in Advanced Technology Use: Adaptive Structuration Theory. *Organization Science*, *5*(2), 121–147.

Dixon, W. J. (2008). Social Networks and KMS Use in US IT Services. *SpringerLink*, 151–162. https://doi.org/10.1007/978-0-387-09682-7-9_13

Dulipovici, A., & Vieru, D. (2015). Exploring collaboration technology use: how users' perceptions twist and amend reality. *Journal of Knowledge Management; Kempston*, *19*(4), 661–681.

Faraj, S., Jarvenpaa, S. L., & Majchrzak, A. (2011). Knowledge collaboration in online communities. *Organization Science*, *22*(5), 1224–1239.

Faraj, S., & Xiao, Y. (2006). Coordination in Fast-Response Organizations. *Management Science*, *52*(8), 1155–1169.

Fayard, A.-L., & Weeks, J. (2014). Affordances for practice. *Information & Organization*, *24*(4), 236–249.

Grgecic, D., Holten, R., & Rosenkranz, C. (2015). The Impact of Functional Affordances and Symbolic Expressions on the Formation of Beliefs. *Journal of the Association for Information Systems; Atlanta*, *16*(7), 580–607.

Hahn, J., & Wang, T. (2009). Knowledge management systems and organizational knowledge processing challenges: A field experiment. *Decision Support Systems*, *47*(4), 332–342.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75–105.

Hutchby, I. (2001). Technologies, Texts and Affordances. *Sociology*, *35*(2), 441–456. https://doi.org/10.1017/S0038038501000219

Johannessen, J.-A., & Olsen, B. (2010). The future of value creation and innovations: Aspects of a theory of value creation and innovation in a global knowledge economy. *International Journal of Information Management*, *30*(6), 502–511. https://doi.org/10.1016/j.ijinfomgt.2010.03.007

Jörn Kobus, & Markus Westner. (2016). Ranking-type delphi studies in IS research: step-by-step guide and analytical extension. In *IADIS International Conference Information Systems 2016* (pp. 28–38). Retrieved from http://www.iadisportal.org/digital-library/ranking-type-delphi-studies-in-is-research-step-by-step-guide-and-analytical-extension

Kendall, M. G. (1945). The Treatment of Ties in Ranking Problems. *Biometrika*, *33*(3), 239–251.

Kendall, M. G., & Smith, B. B. (1939). The Problem of m Rankings. *The Annals of Mathematical Statistics*, *10*(3), 275–287.

Kuhn, O., Dusch, T., Ghodous, P., & Collet, P. (2012). Framework for the support of knowledge-based engineering template update. *Computers in Industry*, *63*(5), 423.

Lami, I. M., & Franco, L. A. (2016). Exploring the Affordances of Collaborative Problem-Solving Technologies in the Development of European Corridors, 65–80. https://doi.org/10.1007/978-3-319-15708-5_4

Leidner, D. E., Gonzalez, E., & Koch, H. (2018). An affordance perspective of enterprise social media and organizational socialization. *Journal of Strategic Information Systems*, *27*(2), 117–138. https://doi.org/10.1016/j.jsis.2018.03.003

Loebbecke, C., & Myers, M. D. (2017). Deploying internal knowledge portals: Three major challenges. *Information & Management*, *54*(4), 491–505. https://doi.org/10.1016/j.im.2016.11.001

Maier, J. R. A., & Fadel, G. M. (2009). Affordance-based design methods for innovative design, redesign and reverse engineering. *Research in Engineering Design*, *20*(4), 225. https://doi.org/10.1007/s00163-009-0064-7

Malhotra, A., & Majchrzak, A. (2012). How virtual teams use their virtual workspace to coordinate knowledge. *ACM Transactions on Management Information Systems (TMIS)*, *3*(1), 6. https://doi.org/10.1145/2151163.2151169

Markus, M. L., & Silver, M. S. (2008). A Foundation for the Study of IT Effects: A New Look at DeSanctis and Poole's

Concepts of Structural Features and Spirit. *Journal of the Association for Information Systems*, *9*(10), 609–632.

