Vers un cycle d’amélioration continue pour la capitalisation des connaissances : un cas d’étude à STMicroelectronics

Manel Brichni

UNIVERSITÉ DE GRENOBLE

THÈSE

Pour obtenir le grade de

DOCTEUR DE L'UNIVERSITÉ DE GRENOBLE

Spécialité : **Informatique**

Arrêté ministériel : 7 août 2006

Présentée par

Manel BRICHNI

Thèse dirigée par **Sophie DUPUY-CHESSA**

préparée au sein des **Laboratoires LIG et G-SCOP, en collaboration avec l'entreprise STMicroelectronics**
dans **L'École doctorale MSTII**

Towards a Continuous Improvement Cycle for Knowledge Capitalization

A Case Study at STMicroelectronics

Thèse soutenue publiquement le **10 Décembre 2015**,
devant le jury composé de :

Mme Nada MATTA
Professeur, Université de Technologie de Troyes, Présidente
M. Camille SALINESI
Professeur, Université Paris 1 (Panthéon Sorbonne), Rapporteur
M. Eric DUBOIS
Professeur, Luxembourg Institute of Science of Technology, Rapporteur
M. Laurent GENESTE
Professeur, Ecole Nationale d'Ingénieur de Tarbes, Examinateur
M. David ROZIER
Ingénieur de recherche, Xerox Research Centre Europe, Examinateur
Mme Sophie DUPUY-CHESSA
Professeur, Université de Grenoble, Directrice de thèse
Mme Lilia GZARA
Maître de conférence HDR, Grenoble INP, Co-Encadrante de thèse
Mme Corinne JEANNET
Ingénieur, STMicroelectronics Crolles, Co-Encadrante de thèse
Mme Nadine MANDRAN
Ingénieur, CNRS-Centre National de la Recherche Scientifique, Invitée

Remerciements

L'art de la réussite consiste à savoir s'entourer des meilleurs (John Fitzgerald Kennedy). C'était bien mon cas lors de ces trois années de thèse. J'ai donc de nombreux compagnons à remercier.

Tout d'abord, avec un grand plaisir, je commence par remercier Sophie et Lilia. Je me considère parmi les rares qui ont eu cette chance d'avoir un tel encadrement, professionnel et humain. Sophie, la directrice de ma thèse, ainsi que Lilia, ma co-encadrante, ont toujours été là pour me guider, encourager et me conseiller. Je les remercie également pour la patience et la gentillesse qu'elles ont manifestéés à mon égard durant cette thèse. Je me félicite d'avoir travaillé avec elles, partager leur expérience et j'espère que j'étais à la hauteur de leur confiance.

Je tiens à remercier les membres du jury qui m'ont fait l'honneur d'examiner mon travail et pour leur apport scientifique. Tout d'abord Madame Nada Matta qui a accepté d'en être la présidente; Monsieur le Professeur Eric Dubois et Monsieur le Professeur Camille Salinesi qui ont été mes rapporteurs. Je les remercie pour leurs riches rapports. Je tiens à remercier Monsieur le Professeur Laurent Geneste et Monsieur David Rozier d'avoir accepté d'être dans le jury. Mes remerciements vont également à Madame Nadine Mandran de m'avoir accompagné durant mes travaux de recherche et d'avoir accepté être dans mon jury.

Je remercie tous mes collègues à *STMicroelectronics*, qui m'ont soutenus tout au long de ce projet de recherche et de m'avoir donné les moyens de mener à bien mes travaux. Je remercie également mes anciens responsables scientifiques à *STMicroelectronics*, David Rozier et Guillaume Chezaud de m'avoir fait confiance et de me permettre d'intégrer leur équipe au sein de l'entreprise. Malgré le peu de temps que nous avons passé ensemble, leurs conseils et leurs encouragements m'ont beaucoup apporté.

Mes remerciements vont également à Corinne, ma responsable scientifique à *STMicroelectronics*, de m'avoir encadré et m'apporté le soutien nécessaire pour poursuivre ma thèse en toute sérénité, malgré la difficulté de la tâche. Je remercie, particulièrement Patrice, qui a su prêter une oreille patiente et attentive à toutes mes interrogations continues. Son aide était d'une importance capitale dans la réussite de cette thèse et j'en suis reconnaissante.

D'une manière générale, j'ai beaucoup apprécié la valeur amicale et humaine au sein de mes équipes à l'entreprise ainsi qu'aux laboratoires. Cela m'a permis de travailler dans une ambiance agréable et profondément formatrice, tant à un niveau professionnel que personnel. Je remercie, bien sûr, mes collègues thésards à l'entreprise, GSCOP et le LIG.

J'adresse toute mon affection à tous les membres de ma famille. Sans eux et leur soutien dès mon arrivé en France, cette thèse n'aurait aboutit. Mon papa "Mongi" et ma maman "Amel" m'ont toujours accompagnée et fais confiance en mes choix dans la vie professionnelle et personnelle. Cette thèse est le fruit de leur patience, investissement et amour.

Des remerciements spéciaux à mon cher oncle "Houssine" et sa famille de m'avoir soutenu depuis mon arrivée en France jusqu'à présent. Je ne finirai jamais de vous remercier. Ma réussite est aussi la votre.

Tous mes remerciements sont à mes petites soeurs, Emna, Malek et Syrine et mon petit frère Iskander. J'espère qu'ils sont tous fièrs de leur grande soeur. Je remercie, mes copines et cousines, qui ont toujours été là pour moi aussi bien dans les moments dûrs et joyeux. Merci Reema, Ikram, Marwa, Nouha, , Sofia, etc.

Enfin, mon cher mari, Sunny, je te remercie pour ta patience, amour et soutien depuis notre rencontre jusqu'au moment de lecture de ces mots. Que notre vie soit pleine de bonheur.

Abstract

At *STMicroelectronics*, the *Business Intelligence* team is daily confronted to exploit data and information to create reports about manufacturing activities in order to supervise it. In such an industrial organization, products change regularly and data can quickly become obsolete. Consequently, over time, the number of created reports is highly growing, while knowledge about their creation is lost. These issues are generally true for large companies, characterized by a continuous evolution of products, technologies and their complexities. As a result, many problems arise.

First, due to the departure of employees and organization restructuring, knowledge is increasingly lost and difficulties in managing new one appear. Second, due to the existence of duplicated and not centralized knowledge, it can quickly become obsolete. This implies in its turn a waste of time in searching for knowledge, re-developing existing business solutions and therefore a rapid knowledge proliferation. Third, knowledge identification is not easy, especially when there is no common structure and space for knowledge capitalization. Fourth, neglecting knowledge sharing aspects prevents an effective reuse. Finally, the absence of effective monitoring and maintaining of existing knowledge and its tools prevent their evolution. As a result, the way knowledge is shared, stored, reused and more generally capitalized could not be effectively and continuously ensured, especially when users are capitalizing in their own manner.

This work must address our main research question, which is:

How to ensure a continuous expert knowledge capitalization?

To respond to our research question, we propose a continuous improvement cycle for knowledge capitalization. Its objective is to effectively and continuously capitalize expert knowledge while targeting business needs and providing an evolving solution. In fact, since knowledge is embedded not only in systems and tools, but also in human minds and practices, involving users throughout our solution definition, development and validation is a key component for its effectiveness and success. A knowledge capitalization solution involves therefore people, organizations and technology.

- A first step in our work was to understand the key part of the knowledge storage and sharing solution. At *STMicroelectronics*, a wiki is used for knowledge storage and sharing. Based on a user-centred approach, its use, weaknesses and strengths were assessed in order to identify areas of progress to accomplish its objectives [1].

- One of previous findings concerns the importance of structuring knowledge in the wiki. To this end, a user-centred approach for knowledge representation and its integration in the wiki is proposed. Three complementary characteristics "What, Why and How" are considered [2, 3]. Each characteristic describes knowledge in a different level and is modelled in an appropriate way. To integrate knowledge representation in the capitalization process, transforming represented knowledge to shareable one is our objective, in our case, through the Wiki.

- Each step is important to ensure an effective use of all what was capitalized and to generate new knowledge, which leads to new needs and therefore, to knowledge evolution. To this end, two complementary solutions are considered in our proposal for knowledge evolution, quantitative and qualitative [4]. First, a Business Intelligence

for Business Intelligence (BI4BI) system is developed. It is in charge of evaluating, analysing and making decisions about the system itself and its knowledge. Second, a questionnaire complements our proposal for BI knowledge evolution.

In this work, the Design Science Research methodology was able to target business needs, to study existing solutions in the literature, to design and implement innovative solutions for knowledge capitalization, as well as to demonstrate their applicability in the appropriate environment, and finally, to contribute to theoretical knowledge base.

Contents

List of Figures

List of Tables

Introduction

1 General Introduction

In manufacturing industries, knowledge based service capabilities have been calculated to be responsible for 65% to 75% of the total added value of the products from these industries [25]. Knowledge can be on required information, where to look for and how to use [26]. More generally, knowledge is a key resource in organizations and it becomes a central subject for organizational decision making. That is the reason why its capitalization becomes a crucial daily activity.

Capitalizing knowledge within organizations is a critical component in their growth. That is why, they always seek to effectively capitalize their expert knowledge [9, 26, 27]. In order to learn more about knowledge and its capitalization, some of its characteristics are presented in the following.

A study done by [25] in industries in Japan, banking, insurance and automotive companies in Europe and US-based internationally operating enterprises, demonstrated several clear lessons to be learned from the experience of organizations at the forefront of knowledge:

- To **identify** internal and external knowledge. First, knowledge resides often in individual people. This is why knowledge capitalization has to be people-oriented. Second, knowledge is embedded in systems and in different forms. This is why it has to be also technology-oriented.

- To preserve and **store** knowledge within organizations [28] and continuously learn from their own experiences in order to improve their knowledge infrastructure for the future.

- To **share** and communicate knowledge with where it would be needed. Thus, knowledge communication should be supplemented with goal-oriented sharing of experience and expertise.

- To promote the application of knowledge in the appropriate environment and processes. In fact, knowledge is not what we know but it is what we do. Therefore, knowledge has value only when it is **reused**.

- To maintain and **evolve** the quality of knowledge and to anticipate and control the required one for the future.

- Knowledge capitalization is a constructive and **collaborative** activity. This stresses the importance of the multifunctional and multidisciplinary teamwork in knowledge intensive organizations.

This summary of findings gives a general flavour of what knowledge capitalization is. It can be seen as knowledge identification, storage, sharing, reuse and evolution. On the one hand, it should involve users since they are both knowledge sources and consumers, while promoting their collaboration throughout the knowledge capitalization. On the other hand, the advent of information technology tools offers new perspectives for knowledge capitalization. It consists, therefore, in selecting the most appropriate tools required for each need and function.

In this thesis, knowledge capitalization is the key aspect to tackle. Our research is applied to a case study at *STMicroelectronics*, where we have noted the need for a knowledge capitalization solution.
However, several problems and challenges should be taken into account to ensure an effective knowledge capitalization.

Knowledge proliferation:

The rapid growth of companies and of their business needs creates the need for new tools, techniques and methodologies. At *STMicroelectronics*, for example, many different tools are used for business activities, for project management or for knowledge capitalization, etc. This implies the increase of the organization's systems and of knowledge required and generated throughout their uses. More these systems evolve more knowledge proliferates [29]. In addition, due to the absence of an effective knowledge monitoring and maintaining, its capitalization becomes more and more complex and a time consuming task.

Knowledge loss:

Within organizations, the departure of employees and restructuring are increasingly frequent [30]. When an employee leaves the company, he takes with him his skills and knowledge. As a result, knowledge is continuously lost and difficulties in managing new one arise.

Knowledge duplication and obsolescence:

Users tend to reuse, share and store knowledge in their own manner implying knowledge duplication, non-centralization and obsolescence [8]. Therefore, serious consequences may occur. For example, at *STMicroelectronics*, miscalculating a manufacturing indicator, required for dispatching a set of wafers and lots in a set of machines, may disturb piloting the production line. Such a problem risks to be reproduced especially when knowledge about indicators, problems and solutions remains obsolete.

Applied to the case study at *STMicroelectronics*, we introduce in the following our research question and goals.

2 Research Question and Goals

This PhD thesis was conducted in cooperation with the LIG laboratory (Laboratory of Informatics of Grenoble) and G-SCOP laboratory (Laboratory of Grenoble for Sciences of Conception), at *STMicroelectronics*(Crolles). It is entitled "A continuous improvement cycle for knowledge capitalization" and addresses the problem of how to ensure a continuous expert knowledge capitalization? while providing an accessible, usable, evolutionary and maintainable solution for its users to meet their business needs. Therefore, we suggest a knowledge capitalization solution including tools and methodologies mainly for knowledge representation, storage, sharing and evolution.

More precisely, this thesis involves the following contributions:

- Knowledge loss is due to the lack of knowledge sharing before departures and restructuring. In order to address this problem, we suggest to study and assess the existing solutions for knowledge sharing within the organization. To this end, *STMicroelectronics* uses a Wiki, called *Stiki*. Therefore, improving its use to accomplish its objectives seems to be our starting point of the knowledge sharing solution. Based on a user-centred approach, we aim at evaluating its use, weaknesses and strengths in order to identify areas of progress and meet its objectives [1].

- In order to address the problems related to knowledge duplication and obsolescence, the representation and structuring of capitalized knowledge is our next step. To this end, we aim at studying the way knowledge should be defined, structured and represented to promote its relevance, completeness and organization. Our solution will be based on a user-centred approach, where we aim at defining and representing knowledge characteristics [2] [3]. To integrate knowledge representation in the capitalization cycle, our objective is to transform represented knowledge to shareable ones, in our case at *STMicroelectronics*, through *Stiki*.

- Knowledge proliferates more with the absence of a solution for its maintaining and evolution. To address this problem, knowledge evolution will be the next step in our knowledge capitalization solution. To this end, our proposal for knowledge evolution aims at involving two complementary solutions, technical and users' points of view [4]. First, based on quantitative evaluation criteria, the quantitative solution is in charge of evaluating, analysing and making decisions about the knowledge system. Second, based on qualitative evaluation criteria, a questionnaire will complete our proposal for knowledge evolution.

To ensure an effective and continuous solution for knowledge capitalization, we based on the Design Science Research Methodology [5, 31]. It is inherently a problem solving process that brings design, people and knowledge together, while ensuring a relevant and rigorous solution.

As a result, in this work, we have been able to target business needs, to study existing solutions in literature, to design and implement innovative solutions for knowledge capitalization, as well as to demonstrate their applicability in the appropriate environment and to contribute to theoretical knowledge base.

3 Structure of this Thesis

This thesis is structured according to the Design Science Research methodology, as follows:

- Chapter 1 presents the context of work at *STMicroelectronics*. It provides an introduction of the business context, including, a brief description of the semiconductor domain, a presentation of *STMicroelectronics*, its history and its activity. After defining our problem statement and objectives, we end this chapter with presenting our research methodology.

- As a part of the Design Science Research methodology, chapter 2 presents business needs by addressing the problems faced and the opportunities afforded with the interaction of people, organizations and technology within *STMicroelectronics*.
- As a part of the Design Science Research methodology, chapter 3 presents a background and a literature review on what we draw to conduct our research. They are related to knowledge capitalization and based on defined business needs.
- As a part of the design cycle of the Design Science Research, chapter 4 constitutes the core of this thesis. Our proposal for a continuous improvement cycle for knowledge capitalization is presented and detailed.
- Finally, chapter 5 includes the two last parts of the Design Science Research: application in the appropriate environment as well as additions to the knowledge base. Both represent practical and theoretical contributions of our proposal. Therefore, in addition to perspectives, they constitute a conclusion of our thesis

Chapter 1

Context of Work

1 Introduction

In this chapter, we provide an introduction of our business context, including, a brief description of the semiconductor domain (section 2) followed by a presentation of the *STMicroelectronics* company, its history and its activity (section 3). We get closer to our workplace by introducing the IT (Information Technology) and Business Intelligence Activity at *STMicroelectronics* on which our research is focused. We end this chapter with an overview of the knowledge capitalization problem and current practices at *STMicroelectronics*. Studying particularities of this field constitutes an important element to define our problem statement and objectives (section 4 and 5), to target real issues and to provide effective solutions applicable, mainly, in our research environment and generally in other work environments sharing some contextual characteristics with *STMicroelectronics*.

2 The Semiconductor Domain

STMicroelectronics is a French-Italian company whose main activity is the engineering and delivery of semiconductors for integrated circuits, an important domain with its specificities that we detail in the following.

The products of the semiconductor industry are daily present. For example, mobile phones, cars, computers and televisions, where 250 integrated circuits are used per person per day. In fact, technological advances have the common point of being associated to the development of its basic component which is the integrated circuit, also known as microchip, detailed in the following section.

2.1 Production in the Cleanroom Environment

The semiconductor domain offers a wide range of semiconductor components including transistors, resistors, diodes and opto-electronic components connected to each other on the same silicon wafer. This constitutes an integrated circuit (invented by Jack Kilby [1] in 1958). An integrated circuit is also known as a microchip.

[1] Jack St. Clair Kilby, (November 8, 1923 – June 20, 2005) was an American electrical engineer who took part (along with Robert Noyce) in the realization of the first integrated circuit while working at Texas Instruments in 1958).

To produce an integrated circuit, it is necessary to perform several steps on various equipments .
The production of an integrated circuit is generally performed on silicon wafers. Figures 1.1 summarizes the manufacturing process. From a silicon bar (1), we obtain the wafer (2) which will serve as a support for the achievement of circuits. Through a series of operations of deposit of insulating film, conductors, or photosensitive (3) lithography operation (4), etching, doping, insulation (5, 6, 7), interconnection (8) and cutting (9), we integrate the components on chips which will then be assembled in housings prior for their incorporation in applications.

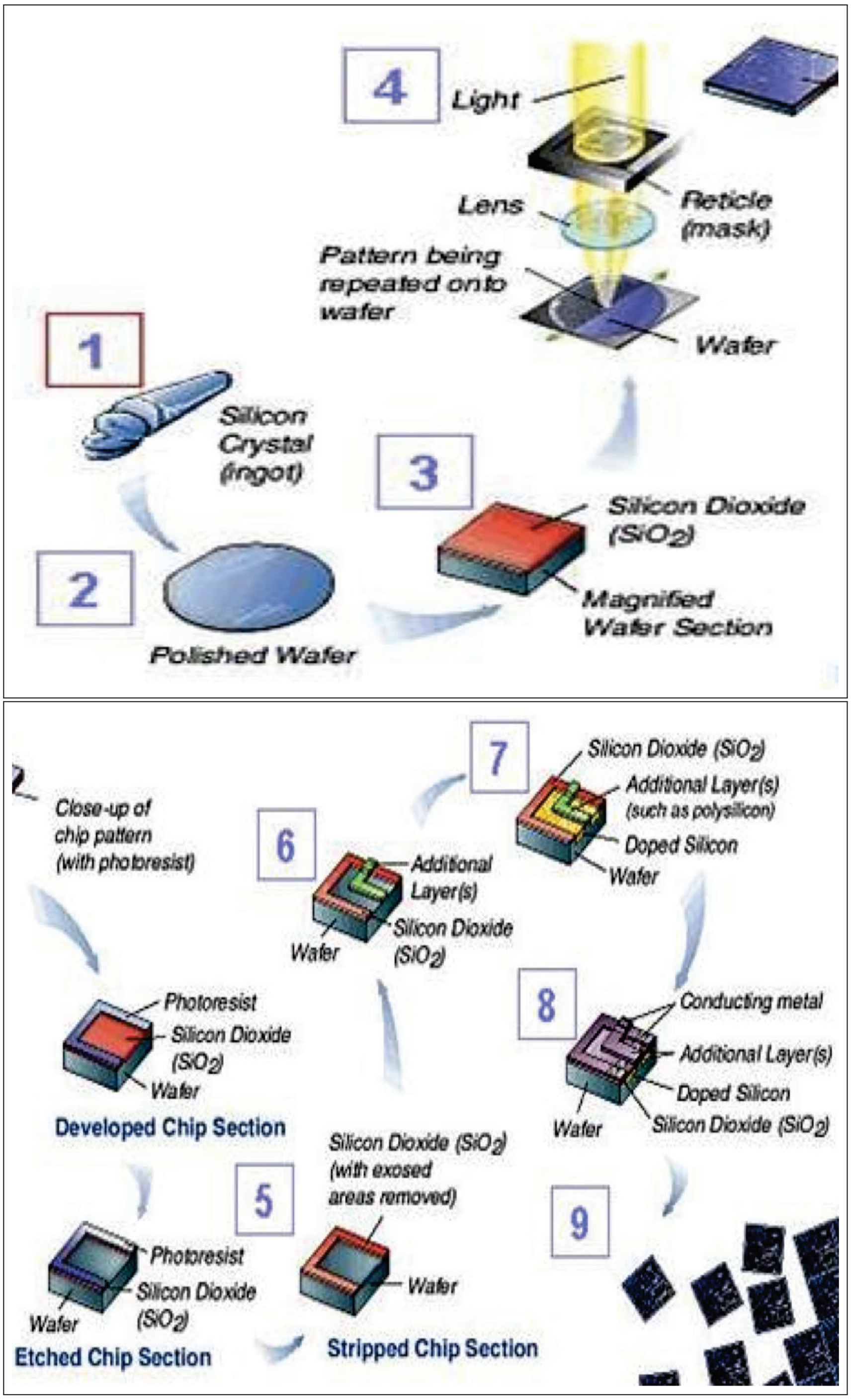


Fig. 1.1. Processes of a microchip manufacturing

In order to maintain their continuity and sustainability, semiconductor industries should master their manufacturing processes, which are characterized by [9, 32]:

- An increasing complexity: the semiconductor domain is a fast evolving domain where technologies become more and more complex and could be quickly obsolete. This requires the production of different functions, design and manufacturing options, as well as more complex technologies.
- A consuming time and resources processes: complexity extends the development time of the technological platform and implies the use of new manufacturing methods and design tools. Since, equipments are working almost systematically, all production processes are revealed consequently very difficult to master and require human and material resources.
- An innovative rhythm: the innovative rhythm in the semi conductor industry requires a new technology and development process every 2 years. Continuous analysis and optimisation are required. To this end, generation development must be agile in order to learn from experiments of other technology generations. In this way, production processes can be changed and adapted to the new conditions.
- A big impact on technology: changes that will be made for one technology could also impact another technology. Therefore it is necessary to exchange information between the different technology generations during their development.
- A very uncertain environment: today, companies change their organizations permanently, and they are confronted with more turbulent, flexible, uncertain organizational and environmental conditions. Therefore, it is crucial to maintain the exchange between the different technological and organizational structures and to adapt to new situations and strategies.
- A variety of technology options and products: semiconductor manufacturing has created a variety of technological options due to the variety of products involving different areas as telecommunications, automotive and general public.

Among other solutions, *STMicroelectronics* has opted for the use of a *Business Intelligence* system in order to supervise its production system. Its context is detailed in the following.

3 The Context at *STMicroelectronics*

This section provides an introduction to the *STMicroelectronics*' *Business Intelligence* system. We demonstrate the need for knowledge capitalization in this context through the study of the *Business Intelligence* activity in this organization.

3.1 STMicroelectronics Presentation

STMicroelectronics is one of the leaders in the semiconductor domain. *STMicroelectronics* is a French-Italian fusion between the microelectronic branch of Thomson and the SGS Microelectronica in 1987. A brief presentation of its history is given in the following:

- ***1987: creation of the alliance SGS-Thomson.*** In June 30, 1987, a merger between SGS (Società Generale Semiconduttori), the Italian company of integrated circuits and Thomson Semiconductors, led to the creation of the French company SGS-Thomson. This merger allowed to consolidate the knowledge of both companies in the field of microelectronics and to create a European leader in the semiconductors field.

- ***1992: construction of Crolles site.*** In order to limit risks and share development and production costs, in 1989, SGS-Thomson and Philips Semiconductors launched the project "Grenoble 92" to develop the technology CMOS 350nm where the Crolles200 clean rooms have been built since 1992 .
- ***1998: birth of STMicroelectronics.*** SGS-Thomson changed its name after the withdrawal of Thomson in 1998 and became *STMicroelectronics*.
- ***2002: expansion of the Crolles site.*** In 2002, Motorola Semiconductors joined the technology partnership ST-Philips, where the Alliance Crolles300 has been created and a new 300mm manufacturing unit has been constructed, in a clean room of $10000m^2$.
- ***2007: partnership with IBM.*** In May 2007, it was the end of the Crolles300 Alliance and the beginning of a technological partnership with IBM.
- ***2017: expansion of the cleanroom.*** 8000 m^2 of additional cleanroom is planned for 2017 allowing a better reception capacity of new equipments and advanced technology.

The Crolles site is composed of two different entities (Crolles200 and Crolles300) having the same business but they do not produce the same products. Indeed, both entities produce microchips, but the different sizes of produced wafers involves different manufacturing techniques and equipments. Crolles200 produces microchips on wafers of 200mm diameter (8 inches) while Crolles300 on wafers of 300mm diameter (12 inches). That is why the manufacturing technology used in Crolles200 is less evolved than in Crolles300.

STMicroelectronics has research and design departments, manufacturing sites and sales offices in many countries. It is a manufacturer of semiconductors, which conceives, produces and sells a wide range of integrated circuits and other electronic products, finding application in the areas of telecommunication, automotive computers. Besides, new types of emerging applications require microelectronic which closely interact with the surrounding environment in different physical domains (optical, mechanical, acoustical, biological, etc.).

Within *STMicroelectronics*, our research is mainly focused on the Crolles site in France, which is one of the biggest R&D sites. In fact, having both a production plant and a R&D unit enables rapid interactions within the organization and promotes its activity. Today, the entire site of Crolles has around 4200 employees.

In this work, we focus our research on the Crolles300 site because among the two sites, it is the one developing a real BI system with its different components (ETL, Data warehouse, Reporting, etc.), that constitutes our research context.

3.2 The IT and Business Intelligence Activities at STMicroelectronics Crolles300

This section provides details about the general context of application at *STMicroelectronics*. In a first stage, we present the IT department, its users, its functions, its issues and its working conditions within the Crolles300 site. This demonstrates how they are confronted with the need to manage a complex system, while considering their business activity within the organization.

In a second stage, particularities of the *Business Intelligence* activity, one service of the IT department of the Crolles300 site, are detailed. This constitutes our research and application context. Introducing the Business Intelligence activity in general and its challenges within the organization will conduct us to our research problem and objectives, described later.

3.2.1 The IT Department at STMicroelectronics Crolles300

The use of information systems is deeply embedded in all stages of the business activity in the Crolles300 plant. Table 1.1 summarizes some business activities supported by information systems of Crolles300. Through its use, the IT department's mission is:

- to support Crolles300 information systems in order to guarantee process conditions, application high availability and easy and quick access to the right information at the right time, for example, by real-time monitoring for equipment maintenance,
- to maintain and adapt over time Crolles300 information systems to the level required by a world class 300mm Manufacturing and R&D, for example with:
  - fully robust architecture of information systems
  - internal competencies and partnership with IT suppliers, with regular training for new technologies and projects management
  - delivering productivity advantages translating directly into a greater technical and economical competitiveness
- to enrich Crolles300 information systems with the integration of new software modules needed by the latest technologies

In Crolles300, to support the information systems activity, the IT team has to deal with a complex technological system. Considering all functional areas, it includes more than 60 applications, about 430 physical servers and over 12 terabytes of data, stored in the application dababases, where data is mostly handled by oracle databases. IT engineers and developers must be able to employ advanced methods and techniques in order to maintain its effective use and respond to their daily needs.

In addition to the Crolles300 site, *STMicroelectronics* Crolles is composed of another one which is the Crolles200 site having the same business but not the same products. Actually, each site has its own strategies, technologies, products, plant and employees. Recently, the IT departments of both sites were merged, in order to reduce the number of used systems to facilitate the management of their uses and to unify their practices. As a result, the number of employees, tools, systems, information and, more generally, resources were duplicated. Not only resources that have been increased but also their daily practices, strategies and knowledge. A merge in such a large industrial company has different important consequences and requires, therefore, a big work of unification, understanding, cleaning, transfer of competencies between and within teams and more generally their activities management.

Actually, this merge allowed us to identify, study and compare existing practices and tools in both IT departments. Tools are summarized in table 1.2.

Applications domains	***Service in charge of the application***	***Functions***
SAFIR (Single Application Fab InteRface)	Decisional Solutions	Management of the production activity, equipment maintenance and management of the production model (web environment)
TGV (Tool for Global Visibility)	Decisional Solutions	Datawarehouse: production data collection, processing and archiving business indicators
SPACE	Process Control and Automation	Equipment alarms management
R2R (Run to Run)	Process Control and Automation	Metrology and dynamic adjustment of the production process
MFA (Move to Full Auto)	Process Control & Automation and Decisional Solutions	Automation of the production activity: dispatching, scheduling and monitoring. It involves the equipments management and the transport system
MES (Manufacturing Execution System)	Manufacturing Execution System	Production management: monitoring the production state, historical data archiving, storage of all production processes, etc.

Table 1.1. Business activities supported by the information system in the Crolles300 [24]

Crolles300	***Crolles200***
SAFIR (Single Application Fab InteRface)	ISA (Interactive Software Application)
SAFIR dispatchers and scheduler	ISA dispatchers
SAFIR Reporting portal	Intranet Manuf and Daily Report
Reporting APF C300	Reporting APF C300 and dev6i
Reporting TGV	Reporting DW
Alarm Reporting Local C300	Alarm Reporting Local C200
Totem C300	Totem C200
Stiki	Sharepoint
Etc..	Etc..

Table 1.2. Tools in Crolles300 and Crolles200

Strengths
Both technical and functional competences and expertise
Sharing skills on similar work perimeters
Coherent functional area (same language, same concepts, sometimes same users)
Weaknesses
Many unknown applications and old technologies
Very few common applications
Functional perimeter of one site is not well known by the other one
Many departures of employees
Opportunities
New environment, new applications and new technologies
A larger scope: a better overview and more development opportunities
Sharing, collaboration, exchange of best practices, solution reuse, comparison and evolution of existing technologies
Threats
Important work for documentation, storage and cleaning
Risk of knowledge loss
Ability to absorb new projects, technologies and practices

Table 1.3. SWOT results

A SWOT analysis [33] was realized in order to evaluate the Strengths, Weaknesses, Opportunities and Threats involved in the merge of the Crolles200 and Crolles300 IT teams. Actually, conducting a SWOT analysis consists in performing diagnostics, using a set of strategic analysis models. On the one hand, opportunities and threats in the external environment to the organization are identified. On the other hand, strengths and weaknesses of the strategic business area are identified. For our purpose, we focus only on findings related to knowledge capitalization.

To summarize, the confrontation between the results established through the SWOT model, will feed the next step for identifying objectives and solutions. Particularly, analysing these results will help us to identify real issues and consequences resulting of the merge between teams and to target effective solutions matching with the new work environment. Table 1.3 summarizes the SWOT results.

Basically, thanks to the SWOT results, we were able to target what we are interested in: unifying their work conditions and technologies, in collaboratively and effectively sharing and reusing their knowledge and competencies, and in taking advantage of both sites' reciprocal experiences in supervising the production system. In our research, we focus on the *Business Intelligence* solution for analysing and making decisions on its activity.

Actually, BI is at the core of these systems and is impacted by these changes. It offers organizations potential for gaining insights in order to support decision making and ensures effectiveness in access to quality information from a variety of sources stored in different forms. In a first stage, we focus on the *Business Intelligence* activity, within the "Decisional Solutions" section of the IT department at Crolles300.

3.2.2 Introduction to Business Intelligence in Crolles300

BI Architecture

To achieve end-to-end visibility into business critical functions, *STMicroelectronics* needs to access volumes of data and information every day to make better decisions, for example, about the daily manufacturing activity. This is performed by means of collecting, storing and managing data [34]. Used BI applications and methodologies aim to support a deeper understanding of the business [34] and a provision of the appropriate data with the appropriate quality according to users' needs [35].

Briefly, as presented in figure 1.2, *STMicroelectronics* employs a traditional BI architecture including several tools:

- To access to data sources, for example, Model, FMM and MES (Manufacturing execution Systems) databases, in charge of storing production data. Each one is different from the other in terms of technology, storing process and data uses.
- To Extract, Transform and Load data, with an ETL [36] process, into a dimensional databases called a datawarehouse. At *STMicroelectronics*, it is called TGV (Tool for Global Visibility), where data is represented with a particular BI modelling structure.
- To use decision making tools, for example, analysis, mining or reporting tools (Business Objects at *STMicroelectronics*).