Maruta, R. (2012). Transforming knowledge workers into innovation workers to improve corporate productivity. *Knowledge-Based Systems*, *30*, 35–47. https://doi.org/10.1016/j.knosys.2011.06.017

Michael H. Zack. (2001). If Managing Knowledge is the Solution, then What's the Problem? In *Knowledge Management and Business Model Innovation* (pp. 16–36). Hershey, PA, USA: IGI Global. https://doi.org/10.4018/978-1-878289-98-8.ch002

Nelson, R. R. (2005). Project Retrospectives: Evaluating Project Success, Failure, and Everything in Between. *MIS Quarterly Executive*, *4*(3), 361–372.

Nonaka, I. (1994). A Dynamic Theory of Organizational Knowledge Creation. *Organization Science*, *5*(1), 14–37. https://doi.org/10.2307/2635068

Nunamaker Jr, J. F., Romano Jr, N. C., & Briggs, R. O. (2002). Increasing Intellectual Bandwidth: Generating Value from Intellectual Capital with Information Technology. *Group Decision and Negotiation*, *11*(2), 69–86.

Oviatt, S., Cohen, A., Miller, A., Hodge, K., & Mann, A. (2012). The Impact of Interface Affordances on Human Ideation, Problem Solving, and Inferential Reasoning. *ACM Trans. Comput.-Hum. Interact.*, *19*(3), 22:1–22:30. https://doi.org/10.1145/2362364.2362370

Paré, G., Cameron, A.-F., Poba-Nzaou, P., & Templier, M. (2013). A systematic assessment of rigor in information systems ranking-type Delphi studies. *Information & Management*, *50*(5), 207–217. https://doi.org/10.1016/j.im.2013.03.003

Pozzi, G., Pigni, F., & Vitari, C. (2014). Affordance Theory in the IS Discipline: a Review and Synthesis of the Literature. In *Smart Sustainability: The Information Systems Opportunity*. Savannah, Georgia, USA: Association for Information Systems (AIS).

Preece, J. (2000). *Online Communities: Designing Usability and Supporting Socialbilty* (1st ed.). New York, NY, USA: John Wiley & Sons, Inc.

Priem, R. L. (2007). A Consumer Perspective on Value Creation. *The Academy of Management Review*, *32*(1), 219–235.

Qureshi, S., Briggs, R. O., & Hlupic, V. (2006). Value Creation from Intellectual Capital: Convergence of Knowledge

Management and Collaboration in the Intellectual Bandwidth Model. *Group Decision and Negotiation*, *15*(3), 197–220.

Rice, R. E., Evans, S. K., Pearce, K. E., Sivunen, A., Vitak, J., & Treem, J. W. (2017). Organizational Media Affordances: Operationalization and Associations with Media Use. *Journal of Communication*, *67*(1), 106–130.

Schmidt, R. C. (1997). Managing Delphi surveys using nonparametric statistical techniques. *Decision Sciences; Atlanta*, *28*(3), 763–774.

Senge, P., Kleiner, A., Roberts, C., Ross, R., Roth, G., Smith, B., & Guman, E. C. (1999). The dance of change: The challenges to sustaining momentum in learning organizations. *Performance Improvement*, *38*(5), 55–58. https://doi.org/10.1002/pfi.4140380511

Strong, D. M., Johnson, S. A., Tulu, B., Trudel, J., Volkoff, O., Pelletier, L. R., … Garber, L. (2014). A Theory of Organization-EHR Affordance Actualization. *Journal of the Association for Information Systems*, *15*(2), 53–85.

Tallon, P. P., & Pinsonneault, A. (2011). Competing Perspectives on the Link Between Strategic Information Technology Alignment and Organizational Agility: Insights from a Mediation Model. *MIS Quarterly*, *35*(2), 463–486.

Terrenghi, L., Fritsche, T., & Butz, A. (2006). The EnLighTable: Design of Affordances to Support Collaborative Creativity. In *SpringerLink* (pp. 206–217). Springer, Berlin, Heidelberg. https://doi.org/10.1007/11795018_19

Thomas, G., & Fernández, W. (2008). Success in IT projects: A matter of definition? *International Journal of Project Management*, *26*(7), 733–742.

Tiwana, A., & Bush, A. A. (2005). Continuance in expertise-sharing networks: a social perspective. *IEEE Transactions on Engineering Management*, *52*(1), 85–101. https://doi.org/10.1109/TEM.2004.839956

Venkatesh, V., & Davis, F. D. (2000). A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science*, *46*(2), 186–204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly*, *27*(3), 425–478.

Wagner, D., Vollmar, G., & Wagner, H.-T. (2014). The impact of information technology on knowledge creation: An affordance approach to social media. *Journal of Enterprise Information Management*, *27*(1), 31–44. https://doi.org/

10.1108/JEIM-09-2012-0063

Wang, W.-T., & Lai, Y.-J. (2014). Examining the adoption of KMS in organizations from an integrated perspective of technology, individual, and organization. *Computers in Human Behavior*, *38*, 55–67. https://doi.org/10.1016/j.chb.2014.05.013

Wint, N. (2016). *An Investigation of Socio-technical Components of Knowledge Management System (KMS) Usage*. Nova Southeastern University. Retrieved from http://nsuworks.nova.edu/gscis_etd/961

Zhao, Y., Liu, J., Tang, J., & Zhu, Q. (2013). Conceptualizing perceived affordances in social media interaction design. *Aslib Proceedings; Bradford*, *65*(3), 289–303. http://proxy2.hec.ca:2098/10.1108/00012531311330656

Appendix A: Definitions of KMS Affordance Categories from the Literature

Abhari, Davidson, & Xiao, 2017	Communication	"discuss opinions, share knowledge, ask for help or votes, or participate in general discussions on forums without being engaged in any particular innovation project"
	Collaboration	"comment on or improve another actor's idea rather than proposing a new idea"
	Ideation	"the ability to propose a new product or service idea. […] the broad range of possible actions from submitting a new solution for an organizational problem to suggesting a new product feature for already proposed products"
Hahn & Wang, 2009	Choose	"assist in the process of selecting alternatives. […] supports the ability to clarify and to analyze"
	Generate	" induce the generation of ideas and viewpoints or the provision interpretive schemes for decision making. […] Iterative brainstorming and idea generation"
Leidner, Gonzalez, & Koch, 2018	Networking	"build relationships, interact with peers, socialize both during and after working hours and take a break during the workday"
	Organizational visibility	"participate in […] sponsored events, build peer relationships, develop and demonstrate leadership skills, and interact with superiors"
	Information gathering	"find resources"
	Information sharing	"helping peers"
	Innovation	"broadening perspective and acquiring new technology skills. […] acquiring insight on new products and services"
Malhotra & Majchrzak, 2012	Virtual co-presence	"allowing members to feel as if others are in the same room, creating a feeling of shared context "
	Monitoring of knowledge evolution	"[keep track of] the past knowledge of team members and how that past knowledge is becoming collectively transformed to accomplish the team's goal state"
Rice et al., 2017	Pervasiveness	"get responses to my requests from others quickly; communicate with others while moving, commuting, traveling; communicate with infrequent or less important work relationships"
	Self-presentation	"identity management"
	Searchability	"search for information or people by entering search words; search for information or people by following links between contents; search for tags or keywords that someone else has added to content"
	Visibility	"see other people's answers to other people's questions; see who has interactions or links with particular employees or their information; see the number of others who have "liked" or linked to the same content"
	Editability	"edit others' information after they have posted it; edit my information after I have posted it; create or edit a document collaboratively"
	Awareness	"be aware of the information others in my department have; be aware of the information others outside of my department have; be aware of activities, opinions, or locations of others; keep up-to-date with the progress of projects; keep up-to-date with organizational policies and norms"
Wagner, Vollmar, & Wagner, 2014	Association	"Established connections between individuals, between individuals and content, or between an actor and a presentation; enable users to make visible their social networks"
	Recombinability	"Borrowing of and building on each other's contributions"
	Experimentation	"Try out novel ideas"
	Reviewability	"Viewing and managing the content of front and back narratives over time; reviewing a range of ideas; reviewing the full range of contributions from a single individual"
	Editability	"Ability to craft and re-craft a communicative act before it is viewed by others; ability of an individual to modify or revise content they have already communicated"
	Authoring	"Generating content and putting it online for a broad audience; authoring can take many forms (an insight, a fact, an experience, a link, an edit) and include various types of media (written status updates, photos, videos, etc.)"
Zhao et al., 2013	Affective	"trigger or stimulate users' emotional reactions. For example, some social media allow their users to show "like" or "dislike" to user generated content by others"
	Control	"user's power of making choices of the situation or the environment rather than of one's own behavior"
	Cognitive	"help, aid, support, facilitate or enable a user's thinking, knowing, and/or cognitively/mentally processing something, which may take effect immediately or have a potential impact"
	Physical	"the attributes of the IT artifact that can be sensed, acted upon, or physically manipulated by users for a particular purpose"

Appendix B: Questionnaire Instructions

Brainstorming phase

How can information technology support the work of engineers?