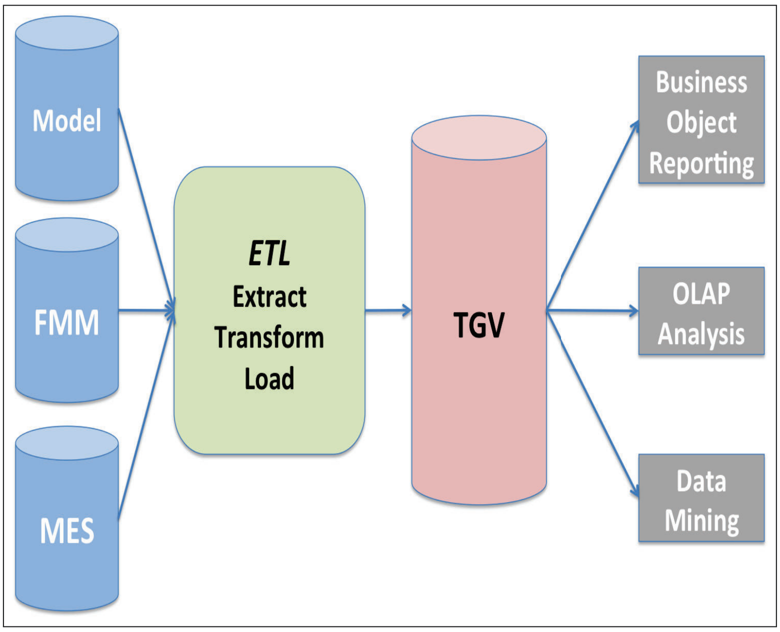


Fig. 1.2. *Business Intelligence* architecture at *STMicroelectronics*

At *STMicroelectronics*, BI is mainly used for reporting the manufacturing activities, using appropriate tools. It allows having a periodically view on the activity evolution and efficiency, equipment maintenance and productivity. One of the most used report at *STMicroelectronics* is about products uses required to continuously supervise successful produced wafers and lots as well as rejected ones.

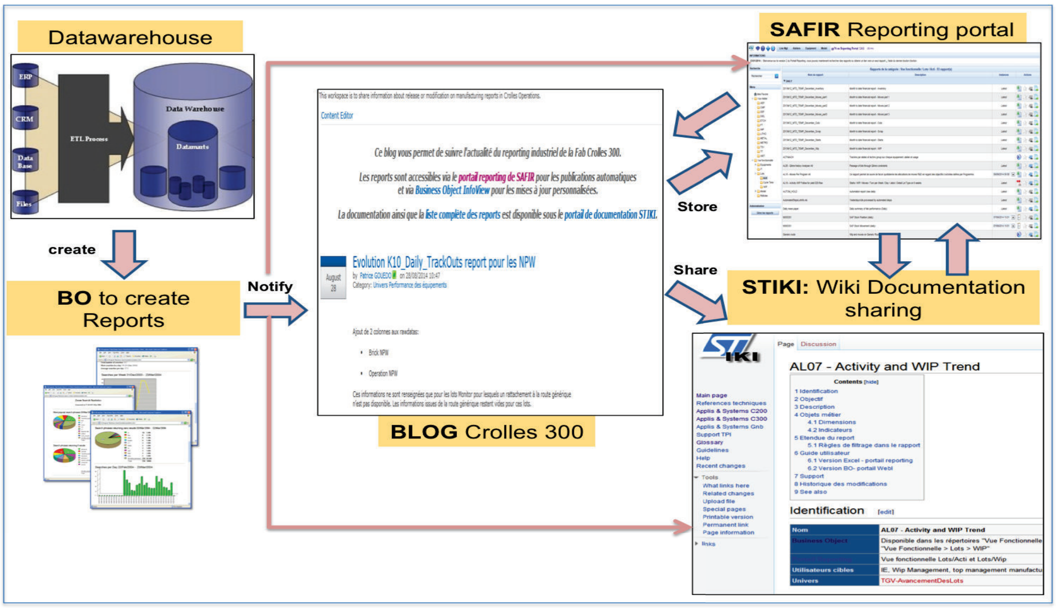


Fig. 1.3. The Business Intelligence System at *STMicroelectronics*

In addition to these tasks, we consider that a BI system should promote the right exploitation of obtained results. Generally, results of BI are presented in the form of reports of different natures. To promote the right use and made decisions, such reports should be stored, shared and documented in order to be effectively reused. This is the reason why the BI System at *STMicroelectronics* is composed of not only BI technical tools but also of knowledge management tools, where each one has its own functions and objectives, while interacting between each other, as shown in figure 1.3.

- A data warehouse is the core technical solution to design BI platforms. It is the collector of several and different data from various transactional information systems for analytical purpose [19, 37]. At *STMicroelectronics*, it treats manufacturing data about processes' evolution.

- Business Objects (BO) is the world's leading BI software company and it is owned by SAP [2]. BO allows accessing to data stored in rational databases, data warehouses and integrated applications (ERP, etc.) [38]. At *STMicroelectronics*, it is used for querying, reporting and monitoring data about the production activity.

- *Safir Reporting Portal* is the platform for reports sharing. It allows *Reporting* engineers at *STMicroelectronics* publishing created reports and making them available for users, for example, for manufacturing or process control engineers, requiring daily reports about the production activity. It integrates some functionalities, such as managing favourite reports, sharing them with colleagues or accessing to their documentation in *Stiki*, presented in the following.

- *Stiki* is a *STMicroelectronics*' wiki, designed and implemented in 2009 to cover the support, technical, business and project documentation, mainly within the IT department. Currently, in the *Reporting* team, it is used as the main tool for knowledge sharing in the BI system as shown in our previous work [1]. We evaluated its use in order to identify areas of progress to accomplish its objectives for knowledge sharing.

[2] www.sap.com

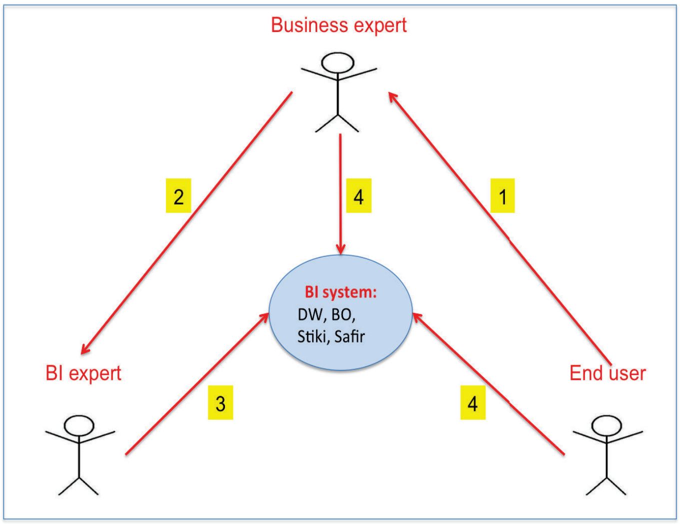


Fig. 1.4. BI users at *STMicroelectronics*

- *Blog Crolles300* is the notification platform used by the Reporting team to notify users by email for each new creation or update of a report. The email redirects them to a brief description of the report and its links to *Safir* and *Stiki*.

BI Stakeholders

At *STMicroelectronics*, three different profiles, having different needs and skills, use the BI system. They interact between each other and should deal with such a complex system. As shown in figure 1.4, users could be:

- An end user: he is the client asking for the creation of a report for his business needs and he is its final user.

- A business expert: he provides the work methodology when a BI need occurs and he ensures consistency, alignment and relevance of users' needs and ensures good communication and use of the report.

- A BI expert: he creates reports and maintains the BI system. Thanks to a collaborative work with both end users and business experts, he bases on his experience to align users' needs with defined specifications in order to provide the most appropriate solution.

As depicted in figure 1.4, to create a report, for example about the last month production activity, an end user transmits his needs and the main objective of the required report to a business expert (1). This one treats the request, defines requirements and the wished result and transmits them to a BI expert (2). For example, among requirements, he specifies the need to analyse the productivity during the last month. According to these requirements, the BI expert selects the most appropriate production data, creates the report, shares it in Safir portal, documents it in Stiki and notifies interested users via the Blog Crolles300 (3). Finally, the end user and the business expert retrieve it (4). We note that such a process requires a collaborative work involving the three users' roles, their skills, experiences and knowledge.

Having different users profiles increases difficulties in responding to each profile needs. For example, a BI expert is daily faced to use technical tools, whereas an end user is only supposed to analyse reported results without elaborating technical issues. This is the reason why the BI System at *STMicroelectronics* is composed not only of BI tools but also of knowledge management tools where each one has its own functions and objectives. This ensures not only an effective BI activity and reports reuse, but to target its users having almost different profiles, skills and needs.

BI Problems

Currently, the BI activity at *STMicroelectronics* is facing several problems, related to the BI system and its different tools:

- **Knowledge loss**, about the objective of existing indicators, their creators, their users, the way they were calculated, etc. More generally, over time, in the BI section at *STMicroelectronics*, the number of created reports is highly growing, while knowledge about their creation is lost. Today, several reasons are behind this loss, for example, the departure of employees, lack of documentation, communication and storage.
- **Knowledge duplication**, is, for example, about indicators stored in the datawarehouse, where some of them exist with the same name but calculated in different manners. As a result, the relevance of the created report depends on the selection of the right indicator. This problem has increased with the merge of the both Crolles sites. Actually, using different tools, with no link between most of them, increases redundancy of manipulated and generated knowledge.
- **Knowledge obsolescence**, for example, in Stiki, many pages are unused and incomplete. It is also observed in Safir, the reporting portal, where many unused and useless reports have exist since a long time. That is especially increasing when users continue to use in their own manner the existing BI tools. This lack of monitoring increases the risk of obsolescence.
- The **waste of time** is due to the absence of a real strategy to maintain existing knowledge. This makes knowledge retrieval a time consuming task and making the right decision more difficult.

4 Problem Statement

This section synthesises the problems related to BI knowledge, previously identified.

At *STMicroelectronics*, we noted problems related to **knowledge loss**. This is particularly true in large organizations known by regular restructuring and departures. The literature [27, 39] shows an important consideration of such a problem by searching for the appropriate solutions to reduce knowledge loss when key people leave a company.

An other problem is about **knowledge duplication**, increasing redundancy of existing knowledge. Such a problem is generally associated to knowledge incoherence, the existence of different versions and missing links between knowledge [9].

Besides, the rapid knowledge proliferation and the lack of its monitoring increase the risk of its **obsolescence**. This is the case of many organizations using knowledge capitalization tools applied to a growing number of systems and continuously use and generate business knowledge [6, 26, 40]. Such a problem is mostly related to knowledge evolution issues.

In addition to issues described above, an effective capitalization solution must enable involving its users throughout its use, as well as its development [25,41]. However, mainly in large organizations, users are of different profiles, skills and needs [15]. Yet, sharing and exchanging manufacturing knowledge among these different actors is difficult. This is due to the difficulty to target users according to their business needs.

5 Objectives and Research Issues

The goal of this work is to address the problems previously discussed. Knowledge loss, duplication, obsolescence and proliferation, all are problems that organizations are always seeking to avoid. Consequently, this research work must address the main research question, which is:

How to ensure a continuous expert knowledge capitalization?

We consider that expert knowledge is the one related to the application domain. Therefore, knowledge capitalization must be integrated in the business work to represent, share, store and maintain expert knowledge in order to be effectively reused. These principles of knowledge capitalization constitute the main objectives and focuses of our research. The goal of knowledge capitalization can be expressed by these following aspects:

- knowledge representation: consists in formalizing and structuring identified knowledge in an appropriate way, while ensuring its completeness and relevance [10,42,43].
- knowledge storage and sharing: consist in providing one or more effective common solutions allowing users accessing to required knowledge and adding their own ones [44,45].

Each step is important to ensure an effective use of all what was capitalized and to generate new knowledge, which leads to new needs, where:

- knowledge evolution: consists in maintaining capitalized knowledge and involved systems according to the evolution of business needs and knowledge [46, 47].

Moreover, knowledge capitalization requires a sustainable solution, both in terms of its reliability as well as continuity of use. To this end, the challenge that our knowledge capitalization solution must address is to provide:

An accessible, usable, evolutionary and maintainable solution with its users to meet their business needs

To achieve these statements, we believe that users' participation is an important component in a knowledge capitalization solution. That is why users' active participation is a primary key to accomplish our objectives. But also, taking into account the organization's working environment, as well as the existing theoretical knowledge in the domain, together ensure a relevant and rigorous solution. This will be the goal of research methodology described in the next chapter.

6 Research Methodology

Design Science Research methodology [5], is a side of the Information System Research. It seeks to create innovations in terms of ideas, practices, technical capabilities, and products. Its fundamental principle is that the knowledge and understanding of a design problem and its solution are acquired in the building and the application of an artefact. The Design Science Research purpose consists in the intersection of people, organizations, and technology when designing an artefact that should impact and be impacted by people and their needs [5]. All of these characteristics lead us to adopt such a methodology.

Proposed by [5], figure 1.5 presents the conceptual framework for understanding, executing, and evaluating a Design Science Research. In fact, it is composed of three cycles:

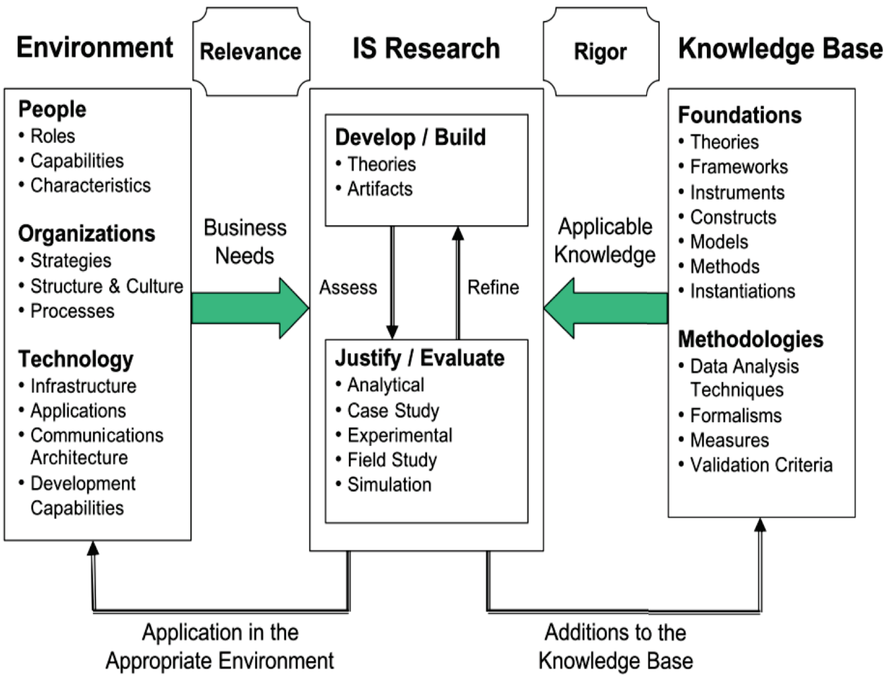


Fig. 1.5. Design Science Research [5]

- Relevance cycle
- Design cycle
- Rigour cycle

According to this sequence, Design Science Research cycles are detailed in the following.

6.1 Relevance Cycle

Any Design Science Research must be relevant to a constituent community. Generally, it could be the practitioners who plan, manage, design, implement, operate, and evaluate systems and technologies that enable their development and implementation. In two ways, designed solution must address business needs and be useful in the appropriate environment.

6.1.1 Business Needs

Research relevance is ensured thanks to addressing business needs. Business needs involve goals, tasks, problems and opportunities within the working environment. This one defines the problem space, composed of people, organizations and technologies. First, business needs depend on roles, capabilities, and characteristics of people within the organization. Second, they are evaluated within the context of organizational strategies, structure, culture, and existing business processes. Finally, they are related to existing technology infrastructure, applications, communication architectures, and development capabilities. Generally, this in-depth look at the current environment allows defining business needs required to provide a relevant solution.

6.1.2 Application in the Appropriate Environment

Business needs must be applied in an appropriate environment and findings of the research must be useful for this environment. Particularly, solutions must respond to people's needs, be integrated into the organization culture and strategies and effectively implemented within the existing technologies and systems. These requirements imply an environment that imposes goal criteria as well as constraints upon a system. A designed artefact that is not useful for the environment will not be used and will be costly in terms of time and means since it is not based on right foundations. To this end, Design Science Research requires that designed artefacts should be implementable within the existing environment.

6.2 Design Cycle

In order to respond to business needs, Design Science Research is inherently iterative and is conducted in two phases, first, to build and design artefacts and second to evaluate designed artefacts.

6.2.1 Design and Build Artefacts

Designing and building artefact is the core of the Design Science Research. It must be a purposeful IT artefact addressing an organizational problem, responding to business needs and enabling its implementation and application in an appropriate environment. During this process, the designed artefact is iteratively refined. After each iteration, the artefact is evaluated in order to assess its utility and compliance with the appropriate environment. Designing iteratively allows to improve previous solutions, identify deficiencies and creatively develop solutions to address them.

6.2.2 Evaluate Artefacts

Evaluation is an important component of the Design Science Research. Rigorous evaluation demonstrates the quality, effectiveness and importance of the designed artefact. Its evaluation is based on the working environment needs and includes testing its integration within the technological infrastructure and existing systems. Since the design cycle is an iterative and incremental activity, the evaluation phase targets problems faced during designing and building the artefact, assesses its compliance with requirements and contributes to its quality and success.

6.3 Rigour Cycle

Rigour is achieved by appropriately applying existing foundations and methodologies, as well as contributing to the archival knowledge basis of foundations and methodologies.

6.3.1 Applicable Knowledge

A rigorous Design Science Research requires applying rigorous knowledge from the knowledge base during the construction and evaluation of the designed artefact. It addresses important unsolved problems in unique or innovative ways or solved problems in more effective ways. An example of a rigorous knowledge base is the literature on the research field, since it provides researchers and practitioners appropriate techniques, theories or artefacts for conducting their building and evaluation phases. Based on existing knowledge base, they can analyse, compare and justify their methods and products selection and the way they could be applied or improved.

6.3.2 Additions to the Knowledge Base

Design Science Research is assessed as it contributes to the content of the knowledge base for further research and practices. According to [5], the objective is to demonstrate what are the new and interesting contributions. In figure 1.5, contributions are of three natures where one or more of them should be achieved. First, foundations in the Design Science knowledge concerns the development of novel and evaluated constructs, models, methods improving the existing foundations. Second, contributing in experience and expertise expects to proceed with creative development and use of evaluation methods and metrics. Third, more the artefact is useful for the environment, more it contributes to the knowledge base as an innovative artefact. This enables both practitioners and researchers to take advantage of the benefits offered by the artefact and to build a cumulative knowledge base for further extension and evaluation. To this end, communicating the processes by which the artefact was constructed and evaluated is crucial for their understanding. This could be achieved for example through publishing academic researches, discussing technology-oriented solutions developed in industry or providing open source solutions, etc. Actually, this is the key differentiator between the Design Science Research and other methodologies, for example, professional, system building or routine design [5], highlighting the clear identification of a contribution to the archival knowledge base of foundations and methodologies and the communication of the contribution to the stakeholder communities.

In this work, we base on the Design Science Research as our research methodology.

6.4 An Overview of the Design Science Research Application

In this work, knowledge capitalization is our main research problem. It consists of providing methods and techniques for knowledge representation, sharing, storage and evolution.

As discussed in this chapter, among challenges for a successful knowledge capitalization solution, we highlighted the importance of its compliance with the appropriate work environment. This may not be achieved without involving its users, since they are both knowledge sources and consumers. In fact, these challenge may be accomplished following the rigour cycle of the Design Science Research.

Knowledge capitalization have been much discussed in the literature, since it has been always a critical component in organizations growth. Foundations and methodologies of existing solutions should be studied throughout our design in order to learn from other experiences and to avoid bad ones. In fact, these challenges could be accomplished following the relevance cycle of the Design Science Research.

Therefore, this work is presented according to the Design Science Research methodology steps. These steps are summarized in table 1.4 in the sequence that we proceed to conduct our research:

Steps	***Cycles***
1. Business Needs	Relevance
2. Applicable Knowledge	Rigour
3. Design and Build Artefacts	Design
4. Evaluate Artefacts	Design
5. Application in the Environment	Relevance
6. Additions to the Knowledge Base	Rigour

Table 1.4. Followed steps in the Design Science Research methodology

We decided to present our research following the order of steps described in table 1.4 because, according to [5], it is the most natural way to present a research project while ensuring rigorous, relevant and evolutionary results:

- Starting with the definition of business needs allows us to study the business environment, to identify business problems, opportunities and goals, as well as to assess the organizational and technological context. Addressing business needs ensures research relevance.
  In our context of knowledge capitalization, the relevance and importance of the problem should be well demonstrated by studying, for example, current practices at *STMicroelectronics* for knowledge capitalization, used tools, users needs, etc.
- Second, the Design Science Research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact. This is often assessed according to business needs and by adherence to appropriate techniques, methods or theories from literature, representing the knowledge base.
  In the context of knowledge capitalization, the work must base on foundations from literature, for example, on developing knowledge systems, evaluation methods, their limitations or success factors, etc.
- Third, design the artefact is the core of the Design Science Research. During this stage, relying on both defined business needs and findings from the knowledge base ensures a rigorous and relevant design. The result of this stage is an artefact responding to business needs and using or inspiring from available fundamental theories, frameworks, models, etc.
  In our context, the design stage includes developing an effective and evolutionary solution for knowledge capitalization. It involves designing and developing solutions for its different components: knowledge representation, storage, sharing and evolution.

- Fourth, evaluating the designed artefact in an iterative manner contributes to its evolution. Different well-executed evaluation methods should be applied in order to satisfy rigorously the requirements and constraints of the problem.
  Considering the different components of knowledge capitalization, a user centred approach allows to qualitatively and quantitatively evaluate the utility, quality, and efficacy of our solution, while taking into account the business environment at *STMicroelectronics*. For example, we base on observations, statistical analysis, interviews, etc.

- Fifth, the designed and evaluated artefact must be applied within appropriate environments, that initially defined business needs. Actually, a solution that is not useful for the environment or do not satisfy its laws prevents its relevance. That is why, in any research, its success is highly related to its success in the appropriate environment.
  Our designed solution for knowledge capitalization, including methods and tools, is applied, tested and validated into *STMicroelectronics*'s technological and organizational environments, while demonstrating its compliance with users' business needs.

- Finally, adding to the knowledge base addresses important unsolved problem in unique or innovative ways or solved problems in more effective or efficient way for further research and practice. In that way, results included in the knowledge base become best practices that could be an input for an other research.
  In our context, our proposal for knowledge capitalization demonstrates its rigour by discussing its contributions and innovation compared to existing solutions in literature and at *STMicroelectronics* work environment. For example, this is achieved throughout publishing our proposal in international conferences and journal.

The rest of this thesis is structured and presented according to the Design Science Research cycles, and particularly, according to its identified steps presented in table 1.4.

7 Summary

As discussed in this chapter, the semiconductor manufacturing industry is a complex domain, involving different users, processes, activities and systems, required for its well achievement. In such a complex context, different problems are revealed, mainly, related to knowledge loss, duplication, obsolescence and proliferation. At *STMicroelectronics*, such problems are particularly present throughout the *Business Intelligence* process, where the redundancy, uselessness and overloading of unused BI objects (reports and indicators for example) may affect making the right decision. To this end, our research question is "How to ensure a continuous expert knowledge capitalization? "

To proceed, as depicted in figure 1.6, this work is structured in 4 main chapters, where each one represents one or more steps of the Design science Research methodology:

- In chapter 2, **Business Needs** for knowledge capitalization are defined.
- In chapter 3, we present **Applicable Knowledge**.
- In chapter 4, **Building and Evaluating** our solution are detailed.
- Finally, in chapter 5, our solution **Application in the Appropriate Environment** is presented and **Additions to the Knowledge Base** are highlighted, as parts of the conclusion of our thesis.

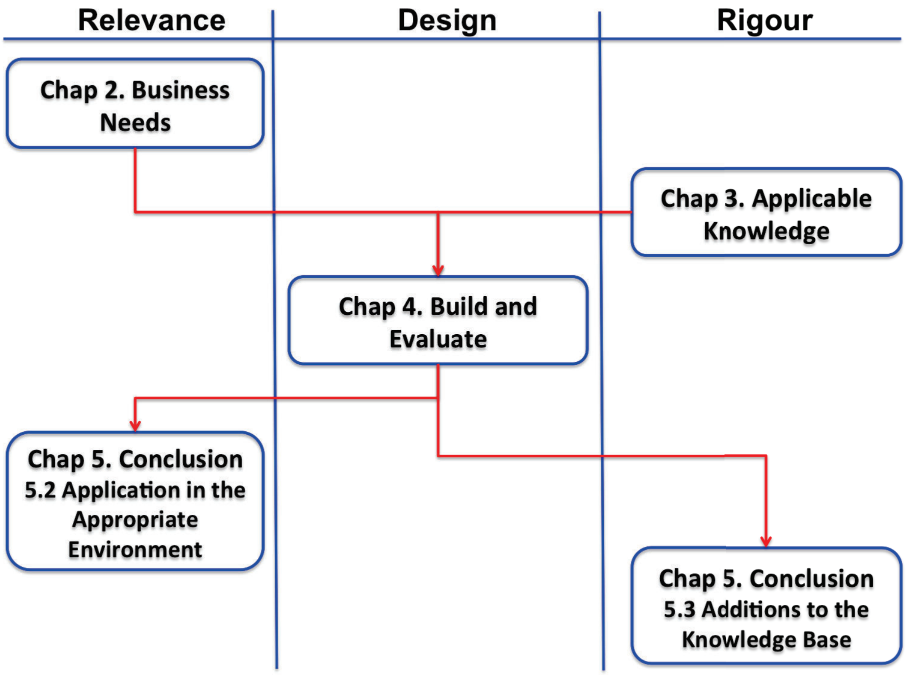
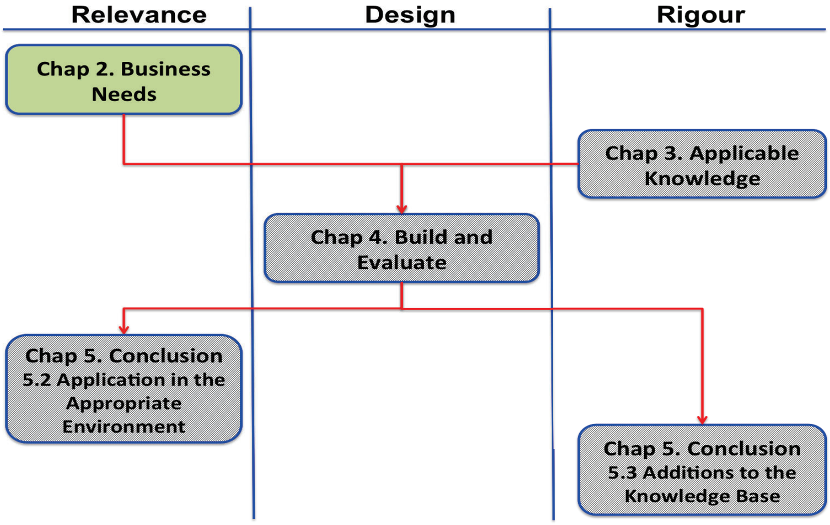


Fig. 1.6. Thesis plan

Chapter 2

Business Needs



1 Introduction

Defining business needs is the first output in a Design Science Research as a part of its relevance cycle. Actually, the relevance of a solution is related to the problem relevance demonstrated throughout the definition of business needs. This is achieved by addressing the problems faced and the opportunities afforded with the interaction of people, organizations and technology. These components constitute the environment in which resides the phenomena of interest.

In our research, we aim at defining business needs at *STMicroelectronics* for knowledge capitalization, mainly within the *Business Intelligence* team. First, we have, to study current practices, identify their limits and address faced problems, while considering people, organizations and information technology involved in the current solution and those affording opportunities. These statements help defining business needs required for the construction of a relevant knowledge capitalization solution.

In this chapter, firstly, considering the knowledge capitalization environment within the *Business Intelligence* team, people roles, capabilities and characteristics are described, organizations strategies, structure and culture are introduced, and technology applications and development capabilities are presented. These findings allow in a second stage define business needs related to knowledge capitalization, on which we will base to define our solution.

2 Business Environment for Knowledge Capitalization

Business Intelligence at *STMicroelectronics* is considered as a knowledge intensive task. It continuously requires and produces knowledge. BI knowledge could be of two main types, where both of them are required to effectively use the BI system. We distinguish the theoretical knowledge and the technical knowledge.

The first type, BI theoretical knowledge, considers the behavioural aspect of the system, its understanding and its functioning. For example, understanding the objectives and justifications behind existing objects (reports, indicators, formulas, dimensions, etc.), their relationships and more generally, business knowledge on the BI domain.

The second type, BI technical knowledge, considers procedures of uses and practical implementation. For example, data warehousing development, indicators formulas, data integration, reports creation, and more generally putting in action BI theoretical knowledge.

Both of knowledge types need to be capitalized in order to ensure a continuous effective use of the BI system.
The *Business Intelligence* activity at *STMicroelectronics* involves various actors with different profiles. They are interacting throughout the use of many tools and organizational strategies in order to achieve their daily activities. In this section, we present the environment in which the BI team is daily working particularly expert knowledge capitalization.

2.1 People roles, capabilities and characteristics

In our context of *Business Intelligence*, many profiles are interacting throughout the use of existing systems, introduced in chapter 1: end user, business expert and BI expert. Their capabilities and characteristics related to BI knowledge capitalization are detailed in the following.

- End users:
  They lack of technical knowledge about the BI system and activity. They typically belong to other teams than BI, such as manufacturing, finance, management, system administration, etc. They are concerned by the BI activity mainly to exploit reports results, to monitor and improve their business activities. They are able to access to reports throughout knowledge management tools involved in the BI system, which are SAFIR (the reporting portal), Stiki (the Wiki for knowledge sharing) and the Blog Crolles300 (to be notified for reports creation). Only a few number of end users are able to use technical BI tools such as BO (Business Objects) to create business reports. However, many of them use it in their own manner because they were not formed, they lack of time, underestimate the task, or even do not know who to approach for help. Their need is related to the use and the understanding of created reports and involved objects. However, they are not really concerned by technical issues behind the BI system. This is the reason why, they are more interested in theoretical knowledge.

- Business experts:
  They typically belong to other teams than BI, such as process control, equipment engineering, management, etc. They represent the intermediation between end users and BI experts thanks to their expertise in both BI and the business environment. They are able to analyse end users needs and to translate them into BI specifications. For example, the specification of required indicators and dimensions. They ensure as well the need behind the creation of a new report and the relevance in its use, if it does not yet exist. One of their most important roles is to expand specific needs of creating a report in order to optimize its use by more actors and for others objectives. This helps actors of all profiles to save time in creating or searching for reports while reducing risks to duplicate existing BI objects. Besides, business experts could be themselves end users. Thus, they need to access as well to SAFIR, Stiki and the Blog Crolles300, in addition to BI tools. Generally, they are able to use BI technical tools and understand its functioning, for example, creating reports and indicators, but lack of advanced technical knowledge, for example, data warehousing. This is the reason why, they require both technical and theoretical knowledge.

- BI experts:
  They are the developers and creators of reports throughout the BI technical systems (data warehouse, BO, etc). To proceed they base on specifications received from business experts. In addition, their function includes storing and sharing reports throughout the BI system (Safir, Stiki and the Blog Crolles300) to make them available for the other actors. They are the main owners of technical knowledge about the BI system and reporting processes, for example, data warehousing, indicators formulas, dimensions hierarchies, their integration into the data warehouse, the universe conception and development. Sharing and storing such knowledge is important not only to help end users and business experts to understand the objective of BI objects, but also BI experts to analyse the way reports were created and used. We believe that capitalizing technical BI knowledge save BI experts' time, prevent knowledge duplication and facilitate involving the other profiles of actors (end users and business experts) in the BI activity. It helps as well involving BI experts in the final use of created reports.

As we discussed above, BI end users, business experts and BI experts are involved in the same system while each one has his/her own role, needs and knowledge about. Table 2.1 summarizes each actor's roles using the *Business Intelligence* system.

Interacting together, each actor reuses other actors' knowledge to generate new one, that will be in its turn continuously reused. For example, as depicted in figure 2.1, a BI expert needs knowledge about the final objective of an existing report stored in SAFIR Reporting portal. Actually, he/she needs to reuse its indicators in an appropriate way. Such knowledge is owned by the end user who was the applicant's report. As a result, even though BI actors are differently involved, they are all of them engaged in knowledge capitalization, where:

- All actors' profiles should be involved in identifying their knowledge in order to answer to different actors' needs.
- BI knowledge is of different natures (technical, behavioural, procedural, etc.). Therefore, providing an understandable structure for BI knowledge facilitates their sharing, storage and reuse. As a result, the three actors' categories should be involved in knowledge representation.