For this question, you are asked to draw up **a list of actions made possible by technology that are or could be useful for an engineer**. The goal is to understand the nature of engineers' needs in information technology. You can include actions you do yourself in your work or that you would like to do but don't have the necessary tools. Do not limit yourself to what exists or what is possible. Each action should complete the following sentence:

"It is / would be useful for an engineer to have technological tools that allow him or her to …"

Do not write action related to administrative or personnel management responsibilities. In the second column of the table, enter a **summary description** of the action with an explanation and comments if applicable.

Finally, in the last column, indicate the **names of the technologies** that you know or use and that make it possible to perform the mentioned action. It can be software, an online service or any other information technology. If you do not know any, leave this column blank.

Take your time to answer this question. You can close this page at any time and continue to answer later using the same link that was emailed to you. The goal is to generate as exhaustive a list as possible. It is required to list a minimum of 10 actions but additional space is available if needed.

Filtering phase

The following list contains the actions that were mentioned by all study participants in the previous questionnaire. Please drag the 20 items that are the most important according to you in the box on the right and sort them from most important (on top) to least important (in the bottom).

Ranking phase

Items that were selected by less than half of the participants in the last questionnaire were eliminated. The following list is therefore final, but the order of importance could still change.

For now, the items that were selected by the most participants are at the top of the list, while the ones that were selected by the least participants are at the bottom. Items that have been selected by the same number of participants are ranked according to the average rank in which they were placed in the last questionnaire.

The order of the items in the following list should therefore be close to the consensus on the order of importance of the items. To ensure this, you are asked to review the items in the following list and make the changes you consider necessary in their order of importance. To do this, you must drag and drop the items to the desired place in the list.

Please remember that the most important items should be at the top of the list and the least important items should be at the bottom. In addition, remember that items represent actions that engineers must be able to do with the computer tools they have at work.

Thank you again for your participation in this study.

Appendix C: Brainstorming Data

P1	P2	P3	P4	P5
Modéliser des processus	simulation de filtre électronique	modéliser des processus	Analyse et statistiques	Erp simulation
Simuler des processus	modelisation 3D	modéliser des bases de données	Simulation des faiblesses matérielles	Information system
Structurer des données	anlayse de données	consigner des bogues à corriger	faciliter le contrôle de la qualité	Information system
Acquérir des données	conception PCB	consigner les fonctionnalités à développer	Programmation micro-controlleur	Information system
Stocker des données	faire des programmes informatique	réunions à distance	Dessins techniques	Information system
Analyser des données	suivre et entrer des données	communiquer des informations par texte	Base de donnée de problèmes	Database modelling
Représenter des données	Validation des concepts et explication des définitions	communiquer des informations par voix	Modélisation 3D	Database modelling
Gérer des projets	transferer des fichiers	consulter des ressources légales	programmation linux	Database modelling
Traduire des besoins fonctionnels en specifications techniques	modifier des formats d'image	stockage de données sécurisé	Prévention de bris	Database modeling
Trouver une information précise au sein d'une organisation	écrire des rapport	partage de données sécurisé	Simulation circuit électrique	Data Analysis
P6	**P7**	**P8**	**P9**	**P10**
Modélisation	trouver de la documentation technique	calculer les débits de fluides lors de la conception de réseau et boucles	Communiquer entre collègues	Layered complexity knowledge transfer
Programmer	Simulation optique (réflexion, réfraction, diffraction, etc.) qui prend en compte les effets électromagnétique de la lumière (application aux optiques de petites dimension)	design d'un procédé en génie chimique, domaine pétrolier	Calculer et dimensionner	Data subset generation and synchronisation
Gérer les différentes phases d'un projet	Simuler rapidement fichier parcours d'usinage très volumineux	communication avec l'équipe de chantier	Schématisation	Automate tedious/repetitive design aspects
Effectuer des calculs	Simuler l'effort de coupe en fraisage	traitement de données statistique en usine pour R&D	Recherche d'information	Customize these automation aspects
Dessins Techniques	Calculer des programmes d'usinage sur des surface mathematiques	production de prototype en R&D	Outil de mise en page pour documents clients	annotate digital files with high flexibility
Gestion du code source d'un programme	corriger des surfaces	visite de chantier et modifications aux plans	Conception / modélisation d'un produit	Make complex operation on data in spreadsheet contexts
Simulation physique	Conpenser des géométrie machine décaler	gestion de la qualité des produits	Base de données	program API interactions with any data storage files
Gérer des machine virtuelles	Gerer l'inventaire d'outils de coupe spéciaux	rétention des documents dans les domaines réglementés	Tableur	Enjoy backward compatibility in software files
Transfer de donnés	Comparer deux fichiers texte voluminueux	visualisation des plans en 3D	Base de données	Seemlessly manage physical units in calculations with NLP
Gestion des projets d'entreprise	Editer de très gros fichiers texte	rencontre d'équipe avec des gens de plusieurs pays dans le monde	Partage d'information	Do version control operations on common files (Commit, Merge, rebase, etc)
				Know who the approriate ressource people are for any given task/document/process
				find information quickly using powerful search features
				Spreadsheet/CSV to web form import/export
				Proper user feedback of software features