Actors	**Needs**	**Specifications**	**Data warehousing**	**Reporting**	**Required knowledge**
End Users	Express	Validate		use and can create simple reports	theoretical
Business Experts		define		use and can create simple reports	theoretical and technical
BI Experts		base on	develop	create	technical

Table 2.1. Actors' roles using the *Business Intelligence* system

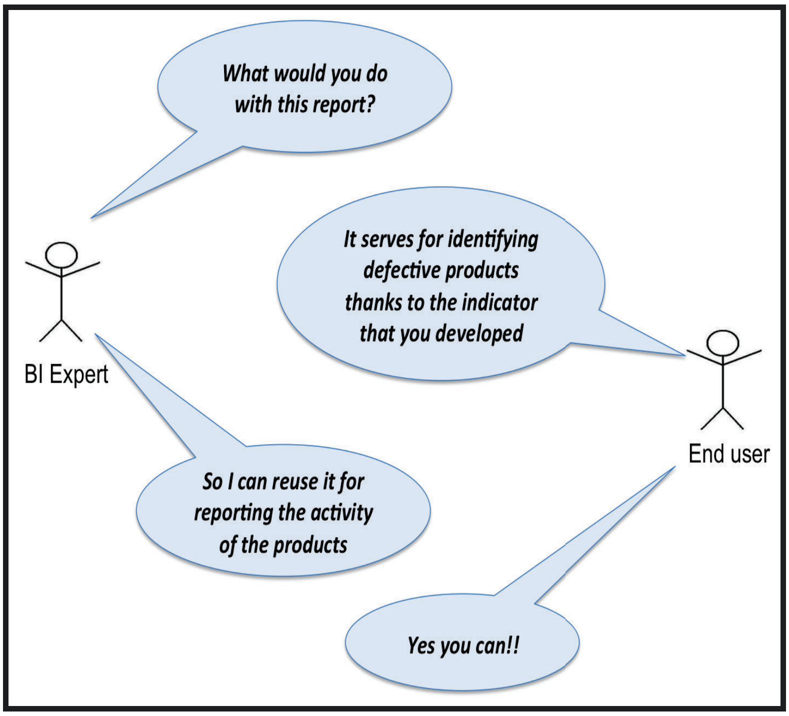


Fig. 2.1. actors interaction

- Represented in an appropriate way, BI knowledge should be effectively stored and shared in order to allow users access and reuse to the right knowledge. These statements involve users of different profiles investment and collaboration.

- Finally, even though users have different needs, maintaining capitalized knowledge involves all of them, according to each role capabilities and characteristics. It ensures an evolving knowledge capitalization solution that meets the scalable nature of the BI environment [48]. This is the reason why providing an evolutionary and a continuous knowledge capitalization is crucial.

To summarize, the identification of different BI actors' profiles implies the existence of different capabilities, characteristics and needs where all of them should interact throughout the use of such a complex system. As a result, knowledge about the use of the BI system differs according to its actors' profiles.

On the one hand, this highlights the importance of different actors' interactions for knowledge capitalization. On the other hand, such facts recognize the need to provide a knowledge capitalization solution to help actors to continuously identify, represent, store, share and maintain their business knowledge and respond to their business needs. In addition, since in the context of *Business Intelligence* actors are themselves knowledge holders and knowledge consumers, we highlight the importance of their involvement throughout the solution design and development.

2.2 Organizations and Technology

In the context of *Business Intelligence* at *STMicroelectronics*, different practices and tools are adopted for knowledge capitalization. Their advantages and limits are more detailed in table 2.2.

Knowledge capitalization phase	**Tools and/or practices**	**Advantages**	**Limits**
Knowledge identification	Telephone, Email, direct contact, searching in folders, etc.	Rapid and focused knowledge	No supporting strategy is available, no synthesis is supported, informal methods, tracks are difficult to identify
Knowledge representation	*Stiki* templates	Knowledge representation and structuring with templates should help in knowledge search, unification and understanding	No real strategy to supervise the respect of Stiki templates
Knowledge storage and sharing	Stiki, Safir, BlogCrolles300, shared folders, desktop drives, SharePoint [a], workspaces projects, etc.	Providing tools for knowledge sharing should help users effectively reuse knowledge	The existence of many sharing and storage tools within the same teams without a real strategy for supervising their contents
Knowledge evolution	No tool to evolve capitalized knowledge	No advantage	stored knowledge is updated, generally during projects, but without providing a continuous solution for its maintaining and evolution.

Table 2.2. Current knowledge capitalization tools and practices

[a] SharePoint is a web application platform in the Microsoft Office server suite.

As depicted in table 2.2, many tools are used to support knowledge capitalization. However, their usefulness are highly dependent on the way they are used and on their users' competencies. For example, since there is no real organization to supervise knowledge capitalization, users may structure, store and update their knowledge in their own manner. Particularly, in the *Business Intelligence* context, a misunderstanding or a wrong identified knowledge may affect business decisions. For example, selecting an indicator with a wrong or obsolete calculation formula implies reporting inaccurate results and can confuse its users. In addition, using independently many tools and practices for knowledge capitalization, for the same phase and having no link, is not beneficial.

The need is therefore to avoid this confusion by offering a coherent and strategic environment for an effective and sustainable knowledge capitalization.

Currently at *STMicroelectronics*, among knowledge capitalization statements, existing solutions are oriented toward knowledge sharing, with the use of few related tools and methods. Actually, methods such as telephone or email are crucial for exchanging daily knowledge, however, alone they do not ensure a continuous knowledge sharing. Such methods are used also for knowledge identification and storage, even though they are not meant to. These observations require a well defined strategy to use the right tools and practices for the right functions in order to respond to the whole knowledge capitalization solution.

Studying knowledge capitalization practices and technologies allowed us to conclude that even though it exists different tools used for knowledge sharing, within the IT department and particularly the *Business Intelligence* team, the main tool used for knowledge sharing is a Wiki called *Stiki*. As introduced in chapter 1, *Stiki* is a *STMicroelectronics*' wiki, designed and implemented in 2009 to cover the support, technical, business and project documentation.

In order to deeply study the current environment for knowledge capitalization and define business needs, we proceed with studying the use of *Stiki* for knowledge sharing, since it is the main considered step among the others.

Stiki has been deployed since several years within *STMicroelectronics* Company in order to improve *Business Intelligence* teamwork. To understand the way *Stiki* is used for knowledge sharing, we proceed with the evaluation of its use, based on a user centred approach in section 3 [1]. The aim of this research is to evaluate this *Wiki* performance regarding knowledge sharing and storage objectives. In our research, we decided to keep the sharing function of a *Wiki*, because we consider that sharing and storing knowledge are highly dependent. If a tool is effectively used for storing it will be effectively used for sharing, and vice versa. This step is crucial since it allows identify its limits, strengths and areas of progress to effectively accomplish its objectives for knowledge storage and sharing.

3 Business Needs for Knowledge Storage and Sharing

3.1 Problem Space for Knowledge Sharing

In order to identify our problem space related to knowledge sharing, a set of criteria that should be met by a *Wiki* is identified. To this end, a literature review of application cases, studying the use of *Wiki* for knowledge sharing in different domains, was conducted.

In manufacturing industry, [49] proposed a wiki called CorpWiki that selects the most appropriate person to improve the quality of an article and consequently ensures its relevance. In education, [50, 51] uses a wiki to encourage a group of students specialized in

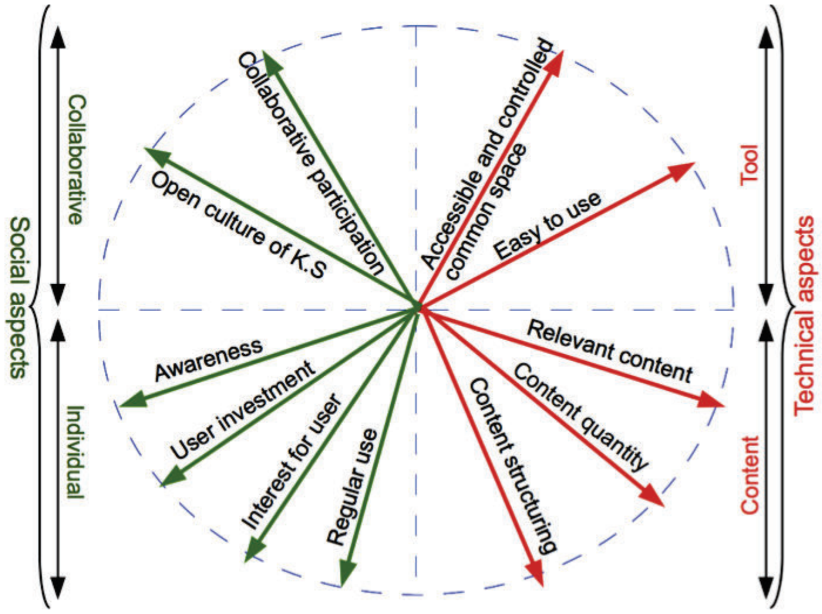


Fig. 2.2. Wiki Evaluation criteria

Japanese language creating learning pages. In research, [44], a wiki is used to enhance collaborative work among a group of researchers and in commerce, by the case of eBay [27, 52], it is used to share commercial knowledge.

From the study of these application cases, two aspects may be considered to evaluate a *Wiki* social and technical. Social aspects concern either collaborative or individual dimensions. Technical aspects concern either the *Wiki* container (tool) or content dimensions. As depicted in figure 2.2, a set of criteria according to these dimensions is identified with dotted axis.

3.1.1 Technical Aspects

Wikis can be evaluated according to two dimensions: the characteristics and functionalities of the tool allowing its use and its content.

Tool Dimension As shown in figure 2.2, providing an accessible and controlled common space is considered as one criterion characterizing social software and particularly Wikis. As mentioned in [51], not having an easy direct link to the *Wiki* limits its use and was one of the reasons explaining the decline in its use. Usually, users of Wikis are expecting to deal with a tool, which facilitates their work in a timely and reliable manner. Therefore, they can easily retrieve the knowledge they search for, and easily transmit to others their own one. In addition to its accessibility, such a tool needs to be controlled since it supports a shared space. Users must have intermediate spaces between public and private use to effectively manage their contributions. Ease of use is one of the criteria that the use of *Wiki* must also meet (figure 2.2). It was a criterion on what the case study in commerce [52] was based.

Content Dimension In [52], regarding an e-commerce *Wiki*, organizing information insured its content relevance. This criterion is also highlighted in [49] regarding the ability of the proposed *Wiki* to select the most appropriate person who will improve the quality of the article and then ensures its content relevance. That explains why in figure 2.2 we integrate content relevance as a criterion the *Wiki* must meet. Dealing with content relevance implies introducing content quantity. This criterion consists of providing enough knowledge so that *Wiki*' users can perform their tasks by reusing existing one and enriching their own one. Such a criterion is highly dependent on users' behaviour and particularly their contributions. Besides, we were inspired by a study about capitalizing software design knowledge with design patterns [53]. The design pattern community provides a formalism for patterns representation called P-Sigma [53]. Such formalism aims at making a uniform expression of product patterns and process patterns allowing a better organization of their libraries. For the same reasons, we consider that content structuring is an important criterion. As the common formalism of patterns makes explicit their selection interface, the page content structure guides users to correctly contribute and to efficiently search for information. That explains why we integrate in figure 2.2, content relevance, content quantity and structured pages content as content criteria.

3.1.2 Social Aspects

Wikis can be evaluated according to: an individual dimension (user behaviour towards its use) and the collaborative dimension (behaviour of all users interacting through it).

Individual Dimension In [44], authors argued that because there was very little interaction among researchers on a regular basis, knowledge sharing via *Wiki* was not taking place regularly. This highlights issues relating to the lack and non-regularity of use. Furthermore, irregularity of use is usually due to lack of awareness regarding knowledge sharing benefits and consequently interest for *Wiki* use. That was the case of research' *Wiki* described in [44]: the impression that *Wiki* does not have much to offer for those who are in the organization since long time does not motivate them to invest time in using it. However, in the case of education' *Wiki* described in [51], although using *Wiki* presented an important interest for each one, students did not investigate as expected. That's why awareness and interest are reasons why users invest less time in sharing knowledge than in other works. These observations explain the integration of these criteria in figure 2.2.

Collaborative Dimension Knowledge sharing is only valid if *Wiki* is collectively used. The case of CorpWiki in the manufacturing industry case [49] includes a 'fairness-based" policy, where the selection is made based on a fair workload distribution, ensuring then collaborative participation. Finally, knowledge sharing, particularly in a large organization, requires an open culture. That means naturally including collaboration at work. In the case of commerce *Wiki*[52], employees have to adapt themselves to the online trading concept and learn the culture and ways of working of eBay. That was one of the success keys of eBay experience in using *Wiki* for knowledge sharing. In figure 2.2, these criteria correspond to the collaborative part of our problem space.

Therefore, based on the literature review and criteria described above, *Wiki* deployed within *STMicroelectronics* Company is evaluated.

3.2 Proposed Evaluation Process: A User-Centered Approach

Studies, about the evaluation of *Wiki*' use within an organization, are limited. They are either related to the adopted assessment methods [45], or the obtained results [51]. The case of CorpWiki [49], for example, addresses the process of setting up a *Wiki* to support knowledge sharing. In our case, the *Wiki* already exists. To conduct our experiment, four researchers conceived the followed strategy and two industrial engineers provided the working environment. Based on a user-centered approach, the evaluation methodology proposed in this research aims at understanding how *Stiki* is used, by collecting users' opinions about its advantages, limits and areas of progress. It takes into account current practices and considers *Wiki*' users as the main source of information. Moreover, it incorporates both qualitative and quantitative methods, closely linked:

- Qualitative Methods: address more precisely the meaning that each individual brings to events. [54] suggests that qualitative data can provide insight on how the participants actually use and respond to intervention, which may vary from one person to another and may be different from the perception of its use and the effectiveness of investigators. Face-to-face interviews, focus groups, forums, blogs and text analysis are examples of qualitative methods. They aim at deeply understanding users and their environment and at identifying a maximum of uses, behaviours and opinions with a maximum of variability [55].
- Quantitative Methods: aim to quantify and to measure the performance of tools. Their strength is that they are based on factual and reliable results that are usually generalized to a large population [56], mainly statistical analysis methods, performance tests and a questionnaire SUS (System Usability Scale) [57]. They allow a quantitative analysis to understand the reasons behind found facts and collect suggestions for improvement for the evaluated tool.

3.2.1 Process Stages Description

Our proposed assessment process follows these stages (2.3):

1. Evaluation criteria identification: this helps specifying the axis on which we focus our evaluation, as well as selecting appropriate assessment methods. This step is considered as a preparatory step before starting with evaluation methods. Identified criteria have been described in section 3.1.
2. *Stiki Review* this weekly meeting established at the beginning of the evaluation process aims at observing and discussing how *Stiki* users proceed in their use during each week. The goal is to test the responsiveness of *Stiki* users regarding our observations. The principle is neither to give nor to get orders. Such meeting allows to observe users' behaviour and then to build a preliminary vision on *Stiki*' use. Evaluation criteria (identified in step 1) are considered during *Stiki Review* in order to make a first evaluation of these criteria.
3. Defining hypotheses and questions: this step is a key element of the proposed approach. The aim of this step is to assess the use of *Stiki* according to each evaluation criterion. To do that, when we have an idea about the criterion (mainly from the *Stiki Review*), a hypothesis to be verified is built; otherwise a question to be answered is defined in order to evaluate the concerned criterion. In that way, the criteria are transformed to hypothesis and questions. Each hypothesis or question treats one criterion and contributes to its evaluation, where each one could be validated thanks to the obtained results of one or more evaluation methods. The list of proposed

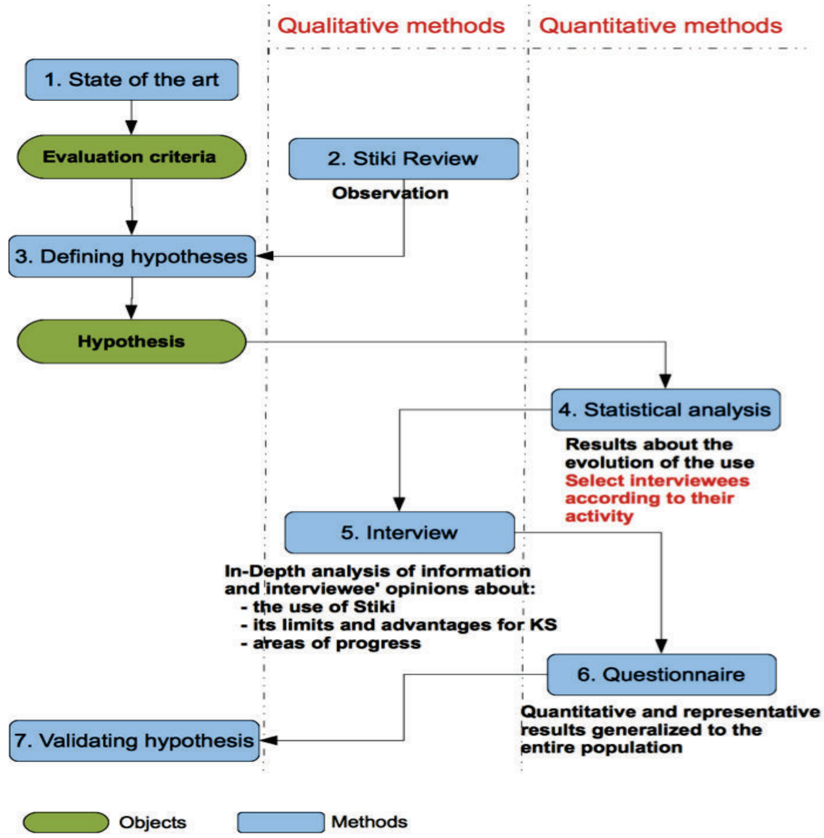


Fig. 2.3. Stages of our proposed assessment process

hypotheses and questions is given in the following, classified according to the group of dimensions they refer to (H: hypotheses and Q: questions):

(a) Tool dimension:
– H1: *Stiki* is an accessible and a controlled common space
– H2: *Stiki* is easy to use

(b) Content dimension:
– Q3: Is *Stiki* content relevant?
– Q4: Is there sufficient content of information in *Stiki*?
– Q5: Structuring pages has an impact on the visibility of its content and facilitates the search and writing of information in the appropriate place. Is it mastered at STMicroelectronics?

(c) Individual dimension:
– H6: *Stiki* users are aware regarding the importance of knowledge sharing as well as the role of *Stiki* to improve it
– H7: Despite the awareness of *Stiki*' users regarding the importance of knowledge sharing, they do not invest enough time in its use
– Q8: Is the use of *Stiki* interesting for users to share their knowledge?
– Q9: Does each user share knowledge regularly?

(d) Collaborative dimension:
– Q10: Did collective participation and collaborative management of pages ex-

ist? Are individual pieces of knowledge available to others? Is modification of one's own writing by others well received?
– Q11: Is STMicroelectronics' culture favorable to improve knowledge sharing?

4. Statistical analysis: the access to the *Stiki* database and extraction of statistic information related to the defined hypothesis and questions allow understanding how *Stiki*' use has evolved. It also allows performing descriptive statistical analysis on some aspects such as:

   (a) The evolution of visits to *Stiki* per week or per month
   This allows determining how the use of *Stiki* has evolved over time. Depending on the type of use, other measures are identified.

   (b) Contribution: number of contributions and contributors per page
   This serves measuring the activity on each page and then identifying those with single contributor, for example, to understand what type of defaults these pages have and need reviewing.

   (c) Consultation: number of readers per page
   These measures could be used to verify the utility of *Stiki* among employees benefiting from its content.

   (d) Modification: the activity of users in revision
   This measure allows us classifying users according to their activity and then, varying the selection of users for the individual interviews.

5. Semi-structured individual interviews: We aimed at gaining insights from users' point of view about the use of *Stiki* for sharing knowledge.

   To this end, a list of participants for interviews is defined based on their activity on *Stiki* (thanks to the statistical measure classifying *Stiki* users from the least active to the most active one). The idea is to vary all of them (240 users) according to their activity on *Stiki* (consultation and contribution), equitably distributed on four categories "not active, relatively active, active and very active". Their membership to different teams is also considered. The idea here is to vary users according to their work and functions (internal architecture, business intelligence, production systems and automation, etc.). Twenty users were selected from the site Crolles300. The interviewees belong to different categories of age, from 20 to over than 40 years old, and are picked from five different teams (Four employees of each team where each one belongs to a category of contributors, from the less active to the most active contributor). Such a selection allows having a representative sample of all the users.

   The interviews lasted between 30 minutes and an hour depending on the interest of users in the experimentation and their activities on *Stiki*. An individual analysis grid summarizing interviewer' answers and ideas are built after each interview. During the interview, explored topics and questions should be related to defined hypothesis and questions (step 3) without constraining interviewees to a particular format.

6. The online questionnaire (Appendix A): Results obtained through the semi-structured individual interviews cannot be quantifiable or generalizable to the whole population. That is why a questionnaire based on interviews results was proposed. It contains questions of different natures (Yes/No questions, multiple choices questions, open

Dimensions	Methods / Criteria	*Stiki* Review	Statistics	Interview	Questionnaire
Tool	Accessible and controlled common space : H1			×	×
	Ease of use : H2			×	×
Content	Relevant content : Q3			×	×
	Content quantity : Q4		×		
	Content structuring : Q5	×		×	×
Individual	Awareness of user : H6			×	×
	Investment of user : H7	×	×	×	
	Interest for user : Q8			×	×
	Regular use : Q9		×	×	×
Collaborative	Collaborative participation : Q10		×	×	×
	Open culture of knowledge sharing : Q11	×		×	

Table 2.3. Methods of our assessment process to respond to our evaluation criteria

questions and leading questions). The questionnaire was mainly designed for *Stiki* users, to quantify interviews' results and opinions on its use. Collected answers are then used to confirm hypothesis or answer questions defined in step 3. Among 200 users invited to participate (from the same site Crolles300 and all teams and functions in the IT section who use or do not use it), 68 answered the questionnaire where two-thirds are from the IT section and the others are either co-contractors or do not belong to the IT section.

7. Validating hypothesis and questions: The aim of our evaluation process was to verify finally hypothesis and questions defined previously. Each hypothesis/question (defined in step 3) was validated by one or more evaluation methods. Through the proposed evaluation process, the aim is to employ a user-centred analysis approach. The principle is to study users' ideas, words they use (Verbatim) and associated meaning. The whole process and methods (qualitative and quantitative) allowed validating hypothesis and answering questions.

Before presenting experimental results in the following section, Table 2.3 shows how each evaluation criterion can be evaluated by one or more methods of our process.

3.3 Experimental Results

In this section, we first discuss the different findings about *Stiki* use from the evaluation methods. Then, we identify areas of progress.

3.3.1 Experimental Results Analysis

Experimental results are classified according to the dimensions of criteria (tool, content, individual and collaborative) and then according to hypotheses and questions treating each one. A synthesis of obtained results is presented in figure 2.5 where each axis (criterion) is graduated according to the obtained result (Low, Medium and High).

Tool Criteria

H1: *Stiki* ***is an accessible and controlled common space***
By studying the use of *Stiki*, different types of use are reported:

- Contribution: action of adding new information. It includes creation of pages, revision of existing information or deletion. The user doing this action is called contributor.

- Consultation: action of reading existing information. The user doing this action is called reader.

Stiki is a fast and efficient tool which is accessible by everyone. All users highlight its accessibility. An interviewee mentioned the draft option as an efficient way to control *Stiki* interface and provide an intermediary page between private and public spaces. That explains why in figure 2.5, *Stiki* is considered verifying totally the "Accessibility to a controlled common space" criterion.

H2: Stiki is easy to use

According to the questionnaire, 80% of users (who participated to the questionnaire) highlight the ease of use and efficiency of *Stiki* especially in consultation. An interviewee said, "I can find the information quickly and simply using a keyword for example", another one said "*Stiki* is an efficient tool; it allows me to share my knowledge quite clearly and effectively".

When asked about its ease of use, 85% say that they feel comfortable using it. One interviewee said, "*Stiki* is a modern tool, it has a friendly interface, ensures quick search and is very convenient in case of absence".

However, one interviewee has a preference for another tool which has more advanced functionalities. He said "I use another tool for sharing my knowledge with my team; I can search any information by keyword even by using images and that functionality does not exist in *Stiki*". In addition, when asking if they feel comfortable in adding information in *Stiki*, about 50% of users find that adding information to *Stiki* is still difficult. When asking them if they need help when using *Stiki*, 35% of them think so. That is why in figure 2.5, "Easy to use" criterion corresponds to "Medium" level particularly due to these difficulties in contribution.

Content Criteria

Q3: Is Stiki content relevant?

When asking users to assign a level of consistency, relevance and utility for knowledge stored in *Stiki*, more than 75% of them confirm having confidence in stored knowledge and believe that it is relevant, useful, updated and slightly obsolete. The relevance of information is very important to ensure the usefulness of *Stiki*. An interviewee said “We need to monitor knowledge update to ensure that it will not become obsolete” especially in semiconductors’ manufacturing field, where products change regularly and data can quickly become obsolete. Despite this, some interviewees point out some inconsistencies in *Stiki* knowledge and claim for regular updating and monitoring. Ensuring a relevant content is one of the most important points highlighted by *Stiki* users during the interviews. Using it regularly to update existing knowledge or provide new one helps avoiding its obsolescence, reassures readers and motivates them to use it, not only as reader but also as contributors.

According to the database of *Stiki*, number of visits to all *Stiki* pages is about 160,000. However, the number of visits depends on the page. Indeed, some pages are more popular than others and it may be an indicator of the value of the page content. For instance, Support_TPI page belongs to the support part of the page structuring. It contains all links to support procedures. That is why each time a user adds a procedure; he has to indicate it in the common page Support_TPI. This type of page is usually characterized by a big number of consultation and contributions, which is explained by its important interest. In order to keep the relevance of such a page, collaborative participation is strongly required.

According to the questionnaire, more than 40% of users access to *Stiki* once a month or less, seeking for information. Some people would consult only to raise a doubt. Others have preferences for other search tools and criticize its limited guidance for IT. Besides, the average of consultations per page is 76, whereas the standard deviation is about 473. This indicates that a big number of existent pages are not consulted and could potentially encounter problems such as content obsolescence, as some interviewees proclaim. These findings explain why in figure 2.5, *Stiki* corresponds to the "High" level for "Relevant content" criterion and not the "Advanced" one due to the existence of some obsolete content that should be treated.

Q4: Is there sufficient content of knowledge in* Stiki*?

Today, *Stiki* contains 2370 pages. All interviewees considered that the number of pages is sufficient compared to the number of realized projects. However, many of them found that the content still targets IT applications without discussing enough functional and operational area. In this context, an interviewee said "In *Stiki*, we mainly find information about IT applications and techniques but rarely functional and operational information to understand why an application exists, what its purpose is and who is the involved staff". That is why; they found that even though there is a sufficient volume of information in *Stiki*, it does not really include all domains as it should do. Moreover, when asked if *Stiki* may be useful for users outside the IT, 85% of the questionnaire participants agreed and many of them proposed expanding its perimeter of application of *Stiki* as an area of progress that should be studied. In addition, when asked about their professions in the questionnaire, 70% of participants are IT staff that shows the limitation of its perimeter application. That explains why in figure 2.5, *Stiki* corresponds to "High" level for "Relevant quantity" criterion.

Q5: Structuring pages has an impact on the visibility of its content and facilitates the search and writing of information in the appropriate place. Is the structuring of pages mastered?

The majority of users consider that structuring pages in the form of templates is a good idea. According to the questionnaire, when we asked users about the degree of their agreement with the utility of structuring pages, on average, 80% of users find that the information structure helps, guides search, unifies content and improves the understanding of the information. Given that the proposed guide for structuring helps users, 65% of them think that it is applicable, easy to follow and adaptable to particular cases. Such a structure is a kind of guide for users facilitating use of *Stiki* for searching and contributing information. An interviewee said for this "providing a guide for structuring pages could only be beneficial".

To launch the official department wide use of *Stiki*, a meeting was held, during which a presentation of the tool and its use took place. This meeting was the only one since its implementation. Several users of *Stiki* have not assisted for many reasons. One of the guides that the administrator has joined to *Stiki* is the structure in the form of templates. This structure was also introduced at the meeting launching the activity of *Stiki* but nevertheless, when asked if they know it, 50% of users do not. Today, it is one of the reasons preventing some people to use *Stiki* or causing difficulties during its use. Yet, the majority is confronted to use *Stiki* regularly. Some make the effort to learn and others use it in their own way. This problem has to be treated by ensuring a regular evaluation of existing problems, a solution proposed by an interviewee, or a regular training, a solution proposed by another. The fact that structuring page is not yet mastered explains why in figure 2.5, *Stiki* corresponds to "Medium" level for "Content structuring" criterion.

Individual Criteria

H6: Stiki users are aware regarding the importance of knowledge sharing as well as the role of Stiki to improve it

According to the questionnaire, all users have recognized the importance of *Stiki* for sharing knowledge and despite the existence of other sharing tools, 60% of them confirmed that *Stiki* is now the reference tool. In this regard, one interviewee said, "the time spent to produce knowledge on *Stiki* can not be considered as a wasted time", another added "Obtaining knowledge about an application of another team via *Stiki* saves me time without wasting others' time". That explains why in figure 2.5, “users' Awareness" criterion corresponds to the "high" level.

H7: Despite the awareness of Stiki' users regarding the importance of knowledge sharing, they do not invest enough time in its use

Several interviewees consider that documenting their work is optional, secondary and takes time. One interviewee said that it is not part of the missions assigned to him by his manager. Another one has even reported that he often uses *Stiki* as a knowledge base but he does not document his own work. Three other interviewees think so. Unfortunately, when asked in the questionnaire about the frequency of contribution in *Stiki*, 30% of users have never contributed and 55% contribute approximately one a month for several reasons. Two users consider that there is no necessity, another one considers that he does not have sufficient knowledge to contribute or update existing one, may be due to fear of judgement or fear to sell their expertise and losing their job. Someone else said that there is no knowledge to add. Finally, some of them do not have enough time for that. These different observations led to consider that "Investment of users" criterion corresponds to the "Low" level in figure 2.5.

Q8: Using Stiki present an interest for users

According to the interviews, 90% of the interviewees consider it as a useful tool in their work and confirmed that *Stiki* saves time. For four interviewees, searching or contributing information on *Stiki* has become a habit. An interviewee said that "Documenting on *Stiki* becomes a reflection", another one said "it becomes a reflection to seek for information first on *Stiki*, and then to contact directly the appropriate person". Knowing the interest of such a tool encourages employees to use it and then ensure the increase in its use.

However, 10% the interviewees does not find interest because they use other tools to share or think that its content is intended for a specific population. That is why, as shown in figure 2.5, despite the awareness of users of its interest for knowledge sharing within the organization, the "Interest for user" criterion corresponds to "Medium" level, identifying here an improvement to seek.

Q9: Does user share his knowledge regularly?

Since the first implementation of *Stiki* in 2009, a significant variation in number of contributions is observed. The total number of contributions is 7193 in 2370 pages. *Stiki* counts 230 users including administrator. However, only 147 are considered as real contributors (who participated at least one for contributing) from different services of MSG (Manufacturing Solutions Group) described above. The number of contributions varies according the period and users' need to contribute; generally related to projects' period.

First, just after the period of its launch, *Stiki* encountered a recession period during which its use had recessed to 0 during three months. Then, throughout 2009, *Stiki* encountered a slight variation on the number of contribution varying between 20 and 100 actions per month. Then, during 2010, a gradual and significant increase appeared to reach a peak of 400 actions on *Stiki* in July 2010 and stabilized in the first half of the year 2011. This peak is explained by a strong documentation for some projects developed in this period. Later, during 2012, the number of contributions is stabilized (around 100 actions per month). However, during the year 2013, it had increased. This can be explained by the launch of our work on *Stiki* assessing, especially during the "*Stiki Review*" period (cf. evaluation process described in Section 3.2).

According to the questionnaire, more than 55% of users contribute once a month. Moreover, the majority of interviewees contributes to *Stiki* for most projects and particularly shares their production procedures. Only a few of them use it as an own personal memory where they find and store their work. Even though users regularly use *Stiki* to search for information, it is less used for contribution. That explains why in figure 2.5, "Regular use" criterion corresponds to the "Medium" level.

Collaborative Criteria

Q10: Did collective participation and collaborative management of pages exist? Are individual knowledge available to others? Is modification of one's own writing by others well received?

The level of contribution may be shown not only by the number of contributions, but also by the number of users participating in these contributions. Despite the large number of contributions during certain periods, one can see that very often it comes from the same user. Some examples are given in figure 2.4. For example, the page M.E.S has been amended more than 100 times by 12 different users, whereas the page "Dispatching rules" has been amended more than 160 times by only 7 different users. This can be considered as an indicator of page quality. Besides, noting that, on average, there is only one contributor per page and that the standard deviation is about 1.34; most pages has then a single contributor. This point can easily influence page content, increase its obsolescence and reduce its content diversity.

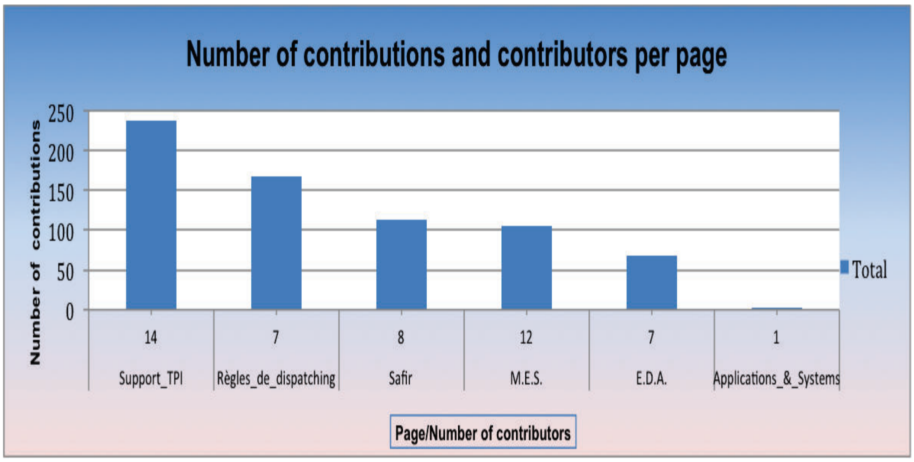


Fig. 2.4. Number of contributions and contributors per page

Despite these findings, according to the questionnaire, 85% of users tend to agree that *Stiki* can be seen as a training tool for new recruits. For different interviewees, reusing knowledge of experienced employees to form new recruits saves time and ensures staff evolution. One interviewee reported that he often invites his trainees to capitalize their work on *Stiki* for further reuse. According to these findings, "Collaborative participation" criterion corresponds to less than "Medium" level in figure 2.5.

Q11: Is STMicroelectronics culture in favor of improving knowledge sharing?

During interviews, some interviewees claimed for including a file converter that converts files formats, for example from a PDF file, to *Stiki* format. This debate has been launched a few years earlier, but did not lead to any solution. Some people consider that one of the principles of collaborative tools is the willingness to share, so to take time to share their knowledge. Others consider it as a waste of time and seek the fastest way even if it is not compatible with the principle of collaboration. It is a proof of the limitation of open culture in industries where technology reigns and the social aspect is lacking focus. That explains why in figure 2.5, "Open culture" level corresponds to "Medium".

Is** Stiki **accomplishing its objectives?

Figure 2.5 summarizes the compliance of *Stiki* with different criteria, defined in figure 2.2. With such presentation, the areas of progress are clearly identified. Therefore, in order to provide a complete *Wiki* that can meet defined criteria and can accomplish its objectives for knowledge sharing, some progress areas are proposed in the following section. Before that, we discuss the adopted evaluation approach.

3.4 Evaluation Discussion and Limitations

Despite the care we took with proposed evaluation method, some limits have been identified. For example, the inability to get detailed information that could enrich assessment results. Actually, in *Stiki*, data about pages creation as well as users' manipulation are not really sufficient to extract important advanced information from the database and better analyse its use. For instance, it was not possible to determine the average of consultation

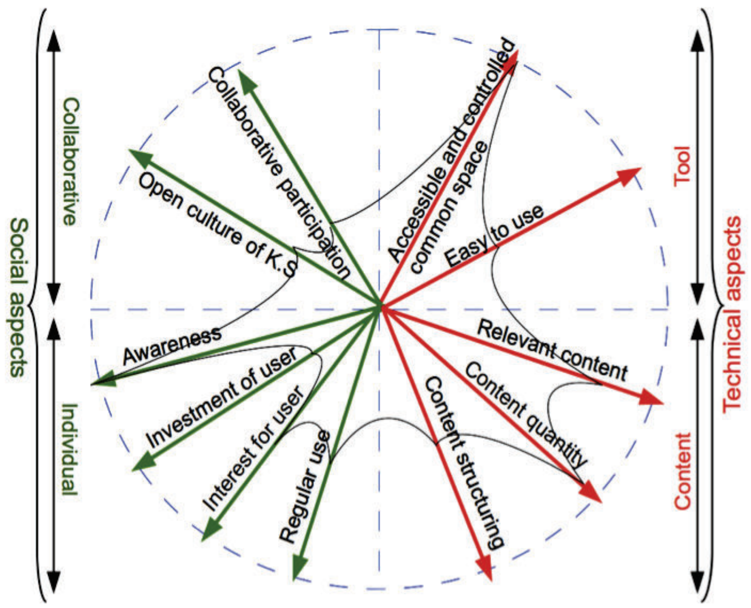


Fig. 2.5. Compliance of Stiki with the criteria that it must meet for knowledge sharing

duration per page. This measure could be used to identify pages with single reader and their interest for users, in addition to the measure indicating the number of contributors per page.

Moreover, realizing such an assessment experiment, particularly interviews, is not a usual procedure within *STMicroelectronics* Company. To ensure credibility and objectivity of results, characteristics such as context and culture are considered and interviews as well as extracted information from the database remained anonymous.

3.5 Business Needs for Knowledge Sharing

Thanks to proposed assessment methods, particularly interviews and questionnaire, some areas of progress proposed by users were identified. They actually constitute the business needs related to knowledge sharing. In addition, based on some *Wiki*' experiences relied on literature; we were able to position proposals. In the following, areas of progress according to groups of identified criteria are detailed:

3.5.1 Tool Criteria

During assessment process and particularly during interviews, 5 interviewees have not been trained on the use of *Stiki*, mainly due to their absence at implementation launch. Despite this, there was no other training or information for those who were absent. Nevertheless, the majority is regularly confronted with the use of *Stiki*. Some people make effort to learn alone; some others use it in their own way. Then, regular training can be an incentive to learn using *Stiki* and can consequently resolve technical issues with its use. For example, *Stiki* offers to its users a subscription system to particular domain so to notify them when a page is modified or created. This functionality reduces search time and let people be up-to-date with recent changes. However, most users do not know this feature.

In addition, current version of *Stiki* dates for 5 years ago. Since this version, several features have been integrated in MediaWiki package. We believe that most of them are useful for *Stiki* users to find interest in its use. Updating the current version and adding new functionalities are required. Unfortunately, as *Stiki* does not have an administrator managing its use, it seems less obvious to do it, especially when creating a knowledge sharing culture is still a challenge. That is why it is important to sensitize people about the importance of knowledge sharing in organizations.

3.5.2 Content Criteria

Content quantity and content structuring are generally less studied despite their importance. For example, content structuring could provide a common formalism to standardize pages content. Thus, there is a clear need for studying knowledge representation. Systematizing the evaluation of *Stiki* is a way to maintain its effectiveness. For instance, set up some indicators about the relevance of publications in terms of content and structure. For example, the number of readers per page, time spent to visit and read one page, assigned scores or comments posted on pages by their readers, etc. This kind of indicators will be beneficial for knowledge evolution.

Besides, to avoid the obsolescence of existing pages, it is interesting to tag pages that need to be updated. This requires participation of all users. Then, when a user perceives obsolete information, he has to take the initiative to update it if he is the appropriate person to do it or to contact the appropriate person. This would be beneficial for knowledge evolution. It seems to be an obvious reaction, but, during evaluation process, we discovered that users' culture in such an organization lacks of social aspects and good practices. For example, when interviewees are asked about their reaction when they find missed information in *Stiki*, most of them confirmed that they do not correct it directly, but prefer contact the author, even if they have the right answer.

3.5.3 Individual Criteria

Regular use was not studied by any application case in literature because of the difficulty to have results based on a long time period. Regular use can help users to better manipulate the *Wiki*, ensure its relevance content and eventually avoid its obsolescence. Regularity of use concerns consultation as well as contribution. Like any collaborative tool, using *Stiki* is mainly based on the goodwill of its users. In the experiment of [44], it is clear that, in the short term, proposing competition and a gift to the best contributor may work, but in the long term, this is an unconvincing way. This proves that there are other problems more related to awareness, motivation and willingness of users of such collaborative tool. Improving such criteria is more related to practical activities. In fact, willingness to share is reflected in practice [44]. Learning to use *Stiki* collaboratively improves the relationship between colleagues and consequently provides a friendly work environment. In that way, each one could feel involved and becomes aware of the importance of such environment based on team collaboration to share knowledge.

3.5.4 Collaborative Criteria

Firstly, a way that can motivate users is to demonstrate the effectiveness of such a tool in accelerating work and reducing time spent in searching for information. This can be achieved by expanding its application not only in the ST network but also with external collaborators, while managing shareable knowledge. Exchanging knowledge between different teams from different sectors or sites makes easier the problems' understanding [49, 58]. Secondly, as suggested by some interviewees, integrating the documentation of *Stiki* in projects life cycle like any other mission will promote its use. One interviewee began to apply this idea, but he has encountered some difficulties in updating information during the project progress. Indeed, he writes and shares his contribution throughout the project, but without knowing that *Stiki* offers a "draft" option to finish his contributions and decide the time of its publication. Apart from this, he believes that integrating documentation of *Stiki* in the project life cycle is easier and more effective in terms of time spent and relevance of information. Such a work methodology seems to be obvious, as well, but we noted during the evaluation process that it exists without being applied. This is due to the lack of awareness and investment of users, as well as some limits in projects supervision. This solution should be investigated in future. Integrating such work methodologies can be limited by the inability of organizations to change. A methodology will be developed following human factors principles in a way that enables them to quickly embrace the novelty and effectively act on it.

To summarize, the evaluation of *Stiki* revealed several needs for knowledge sharing. Classified into four categories, tool, content, individual and collaborative, their satisfaction will help improving knowledge sharing. In addition, throughout this evaluation, we identified other needs all as important as each other. In fact, first, we noted the importance for knowledge representation for providing a content structuring and a common formalism to standardize *Stiki* pages' content. Second, the need for knowledge evolution will be beneficial to maintain shared and more generally capitalized knowledge. For example, we proposed, in a first stage, defining a set of indicators able to maintain *Stiki*'s content.

4 Business Needs for Knowledge Capitalization

In a first stage, we defined business needs arising from the evaluation of *Stiki* for knowledge sharing and storage. They represent together one step of the knowledge capitalization cycle. However, as discussed in section 2.2, there is no real strategy or tools used for the remaining steps of knowledge capitalization. The results of the evaluation have demonstrated that in addition to knowledge sharing and storage, we have to expand our business needs to provide solutions for: representation and evolution as parts of the knowledge capitalization cycle.

To summarize, in our research, business needs related to *Business Intelligence* knowledge capitalization require providing a solution that meets its different users and needs for:

- Knowledge representation: to study its characteristics that should guide the way knowledge can be effectively stored, shared and reused. Our objective is to ensure the completeness, relevance and organization of capitalized knowledge.

- *Stiki* improvement for knowledge sharing and storage: our aim is to improve the use of *Stiki* according to the findings of its evaluation.

- Knowledge evolution: our aim is to allow maintaining capitalized knowledge and involved systems according to the evolution of business needs and knowledge.

5 Conclusion

This chapter defines business needs related to knowledge capitalization, as a part of the relevance cycle of the Design Science Research. To proceed, we studied the current business environment, in our case, the *Business Intelligence* activity at *STMicroelectronics*. Particularly, BI users' capabilities and characteristics were described and assessed in order to address faced problems and afforded opportunities throughout the knowledge capitalization environment.

Among knowledge capitalization steps, sharing and storage were the main studied ones since they are the most considered within *STMicroelectronics*, with the use of a *Wiki* called *Stiki*. We assessed its use, identified its advantages, limits and concluded with business needs related to knowledge sharing and storage, through its areas of progress to accomplish its objectives.

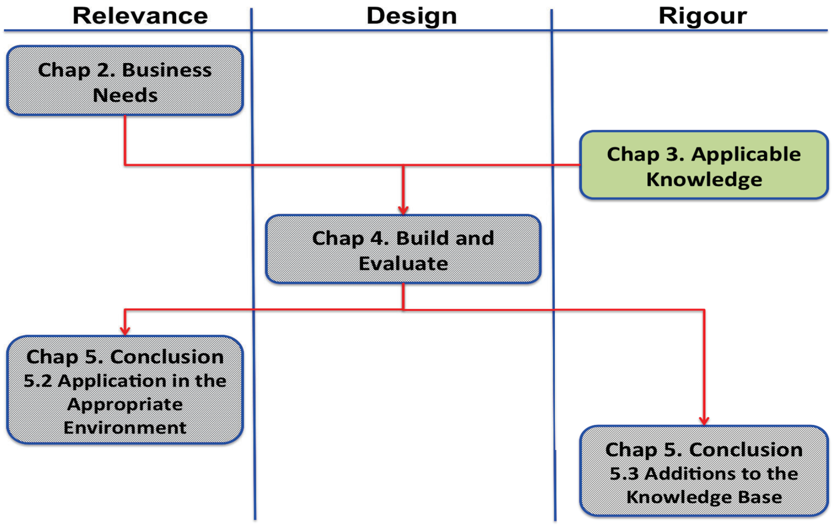
To this end, a user-centered approach was developed [1]. It allowed verify that *Stiki* is a useful tool for knowledge sharing even if it should be improved. *Stiki* is increasingly used as the reference tool, we highlight its success to ensure an effective collaborative knowledge sharing. However, based on the obtained evaluation's results, some areas of progress have been identified. For example, we noted the importance of knowledge structuring and representation, users' involvement, content relevance and technical evolutions promoting its use. Their aim is to improve its use, to support users' working and to provide an efficient environment for knowledge sharing.

More generally, this chapter concludes with the need to provide effective solutions for knowledge identification, representation and evolution, while taking into account users' needs.

Based on defined business needs, as a part of the rigour cycle of the Design Science Research, the next chapter provides a literature review. The particularity of this chapter is its focus on literature directly related to defined business needs. This is the reason why, it includes a state of the art on *Business Intelligence*, as well as knowledge capitalization, while considering its different steps.

Chapter 3

Applicable Knowledge



1 Introduction

This chapter is derived from findings and studies of theoretical foundations and existing solutions and techniques, as required in the Design Science Research. As part of its rigour cycle, this chapter presents a background and a literature review on what we rely to conduct our research.

On the one hand, the content of this chapter bases on the identified business needs related to *Business Intelligence* knowledge capitalization (presented in chapter 2). On the other hand, it should help us to compare existing solutions and provide clear and verifiable contributions for knowledge capitalization.

The previous chapter presented the business context and summarized some current problems in the *Business Intelligence* environment which are related to knowledge. Therefore, in a first stage, this chapter gives a background on knowledge and knowledge management while presenting knowledge types and sources (section 2). In addition, since knowledge is related to the BI system, the background section discusses, as well, this domain, its tools, its technical architecture and its components. This overview will help to target potential solutions to respond to the business needs identified in the previous chapter.

Particularly, we note that identified business needs related to BI knowledge capitalization are knowledge representation sharing, storage and evolution solutions. That is why, section 3 presents a state of the art on these steps and the way they are discussed and resolved.

2 Background

In this section, several fields of background are discussed. First, we present *Business Intelligence*, as the business environment in which we conduct our research. Next, knowledge and its capitalization cycle are presented and discussed.

2.1 *Business Intelligence*

In this section a background on BI is given. First, we present BI data flow describing the evolution of data throughout BI tools. Next, we present its technical architecture, followed by its modelling.

2.1.1 BI Data Flow

Throughout the BI process, data is evolving from row data to decisional one. To this end, BI proposes to transform the data transmitted by the information system, production data most often, to information that could be used for decision making purposes [37, 59-61]. To this end, four stages are required:

- Data collection: data used in BI tasks is of different sources typically from multiple databases. Data is of varying quality and formats, which requires preparing those needed for BI tasks. To this end, it should be continuously collected, cleaned and formalized in order to be effectively integrated within the BI system. To proceed, data is extracted from the production systems, structured and adapted for a decisional use. Adaptation could be for instance on the date transformation into an appropriate format required by the system.
- Data storage: it consists in centralizing structured and processed data in order to be available for a decision making purpose.
- Data distribution: it facilitates and allows the accessibility to information depending on the kinds of use.
- Data exploitation: once the data is stored, cleaned, consolidated and accessible, it becomes usable. Depending on users' needs, different kinds of extraction and exploitation tools can be considered to assist users during their querying.

2.1.2 BI Technical Architecture

Developing a BI solution aims at supporting decision making in the organization. As depicted in figure 3.1, a typical architecture for developing a BI solution [37, 59-61] is composed of a set of techniques and tools, throughout data is evolved:

- Preparing data for collection. It is performed thanks to Extract-Transform-Load (ETL) technologies [62]. ETL tools are in charge of the extraction of data from several and different sources, of cleaning the data and of its customized insertion into a repository called the data warehouse. At *STMicroelectronics*, data is basically

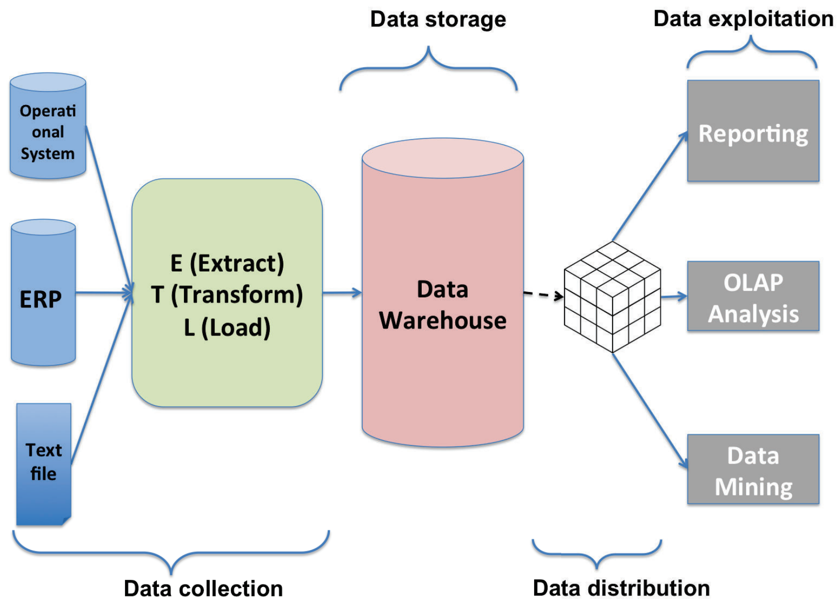


Fig. 3.1. *Business Intelligence* architecture

stored in different databases. As an ETL, Advanced Productivity Family (APF) [63] is used to extract and transform production data and Oracle Data Integrater (ODI) [64] is used to load it into the data warehouse called TGV (Tool for Global Visibility). For example, data could be about the time spent by a wafer for its manufacturing or the set of wafers during their production.

- A data warehouse, for data storage, is a specialized database that is designed for fast and easy query and analysis. A data warehouse is an OnLine Analytical Processing (OLAP) database [59]. Data is denormalized to enhance analytical query response times and to provide ease of use for business users [65]. In a data warehouse, data modelling is based on two main objects: indicators measuring a performed task and dimensions constituting their context of use (detailed in section 2.1.3). Such a simple structure allows semi-technical users fill their own needs.

- Actually, a data warehouse is the physical location for data storage, while the OLAP is the technique allowing multi dimensional analysis on the data warehouse. With OLAP, data is represented by a cube (figure 3.2), where its sides constitute a set of dimensions and its cells constitute the indicator. For example, in figure 3.2, the cube allows analysing the "number of produced wafers" indicator according to three dimensions: lot, time and plant. We note that even though we talk about a cube, it is not limited to three dimensions. Once the data is stored in cube, it can be used by analytical applications.

- Finally, for exploitation, there are analytical applications, such as Data Mining and Reporting. They are in charge of collecting users' queries and communicating them to the data warehouse in order to produce required analysis results, in the form of reports, for instance. Taking the example of figure 3.2, one report can include the list of produced wafers per lot, per plant or per year. Such a report helps checking the achievement of objectives for each dimension.

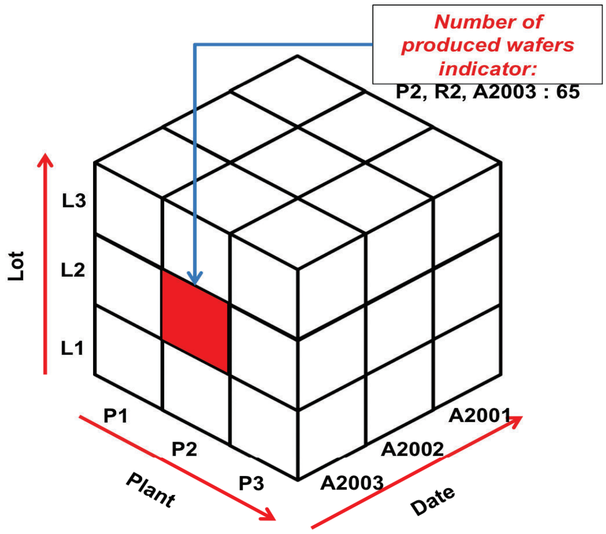


Fig. 3.2. OLAP cube

2.1.3 Data Warehouse Modelling in BI

Data warehouse modelling specifies the data structure [59,66]. It is particularly important to ensure an effective modelling, since it can have a significant impact on data used and its performance. Modelling data in a data warehouse is different from that of a transactional database (E/R model), for two main reasons. First, the intelligibility of data, where in a data warehouse, the data must be understandable, meaningful and in an appropriate granularity for its user. Second, the performance, where analytical operations must be interactive and a minimal response time.

To overcome these issues, in a data warehouse, a dimensional modelling is used [67,68]. It is based on two main concepts, indicator and dimension. An indicator corresponds to the aggregation of data, usually numerical, called a measure. Each measure is related to a context called a dimension. Relying on these two concepts, a dimensional modelling consists in storing dimensions, measures and indicators in two types of tables.

First, a large table of facts is called fact table. It stores records to calculate one or more indicators. Second, a number of other tables surrounding it contain descriptive data, called dimensions. Figure 3.3 gives some examples of fact and dimension tables. In the "Manufacturing" table (fact table), the indicator "Quantity" measures the number of produced products. The "Date" table (dimension table) stores information related to the date dimension, "Year", "Month" and "Date". In addition, as depicted in figure 3.3, dimensions can often be grouped into meaningful sets, called dimension hierarchies. Each hierarchy is composed of a set of levels having many-to-one relationships between each other, and the set of levels collectively constitute a dimension or a tree. For example, the date hierarchy contains information on the year, the month and the day. Based on this structure, we distinguish two types of dimensional modelling in BI.

The dimensional modelling can be implemented according to one of the two types of schemas, the star schema and the snowflake schema (figure 3.4). First, in the star schemas, a central table contains fact data and several dimension tables surround it. It is connected to dimensions by the primary and foreign keys of the database. The dimension tables in the star schema are not normalized, where all the dimension levels are stored in a single

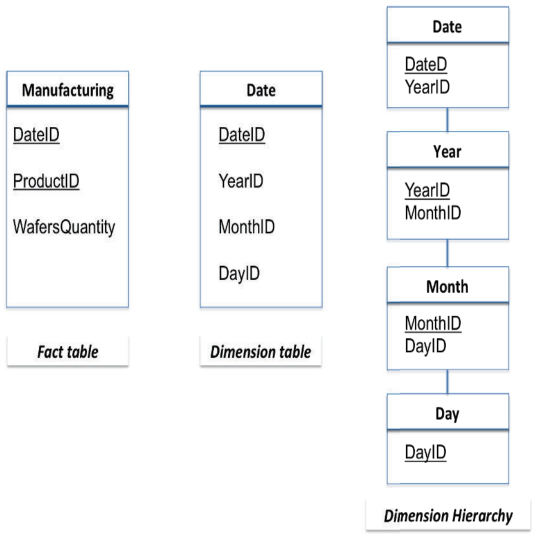


Fig. 3.3. Examples of fact and dimension tables

dimension table. Second, the snowflake schema is also composed of a central fact table and a set of dimension tables which are further normalized into sub-dimension tables. It uses more than one table to store the dimension data, while linked back into the original dimension table.

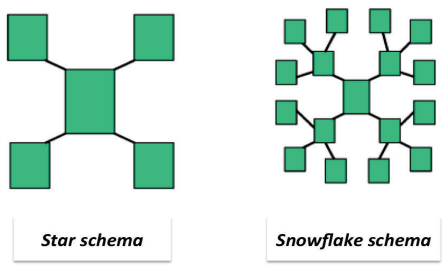


Fig. 3.4. Types of dimensional models

In figures 3.5 and 3.6, we present respectively the star model and the snowflake model applied to the example at *STMicroelectronics*, measuring wafers' manufacturing quantity. As depicted in these examples, each dimension hierarchy is stored in a single table in the star model. For example, the plant information is stored in the table "Plant". Whereas in the snowflake model, each dimension hierarchy is normalized into sub-dimensions. For example, the plant information is stored into "City", "Region" and "Country" dimension tables.

We note that in most cases, star models are a better solution, for two reasons. First, although redundancy is present, query performance in the star model is advanced. This is due to the absence of joins, which is not the case for the snowflake model. Second, the simplicity of the star model makes users' understanding easier than the snowflake model.

In the current section, we presented a background on the *Business Intelligence* domain, that is the business environment in which we conduct our research for knowledge capitalization. However, capitalizing BI knowledge requires an understanding of its provenance and sources. In fact, in addition to human efforts, BI involves several IT tools, such as a

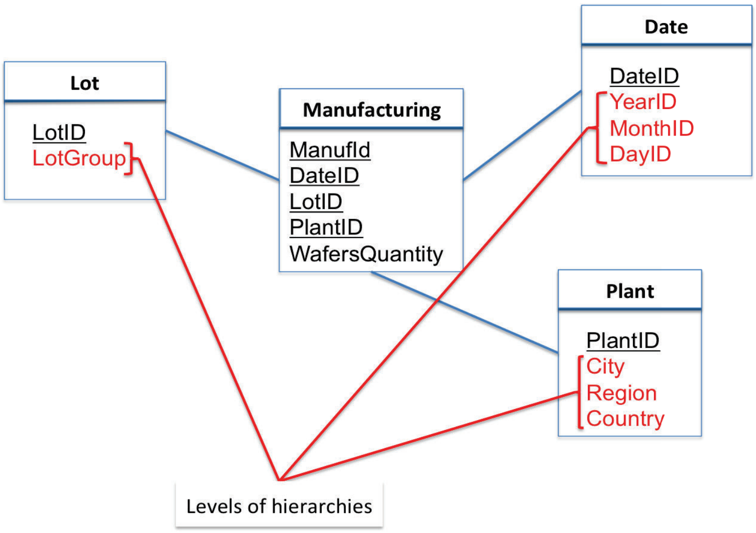


Fig. 3.5. Star model application

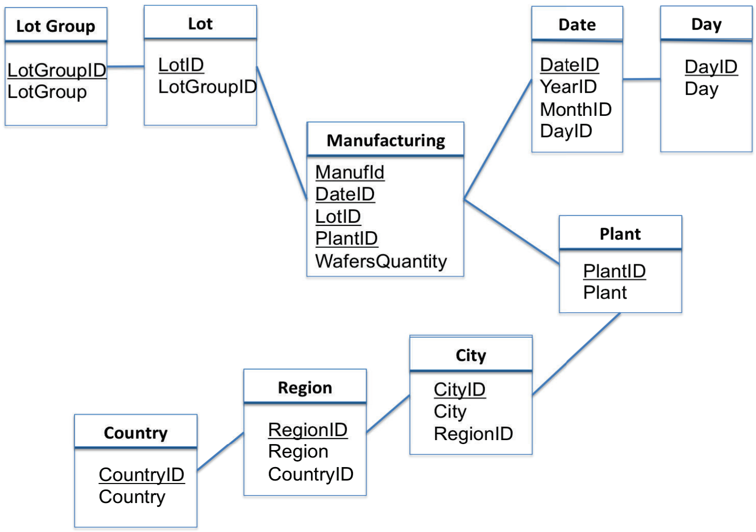


Fig. 3.6. Snowflake model application

data warehouse, that contain data and information. This is the reason why, we focus, in the following, on discussing the relationships between knowledge, information and data.

2.2 Data, Information and Knowledge

Knowledge is commonly defined by data and information used by an actor in a specific context [69]. This is the reason why data, information and knowledge are usually encountered together and lead to continuing confusion [25]. In literature, a hierarchy from data to information to knowledge is differentiating these notions according to some dimensions, such as context, usefulness, or interpretation [70]. Inspired from [71], figure 3.7 presents the relationship between data, information and knowledge as a pyramid or a chain to emphasize their hierarchy, where data is in the bottom and knowledge in the top of the pyramid. In the following, data, information and knowledge are defined and some examples are given.

- **Data** is a real fact, value, often a measurement or a description with no context. By

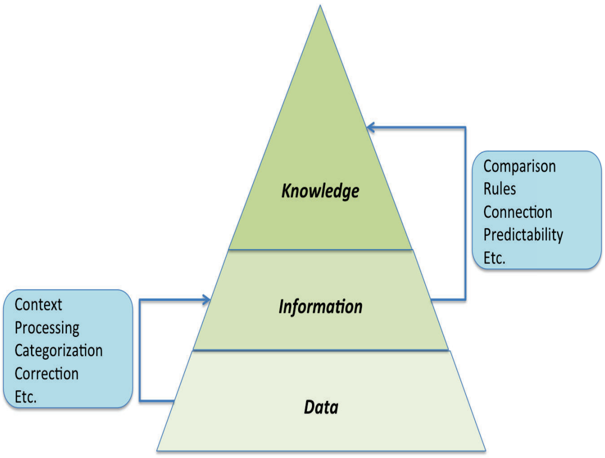


Fig. 3.7. The relationship between data, information and knowledge

itself, data has no meaning and significance beyond its existence [71, 72]. It can be qualitative, quantitative, in any form, usable or not [9].

- **Information** is well-organized and structured data collection that gives meaning by ways of relational connection [72]. Information is data with context, relevance and purpose [73]. Information could of two types, qualitative (the sky is gray) or quantitative (the water temperature is 25°C), having therefore a sense of character [9].

- **Knowledge** is the appropriate collection of information intended to be useful [72]. Knowledge is closely linked to doing and implies understanding [73]. It is brought to bear to practical use in action. It adds two distinct aspects: a sense of purpose, since it is used to achieve a goal and a generative capability, since it produces new information [25].

An example is given in figure 3.8, showing the difference between the Data, Information and knowledge concepts.

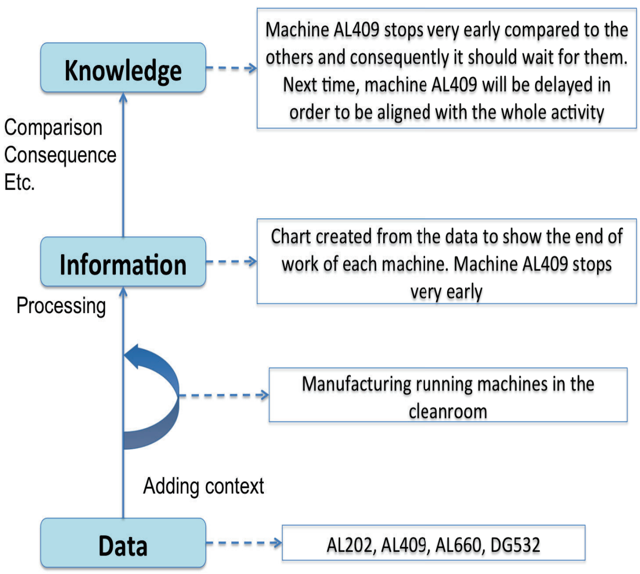


Fig. 3.8. Example of data, information and knowledge

- Data
  Data in this example is a list of raw data that could be anything (AL202, AL409, AL660, DG532). These alphanumeric data are references of machines in a clean room of an industrial organization. Currently, the data has some context and make sense.

- Information
  Processing allows to sort the end of work of each machine. Machine AL409 stopped very earlier than the others. This shows a gap in their activity. Processing in this example consists of creating a chart.

- Knowledge
  A gap is shown between the activities of machine AL409 and the others. Consequently, machine AL409 should be delayed in order to align the whole activity. In this example, applied rules are comparison and consequence.

In our context at *STMicroelectronics*, knowledge which is embedded in the BI system, concerns BI data and information. These latter are in the form of manufacturing data, dimensions and indicators. That is the reason why, this section is focused on studying data, information and knowledge embedded in systems as an important step to ensure an effective knowledge capitalization solution.

Within knowledge capitalization, two types of knowledge are usually defined, namely explicit and tacit [9], presented in the following.

2.3 Explicit and Implicit Knowledge

Since a long time, researchers [74-76] have recognized that knowledge is of two kinds: explicit and tacit, where:

- Explicit knowledge is presented in formal and systematic language. Typically, it has been documented with papers, books, presentations, etc. It is therefore easily stored, communicated, shared and reused.

- Tacit knowledge is personal, subjective and held by each individual. It is deeply rooted in their actions and experience. It is not easy to capture, express, formalize or communicate.

[77] gave a relevant example to understand the two forms of knowledge. It is about riding a bicycle, where he proposes to explicit knowledge with a set of basic instructions:

1. Stand besides your bike, hold both the handlebars and look forward.

2. Walk briskly forward or run a few paces taking the bike with you.

3. Now mount the bike, putting one foot on each pedal

4. Start pedalling while maintaining you balance

5. If you start to swerve or lose balance steer the bike into the direction in which you are falling.

6. Etc.

However, riding a bicycle is difficult to put into words. It is learned with regular training and experience. Although the first steps could be explicit, the steps 4 and 5 are difficult to formalize. Such knowledge remains tacit, embedded in human minds and is used subconsciously.