Appendix D: Filtering Data

Item	P01	P02	P03	P04	P05	P06	P07	P08	P10	N	Avg Score
Issue tracking	7	4	2	9	8	8	5	12	12	9	7.44
Data analysis	13	9	9	8	15	6	10	5	17	9	10.22
Modelling	5	1	4	19	3	2	1	1	30	8	7.33
Manage Projects	6	3	19	3	4	17	2	30	10	8	10.44
Search for information quickly and efficiently in all available internal and external documentation	3	10	5	12	11	5	30	20	1	8	10.78
Code (programming)	15	12	3	16	5	4	12	4	30	8	11.22
Requirement management and elicitation	2	8	18	4	1	3	30	30	11	7	11.89
Simulation	8	11	30	15	6	19	3	2	30	7	13.78
Resource planning (tools, materials, product orders, etc.)	19	6	14	1	19	30	6	30	19	7	16.00
Automate tedious or repetitive tasks	20	14	15	30	17	1	16	30	8	7	16.78
Quickly grasp your mind around a subject	1	7	30	2	2	30	15	30	13	6	14.44
Calculate	18	2	30	6	30	12	4	3	30	6	15.00
Manage file versioning	12	20	10	30	12	30	30	7	9	6	17.78
Make complex data operations on data in spreadsheets with a programming language	16	16	13	17	30	30	20	30	6	6	19.78
Written communication	30	5	6	30	30	14	7	17	30	5	18.78
Know who to ask for questions about any given task/document/process	4	30	30	13	20	16	30	30	2	5	19.44
Transfer and share files (securely)	30	30	20	30	9	15	8	8	30	5	20.00
Create data visualizations	9	30	11	30	14	9	30	30	18	5	20.11
Facilitate quality control	30	15	12	5	18	30	30	11	30	5	20.11
Data storing	10	19	8	30	7	18	30	30	30	5	20.22
Remote meetings	14	30	7	14	30	13	30	16	30	5	20.44
Collect data from measuring devices	17	30	30	20	30	10	9	9	30	5	20.56
Manage tools inventory	30	18	30	30	16	30	19	18	20	5	23.44
Annotate digital files of different formats	30	30	30	30	30	11	14	13	4	4	21.33
Text editing	30	30	1	30	30	7	30	30	16	3	22.67
Automatically generate documentation elements from CAD files	30	17	30	30	30	30	30	10	3	3	23.33
Program micro-controllers	30	13	30	7	30	30	13	30	30	3	23.67
Convert measure units seamlessly	30	30	30	30	30	20	30	6	15	3	24.56
Import web form data into spreadsheet	30	30	30	10	30	30	30	30	5	2	25.00
Program API interactions with any data storage files	30	30	30	30	10	30	30	30	7	2	25.22
Create business application forms	11	30	16	30	30	30	30	30	30	2	26.33
Edit images	30	30	17	11	30	30	30	30	30	2	26.44
Convert different file types	30	30	30	30	30	30	30	15	14	2	26.56
Be aware of tasks automatically performed in the background by software	30	30	30	18	13	30	30	30	30	2	26.78
Detect differences between two large text files	30	30	30	30	30	30	17	19	30	2	27.33
Manage virtual machines	30	30	30	30	30	30	11	30	30	1	27.89
Manage document retention calendar to comply with regulations	30	30	30	30	30	30	30	14	30	1	28.22
Use outdated file formats with backward compatibility	30	30	30	30	30	30	18	30	30	1	28.67
Edit very large text files	30	30	30	30	30	30	30	30	30	0	30.00

N = number of participants who selected the item in the filtering phase

Appendix E: Calculating W in the Filtering Phase

	P01	P02	P03	P04	P05	P06	P07	P08	P10
Issue tracking	7	4	1	8	8	7	5	10	8
Data analysis	12	9	8	7	13	6	10	5	10
Modelling	5	1	3	15	3	2	1	1	17.5
Manage Projects	6	3	16	3	4	15	2	18	6
Search for information quickly and efficiently in all available internal and external documentation	3	10	4	9	10	5	18.5	13	1
Code (programming)	14	12	2	13	5	4	11	4	17.5
Requirement management and elicitation	2	8	15	4	1	3	18.5	18	7
Simulation	8	11	20	12	6	17	3	2	17.5
Resource planning (tools, materials, product orders, etc.)	18	6	13	1	16	20	6	18	12
Automate tedious or repetitive tasks	19	13	14	19.5	14	1	13	18	4
Quickly grasp your mind around a subject	1	7	20	2	2	20	12	18	9
Calculate	17	2	20	6	20	10	4	3	17.5
Manage file versioning	11	17	9	19.5	11	20	18.5	6	5
Make complex data operations on data in spreadsheets with a programming language	15	15	12	14	20	20	14	18	3
Written communication	21	5	5	19.5	20	12	7	12	17.5
Know who to ask for questions about any given task/document/process	4	20	20	10	17	14	18.5	18	2
Transfer and share files (securely)	21	20	17	19.5	9	13	8	7	17.5
Create data visualizations	9	20	10	19.5	12	8	18.5	18	11
Facilitate quality control	21	14	11	5	15	20	18.5	9	17.5
Data storing	10	16	7	19.5	7	16	18.5	18	17.5
Remote meetings	13	20	6	11	20	11	18.5	11	17.5
Collect data from measuring devices	16	20	20	16	20	9	9	8	17.5
Number of tied items	3	5	5	6	5	5	8	9	10
T	24	120	120	210	120	120	504	720	990

Appendix F: Ranking Data

Previous rank	Item	P01	P03	P04	P05	P06	P07	P08	P09	P10
1	Issue tracking	2	1	4	18	1	6	11	1	8
2	Data analysis	12	3	6	3	2	11	2	2	13
3	Modelling	3	4	9	2	4	1	1	4	11
4	Manage Projects	4	6	1	1	6	4	12	3	6
5	Search for information quickly and efficiently in all available internal and external documentation	5	5	13	10	3	13	14	11	1
6	Code (programming)	6	8	8	4	7	14	5	8	16
7	Requirement management and elicitation	7	2	14	15	5	15	17	13	7
8	Simulation	8	9	11	5	8	2	3	7	12
9	Resource planning (tools, materials, product orders, etc.)	9	10	12	6	9	5	8	6	10
10	Automate tedious or repetitive tasks	10	11	15	11	10	16	16	12	4
11	Quickly grasp your mind around a subject	11	12	2	14	11	12	22	10	9
12	Calculate	1	13	3	7	12	10	4	5	17
13	Manage file versioning	13	7	16	17	13	7	15	14	5
14	Make complex data operations on data in spreadsheets with a programming language	15	14	7	13	14	9	6	15	3
15	Written communication	16	15	10	22	15	3	19	9	15
16	Know who to ask for questions about any given task/document/process	14	16	17	16	16	17	21	16	2
17	Transfer and share files (securely)	21	17	18	12	17	8	13	17	18
18	Create data visualizations	17	18	19	8	18	18	18	18	14
19	Facilitate quality control	18	19	5	20	19	19	10	20	21
20	Data storing	19	20	22	9	20	20	9	19	19
21	Remote meetings	20	21	20	21	21	21	20	21	22
22	Collect data from measuring devices	22	22	21	19	22	22	7	22	20