As mentioned above, knowledge capitalization within organizations should involve explicit and tacit knowledge. To this end, the Nonaka and Takeuchi theory [74] suggests interaction between both of them as a spiralling process. As depicted in figure 3.9, there are four basic patterns for creating knowledge in organizations:

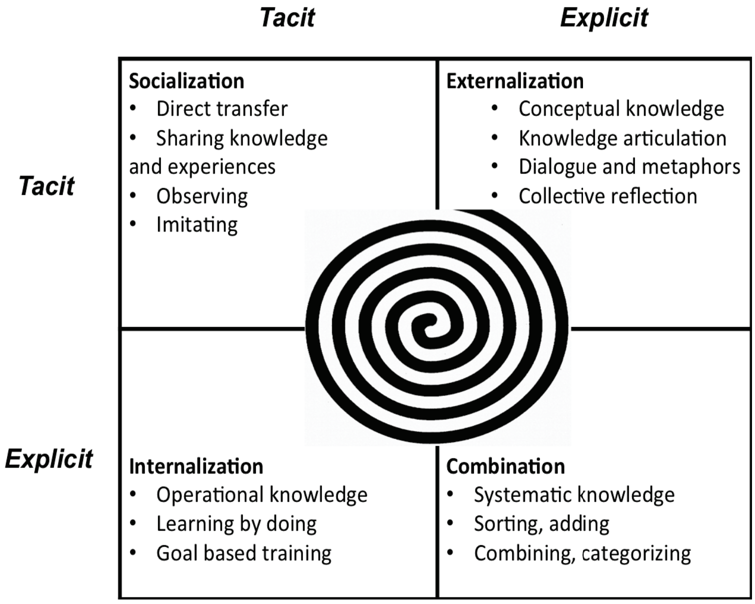


Fig. 3.9. The SECI cycle of knowledge creation (Nonaka and Takeuchi, 1995)

First, socialization is the direct transfer from tacit to tacit through interaction. Experiences and knowledge are shared with observation, practice and imitation. Individuals can acquire knowledge without language but with experience.

Second, externalization is the conversion of tacit knowledge into explicit knowledge. It is based on articulating knowledge with dialogue and collective reflection. Metaphors are usually used to explain tacit concepts that are otherwise difficult to articulate.

Third, combination is combining different bodies of explicit knowledge. It is based on reconfiguring of existing knowledge through sorting, adding, recategorizing of explicit knowledge.

Fourth, internalization is the conversion of explicit knowledge into tacit knowledge. It represents an active process of learning by doing, where knowledge is shared through interaction and a process of trial-and-error.

According to [74], all four types of knowledge production are continuously required for organizational knowledge creation. These statements emphasize that knowledge could be embedded not only in information sources (documents, databases, emails, etc), but also in human minds and practices.

On the one hand, creating new knowledge and organizational learning throughout explicit and tacit knowledge should support a climate of social exchange necessary for capitalizing, and enlarging individual knowledge. To this end, individuals as the organization as a whole must support this effort [78].

On the other hand, in addition to human efforts, IT tools, inside information systems, are as well important sources of knowledge. Therefore, the relationships between knowledge, information and data, are discussed in the following.

To summarize, what we can retain from this section is, first, the importance of considering explicit and tacit knowledge. In addition, we should note the importance of considering the appropriate tools and methods that should be able to explicit knowledge before its capitalization. Particularly, they should promote knowledge creation and allow its capitalization within organizations.

In the following, we discuss how knowledge management is considered in the literature. Particularly, we give an overview about its cycles, practices and components.

2.4 Knowledge Management

Many researches [6-10] have discussed the knowledge management issue. Several definitions have been given. From them, we propose a knowledge management cycle, where important phases are highlighted in bold:

One of the most known definition is of [79], considering knowledge management as **providing** the right knowledge to the right persons at the right moment, in order to **reuse** it and to **profit** from existing ones. In this definition of knowledge management, the author highlights the importance to provide, profit and reuse knowledge. We consider that these statements target two stages of knowledge management: identification (provide) and reuse (profit, reuse).

To enrich previous definition, in his thesis, [9] emphasizes that "knowledge management activities should help to **capture** and to **spread** the existing knowledge in order to keep the information current and to optimize the enterprise and individual performance by a reuse. Therefore, the **creation**, **diffusion** and **reuse** process is a transversal activity integrated in people's daily work activities and decisions". Analysing this definition, we consider that, in addition to knowledge identification (creation, capture) and reuse, [9] considers also knowledge sharing (spread, diffusion).

In his turn, the author in [8] says: "knowledge management allows effectively and rapidly **retrieve** what we are searching for, **transfer**, make **use** and **reuse**, **enrich** and **evolve** knowledge. To this end, it aims to **collect**, **organize** and**structure** explicit and tacit knowledge in order to allow their use". As a result, two new components are added to last ones, which are knowledge representation (organize, structure) and evolution (evolve).

Finally, [7] believes that "knowledge management requires abilities to manage disparate know-how and heterogeneous viewpoints, and it must **integrate** and **store** this knowledge in **different forms** that should be easily **accessible**, **usable** and **maintainable**". This definition confirms all the last knowledge management components and adds a new one, which is knowledge storage (store).

To summarize, based on these definitions, knowledge management considers, therefore, the following statements:

- Retrieve, provide, integrate, collect, capture, creation
- Organize, structure
- Store
- Transfer, spread, diffuse
- Reuse, profit, access, use
- Maintain, enrich, evolve

A a result, figure 3.10 summarizes the different components required to ensure an effective knowledge management cycle:

- Identification: is the collection of knowledge to capitalize.
- Representation: is structuring knowledge to capitalize.
- Storage: consists in saving capitalized knowledge in a workspace.
- Sharing: provides solutions to diffuse capitalized knowledge.
- Reuse: is the ability to apply capitalized knowledge on a give context.
- Evolution: is the ability to maintain capitalized knowledge.

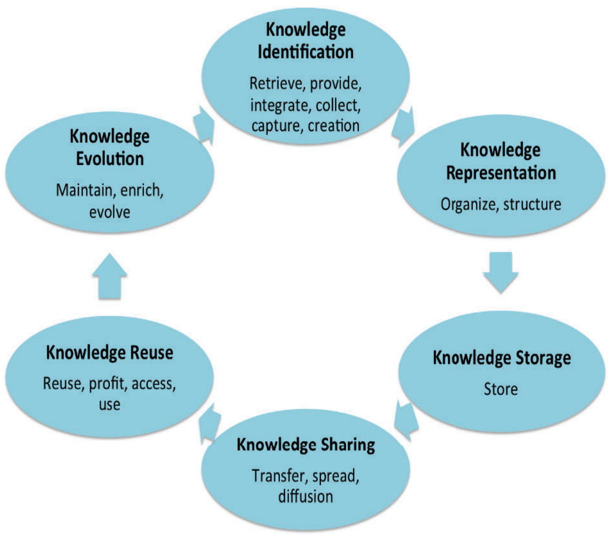


Fig. 3.10. Knowledge management cycle in literature [6-10]

We note that our main business needs, identified in chapter 2, involve knowledge representation, sharing, storage and evolution. This is the reason why, among the knowledge management components, in this research, we focus only on these ones.

First, we consider representation, sharing and storage as the phases constituting a knowledge capitalization cycle. Second, the knowledge evolution will ensure their maintaining over time. In the following, we discuss how they are considered in the literature.

3 State of the Art

A literature review on knowledge capitalization gives an overview about the advantages, problems and difficulties of current practices and solutions, related to its different phases. We note that, in our research, knowledge capitalization involves representation, sharing and storage. In addition, we consider knowledge evolution as a required step for an effective knowledge capitalization. These components are discussed in this section. Before that, we discuss how knowledge is considered in the literature and the impact on the way it should be capitalized.

3.1 Knowledge Capitalization Requirements

In order to define requirements related to knowledge and its capitalization, we start with presenting the way it is perceived and defined in the literature. This analysis will allow us to guide the way it should be effectively capitalized.

The term "knowledge" is widely used for different applications in literature. However, its definition is still a debate for researchers, philosophers and scientists [70, 80]. This is the reason why there are many definitions of knowledge. Let's have an overview of how it is defined in literature.

In [80], the author bases on a frequently used definition which is "the ideas or understandings which an entity possesses that are used to take effective action to achieve the entity's goal(s)". These characteristics are adopted also by the authors of [81]. They suggest that knowledge is a state or fact of knowing gained through experience or study of what has been perceived, discovered, or learned. This claims that knowledge is understanding, it can not be mechanized and is therefore, a state of mind.

The previous definitions suggest that knowledge is only a state of mind. Therefore, they consider that knowledge remains tacit. We think that such definitions limit its scope by considering it transferable only between humans. This implies that making tacit knowledge usable remains difficult. These considerations increase the risk of knowledge loss and misunderstandings.

This is why, unlike previous statements, others believe that knowledge could be considered as rather a thing to be stored and manipulated [82]. This definition considers that knowledge is only explicit, which limits also its scope. In fact, it neglects the importance of humans in its creation, use and evolution.

An other point of view joining the last one, is about recognizing knowledge as a condition of access to information. Therefore, it must be developed and organized to facilitate access to and retrieval of content [83]. This point of view implies that knowledge is related to access to documents and databases. Once again, knowledge is limited to its explicit form. However, this time it highlights more its limitation to technical issues of storage and access.

To overcome these limitations, [83] considers knowledge as a process of simultaneously knowing and acting-applying expertise. On the one hand, with expert system for example, explicit knowledge is most easily embodied in sets of rules. On the other hand, process re-engineering can help to embody tacit knowledge into a design for a business process. In that way, viewing knowledge as a process involves both tacit and explicit knowledge.

Finally, Knowledge is also considered by [84] as a capability with its ability to influence future actions. It bases on human knowledge to be converted into actions. However, [85] demonstrated that Knowledge is not capability. He considers that capability refers to the knowledge of converting the knowledge into a desired result.

Comparing these different views of knowledge and their limits, we are able to provide our definition, based on our research context and needs. In our context, people, organization and technology should be considered as a whole environment defining the context. Together, they help to identify business needs while being the applicable environment. Therefore, they are at the same time, the providers and consumers of knowledge. As a result, we consider that knowledge is:

A set of understandings, experiences and learnings from people and of technology to be able to execute actions and make decisions in a given context.

In our definition of knowledge, two aspects are considered, **knowledge content** (A set of understandings, experiences and learnings) and **provenance** (people and technology).

We believe that these aspects should lead to the way knowledge should be capitalized. As a result, according to each definition and perception of knowledge, different solutions for its capitalization can be proposed. Therefore, **involved resources** in proposed solutions, depending on **knowledge nature**, should also be able to **cover the knowledge capitalization phases**. In the following, we suggest to analyse how knowledge definitions tackle these aspects.

First, viewing knowledge as a state of mind suggests involving humans for searching for knowledge from its owners. Knowledge is therefore tacit and human centred techniques are required (brainstorming, for example). This helps users enrich their personal knowledge and apply it to their business needs. Second, considering knowledge as an object or information access requires technologies focusing on knowledge storage and content access and retrieval from existing systems. Knowledge is therefore explicit and technological tools should be used. Third, viewing knowledge as a process implies a focus on the knowledge processes including creation and sharing. This view holds that explicit knowledge is embodied in processes rules and tacit knowledge is owned by business experts who have extensive experiences. As a result, both technological and human centred solutions can be used. For example, engineering and machine learning techniques are important in converting the understanding of an expert, or the hidden meaning in a database. Finally, knowledge view as a capability suggests focusing on building competencies basis based on humans' experiences. However, even though in this view, knowledge identification and reuse capabilities are crucial, it remains difficult to convert tacit knowledge to explicit one

Table 3.1 summarizes these aspects according to knowledge definitions.

To summarize, being a state of mind, a stored object, a process or a capability means that knowledge is located differently, in humans or in technologies. This involves different resources for its capitalization, human capabilities or IT resources. Both types of resources depend on the nature of knowledge (explicit or tacit). However, in these definitions, none of them implies a focus on the whole cycle of knowledge capitalization. For example, considering knowledge as a state of mind implies efforts to identify humans who possess the right knowledge. Being tacit, the main difficulty is, therefore, its identification.

What is knowledge? (its content)	Knowledge provenance	Knowledge nature	Involved resources in knowledge capitalization	Coverage of the knowledge capitalization cycle
Knowledge is a state of mind [80, 81]	Humans	Knowledge is tacit	Humans	Search (identification)
Knowledge is an object [82] or a condition to access to information [83]	Information Technology (IT)	Knowledge is explicit	IT resources	Knowledge storage, sharing and access (reuse)
Knowledge is a process [83]	Humans and IT	Knowledge is tacit and explicit	Humans and IT resources	Knowledge creation (identification) and sharing
Knowledge is a capability [84]	Humans	Knowledge is tacit	Humans	Knowledge identification and reuse

Table 3.1. Knowledge views

More generally, none of these definitions considers the two types of knowledge provenance (humans and IT), its two natures (explicit and tacit), required resources (human capabilities and IT resources) to cover the whole process of knowledge capitalization. These limits allowed us to identify the following criteria for a successful knowledge capitalization solution:

- (1) It should use the appropriate back-end support for the considered solution throughout knowledge capitalization. For example, models, guides, intermediate representation, etc.
- (2) It should use the appropriate IT support tools throughout knowledge capitalization. This criterion implies providing the appropriate front-end support platforms.
- (3) It should involve humans throughout its design and/or evaluation processes, since they are its end users.
- (4) Involved humans should have different roles in the considered domain. For example, in the context of BI knowledge capitalization at *STMicroelectronics*, it should consider BI end users, business experts and BI experts.
- (5) It should take into account tacit and explicit knowledge, respectively owned by users and embedded in IT tools and systems.
- (6) It should promote the cycle of knowledge capitalization.

In the following, we present how knowledge capitalization is discussed in the literature and how proposals respond to our identified criteria for an effective solution.

3.2 Knowledge Capitalization

Our state of the art focuses on the knowledge capitalization steps that we tackle in this thesis. We note that our main business needs, identified in chapter 2, involve knowledge representation, sharing, storage and evolution. In the following, we present how related work, dealing with these steps in the literature, respond to our identified criteria for an effective solution.

3.2.1 Knowledge Representation

Knowledge Characteristics

The way knowledge is represented is much discussed in literature. Case studies on knowledge representation aim to represent knowledge required and involved in organizations' daily work. To proceed, different aspects or characteristics of knowledge should be considered. One of the most known method including all knowledge characteristics is the 5 WH questions (What, Who, Where, When, How, Why). It adopts a constructive critical analysis approach based on asking questions on:

- *What*: implies a description of the the elements that characterize a task. It targets the products, objects, natures, quantities, etc.
- *Who*: allows a description of involved actors. It targets those who are affected, interested in the results, etc.
- *Where*: concerns the description of the premises. It involves places, machines, positions, etc.
- *When*: allows clearly defining the times. It involves years, days, frequency, term planning, deadlines, etc.
- *How*: details the tasks performing and the way they can be accomplished. We note, for example, methods, processes, techniques, equipment, raw material, etc.
- *Why*: allows to conduct a critical analysis of each answer of the above questions. It targets therefore the behavioural aspect behind performed tasks.

Analysing these aspects of knowledge allowed us to deduce some dependencies, similarities and/or particularities between each other.

First, the *What* and *How* aspects are complementary. On the one hand, the *What* statically presents the elements required for a task. It includes a description of the involved objects and their characteristics. On the other hand, the *How* dynamically presents the way they interact to achieve the task. It includes processes, equipments, methods, etc. Therefore, each of them has its own function but both should be considered.

Second, the *Who* includes knowledge on actors according to their tasks and needs. Actually, knowledge on involved actors are depending on the actions they perform. Therefore, their roles can not be dissociated from their performed tasks in processes. This is the reason why we suggest to include the *Who* in the *How* aspect of knowledge.

Third, the *When* and *Where* include knowledge highly related to the performed tasks. For example, in the same process, several tasks are achieved. Each one is located in a different place or machine and performed at different times. This is the reason why, we believe that this knowledge should also be related to the How aspect of knowledge.

Finally, the *Why* aspect keeps specific functions different from the others. It allows keeping track on behaviours and explanations.

The " 5 WH questions" method allowed us to identify which knowledge to represent. To summarize, previous findings highlighted the need for a better capitalization of:

- What users manipulate through processes (know *What*): what knowledge is needed and exists, and their relationships.

- Why things are done (know *Why*): knowledge explanations, exceptions and behaviour.
- How they are integrated within the technical system and daily practices: knowledge flows, processes and sources.

There are several case studies in the literature that consider these three components: the know *What* [10, 12, 15], *Why* [15, 86, 87] and *How* [88]. However, most of them do not consider all of them together or do not differentiate between them. For example, in his work, [12] considered only the know *What* component to be represented. Also, [89] considers the know *What* as the know *How*.
In the following, we present some examples of how each knowledge component (*What*, *Why*, *How*) is described and represented in the literature. To present and evaluate studies in the state of the art on knowledge representation, we base on our identified criteria for an effective solution. We note that we should take into account technical and human criteria. Solutions should involve the appropriate tools and their back-end support. They should involve humans in the design and/or evaluation process while considering different users' roles. Explicit and tacit knowledge should be therefore considered. Finally, specifically to knowledge representation, we will discuss if existing proposals are able to be integrated in the whole capitalization cycle.

Know-*What*

In his thesis, [15] considers that the know-*What* concept treats procedural aspects of knowledge, while [8] describes the know-*What* as "a set of concepts, knowledge and experience concerning operations or methods useful in producing a product or service". In both cases, we note that the know *What* concerns describing what knowledge to be considered throughout the execution of a task. In the following, we present the main solutions representing this aspect of knowledge: ontology based solutions, symbolic models and static UML diagrams.

Ontology Based Solutions

The advent of semantic technologies has served for the development of knowledge representation solutions. It leverages knowledge representation with ontological approaches [90]. These latter provide means to classify all existing things in a structured way. [91] defines an ontology as follows:

An ontology is a formal explicit specification of a shared conceptualisation of a domain of interest.

Based on this definition, several aspects, characterizing ontologies, can be identified [92]. First the *formal* aspect of an ontology allows to express knowledge in a semantic representation. Second, the *explicit* aspect allows stating knowledge explicitly to make it accessible for machines and humans. Third, *being shared*, ontologies is the result of an agreement on a domain representation among people in a community. Fourth, the *conceptual* aspect of ontologies allows representing knowledge as a set of concepts and their relationships [93]. Finally, the domain *specificity* in an ontology limits the represented knowledge to a particular domain of interest.

These characteristics of ontologies are the reasons why several researches use it for knowledge representation [11, 92, 94, 95]. For example, [11] proposes an ontology as a semantic framework for standardization and representation of a large amount of heterogeneous data and knowledge in the field of Parkinson's disease (PD). Figure 3.11 presents a part of the Parkinson's disease ontology. This ontology illustrates events starting from the causal effect of defined mutations on cellular processes and ending in clinical manifestations of disease outcomes. The part of ontology shown in figure 3.11 focuses on the PINK1 which is responsible for an early and familial Parkinson's disease. It represents, for example, the causal association of upstream variants of PINK1 (highlighted in yellow) with downstream pathways and biological processes (highlighted in red). Relationships have been represented as increase (delta-shaped arrows), decrease (T-shaped arrows), association (diamond-shaped arrows) or variation (circle-shaped arrows).

This ontology delivers the knowledge domain in a compact, computer-readable form, which can be further used to construct, represent and automatically extend related computable models in the domain. The Protégé OWL editor was used as a tool for building the ontology in Web Ontology Language (OWL) format. It is one of the most known ontology editors. Besides, structural features of the ontology were computed using a developed java script.

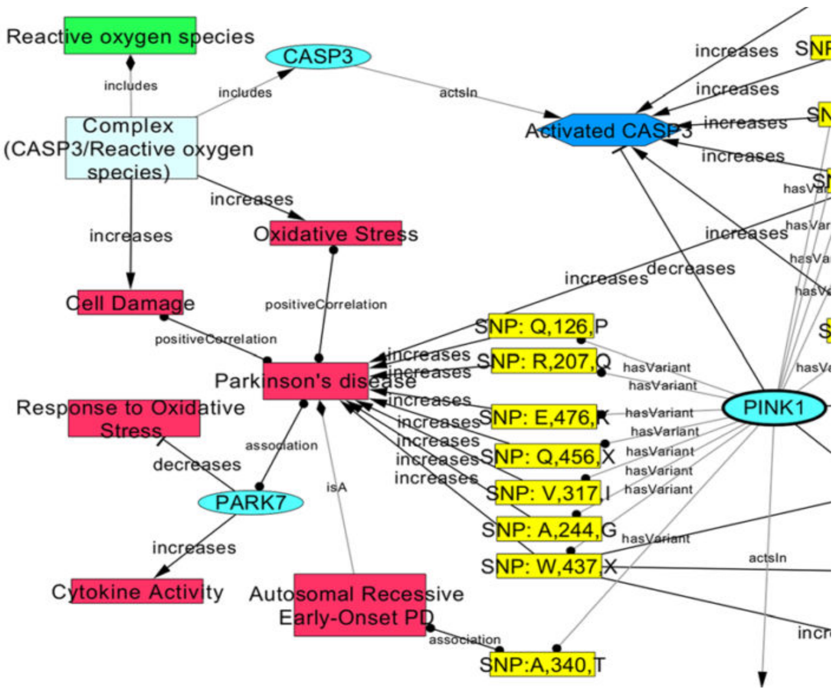


Fig. 3.11. Know *What* representation with the Parkinson's disease ontology in [11]

An important advantage that can offer ontologies for knowledge representation is its ability to be easily integrated in the knowledge capitalization cycle. In fact, they can offer knowledge retrieval and extraction solutions. For example, [11] proposes to transform the ontology OWL format into a dictionary file using a Java program that extracts the concept names and the corresponding synonyms from the ontology OWL structure and assigns unique identifiers to each concept which can be stored in form of a dictionary. This one promote itself knowledge sharing.

Besides, the construction of ontologies allow easily involving knowledge from different sources. It can easily involve explicit and tacit knowledge, while basing on accessible sources as well as experts from different profiles throughout the design and evaluation processes. For example, in his work, [11] is able to collect the appropriate concepts by scanning various knowledge sources. He bases on medical text books, encyclopaedias on the Parkinson's disease, online books, etc. Besides, experts in the domain can be involved to evaluate or perform revisions of the ontology structure and content. For example, in his work [11] is able to base on the presence of an expert panel of 6 experts in PD composed of molecular biologists, clinicians and physicians, etc.

To summarize, in the following, knowledge representation with ontologies is compared to our criteria for an effective solution. First, ontologies are able to offer a structured model representing the set of objects and their relationships involved in a particular domain. It offer a semantic specificity able to harmonize a large amount of heterogeneous data and knowledge. But also, it allow creating new knowledge from the existing one. This specificity is beneficial mainly for knowledge intensive tasks. Second, currently, several tools offer ontological representation. We mentioned, for example, the open source Protegé OWL editor. Third, ontologies help storing and sharing knowledge in a standard form and support text-mining and knowledge discovery. Fourth, the ability to involve experts and to base on existing sources to construct ontologies makes it possible to consider both explicit and tacit knowledge. Finally, since ontologies involve concepts at various granularity levels, involving humans of different roles throughout the design, evaluation and validation processes is required. All these characteristics make ontologies an interesting and effective solution for knowledge representation.

Actually, using ontologies for knowledge representation is mainly interesting when knowledge is dispersed across multiple systems. Otherwise, it can be considered as pointless. In fact, it requires an important effort on choosing the appropriate vocabulary and it does not seem to be intuitive. These disadvantages do not encourage using ontologies in some case studies.

Symbolic Models

Symbolic models are defined as a set of representations (or symbols) of something. They are processed and manipulated based on a set of rules integrated into the model [96]. The rules operate on the representations according to their 'shape' or syntax, not according to what they represent (their semantics). [97] gave the example of the symbol '1'. In a simple way, it can be read as the number one. However in a symbolic model, it could be used to represent the state of being 'on'. Symbolic models are therefore extremely related to the considered field to represent.

Therefore, symbolic models can be used for expert knowledge representation [10,96,98]. For example, [10] proposes a principle of knowledge integration for the improvement of a system of defects recognition by vision in wooden boards. To represent his knowledge, the author uses symbolic models based on a method formalizing the expert knowledge expressed in natural language. Thus, in the field of the wood profession, to represent knowledge on wood defect, figure 3.12 shows a symbolic representation of a default with its type (1), uniqueness (2,4) and a position (3). For example, "A black node (default) is black (color), having a round form (form), etc.". An example of symbolic model for knowledge representation is used in [10], which is the NIAM method (Nijssen Information Analysis Method). This method can be used into computer applications (generating database structures, prototyping interface, etc.), and gives the possibility of developing a reusable database.

However, such a solution is based mainly on symbolic forms. As a result, there are as many forms as the number of objects and features to represent. We believe that the simplicity and abstraction are important to represent knowledge. This is considered as a limit, mainly in knowledge intensive tasks.

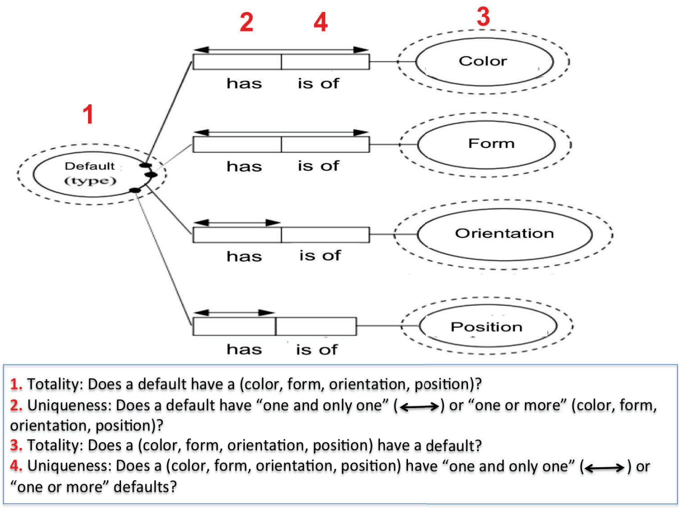


Fig. 3.12. Know *What* representation with the NIAM method in [10]

In addition, being dependent on the considered domain prevents symbolic models considering explicit knowledge. Actually, they are mainly based on experts' knowledge in the domain. For example in [10], different experts' roles are considered to fulfil the models, according to their knowledge, for example, experts in processes, products or norms. Not relying on explicit knowledge implies therefore expert' regular participation, which is a difficult task in companies. As a result, we consider that knowledge identification as well as its evolution and maintaining using such a model remain difficult to perform.

To summarize, compared to our defined criteria for an effective solution, some advantages and limits are identified with symbolic models. The main advantage is the ability to use them into computer applications, databases for example. This helps their knowledge storage and sharing. However, being very dependent to the considered field generates more limits. We note, difficulties in considering explicit knowledge, where experts are the only ones who decide of the models structure, symbols and meaning. These limit involves itself difficulties in evolving, maintaining and identifying knowledge.

Static UML Models

UML has become the standard for object-oriented modelling and there are several graphical tools that support it. Even though it is a graphical language, it consists of a set of constructs common to most object-oriented languages [99]. Besides, based on diagrammatic representation, UML offers several complementary diagrams, but each represents a different aspect. For example, the class diagram represents the logical view of objects' structure, whereas the use case diagram shows the features required by users. These characteristics differentiate UML from the symbolic models, such as the NIAM method, previously presented.

UML models provide graphical notations facilitating communication among developers and users. [12] considers the know-*What* as a set of connected objects, constraints and queries involving objects and connections. This is why he uses a UML diagram, based on classes and associations, and an algebraic modelling language to write constraints and queries. For example, knowledge on a teacher includes three classes, teacher, training and course, with two hierarchies of associations, manage and teach (figure 3.13). A constraint could be about each teacher work schedule according to his function. Besides, UML models can be effectively associated with easy to use platforms, considering various users' skills. For example, [12] bases on a platform called AROM developed in Java that offers a graphical representation with UML.

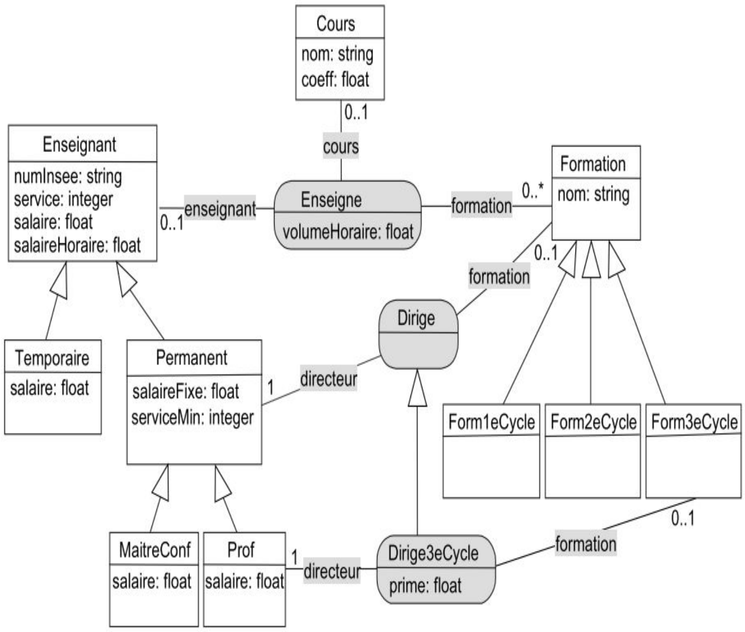


Fig. 3.13. Know *What* representation with UML class diagram in [12]

Besides, currently UML offers several methods able to consider both explicit and tacit knowledge. First, UML platforms can easily involve explicit knowledge, extracted automatically from databases or source code. For example, we cite ArgoUML [1] and Rational Rose [2]. Second, UML diagrams' design requires knowledge of the domain experts. For example, in his work, applied to education, [12] relied on different experts' knowledge in the domain to fulfil his models. Besides, since he chose a graphical notation easy to understand and use, he was able to validate his work by suggesting a textual description to represented knowledge. His solution was easily evaluated and validated by its users. Throughout his case study, he demonstrated that represented knowledge with a UML diagram can be easily shareable and reusable by users.

[1] ArgoUML is the leading open source UML modeling tool and includes support for all standard UML 1.4 diagrams (http://argouml.tigris.org/).

[2] Rational Rose is an object-oriented Unified Modelling Language (UML) software design tool intended for visual modelling and component construction of enterprise-level software applications (http://searchsoa.techtarget.com/definition/Rational-Rose).

To summarize, comparing static UML models with our identified criteria reveals that it can be effectively used for the know *What* representation. First, particularly, the class diagram provides a statical representation of the manipulated objects and their relationships. It can meet therefore the know *What* representation. This can be easily achieved with several UML platforms (AROM, ArgoUML, etc). Second, explicit and tacit knowledge are respectively considered through knowledge embedded in systems (databases, for example) and the involvement of experts. Being an easy to understand representation, the UML class diagram helps experts to participate throughout the conception and validation processes. Finally, most of UML platforms offer textual explanations promoting knowledge storage, sharing and reuse among users with different skills.

In this section, we discussed the way the know *What* can be represented. Ontology based solutions, symbolic models and static UML diagrams were presented and compared with our identified criteria for an effective solution. Each solution has its limits and advantages that can lead us to select one among the others. First, symbolic models are very dependent on the considered domain, lacks of simplicity and abstraction and bases mainly on experts' knowledge and involvement. These limits prevent their use for knowledge representation. Second, despite all the advantages that ontologies offer for knowledge representation, their use depends a lot on the application context. As we discussed above, ontologies become interesting mainly when applied to dispersed knowledge across multiple systems. In other contexts, it is rather not intuitive and complex to construct. Third, static UML models and mainly the class diagram seems to be the most appropriate solution for representing static knowledge. It is easy to understand, implement and remains an intuitive solution for its users.

The solutions presented above are not formal enough to permit reasoning. That is why, the next section presents a similar work for the know *Why*.

Know-*Why*

It represents "a deep understanding of causal relationships. It involves an understanding of reasons underlying theory and/or a range of experiences that include interaction effects, and exceptions to the norms of an area" [100]. This is why [88] highlighted the importance of considering the know *Why* as a crucial component of knowledge. Generally, the reasons for design decisions, can change throughout the designing process and context, which could make them easily lost. According to [86], usually a system is defined in terms of specifications and parameters to describe the way it works. But it does not include a description of *Why* it is designed the way it is. This is not usually completely capitalized, which implies ambiguity. Therefore, keeping track of the know-*Why* will provide help to users and designers to resolve problems and to explore more design options.

To this end, design rationale techniques are, actually, an effective solution for the know *Why* representation [14,15,101,102]. Their ability to involve different actors in their design and evaluation, while considering their tacit and explicit knowledge, lead us to deepen the solutions offered by this area.

Different design rationale notations have been proposed in the literature to represent design options: DRAMA (Design Rationale Management) [103], EMMA (Evolution Memory Management Assistant) [104], SAGACE [105], DRL (Decision Representation Language) [106], IBIS (Issue Based Information Systems) [102], DRCS (Design Rationale Capture

System) [107], QOC (Questions, Options, Criteria) [101].

They classically use notations to help representing knowledge. [108] compared and categorized them according to their application objectives. Her conclusions and findings reveal that some methods are focused on design rationales in projects (IBIS, DRL and QOC). Others are more general (DRCS, DRAMA, EMMA, SAGACE and DRCS). For example, DRCS is focused on concurrent engineering (i.e. performing tasks concurrently), which is not our case.

This is the reason why, in this section, we decided to focus our state of the art mainly on methods for design rationales in projects. Besides, several platforms exist to support the design rationale representations while providing sharing and reuse functionalities. We note, for example, gIBIS (Graphical hypertext software tool for building IBIS network) [6, 15] or SIBYL [14]. As a result, in the following, IBIS, DRL and QOC methods are discussed and compared to our criteria for an effective know *Why* representation.

IBIS Method

The IBIS method [102] aimed to provide a structure for the dialogue in solving complex design problems. Next, the method has evolved and several supporting tools were developed, for example, gIBIS (Graphical hypertext software tool for building IBIS network). Currently, the method is used to represent the Design Rationale in projects. The IBIS method is based on a structured decision making, conducted in a design project. It is composed of three elements: Issues, Positions and Arguments, linked with nine relationships (figure 3.14). We note for example, Position answers Question, Argument supports Position, Argument opposes Position, etc.

An example was proposed by [13] (figure 3.15). It describes some of the design and implementation issues explored in a given process. The considered issue is "I: What is the appropriate architecture?". The first position "P" proposes to "Design a pure java". This Position has the following Arguments: "+A: There are plenty of open source applications that may be used", "+A: High level of security can be achieved" and "-A: It is dependant on java compiler". The first two arguments support the first position and the last argument opposes it. This position implies itself an new issue "I: Are there any existing drawing tools?" and so on.

As shown in this example, the method is considered as narrative [108] since it takes note about the decision made at every stage of the design process. This is why, it is called "process-oriented approach". This makes the IBIS solution not suitable to our purpose.

DRL

To overcome the narrative aspect of IBIS, DRL [14, 106] aims to provide a language for representing the qualitative aspects of decision making processes. To this end, it keeps track of multiple view points. Its fundamental objects are: "Goals", specifying the properties of the ideal option, "Alternatives", representing the options to choose from, and "Claims", constituting arguments relevant for making the choice.

An example, given in [14], is shown in figure 3.16. It shows made decisions about which programming language to use for implementing a project called Xanadu. "Choose

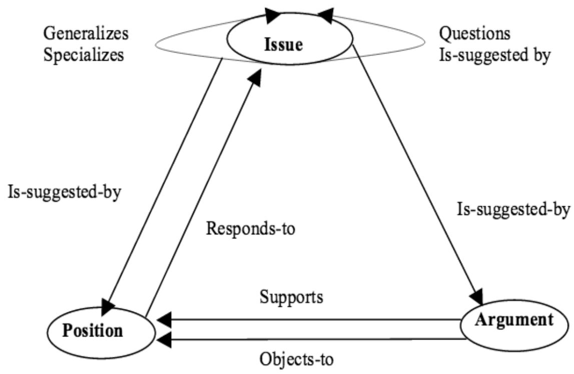


Fig. 3.14. Know *Why* representation with IBIS

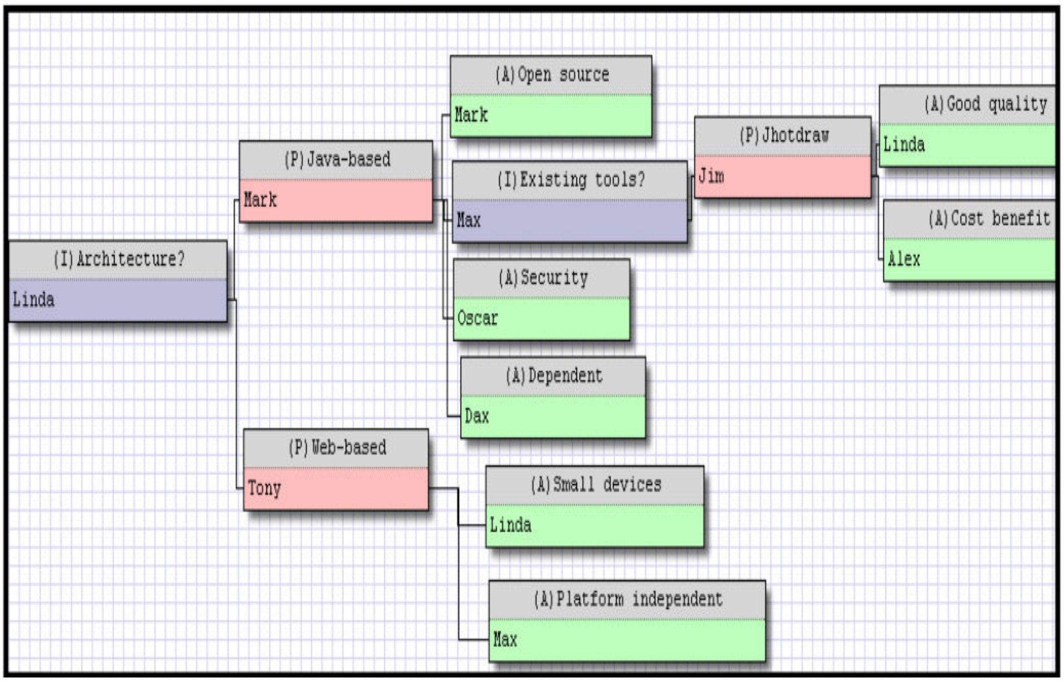


Fig. 3.15. An example of IBIS model in [13]

the best programming language for implementing Xanadu" represents the decision problem. Goals are "Supports Rapid Prototyping", "Minimizes Development Time", "Is Very Portable", etc. The relationship "IS-A-SUBGOAL-OF" relates two goals if one facilitates satisfying the other. For example, "Has a Good Debugging Environment" is a sub-goal of "Minimize Development Time". The alternatives are linked to the decision problem via IS-AN-ALTERNATIVE-FOR: C, C++, Lisp, etc. Finally, each alternative is related to each goal via a FACILITATES relation. In DRL, every relation is a CLAIM. Therefore, the FACILITATES (ALTERNATIVE, GOAL) relation is interpreted as the claim that ALTERNATIVE facilitates satisfying the GOAL.

To support the DRL modelling, SIBYL is an example of one tool that allows managing the qualitative aspects of decision making processes.

Actually, DRL focuses on the representation of elements of decision making and its rationale. However, representing the reasoning behind the implementation of particular

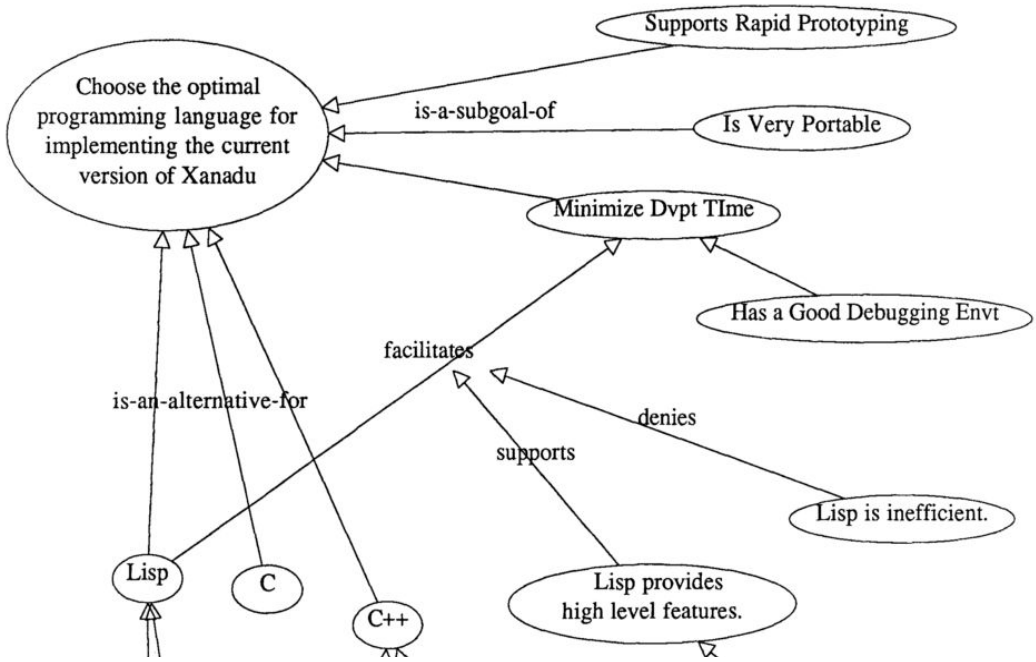


Fig. 3.16. An example of DRL model in [14]

features is limited. This is the reason why, we consider that DRL does not fully meet our objectives.

QOC

With IBIS and DRL, we noted two main limits, the narrative characteristic of IBIS and the limitation in representing particular features in DRL. These ones are treated in the QOC model [101]. It represents design reasoning as a network of "Questions", representing the issue, "Options", representing alternative solutions and "Criteria", evaluating the options, such as desired properties. Such a simple representation solution allows its designers and users understand the reasons for or against the various options. The advantage of the QOC model is its ability to target alternatives on specific artefact features.

An example of application was given by [15] and shown in figure 3.17. It presents two options widgets allowing a user to enter a date. The first option of interactor is composed of three input fields that the user must respect. The second option of interactor is a calendar widget that allows to select a date by clicking instead of typing. As shown in the figure, the calendar option satisfies the three criteria (represented with normal lines) while the option composed of three input fields does not (represented by dotted lines). As depicted in this example, the main advantage that offers the QOC model is the discussion of alternatives on specific artefact features.

Besides, the QOC model is a semi formal language that is actually based on a meta-model, defined into the UsiXML language [15]. It offers to its users a simple formal structure of its concepts, Questions, Options and Criteria, and their relationships. Nevertheless, their content remain informal and unrestricted. This is why QOC representations were considered by [101] as "effective communication vehicle, because they are simple enough to be understood by a variety of people, they are flexible enough to represent a variety of issues

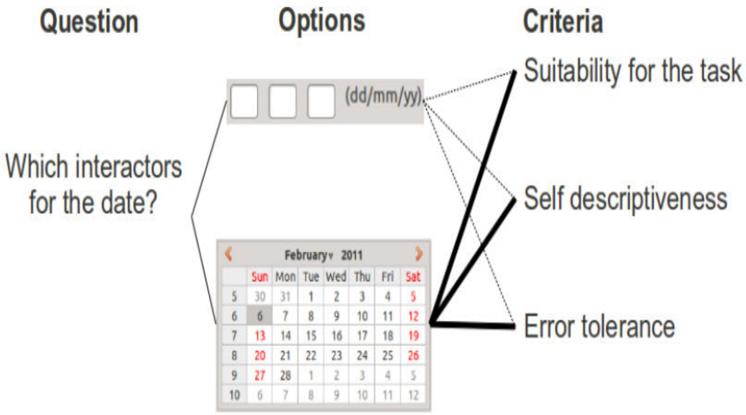


Fig. 3.17. An example of QOC model in [15]

from a variety of viewpoints, and they are explicit enough to expose assumptions that can be challenged by others".
These advantages make the QOC model suitable to the know *Why* representation. Technically, it exist many platforms to construct the QOC model, for example SIBYL, gIBIS, etc.

To summarize, the state of the art on the know *Why* modelling, presented in this section, focuses on three design rationale models, IBIS, DRL and QOC. As a result two main limits have been identified in IBIS and DRL: the narrative aspect within the IBIS model and the limited representation of the reasoning behind the implementation of particular features within DRL. These limits are absent within the QOC model. In its turn, QOC presents interesting advantages for representing behaviours and explanations. Particularly, being flexible and easy to understand, it is able to tackle several features characteristics according to its users' skills and points of view. Users can therefore be involved throughout its design and evaluation. In addition, currently, many platforms for design rationale exist and offer sharing, reuse and systems integration functionalities, such as, gIBIS, SIBYL, etc. First, this makes it easily shareable and reusable among people. Second, it facilitates considering not only on tacit knowledge but also explicit one embedded in other systems accessible by design rationale tools.

Know-*How*

The know *How* consists in representing the technical aspect of processes. For its representation, different approaches have been proposed, in particular for the software development process. [109] considers that process models can be activity, product, decision, context or goal oriented. But a deeper analysis of these possibilities shows that decision, context and goal oriented models are actually more related to the behavioural aspect of knowledge throughout processes than its technical achievement. More precisely, first, decision oriented models care about the context of the decision, i.e. the arguments and the alternatives. They try to identify and memorize the rationale of the decision process all along the project. Second, context oriented models are focusing on the context during the development process and the made decisions. Third, goal oriented models focus on the choice of a strategy in a set of possibilities, in order to achieve an intention. It present therefore alternatives, choice criteria or intentions. Consequently, we consider that these three kinds of models are rather behavioural representations. That is why, in the following, we focus on the product and activity oriented models.

Product Oriented Models

Product-oriented models do not focus on the activities of a process but on the result of these activities. They aim to model the evolution of the product and to link the state of the product to the activities that led to this state. [110] explains that product oriented models "represent the development process through the evolution of the product", and [111] represents them with a statechart diagram, focusing on the state of the product at the end of each task. An example could be the study of the successive states of a document: first, it could be "to be done", then "prepared", eventually "refined" and finally "validated". In this example, the process model would have to define the activities leading to each state. The main limit in such models is its limited application. Actually, it is more dedicated for representing activities where products states change regularly. For example manufacturing or maintenance activities. It is related to the states' evolution of products throughout processes but not in the way they are developed.

Activity Oriented Models

According to [112], activity oriented models suggest a set of activities, decomposed when needed into simpler ones, and linearly ordered. For instance, such a process model could propose the following activities: study the users' needs, describe the use cases, identify the objects and so on. Such a model would for example recommend that a designer makes a behaviour analysis which includes three stages: use case analysis, design elements identification and design refinement. Including these three components together constitutes the advantage of this type of models. In fact, activity oriented models involve at the same time roles and their tasks and needs, objects manipulated throughout the process (inputs and outputs), while decomposing activities to simpler ones. We cite for example, UML activity diagram [99], BMPN [113], IRTV [114]. We consider these statements as important requirements for the know *How* content.

IRTV answers all these requirements [114]. IRTV means Information, Roles, Tasks and Views and deals with platforms' configurations. Its advantage is its ability to be easily adapted to all types of knowledge, particularly the technical aspect. An other advantage that differentiates this model among the others is its ability to integrate them within it [16]. For example, it is able to include the BPMN model to represent the process modelling. Figures 3.19 and 3.18 summarize the main aspects of this methodology. Among these aspects, in our research, we are interested in the ability to involve different roles, to represent the views they are interested in, the platforms they use and their performed tasks.

In addition, the IRTV model is supported by the AKM (Active Knowledge Modelling) platform as a support tool. AKM is. Among its functionalities, we note integrating modelling and execution, concurrently at runtime, as well as providing a simple and easily configurable collaboration infrastructure for companies.

Involving different actors' roles implies considering their knowledge (tacit). Besides, the ability to integrate knowledge within other models (BPMN for business process for example) implies considering explicit knowledge. Its representation, particularly based on each role's view and needs, facilitates identifying, sharing and reusing the knowledge among different skills. It is actually able to target developers as well as novice roles needs.

Target roles	- Consultants and internal IS people who build solutions - Super users who support and customize solutions - Users who want to adapt their own solutions - Methodology developers who define reusable solutions - Application integrators who set up data exchange and notification protocols with legacy tools
Knowledge modeling dimensions	- Information - Roles - Tasks - Views
Tasks	- Concept development - Scaffolding - Scenario modeling - Solutions modeling - Platform configuration - Platform delivery - Performance improvement and operations support
Views and tools	- Configurable visual workplaces (CVW)

Fig. 3.18. IRTV aspects [16]

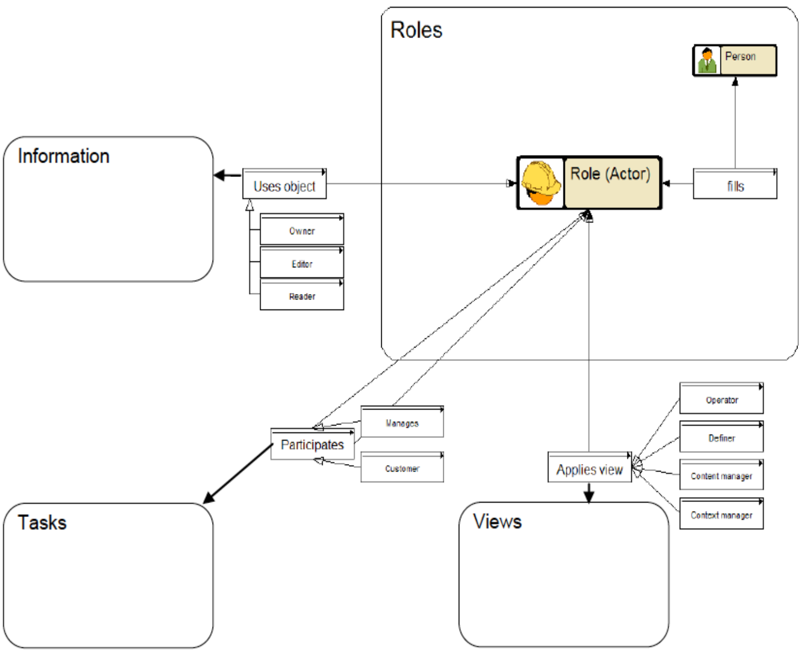


Fig. 3.19. IRTV model

Discussion

We carried out a comparison of the methods discussed in this section. This comparison is based on our identified criteria for effective solution for an knowledge representation. As a result, table 3.2 summarizes findings in literature about the know *What*, *Why* and *How* representation.

As we have seen in the current section, studies in the literature do not define (ie with the same names), consider (all of them together) and represent knowledge characteristics

	What			*Why*	*How*
Comparison criteria	[11,90,93]	[10,99]	[12]	[14,101,102,106]	[16,112,114]
To involve the appropriate representation	Ontologies	Symbolic models	Static UML and algebraic modelling	Design rationale	Activity Oriented Models
To involve the appropriate tool support	Protegé OWL editor	Databases	AROM (Ally Relationships and Objects for Modelling)	gIBIS (Graphical hypertext software tool for building IBIS network), SIBYL (a tool for managing group design rationale)	AKM platform
Humans' involvement	Knowledge evaluation, ontology construction, content revisions	Models filling	Models filling and validation	Design and validation of the models and their contents	Design and validation of the models and their contents
Humans' roles	Molecular biologists, clinicians and physicians in [11]	Experts in processes, products, norms in [10]	Teachers of different grades in [12]	Rationales differ according to each role's point of view	Different roles
Kind of considered knowledge	Tacit and explicit	Tacit (Experts knowledge)	Tacit and explicit	Tacit and explicit	Explicit and tacit
Supported parts of the knowledge capitalization cycle	Knowledge storage and sharing based on dictionaries [11]		Sharing and reuse with textual descriptions	Identification, sharing and reuse	Identification, sharing and reuse

Table 3.2. Knowledge representation solutions' analysis

similarly (know *What*, *Why* and *How*). We believe that selecting one technique among others depends on its context of use, as well as its language nature. Actually, we do not process similarly with natural language (Symbolic models for example) and formal or semi-formal languages (UML or qoc for example). Besides, some methods can correspond to knowledge content representation but not easily integrated to the whole capitalization cycle or do not offer suitable techniques in the applicable environment. In addition, some of them offer the ability to base on explicit and tacit knowledge while involving tools and humans as knowledge sources (Ontologies, UML and QOC for example), and others not (Symbolic models for example).

As a result, considering the methods that meet the whole identified criteria together is our objective. In addition, we note the importance to represent all of the three knowledge characteristics together as a system while representing their interactions and involving users. In this work, knowledge representation is an important step that should be effectively considered. In fact, it will serve as a basis to mainly promote knowledge sharing and storage.

3.2.2 Knowledge Sharing and Storage

In this section, we propose to study and compare existing knowledge sharing and storage tools, in a first stage. Next, we will detail the most appropriate solution.

Existing Solutions for Knowledge Sharing and Storage

Knowledge sharing and storage is naturally a social action. It consists in mutual engagement, shared repertoire and joint enterprise [45,115,116]. As a result, humans' involvement characterises knowledge sharing and storage tools. In this section, a literature review is presented to compare and discuss existing knowledge sharing tools.

To preserve the knowledge of their employees, organizations provide shareable and accessible workspaces: wikis, Social Bookmarking, collaborative filtering, social networks, blogs, Facebook, LinkedIn, etc [44]. Despite the success of this type of tools, some of them are less professional or less effective than others [117]. For instance, there is a tendency to include email, discussion lists or message board under the umbrella of social software. However, there is an important distinction between traditional communication software and social software enabling people to organize themselves into a network based on their preferences. In fact, we take into account this distinction and we consider, therefore, that knowledge sharing tools correspond to the second type of tools, which are social software.

Several studies in the literature have discussed the problem of distinguishing and selecting the appropriate tool for knowledge sharing [27, 44, 118, 119]. All of them argued with the growing popularity of Enterprise Social Software also known as Enterprise 2.0. It is known as the concept of using tools and services that employ Web 2.0 techniques such as tagging, ratings, networking and RSS [120]. They provide rapid and agile collaboration, information sharing, emergence and integration capabilities in the extended enterprise. [27] noted that organizations such as IBM, General Electric, Procter & Gamble, Shell and Airbus have replaced their knowledge management systems with Web 2.0 applications. [44] demonstrated that the literature contains many more reports of successful Enterprise 2.0 initiatives than of failed ones. However, he distinguishes those that support collaboration and those that allow the posting of information in a common space for other people to access it. We are interested in the first type of solutions. The most collaborative ones are wikis, social bookmarking, collaborative filtering and social networking. We briefly present them in the following:

- Wikis are a group of web pages that can be edited by anyone who accesses them. They allow their users to create new pages and to view and edit existing ones (Wikipedia). Therefore, they base on collaborative knowledge elicitation and sharing.

- Social bookmarking is a centralized on-line service which enables users to add, annotate, edit, and share bookmarks of web documents. This method is relevant for organizing and storing links (definition in Wikipedia). However, it does not allow knowledge elicitation on the content of the considered web document.

- Collaborative filtering is the process of filtering for relevant information or patterns using techniques involving collaboration among multiple agents, viewpoints, data sources, etc (definition in Wikipedia). Therefore, it is more dedicated to build recommendation systems.

- Social networking is a social structure made up of a set of social actors, such as individuals or organizations. We note, for example, Facebook and LinkedIn. However, with such tools, there is often overlap between personal and business. Besides, they tend to transcend organisational boundaries and hierarchies [117]. This does not encourage their uses within organizations.

Among these solutions, some are more relevant for knowledge elicitation and sharing. This is the case of wikis that can be collaboratively used for knowledge elicitation, storage and sharing within organizations. In addition, in our business needs (defined in chapter 2), we noted that *STMicroelectronics* uses a *Wiki* for knowledge sharing. Throughout its evaluation, we have considered that its use can be beneficial within the organization. These results support our choice to use a wiki for knowledge sharing.

This is why, we focus in the following on the use of Wikis in the literature. In our research, we decided to keep the sharing function of a *Wiki*, because we consider that sharing and storing knowledge are highly dependent. If the *Wiki* is effectively used for sharing it will be effectively used for storing.

Wikis for Knowledge Sharing and Storage

A *Wiki* is a fully interactive site designed to be a dedicated web server generating dynamic pages from editions of visitors [121]. It allows users to post their knowledge in a common area. In fact, discussing the existing knowledge on a platform allows users to easily and collaboratively create and to edit pages [116, 121]. In this regard, according to [122], a *Wiki* stimulates writing, promotes effective communication and low cost collaboration, and promotes close reading, revision, and tracking of drafts.

Nowadays, Wikis contribute to several areas of activities such as teaching and education [123], commercial sites [52], industry [124], etc. In the following, we propose a review of some experiences using Wikis for knowledge sharing in different sectors in order to learn about their uses. This review has helped us to identify evaluation criteria of wikis that are actually constituting our problem space related to knowledge sharing. They are required to ensure an effective use from different points of view.

- **Industry**

  [49], A controller *Wiki* system called "CorpWiki" is proposed. This tool was developed to examine the quality of articles inserted by employees within an organization to decide whether an article requires improvement. The particularity of CorpWiki is its ability to appoint the most appropriate person to improve the quality of the article, thanks to an advanced matching algorithm. In that way, not only explicit knowledge is considered but also the tacit based on the appropriate person's experience.

  On the one hand, CorpWiki is described as a self-regulating wiki-based system to collect corporate knowledge and combine it with the individual intelligence of the organizational members. Each article inserted in CorpWiki undergoes as many contributions and review processes as necessary to reach high-quality levels, within minimum time. CorpWiki provides an accessible common space easy to use, since users can easily retrieve the information they search for and ensures its content relevance.

  On the other hand, to select the appropriate reviewer, CorpWiki includes a 'fairness-based" policy, where the selection is made based on a fair workload distribution. This ensures therefore collaboration and collective participation as well as verity in correctors' designation. Its strength is that different persons, from the same domain but with different skills and orientations, are collaboratively contributing on a specific subject. This ensures the involvement of different roles in its use. However, even though they are effectively involved in its use, authors did not note how users are

involved in its design, evaluation and validation.
CorpWiki is highlighting important aspects promoting the use of wikis: accessibility, ease of use, content relevance and collaboration. Such characteristics should be considered when adopting a wiki for knowledge sharing.

- **Education**

  The study in [125] was conducted at Oxford Brookes University in the UK, one of the higher education institutions. It was realized to encourage a group of students specialized in Japanese language or studying a module in Japanese to conduct researches on grammar and create learning pages based on users' knowledge (tacit) and documented ones (explicit). The objective of this study was to learn about the use of a *Wiki* to facilitate group work. Particularly, how a *Wiki* can be designed to ensure collective learning? And how the centralization of the learning space can affect the experience of the participants in the study of Japanese? Even though the users are basically of the same profile, this process ensures the participation of the solution users in its design and evaluation.

  To assess this experience, quantitative and qualitative methods consist mainly of statistics methods and face to face interviews. The majority of students found that the use of a *Wiki* provides an interest for their study to learn Japanese. They were highly motivated to discover new skills and consider the *Wiki* as a suitable technology for sharing and editing the content. This experience has encouraged many participants to reflect on their learning styles and preferences. One student noted his preference for "learning by doing" rather than passive transmission of information.

  However, some students have encountered technical problems during its use which is explained by the lack of users' experience with such a tool especially for contribution. In such cases, **ease of use** becomes a required criterion ensuring effective use. Besides, according to students, creating working groups and including a discussion tool helped to develop team work skills and supported collaborative, constructive and interactive learning. That makes therefore collaboration and collective participation important concepts characterizing *Wiki* for knowledge sharing.

- **Research**

  This case study [44] was conducted within a group of researchers who work primarily in fields such as engineering, applied science and management. Shared knowledge is therefore based on their experiences (tacit) as well as on their researches and publications (explicit). Its objective is to assess how researchers share their knowledge and how it can be improved. The problem that was found is that researchers do not communicate as it should be and that knowledge sharing has not been effectively treated. Some features considered important were implemented: Identify users' profiles, as well as groups and categories of work, user guide and a section of general problems, discussion areas, etc. However, despite considering different profiles in its use, it was not the case for its design and evaluation.

  Researchers were aware of the benefits of a *Wiki* and it was then adopted voluntarily by the community. However, its use has been declined over time. This was explained by the lack of time of researchers, the impression that the *Wiki* does not have much interest for users particularly those who are in the organization for more than two years, Besides, not having an easy direct link to the *Wiki* on computers limits its accessibility.

In his research, in order to effectively use a Wiki for knowledge sharing, [44] relied on the participation of actors in the design and evaluation of his *Wiki* by identifying its limits, advantages and functionalities using interviews, questionnaires and statistics. Such methodologies are important to ensure the effectiveness of a knowledge sharing solution.

To summarize, in this case study, the use of the *Wiki* showed a lack of **collaboration and collective participation**, as well as luck of **users' investment and awareness** of what it offers. The decline in its use demonstrates the importance of such concepts in its use for knowledge sharing.

- **Commerce**

  In [27,52], the author describes the experience of eBay in the use of a *Wiki* for knowledge management. According to [52], more than 100,000 messages posted on the forums every week. These messages must be organized and indexed to be consulted and revised. After much review, eBay decided to use a *Wiki* to amass community members to one coherent common space to share their experience. Certainly, in sites like eBay, the open culture ensured reputation and trust between members and clients which played a crucial role in the success of knowledge sharing within the site.

  Wiki allows all registered members to contribute and edit content. Their *Wiki* already has 346 articles on issues of trading on eBay. Some features have been added:

  – The user-friendly interface takes into account the skill level of the user and ensures its ease of use.
  – Indexing and organizing information keeps its content relevant.
  – Many articles are collaboratively written for new users by experts which demonstrates their **investment and interest in its use**. Shared knowledge can help novice users adapting themselves to the concept of online business and self learning.

  The experience of eBay is considered as successful because the integration of *Wiki* achieved its desired goal which is disseminating knowledge among users. The Ebay Wiki considers different best practices promoting its use and success: Common space, open culture, user friendly interface, ease of use, content relevance, content structuring, collaboration, investment and interest in its use.

  However, in his experience with a Wiki, eBay did not detail how the solution involved actors throughout its design, evaluation and evolution.

Experiences using wikis for knowledge sharing and storage are various and allow us learn about their uses and analyse their best practices, success and failure factors. As a result, we identified a set of evaluation criteria for knowledge sharing. As depicted in figure 3.20, they actually constitute our problem space that the wiki, in the context of *STMicroelectronics*, should meet.

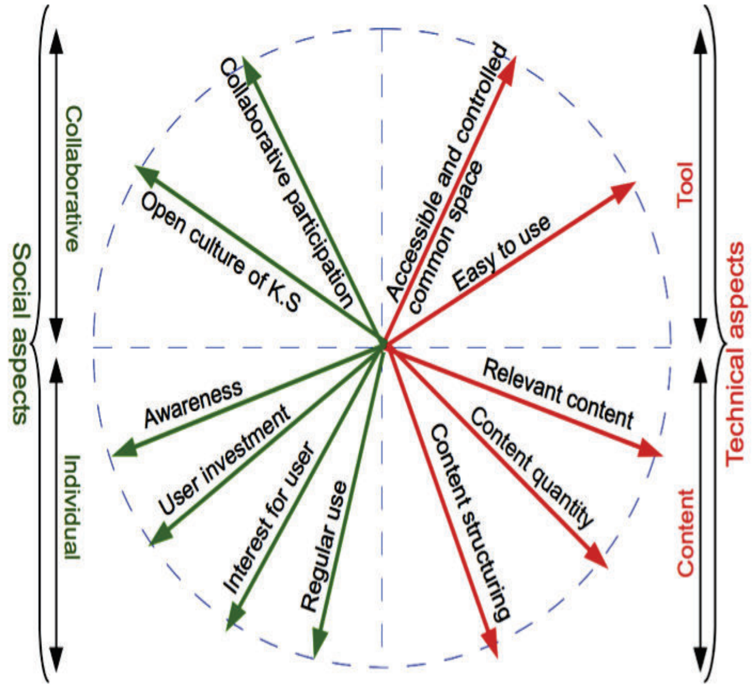


Fig. 3.20. Wiki evaluation criteria

3.3 Knowledge Evolution

3.3.1 Knowledge Evolution Characteristics

The rapid growth of business promotes a fast changing knowledge. The process by which knowledge assets of an organization change over time to cope with the pressure of environmental variation is called knowledge evolution [18].

In the following, we compare contributions in the literature and discuss how they meet our criteria for en effective knowledge evolution solution (section 3.1).

- (1) To involve the appropriate methods.
- (2) To involve the appropriate IT tools.
- (3) Humans' involvement.
- (4) Humans' roles.
- (5) Kinds of considered knowledge.
- (6) Considered tasks for knowledge evolution.

[17] proposed a cycle of knowledge evolution, where he explained how knowledge is adapted to the environment. As depicted in figure 3.21, knowledge is described as evolving through a series of stages, chained in a recursive cycle. First, the cycle starts with the variation stage, where a set of ideas or new challenges are generated. This is achieved thanks to external stimuli for example, normative changes, scientific discoveries, substantial creativity, etc. Second, internal selection allows evaluate the potential of these sets of ideas through collective analysis and debate of their advantages and limits. Third, the replication phase serves the function of diffusing and sharing the newly minted knowledge to the places and times where it is needed. It can also contribute to new information that can allow start

a variation phase of a new knowledge cycle. Finally, the new knowledge is internalized in the organization's routines in the retention stage. To summarize, 3.21 considers four stages for knowledge evolution: identify knowledge and evaluate, share and internalize its content. Actually, the most considered action promoting knowledge evolution in his proposal is, in fact, its **evaluation**. As a result, he basically, considers **knowledge content evaluation**.

In addition, such a process makes knowledge evolve towards a more tacit form as it becomes highly embedded in the behaviour of the individuals involved in the multiple executions of the task. Besides, based on external environment including explicit and tacit knowledge (stimuli and feedback), it allows to reflect on possible evolution and viability of the organization's current knowledge. Actually, this model describes the evolutionary nature of knowledge throughout its different phases. Even though [17] explained how actors can evolve their knowledge collaboratively, he ignored considering variance and divergence in actors' knowledge.

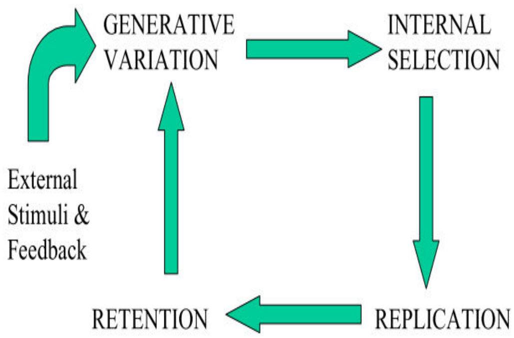


Fig. 3.21. The knowledge evolution cycle in [17]

To deal with the limits identified in [17], [18] extended the knowledge evolution model presented above (figure 3.21). He conceptually defined and empirically tested two knowledge evolution strategies: knowledge mutation and knowledge crossover strategies (figure 3.22). First, knowledge mutation allows creating knowledge from existing one, by internal forces, such as internal Research and Development (R&D) projects. This strategy helps **continuously** updating knowledge. The knowledge crossover strategy acquires new knowledge from outside the organization. It assimilates it with existing knowledge, in order to take advantage of learning from others and reusing their knowledge. With an empirical study, authors demonstrated that proposed strategies affect different dimensions of organizational performance, for example, internal processes, learning, growth, finance, customer, etc. These findings suggest to include both internal and external strategies for knowledge evolution. This extension allows consider at least two roles acting on knowledge evolution, internal and external actors. We believe that involving actors in both design and evaluation ensures an effective solution, in this stage for knowledge evolution.

Actually, since the solution in [18] is an extension of the solution in [17], it keeps the same evolution cycle, that includes, as well: identification, evaluation, sharing and internalization. However, two additional contributions are included. First, it expands the type of the considered knowledge content to include external and internal. Second, it highlighted the importance of **continuously evaluating** the content of the external and internal knowledge.

A more advanced solution is proposed by [126]. He presents an architecture for a community knowledge evolution system called CKESS (Collaborative Knowledge Evolution

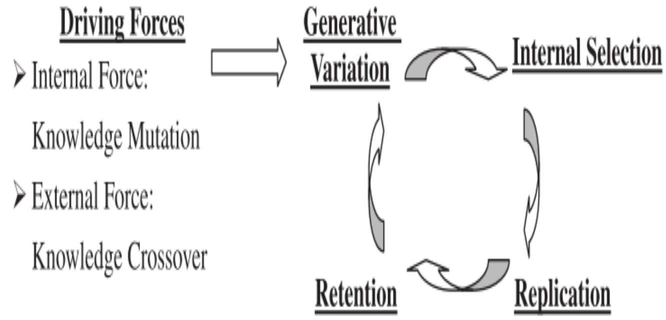


Fig. 3.22. An extended knowledge evolution model [18]

Support System). The contribution involves augmenting a multimedia document repository, in which users collaborate to share and evolve their knowledge. An innovative knowledge evolution support includes computer-mediated communications, community process support, decision support, advanced hypermedia features, and conceptual knowledge structures. The main idea behind this solution is to allow collaborative knowledge evolution and continuous meta improvement within virtual communities.

As a result, the knowledge evolution proposal in [126] considers identifying, sharing and **continuously evaluating knowledge**. However, in addition to continuously evaluating knowledge content for its evolution, [126] expands his solution to evaluate the whole knowledge system. Its considers, the knowledge content, but also knowledge on the involved systems (computer-mediated communications, decision support, conceptual knowledge structures, etc).

Such considerations ensures an effective and **continuous evaluation for the whole knowledge system**'s evolution. The considered community's knowledge has both explicit and tacit components, The explicit includes documents, recorded discussions, etc. Its implicit knowledge resides in the heads of the community members themselves. In his research, [126] involves different communities including educational, medical and professional ones in the design. An example is about building a form of collaborative knowledge base allowing model, view and to a limited degree, execute many tasks in the CKESS system. In addition to design, communities are as well **continuously** involved in its **evaluation**, where data, could be collected from community leaders/officers (measured through periodic semi-structured interviews), general community members (measured through surveys), and if possible, people outside the community.

Table 3.3 summarizes how previous solutions for knowledge evolution deal with our identified criteria for an effective solution.

As discussed above, literature presents limited but different proposals for knowledge evolution, which can be technical and/or organizational. Based on these studies, different criteria could promote the success of a knowledge evolution solution. We note for example, co-construction, collaboration and technical capabilities, as summarized in table 3.3.

As a part of a knowledge capitalization cycle, knowledge evolution should ensure the evolution of capitalized knowledge, as well as the involved systems in the knowledge capitalization solution. This should be achieved in a continuous manner. It should involve users' knowledge (tacit and explicit) and users' roles in our solution design and evaluation.

Comparison criteria	[17]	[18]	[126]
To involve the appropriate method	Knowledge evolution cycle	Knowledge mutation and knowledge crossover strategies	Advanced hypermedia features, and conceptual knowledge structures
To involve the appropriate IT tools and methods	No	No	Collaborative Knowledge Evolution Support System (CKESS)
Humans' involvement	Collective analysis and debate	Research and Development projects	Collaborative knowledge base allowing model, view and execute tasks
Humans' roles	No	Internal and external actors	Different communities of professional in education, medicine, etc.
Kind of considered knowledge	Tacit and explicit	Tacit and explicit	Tacit and explicit
Considered tasks of the knowledge evolution	Knowledge content evaluation	Continuous knowledge content evaluation	Continuous evolution for the whole knowledge system

Table 3.3. Knowledge evolution solutions' analysis

In fact, some types of evolutions or changes inevitably need a major work, meaning months of hard work, big budgets and new changes. With knowledge evolution, improving and renewing existing knowledge are our concerns. However, a complementary approach to improve systems, processes and knowledge content, is through ongoing changes and continuous improvements.

As shown in this literature review, knowledge evolution is highly related to a continuous evaluation of not only knowledge content but also the whole knowledge system [126]. We believe that these characteristics should be taken into account in a knowledge evolution solution.

Regarding the context at *STMicroelectronics*, we previously identified business needs related to *Business Intelligence* system's knowledge evolution. Thus, combining this need with findings from the literature review, we study in the following, *Business Intelligence* knowledge evaluation as a part of its evolution.

3.3.2 BI Knowledge Evaluation

[127] provides a systematic approach for selecting BI tools. He proposed a general quality model for BI tools supported by appropriate functions of assessment and a set of rules for measuring processes. To this end, he elaborated a method for comparison of existing BI systems that are supporting data mining. He based on a literature review and existing standards of ISO to create a quality model and proposed a set of basic measures for BI systems evaluation. A case study showed the usefulness of proposed evaluation method for comparison of real BI systems.
For the same reason, [20] sought to learn from organizations that have implemented a BI system. He examined the interrelationships of BI success dimensions. As a result, he proposed a BI success dimensions affecting its use. As a result, a BI success model was elaborated. He believes that the evaluation of such a model and interrelationships between its dimensions enables the understanding of BI problems and key success factors.
[21] examines the role of the decision environment in how well BI capabilities are leveraged to achieve BI success and evolution. In his study, [21] examined the relationship between technological and organizational BI capabilities, decision environment characteristics and

BI success.

All these works aim to identify success factors for BI evaluation. However, two main categories of limits have been identified in literature case studies. First, they limited the topic of knowledge improvement to an evaluation problem where most of works suggest evaluation criteria with almost no particularities to BI systems. The second limit concerns the proposed solutions for BI evaluation. In the following, we will investigate the literature on BI evaluation criteria and solutions.

3.3.3 BI Evaluation Criteria

In literature, case studies [19, 20, 22, 34, 127, 128] limited the improvement of BI topic to an evaluation problem. The evaluation, in general, has been much discussed in literature. Two main kinds of solutions are proposed, respectively based on standards and elaborated models.

Standards

The ISO 25000 family is one of the most known models dedicated for the development of software products. It specifies quality requirements and evaluation quality characteristics. It provides a quality model allowing to decide which quality characteristics will be taken into account when evaluating the properties of a software product [129]. As depicted in 3.23, the product quality model defined in ISO 25000 comprises eight quality characteristics and their sub-characteristics:

- Functional suitability: represents the degree to which a product or system provides functions that meet stated and implied needs when used under specified conditions. Its sub-characteristics are functional completeness, functional correctness and functional appropriateness.

- Performance efficiency: represents the performance relative to the amount of resources used under stated conditions. Its sub-characteristics are time behaviour, resource utilization and capacity.

- Compatibility: is the degree to which a product, system or component can exchange information with other products, systems or components. Its sub-characteristics are co-existence and interoperability.

- Usability: is the degree to which a product or system can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. Its sub-characteristics are appropriateness recognizability, learnability, operability, user error protection, user interface aesthetics and accessibility.

- Reliability: is the degree to which a system, product or component performs specified functions under specified conditions for a specified period of time. Its sub-characteristics are maturity, availability, fault tolerance and recoverability.

- Security: is the degree to which a product or system protects information and data. Its sub-characteristics are confidentiality, integrity, non-repudiation, accountability and authenticity.

- Maintainability: represents the degree of effectiveness and efficiency with which a product or system can be modified for improvement. Its sub-characteristics are modularity, reusability, analysability, modifiability and testability.

- Portability: is the degree of effectiveness and efficiency with which a system, product or component can be transferred from one hardware, software or other operational or usage environment to another. Its sub-characteristics are adaptability, installability and replaceability.

The idea to base on formal specifications described in international standards is very interesting. This is the reason why many researchers in the literature reuse standards for BI systems' evaluation. On of the most used standards for this purpose is the ISO 25000 family, previously presented. For example, we find works proposing criteria according to the software functional complexity [128], functional suitability [22], and more generally, according to its external and internal quality and quality in use [127]. For example, their criteria are defined for information delivery, BI integration and BI analysis points of view [128].

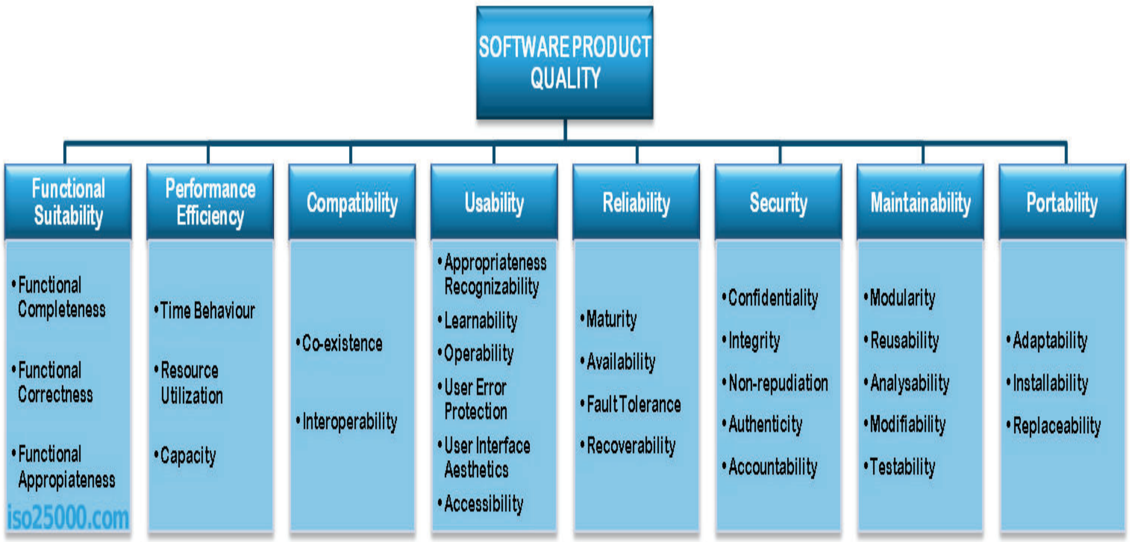


Fig. 3.23. ISO 25000 quality model

Elaborated Models

In addition to existing standards, in the literature, authors propose many BI evaluation models to elaborate their solution. They study the BI system from different points of view and elaborate a set of evaluation criteria.

In order to help organizations to understand how to achieve success with their BI systems, BI evaluation criteria are, generally, represented with maturity models. For example, [19] integrates the following characteristics in his impact-oriented maturity model (figure 3.24): BI deployment, BI usage, individual impact and organizational performance. [20] proposes a BI success dimensions affecting its use (figure 3.25). He payes special attention to data integration, analytical capabilities, information content, access quality, the use of information in business processes and the analytical decision-making culture. In addition,

[21] suggests that technological capabilities such as data quality, user access and the integration of BI with other systems are necessary for BI success (figure 3.26).

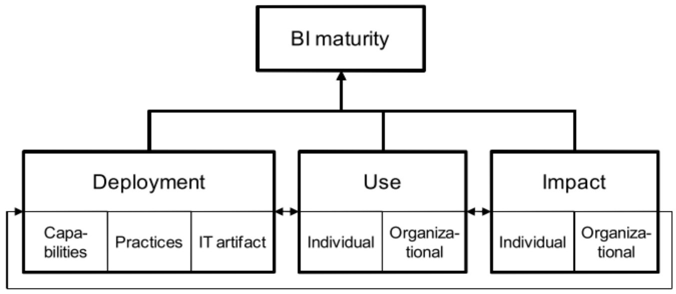


Fig. 3.24. BI maturity model in [19]

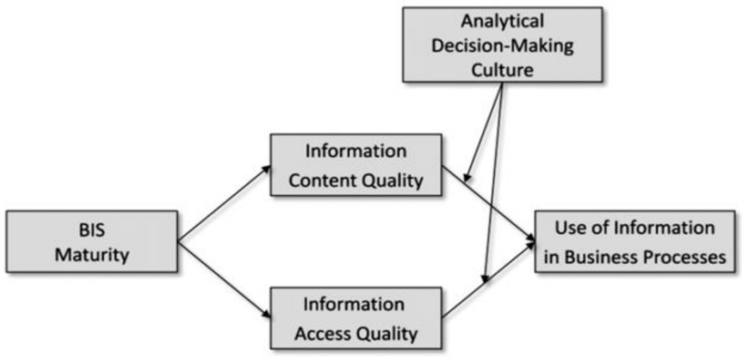


Fig. 3.25. BI success dimensions in [20]

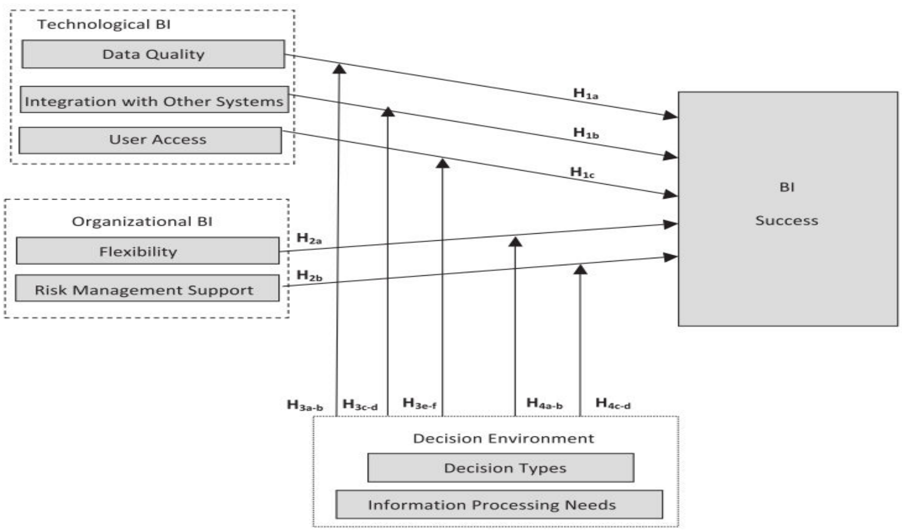


Fig. 3.26. BI success factors in [21]

In all cases, we note that authors efforts was focused on evaluating the BI system like any other tool. This means that we did not note particularities to BI systems. For example, they studied its organizational and technical environment as well as its quality and quality in use. Actually, the aim of BI is to offer users solutions to effectively make business decisions. This is the core of the BI activity. Therefore, analysing the system business content itself should be considered in the identified evaluation criteria. For example, analysing the use of business indicators, dimensions, reports, etc. Despite its importance, this point of view is not studied in literature.

3.3.4 BI Evaluation Solutions

Literature suggested different solutions for BI evaluation. Most of them do not employ evaluation systems but used models or techniques. Three categories of solutions are detailed in the following: fuzzy TOPSIS technique, BP Neural Network and BI maturity model (MM).

Fuzzy TOPSIS Technique

Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Situation) is a method that can be applied to multiple criteria decision-making to classify preference by similarity. For example, it is able to maximize the benefit criteria and minimize the cost criteria, while using qualitative information, incomplete information; non-obtainable information and somewhat ignorant facts into the decision model. Generally, in Fuzzy TOPSIS an alternative that is nearest to the positive ideal solution and farthest from the negative ideal solution is chosen as optimal.

Applying this method to BI aims to help the decision-makers to select the enterprise system which has suitable intelligence to support managers' decisional tasks. This is the case of [22] who proposed a model to assess enterprise systems in BI aspects. 34 qualitative and quantitative criteria about BI specifications were identified based on a literature review (explicit knowledge). For example, data mining techniques and stakeholders satisfaction. To this end, he suggested a model that exploits Fuzzy TOPSIS techniques. Figure 3.27 summarizes the stages of Fuzzy TOPSIS BI Evaluation Model. As depicted in this figure, experts are involved in the design and evaluation of the solution. They assessed alternatives with regards to criteria and they assigned appropriate weights to each one. In addition, the BI evaluation criteria used in [22] are totally based on a literature review. As a result, only explicit knowledge on BI is considered, while neglecting the importance of tacit one that comes from experts. This solution design should also take into account users' involvement as a source of knowledge.

Backpropagation (BP) Neural Network

A BP neural network is a multi-hierarchic feedback structure, which aims at adjusting the network weights through back-propagation algorithm, including input layer, hidden layer and output layer "[23]. Two mechanisms are included within the method: forward propagation and back propagation. First, the forward propagation is in charge of transmitting the information from the input layer, through the hidden layer, in the direction of the output layer. If the output value does not correspond to the wished result, the back propagation process should return the error of output along the original connection to the input layer. This latter should adjust the connection weights and therefore adapt the requirements of mapping. The model structure of BP neural network is given in figure 3.28.

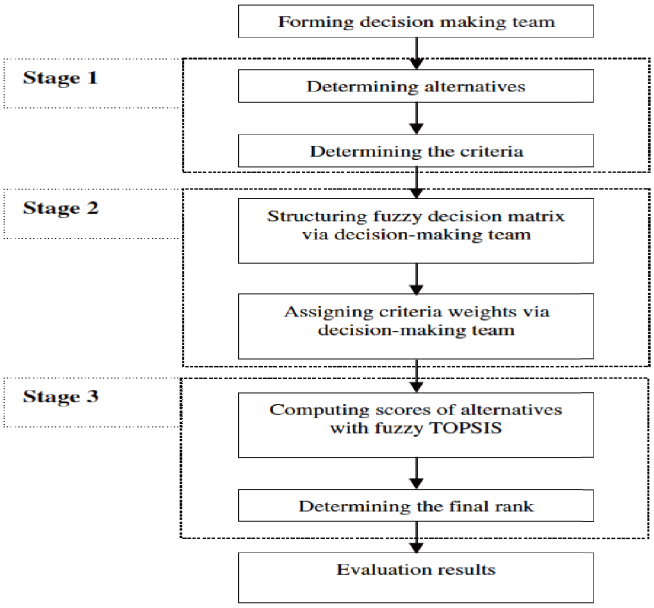


Fig. 3.27. Stages of Fuzzy TOPSIS BI Evaluation Model for enterprise systems in [22]

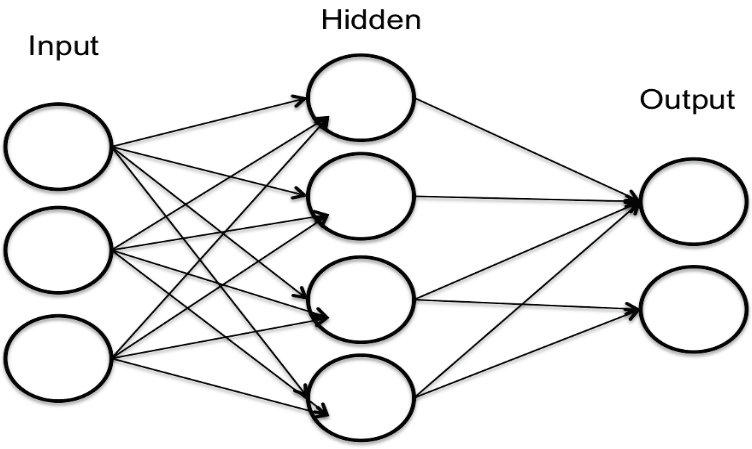


Fig. 3.28. BP neural network structure

An example of application of BP neural to BI was given by [23]. He established a comprehensive evaluation index system according to the construction principles of BI systems. A set of criteria, sub-criteria and indicators were identified, to meet the construction principles (figure 3.29) based on a literature review (explicit knowledge). First, the index system should meet: "the overall evaluation function is greater than the simple sum of sub-indicators" (system principal (A)). Second, the selected indicators can reflect the implementation of BIS in firms (accuracy principle (B)). Third, the indicators in the same level should not have containing relationships and too much information inclusive (independence principle (C)). Fourth, the chosen indicators, whether qualitative or quantitative, can be used for horizontal and vertical comparison (comparability principle (D)). To proceed, he proposed an overall evaluation method based on BP neural network. 18 evaluation criteria (qualitative and quantitative), for example, system construction, users' satisfaction, etc. These latter are graded on a basis of 4 evaluation levels by an expert. As a result, the input layer nodes of neural network are the 18 identified BI indicators. The output layer nodes are synthetically scores given by different companies' BI systems. Therefore, the objective is to propose for each one an optimal BP neural score evaluating the system.

[23] believes that BP neural network method has a strong applicability in overall evaluation of BI systems to provide guidance for a successful use of BI within organizations. However, we identified some limits. First, expert are only involved to grade the identified indicators. They are not considered neither in the selection of the indicators assessing the BI system nor in the solution evaluation. They are almost not considered throughout the solution. We consider that it is important to involve them not only as users but also as the source of knowledge and its consumers.

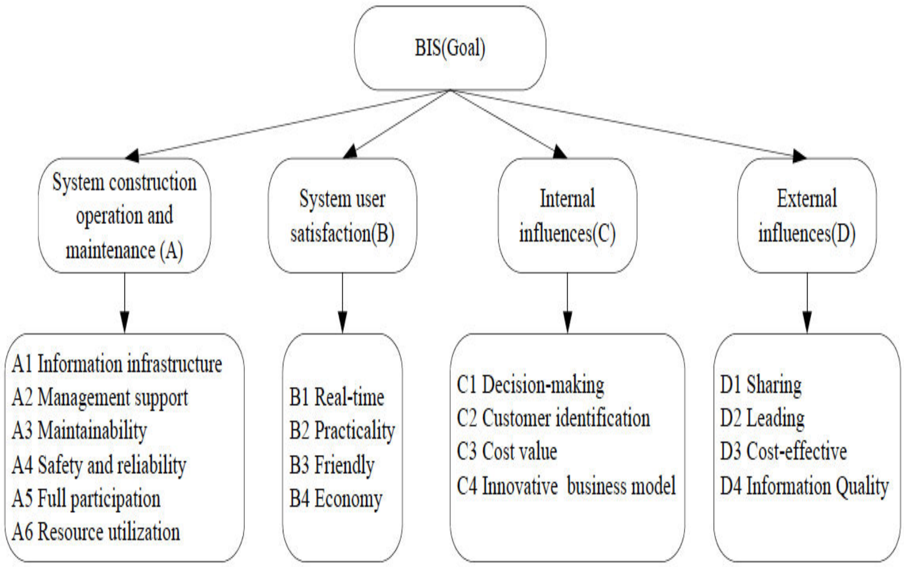


Fig. 3.29. BI comprehensive evaluation index system in [23]

BI maturity model (MM)

[19] developed a theoretical model of impact-oriented BI maturity. This BI maturity model (MM) aims to clearly guide its users how to design BI in order to contribute to overall organizational performance.

As a result, a BI maturity model has been proposed (figure 3.30). To summarize this work, three levels are considered. First, in an individual level, the BI value lays in enabling better decisions (individual impact) and, in an organizational level, this will lead to a better overall organizational performance (organizational impact). Second, the impact of BI is a consequence of individual and organizational use. Third, BI deployment system considers BI capabilities, BI practices, BI IT, and organizational support. This model will be the foundation for the development of an assessment instrument for impact-oriented BI maturity and the confirmation and broad application of an impact-oriented BI MM. To proceed, this work based on a literature review on BI maturity models to select the most appropriate one regarding the identified research objectives. Questionnaires with experts were used throughout the design and evaluation processes. Experts were with different roles (business, IT, management and other). However, experts are only involved in the evaluation and validation of the maturity model content, but not directly in its construction. We consider that experts points of view are as important in the design as in the validation of a solution, while considering them as an important source of knowledge.

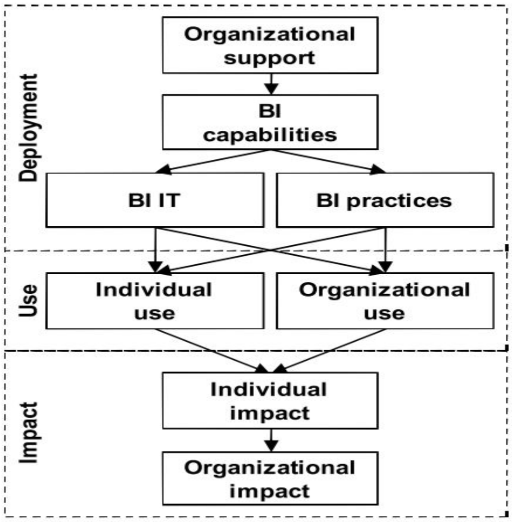


Fig. 3.30. BI Maturity Model in [19]

Comparison criteria	[22]	[23]	[19]
To involve the appropriate representation	Fuzzy TOPSIS	BP neural network	BI Maturity Model (MM)
To involve the appropriate tool support	NO	A comprehensive evaluation index system of BI	An assessment instrument for impact-oriented BI maturity
Humans' involvement	Assignment and assessment of appropriate weights to each BI indicator	Grading the identified BI indicators	evaluation and validation of the maturity model content
Humans' roles	No	No	business, IT, management and other
Kind of considered knowledge	Explicit	Explicit	Explicit and tacit
Types of considered BI evaluation criteria	Qualitative and quantitative	Qualitative and quantitative	Qualitative and quantitative
Continuous BI evaluation?	No	No	No

Table 3.4. BI knowledge evaluation solutions' analysis

Table 3.4 summarizes these case studies on BI evolution solutions. We note several limits in the whole proposed solutions. We consider that each of the identified criteria contributes to the effectiveness of our solution and should be considered as much as the others. The main limit that we highlight in the presented solutions is their statical contribution. More specifically, proposals in literature are able to evaluate BI systems only to statically measure their qualities without helping to make decisions about their use and evolution. Actually, what BI systems need is a solution that continuously analyses its use while allowing making decisions about.

To conclude, an effective knowledge evolution solution should allow to continuously evaluate, analyse and make decisions on the considered knowledge system.

4 Summary

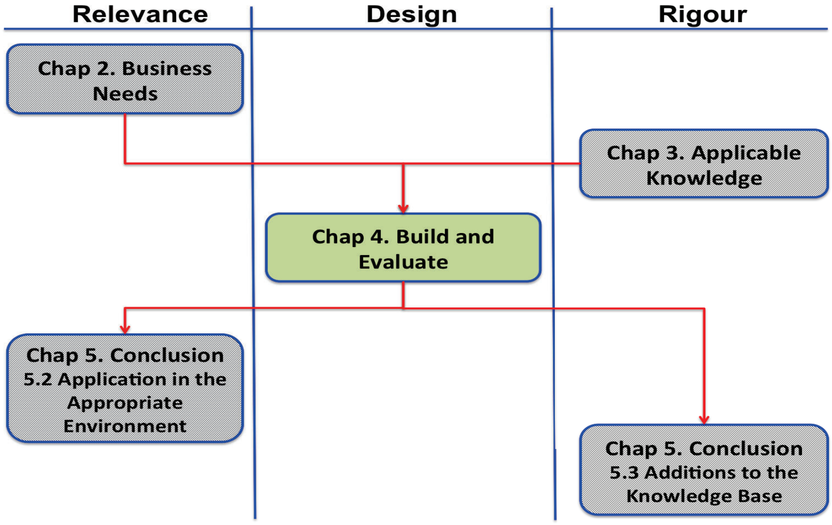
This chapter presented a literature review as a part of the rigour cycle of the Design Science Research. Two main areas of related work were studied. On the one hand, a background on *Business Intelligence* allowed to learn about its objectives, principles, techniques and challenges. On the other hand, we discussed in a first stage, knowledge, its sources and forms. In a second stage, we studied the knowledge capitalization cycle, phases, their characteristics and challenges.

Our literature review showed that knowledge capitalization and *Business Intelligence* have been much discussed. This is due to the importance of such fields within organizations. BI aims to support decision making and knowledge capitalization allows to identify, represent, store, share, reuse and evolve expert knowledge. Throughout different case studies, we demonstrated that several challenges should be taken into account, for example, the complexity of the BI activity, its users skills, understanding, identifying and reusing BI knowledge, as well as involving the appropriate resources (tools and humans). BI knowledge capitalization requires a solution that involves its actors, their uses and needs, the organizational and technical environment, as well as the evolutionary nature of these fields. This is the reason why in this thesis, we suggest a solution based on a continuous improvement cycle for knowledge capitalization.

Based on the Design Science Research, next chapter describes our proposal, as a part of the Building and Evaluating step of the Design cycle. This chapter is based on findings of the two previous chapters: business needs and the state of the art. Particularly, it includes defining our proposal for *Business Intelligence* knowledge capitalization, involving solutions for its different steps.

Chapter 4

Build and Evaluate



1 Introduction

As a part of the design cycle of the Design Science Research, this chapter consists in iteratively building and evaluating solutions. In our context, a knowledge capitalization solution is implemented and evaluated. For each iteration, one step is considered and its solution is built and evaluated. Actually, in this work, building and evaluating are not really separated. They are considered simultaneously to progressively evaluate the feasibility of the built solution. Evaluating the applicability of the solution in the work environment will be a part of the rigour cycle. An overview of our cycle of improvement cycle for knowledge capitalization is given in the next section.

2 A Continuous Improvement Cycle for Knowledge Capitalization

In this section, we present our proposal for knowledge capitalization and evolution. We present first our proposal scope followed by the principles of its application in our research.

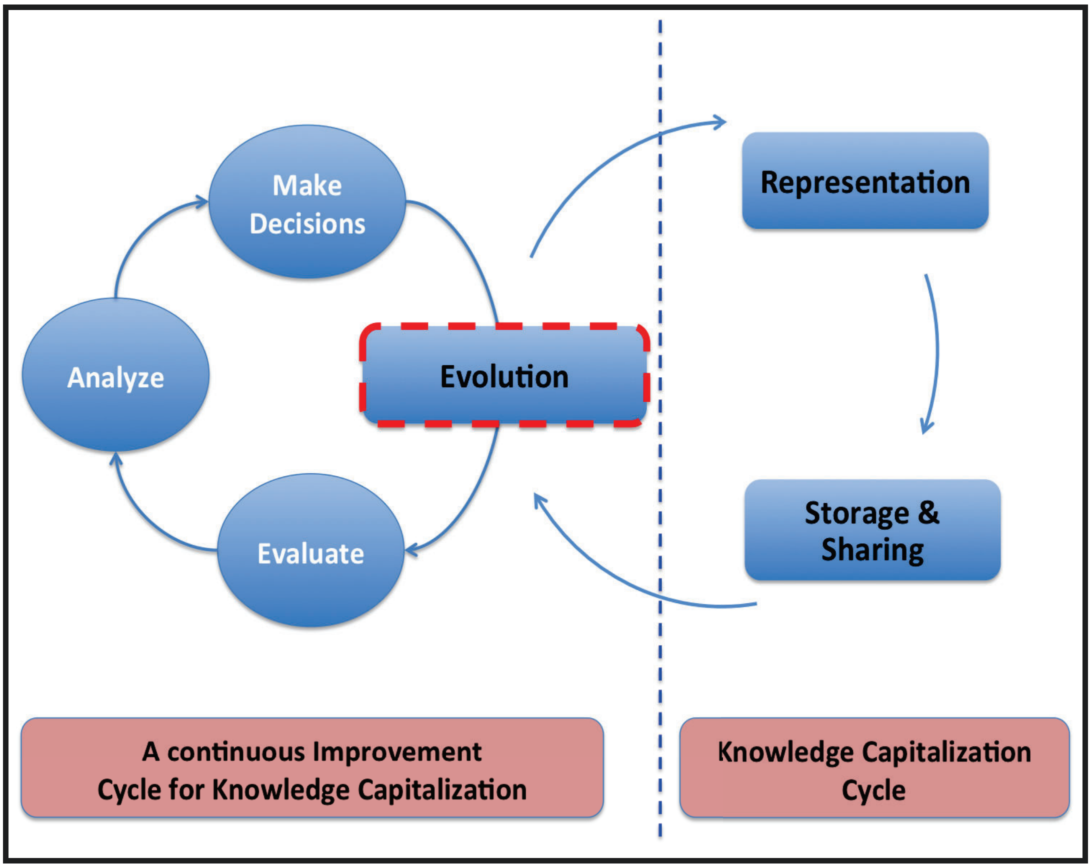


Fig. 4.1. Our solution for a continuous improvement cycle for knowledge capitalization

2.1 Our Proposal Scope

As discussed in previous chapters, knowledge management is composed of several steps: identification, representation, storage, sharing, reuse and evolution. In our research, we address the problem based on findings of business needs at *STMicroelectronics* (presented in chapter 2), as well as on the background and state of the art (presented in chapter 3).

Business needs at *STMicroelectronics* require providing a solution that meets its users and their business needs for: knowledge representation, knowledge sharing and storage and knowledge evolution. In the state of the art, several solutions address these steps. However, in chapter 3, we demonstrated that they do not completely meet our needs for an effective knowledge capitalization solution. We note for knowledge representation the fact to consider the three characteristics (*What*, *Why* and *How*) together and in the appropriate manner. For knowledge sharing, we demonstrated how wikis do not meet all the identified evaluation criteria of our problem space. Finally, we demonstrated how researches statically evaluate knowledge systems and/or limit the content of the evaluation solution for knowledge evolution.

Based on these findings, we suggest in this work a continuous improvement cycle for knowledge capitalization, detailed in the following.

On the one hand, as depicted in figure 4.1, we consider that capitalized knowledge is the identified, represented, stored and shared one. Each step should be addressed in an appropriate manner but also with respect to the other steps, as a whole cycle. Hence, our objective is to have a consistent solution for knowledge capitalization.

On the other hand, due to the evolving nature of knowledge, effectively ensuring its evolution remains crucial. In this work, we suggest a continuous improvement cycle. It aims to continuously evaluate, analyse and make decisions on capitalized knowledge, both in terms of reliability as well as continuity of use [130]. A a result, our continuous improvement cycle is achieved throughout the knowledge evolution step (figure 4.1).

Then, our contribution for a continuous improvement cycle for knowledge capitalization in two parts. First, a knowledge capitalization solution describes proposals for knowledge representation, storage and sharing. At this stage, our objective is to provide effective solutions to accomplish these tasks as a whole consistent cycle. Second, a knowledge evolution solution includes a continuous improvement cycle for knowledge capitalization. It is applied to capitalized knowledge throughout the different steps of the cycle (identification, representation, storage and sharing).

2.2 Our Proposal Application

Applied to *Business Intelligence*, our objective is to provide a solution allowing a continuous improvement cycle for BI knowledge capitalization.

Actually, among knowledge capitalization steps, in this work, we focus only on some of them: representation, storage and sharing (both as one single step) and evolution. For cost reasons, but also to make actors throughout our solution, we made the choice to base on existing tools and practices. For example, *Stiki* for knowledge sharing or *Business Intelligence* for knowledge evolution. Such a strategy allows promote and evolve existing solutions in the best conditions and at lower costs.

To proceed, we started with the most known tool within the IT department at *STMicroelectronics*, related to knowledge capitalization, which is *Stiki*, the wiki used for expert knowledge storage and sharing. Previously in chapter 2, we assessed its use, identified its advantages, limits and concluded with business needs and areas of progress related to knowledge sharing and storage. As a result, *Stiki*'s evolution is the first stage to perform as a part of knowledge sharing and storage solution.

Second, among other results of *Stiki*'s evolution, knowledge structuring was required to ensure the relevance, completeness and organization of stored and shared knowledge. This is why, we focus then on knowledge representation.

These two steps are parts of the knowledge capitalization cycle (figure 4.1). Finally, to allow continuous improvement cycle, a knowledge evolution solution is implemented in section 4. Applied to *Business Intelligence* knowledge, the challenge to meet is to provide a consistent solution considering the different steps as a whole system.

3 Knowledge Capitalization Cycle

In chapter 2, we used a user centred evaluation approach to assess *Stiki*'s use and to identify its advantages and limits for knowledge sharing [1]. As a result, we concluded with a set of business needs and areas of progress that should be accomplished on *Stiki*. Among these findings, we noted the importance of knowledge representation. Therefore, in the following, we present how *Stiki* has evolved to accomplish its objective. Next, we present our solution for knowledge representation.

3.1 Knowledge Storage and Sharing: *Stiki*'s Improvement

As a part of the design cycle of the Design Science Research (figure 1.5), our proposal for *Stiki*'s improvement is based on two entries:

- First, we based on defined business needs, presented in chapter 2, where we assessed *Stiki*'s use, identify its advantages and limits for knowledge sharing.
- Second, we based on a literature review on wikis' uses, successful and failed experiences. This is presented in chapter 3 as a part of the rigour cycle of Design Science Research, ensuring innovation for our proposal.

Before presenting our contributions and obtained results , table 4.1 recaps findings of *Stiki*'s evaluation process, where we present identified problems and areas of progress according to our problem space [1].

In the following, we present how the identified issues are evolved mainly throughout technical and organizational contributions, statistics and observations. In the same manner, improvements are discussed according to evaluation criteria.

3.1.1 Technical Improvements

1. Tool criteria

   Ease of use: In order to help users in its use and in the long term to ensure maintaining its activity, an administration role is assigned for *Stiki*. In the short term, the administrator plays a key role in the improvement of *Stiki*. This is the reason why, an engineer from the *Business Intelligence* team was designed, since it is the team behind the selection and development of *Stiki*. Besides, assigning to the administrator the mission of *Stiki*'s technical improvement is due to the fact that he is the one who will be in charge of its maintaining and respond to technical issues in the long term. To proceed, he bases on our findings, guide, recommendations and more generally, our *Stiki*'s evaluation results.

   Accessible and controlled common space: The administrator was in charge of updating the version of *Stiki*. We note that its current version has dated for five years ago. Currently, it evolved from the version 1.13 to the version 1.22 of MediaWiki. This upgrade allowed integrating new functionalities making its use easier, faster and more ergonomic. In fact, based on our findings and recommendations, the administrator was himself in charge of integrating these functionalities within the tool, in order to ensure the technical support of their uses. Among new functionalities, we note for example:

   - An advanced text editor makes formatting the text easier (figure 4.2).

Issues	**Areas of progress**
Tool criteria	
Limited competences in the use of *Stiki*	Regular training
An old version of *Stiki*	Updating the current version
Limited functionalities and options	Adding new functionalities promoting its use and evolution
No administrator	Ensuring *Stiki*'s administration
Content criteria	
A decreasing number of created pages where only few ones are structured according to *Stiki*'s templates	Managing content quantity and structuring
No monitoring of *Stiki*, its use and content	Regular evaluation of *Stiki*
Many pages' content obsolete	Ensuring pages' relevance and avoid their obsolescence
Individual criteria	
Knowledge sharing culture is still a challenge among employees	Creating a knowledge sharing culture
Only few users are conscious and motivated to use *Stiki*, especially for contribution	People's involvement, motivation, goodwill and awareness of knowledge sharing
There is no regularity in use. *Stiki* is mainly used during important projects	Regular use
Collaborative criteria	
Most of pages are mono contributor	Contribution efforts on existing business knowledge
Stiki is mainly intended to be used by IT teams	Expanding *Stiki*'s scope of application
Few works are documented in *Stiki*	Integrating *Stiki* in projects life cycle

Table 4.1. *Stiki*'s assessment results

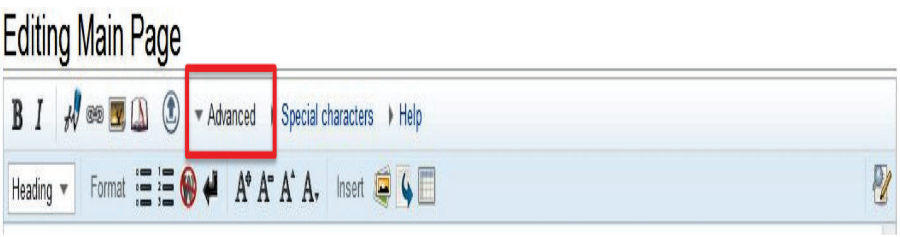


Fig. 4.2. *Stiki*: an advanced text editor

- Files upload could be directly realized in the writing current page (figure 4.3).

- Help functions are directly suggested in the writing current page, for example about the writing syntax (figure 4.3).

Fig. 4.3. *Stiki*: help and upload functionalities

- The search engine is more advanced and able to guide users in their searches. Compared to the old one, the current search engine is able to provide suggestions according to the entered word or sentence.

2. Content criteria

Content relevance and quantity: To promote the relevance of *Stiki*'s content, a page rating system has been implemented into the tool where users are able to systematically mark the relevance of its content (figure 4.4). To proceed, on the bottom of the each page, readers can attribute a rate to the content of the read page. This functionality provides statistics on top rated pages, top voters, latest votes for: a page, a category, or globally and latest votes by a specific user. Currently, thanks to this functionality, pages can be classified according to their relevance and usefulness, and users feel more confident when reusing stored knowledge in *Stiki*. A bad rating incites users to review the content, as well as the administrator to regularly maintain the tool. In addition, it encourages users to contribute better, while being a motivation for the others.

Fig. 4.4. *Stiki*: rating functionality

In addition, as part of the evolution process of *Stiki*, reviewing the content of pages allowed the administrator categorizing pages according to their application domain. With the new content organization in *Stiki*, users are able to search and contribute faster and easier, for example, organizing pages describing applications according to the appropriate site (Crolles200 or Crolles300).

Content structuring: Among areas of progress related to *Stiki*'s content, structuring pages has been identified as an important aspect to deal with. This is why we suggested to base on pages templates to ensure the completeness, relevance and structure of shared knowledge in *Stiki*. This contribution will be detailed, next, as part of the knowledge representation step.

3.1.2 Organizational Improvements

1. Individual criteria

   Awareness, investment and regularity of use: have been highlighted when evaluating the use of *Stiki* for knowledge sharing. To this end, the role of the hierarchy was important to achieve this objective. In fact, knowledge storage and sharing tasks have been highlighted and demonstrated by managers during different meetings and opportunities. For example, in order to increase employees' awareness and motivation, the workload for knowledge sharing increased from 25% to 50% after the merge of the two Crolles sites.

   Interest for users: Following the upgrade of *Stiki*, an open training was achieved, for several objectives. On the one hand, it allowed inform *Stiki*' users about made changes, new functionalities and recommendations. On the other hand, due to the merge of the Crolles200 and Crolles300 sites (chapter 1), *Stiki* was presented mainly to the Crolles200 site which is an unknown tool for them. It was the opportunity to encourage them to effectively use *Stiki* for documenting their respective work in order to promote their skills transfer. In addition, training sessions on the use of *Stiki* and its presentation are planned for its potential users, for example, after restructuring or recruitment.

2. Collaborative criteria

   Collaborative participation: Collaboration is an important factor for knowledge sharing success and constitutes the principle of the use of *Stiki*. To this end, a "rotating support" has been established, where, weekly, one member of each team takes the responsibility to resolve encountered business problems (errors, tools functioning, etc.). During this task, he has to share his knowledge throughout documenting in *Stiki* encountered problems, made improvements and proposed solutions. Such a process naturally involves all users and ensures a collaborative use of *Stiki* for knowledge sharing.

   Open culture: Among made improvements, expanding the scope of application of *Stiki* has been required. It allows not only enrich its content but also strengthen its use by users of different fields, contexts and knowledge, which makes it more powerful. For example, this has been effectively achieved within *STMicroelectronics*, mainly after the merge of the Crolles200 and Crolles300 sites. New applications have been integrated, evolved or merged, which has increased the use of *Stiki* for sharing skills.

   In addition, officially integrating *Stiki* in projects' life cycle and ensuring its collaborative use during projects have been beneficial. This means that at each stage of the project, gathered knowledge is integrated into *Stiki*. the draft option helps users to progressively proceed at their own rhythm. Recently, among other practices, it helped *STMicroelectronics* to get an international quality certification. Particularly, the IT department demonstrated the importance of knowledge sharing thanks to

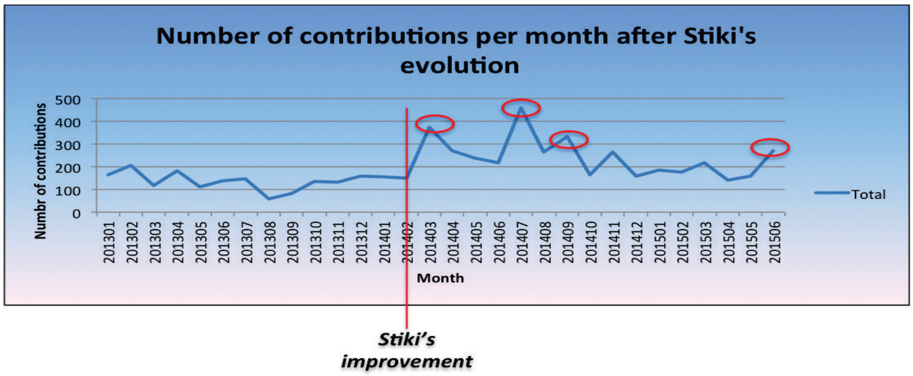


Fig. 4.5. Number of contributions after *Stiki*'s evolution

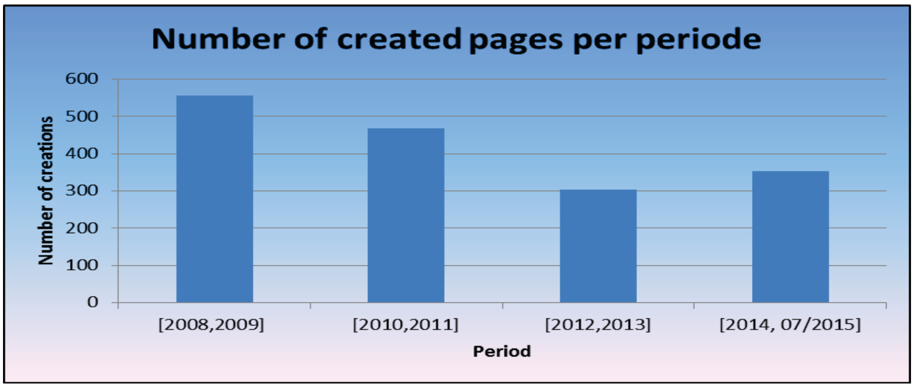


Fig. 4.6. The evolution in the creation of new pages in *Stiki* after its evolution

the regular and collaborative use of *Stiki* during projects. These information were presented to employees just after getting the certification.

3.1.3 Improvements' Results

In order to demonstrate the success of the evolved *Stiki*, we proceed with statistical measures, put in place for its evaluation before its evolution. Among those, we base on the evolution of contributions (action of adding new knowledge), contributors (who add new knowledge) and created pages. We note that these measures will be always helpful for its evaluation, that could be regularly conducted by the administrator, for example.

As depicted in figure 4.5, following the open training realized by early 2014, we note an important continuous increase in the number of contributions in *Stiki*, compared to realized statistics before its evolution. For example, we record more than 450 contributions during July 2014, against 200 contributions during February 2013 (just before our *Stiki*'s evaluation process). This demonstrates the important role that *Stiki* takes today for knowledge sharing.

Besides, since *Stiki* has been officially selected to be the reference tool for knowledge sharing, by early 2014, an objective has been identified. It consists in progressively transferring all the important documentations to *Stiki* before the first half of 2015. This is demonstrated by the peaks of the number of created pages since the evolution of *Stiki* by early 2014 (figure 4.6).

The success of *Stiki* was demonstrated thanks to a regularity in its use, mainly for contribution. For example, we noted its use for 265 times a week on average per 19 different

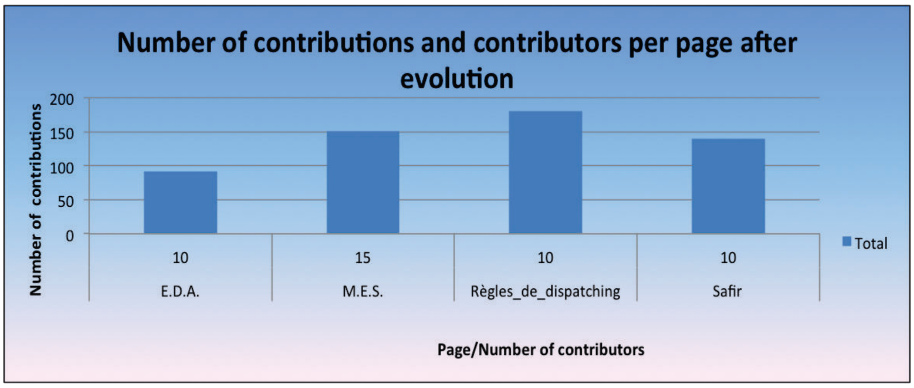


Fig. 4.7. Number of of contributors and contributions per page after *Stiki*'s evolution

users, whereas before its evolution it was used 150 times a week on average per 10 different users.

Finally, collaboration efforts have been demonstrated in figure 4.7, where we note an increased number of contributors per page compared to observation before *Stiki*'s evolution. For example, sharing knowledge about E.D.A involves today 10 contributors, while we noted only 1 contributor before *Stiki*'s evolution.

3.1.4 Conclusion

As described in this section, different practices and solutions have contributed to the success of a wiki for knowledge sharing. This is demonstrated throughout its effective use. We presented several solutions that we integrated into *Stiki* for its improvement. We focused on technical and organizational improvements, for example, integrating a page rating system, an advanced text editor, files upload for each page, but also organizational recommendations, for example, integrating *Stiki* in projects life cycle and expanding the scope of its application. These solutions have been implemented and as a result, today, *Stiki* is considered the principal tool for knowledge sharing at *STMicroelectronics*, while providing an ergonomic and easy to use tool. Statistics about its use demonstrate its success, for example, by showing an important increase in the number of contributors and contributions per page and in general.

3.2 Expert Knowledge Representation: *What*, *Why* and *How*

3.2.1 Introduction

In a previous work [1], we evaluated the use of wikis for knowledge sharing (presented in chapter 2). One of the findings concerns the importance of pages structuring. It helps not only readers searching for knowledge, but also contributors when capitalizing their work, in an appropriate and effective way. This corresponds, actually, to knowledge representation. Moreover, a literature review has supported its importance to ensure the completeness, relevance and organization of capitalized knowledge.

In this section, our proposal for knowledge representation, as one step of knowledge capitalization, is presented. We suggest a user centred approach for the definition and representation of knowledge characteristics, *What*, *Why* and *How* [2]. It consists in studying its different aspects and characteristics to integrate those required by users in the capitalization tool for promoting its reuse and exploitation, in our case, in *Stiki*. In the following,

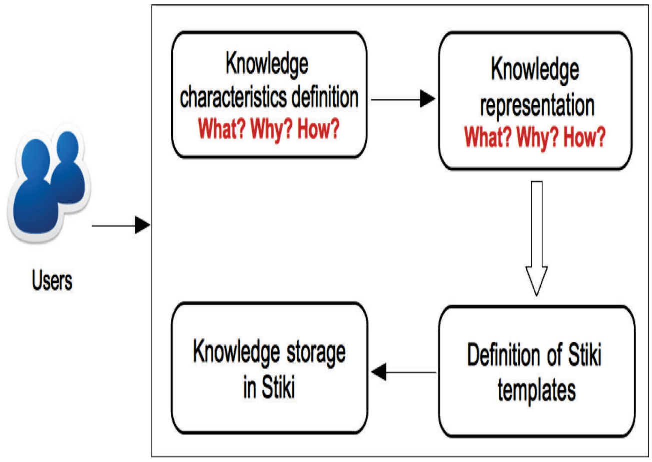


Fig. 4.8. Our proposed cycle for knowledge capitalization

we present the scope of our proposal and define knowledge characteristics. Next, we describe the *Reporting* process since it represents our case study at *STMicroelectronics*. We conclude this section with a presentation of our user centred approach application.

We note that as a part of the design cycle of the Design Science Research (figure 1.5), our proposal for knowledge representation is based on two entries:

- First, we based on defined business needs, presented in chapter 2, where we demonstrated the need to knowledge structure, formalization and representation, in our case, in *Stiki*.
- Second, we based on a literature review on knowledge characteristics definition and representation. This is presented in chapter 3 as a part of the rigour cycle of Design Science Research, ensuring innovation for our proposal.

3.2.2 Our Proposal Scope

As depicted in figure 4.8, we aim at defining a format to represent knowledge by studying its different characteristics, in order to support the knowledge capitalization cycle. We are interested in the meta level that allows to establish an environment for designers wishing to capitalize their knowledge.

To this end, we propose to study its characteristics that should guide the way knowledge can be effectively stored, shared and reused. We classify knowledge into different characteristics where each one describes one of its required aspects. For example, when users need to know "how to create a report describing the number of completed wafers of a set of lots in the clean-room per day", they need to find and to understand the information mentioned above. In this case, the required knowledge, corresponding to their request, should be effectively shared and capitalized in order to be effectively reused. The effectiveness of sharing and capitalizing knowledge is highly associated to its completeness, relevance and organization.

In this example, one characteristic of the required knowledge corresponds to know "the required objects to create his report". Another one corresponds to "the required knowledge to integrate it in the reporting system". The user will also want to understand "why should the number of wafers be calculated in a particular way in some cases?". Together, these parts of knowledge, that we call *characteristics* will help users to have and understand the required knowledge for creating their reports. Each *characteristic* provides a required aspect of knowledge.

To proceed, a user centred approach for knowledge capitalization involves, therefore, users throughout the cycle. The particularity of such an approach consists in including users in the exploration, co-design, and validation of the knowledge representation.

Decomposing knowledge to characteristics corresponds, in figure 4.8, to the **knowledge characteristics definition** (know *What*, *Why* and *How*) about the *Reporting* process at *STMicroelectronics*. It requires the participation of BI experts, business experts and end users to gather their opinions and expectations about required aspects of knowledge. By defining knowledge characteristics, we aim at supporting their **representation**. It consists in modelling these characteristics while iterating proposed solutions with users until meeting the defined requirements. During this stage, users are involved to gather their opinions about proposed solutions and identify areas of progress to correspond to the real word. Based on the knowledge representation, we aim at providing the *Stiki* **templates** in order to promote **knowledge storage** in *Stiki*. Representing knowledge ensures the organization, the completeness and the relevance of *Stiki* templates.

We present in the following our proposal for the definition of knowledge characteristics that we will apply next to the *Business Intelligence* activity, considering mainly the *Reporting* process. Before that, we present how users were involved throughout our solution for knowledge representation.

3.2.3 Our User Centred Approach for Knowledge Representation

A user centred approach for knowledge representation allows place the human actors in a central position during the process. The objective is to gather users' uses, needs, expectations and performance during the various phases of the process [131]. As depicted in figure 4.9, a user centred approach is composed mainly of three steps: Exploration, Co-Design and Validation:

- Exploration of current uses, users' expectations and needs, advantages and limits of existing solutions and desired improvements.
- Co-Design a new solution, evaluate its usability and identify the desired improvements.
- Validation consists in applying the proposed solution of the Co-Design on real problems and testing its performance and usage.

To accomplish our work, the proposed user centred approach aimed at identifying users' needs and expectations while supporting knowledge relevance and the interaction between users and developers. That is why, we believed that co-designing and validating solutions based on users' points of view (end users, managers and engineers) was a crucial condition to successfully accomplish our objective.

In the next paragraphs, we describe the steps that we used at *STMicroelectronics* to apply our approach and we share what we learned along the way.

Following the user centred approach steps, we proceeded as follows:

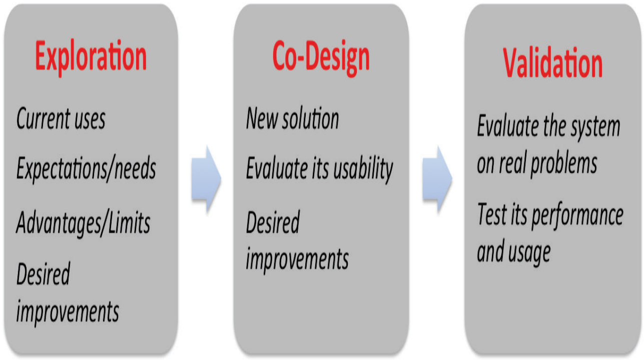


Fig. 4.9. A user centred approach

Exploration:

Observational methods: In a first stage, we focused on observing how reports were created by engineers and users, what objects and tools were required and how they were related. Analysing these parts allowed us to describe the know *What* of the *Reporting* process. In addition, attending a first working meeting between engineers and users (three engineers and four end users) clarified their needs and specified objectives and particularities of use. Thanks to these observations, we were able to describe the *Reporting* knowledge characteristics and to specify its parts that should be modelled.

Co-Design:

Descriptive methods: Relying on the literature review and the participation of users, we defined knowledge characteristics (*What*, *Why* and *How*) and proposed a solution for their representation, as well as their integration into *Stiki* for their sharing.

Validation:

Experimental methods: After modelling knowledge characteristics (Co-Design), the experimental methods consisted in instantiating models on case and field studies. For that, four engineers were continually keeping in touch with the advancement of the modelling process to ensure the relevance and compatibility of this work with reality. This stage was very important especially due to the complexity and variability of the case studies in this area. To validate our know *What*, *Why* and *How* models, representing reporting knowledge, we instantiated them and verified if it corresponds to the objective of use. To this end, regular meetings with different users during several weeks (at least one per week with the manager and four engineers) allowed to discuss and generate modelling alternatives according to the requirements and constraints.

3.2.4 The Definition of Knowledge Characteristics

Our proposal to define knowledge characteristics is presented in figure 4.10. In fact, we consider that knowledge presents three different and complementary characteristics: *What*, *Why* and *How*. Each one describes knowledge in a different level and should be modelled in an appropriate way:

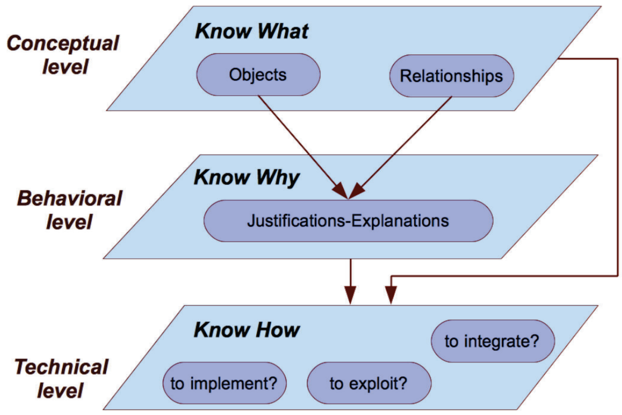


Fig. 4.10. Knowledge components representation

- First, the *What* characteristic corresponds to the conceptual level of knowledge which is characterized by a static description. It represents manipulated objects throughout tasks and their relationships [12, 15].

- Second, the *Why* characteristic is described in the behavioural level of knowledge which involves an understanding of principles behind the considered tasks [100, 101]. For example, explanations, justifications and options behind designed artefact throughout performed tasks are important. They should be capitalized and therefore effectively represented.

- Finally, the *How* characteristic addresses the technical level of knowledge [88]. It concerns knowledge integration, implementation and exploitation in systems. It particularly considers *How* to add, remove or update existing knowledge in systems, as well as *How* it could be manipulated by engineers and end users.

In the following, we present these three knowledge characteristics. Before that, we present the *Reporting* process, our case study, on which our proposal is applied.

3.2.5 The *Reporting* Process Description

As one function of *Business Intelligence*, the *Reporting* process is our case study, that we detail in this section.
As depicted in figure 4.11, to create a report, the engineer has to define his/her objectives, to access to datasets, to select his/her data, to define his/her objects (indicators, dimensions, etc.), to create the report, to share and capitalize it and to exploit it. To this end, the *Business Intelligence* team have opted for "SAP BusinessObjects" software (BO). When creating a report, many objects interact via relationships in BO. Objects and their relationships are of different natures. In fact, in a report, objects are mapped to or derived from data in databases. The name of an object must be derived from the field vocabulary of the targeted user group. They are either "Indicators" or "Dimensions" [132], where:

- Dimension is an analysis parameter that carries the analysis in a query and corresponds to one or more columns or functions of the database, essential for a query.

- Indicator provides numerical information used to quantify a dimension object. Generally, it is the calculation result on data from databases.

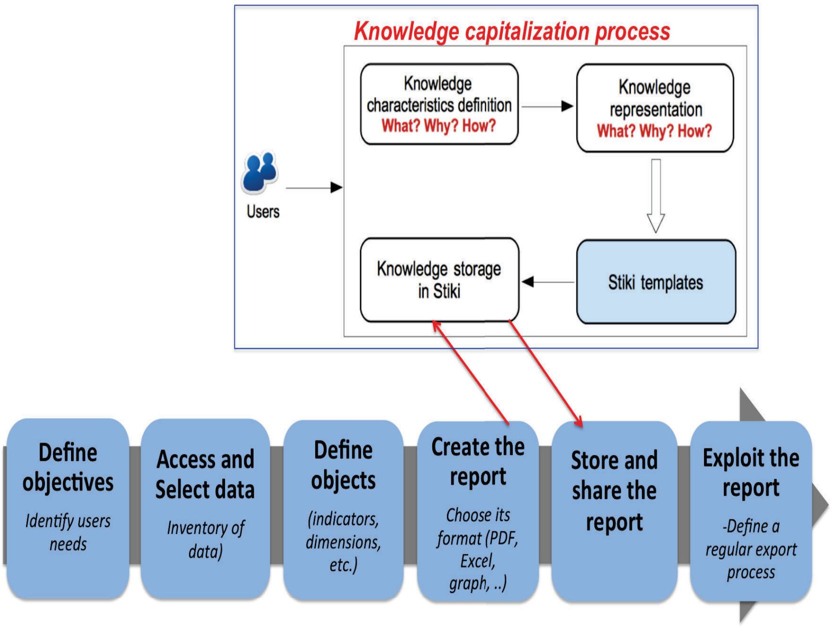


Fig. 4.11. The *Reporting* process

For example, we wish to measure the evolution of the turnover of different product lines within an organization. In this case, "the turnover" represents the indicator that is calculated according to the dimensions "years" and "product lines".

Therefore, both dimension and indicator are related to data from databases but each one plays a different role. Objects in the *Reporting* process interact with each other. For example, values returned by an indicator vary according to the selected dimensions. Besides, depending on the objective of the report, the engineer has the possibility to filter objects (data, indicators and dimensions) in order to restrict results and target specific knowledge (about a specific type of products, for example).

In fact, in the *Reporting* process, knowledge is created through the process in many forms. It is not only related to the nature of manipulated objects, but also to the context of their use in the target report. For example, an indicator could be calculated in different ways according to its context of use. At *STMicroelectronics*, many indicators having the same goal and name are calculated in one manufacturing site differently from the others.

This is the case of the indicator "Performance" that measures the performance of an equipment. It is calculated differently at the Crolles200 site from the Crolles300 site. At Crolles300 site the performance is "the time spent by an equipment in work divided by all the time spent by it". The notion of "in work" at the Crolles200 site does not take into consideration the time spent by the equipment when it is blocked. However, in the Crolles300 site the time spent "in work" includes the time when the equipment is blocked. This is because at both sites, we do not have the same data and objects to calculate the indicators. The site location represents in this case the context of use. Therefore, our goal is to to represent different knowledge created through the Reporting process, taking into account manipulated objects, their relationships, their context and particularity of use, as well as their technical aspects.

3.2.6 Our Proposal for Knowledge Characteristics Representation

Relying on the findings, presented previously, we detail in the following how each knowledge characteristic is represented. We take as a case study the *Reporting* knowledge. *Reporting* process is considered to illustrate our proposal.

Conceptual Level: *What* Representation

By describing the know *What*, we aim at representing manipulated objects through the process and their relationships. This is the reason why, we suggest to represent the know *What* characteristic with a class diagram. It makes explicit the description of manipulated objects as well as their relationships, representing therefore the created and manipulated knowledge throughout processes.

In the BI domain, the relationship between Indicator and Dimension is represented with a cube which corresponds to a particular modelling in BI. Its edges are made of dimensions and its cells' content corresponds to the value of the indicator according to the combination of the selected dimensions. [133] demonstrated how the cube presentation can be modelled using UML extension to be easily perceived by designers and programmers. In our work, we are not interested in the cube but its concepts, i.e, indicators and dimensions. As indicator and dimension belong to manipulated objects in the *Reporting* process, based on the cube representation, we propose in the following our representation of the know *What* with a UML model applied to the *Reporting* process (figure 4.12).

As depicted in figure 4.12, first, each created **report** should belong to at least one **universe**. A **universe** is a manner to classify reports according to their content description. For example, a report describing the number of finished products belongs to the universe "products advancement". Universe is as well decomposed in several **domains**. Such a classification is required at the beginning of the process to help in the selection of objects to create reports. For example, in the universe "products advancement", the domain "Move" contains objects describing products job throughout the process. Therefore, the report should contain objects from the domain "Move".

Second, a **report** is decomposed of **objects** that could be **indicators** measuring a production activity: for example, how many products are successfully completed. An object could be as well an **expert attribute** representing an **expert object**. For example, a report describing the number of finished products per technology, is composed of an **indicator** measuring the **"number of products"**, as well as **the expert attribute "technology group"** representing **the expert object "technology"**. The set of expert attributes in a report composes **a dimension set** representing analysis parameter that carries the analysis of the report.

Third, like **dimensions**, an indicator is also calculated from expert attributes. One of particularities that characterize reports at *STMicroelectronics*, is that an **indicator** could be calculated by several calculation formulas according to its context of use. For example, in the Crolles300 manufacture, an indicator could be calculated differently from Crolles200 manufacture, while it has the same name and the same objective of use. This could be due to the difference between data used in the manufacturing process between the two sites. Thus, the location could be a context that differentiates the way an indicator is calculated. Therefore, an indicator result varies according to the selected set of dimensions. For example, the number of finished products per technology is not the same as the number of

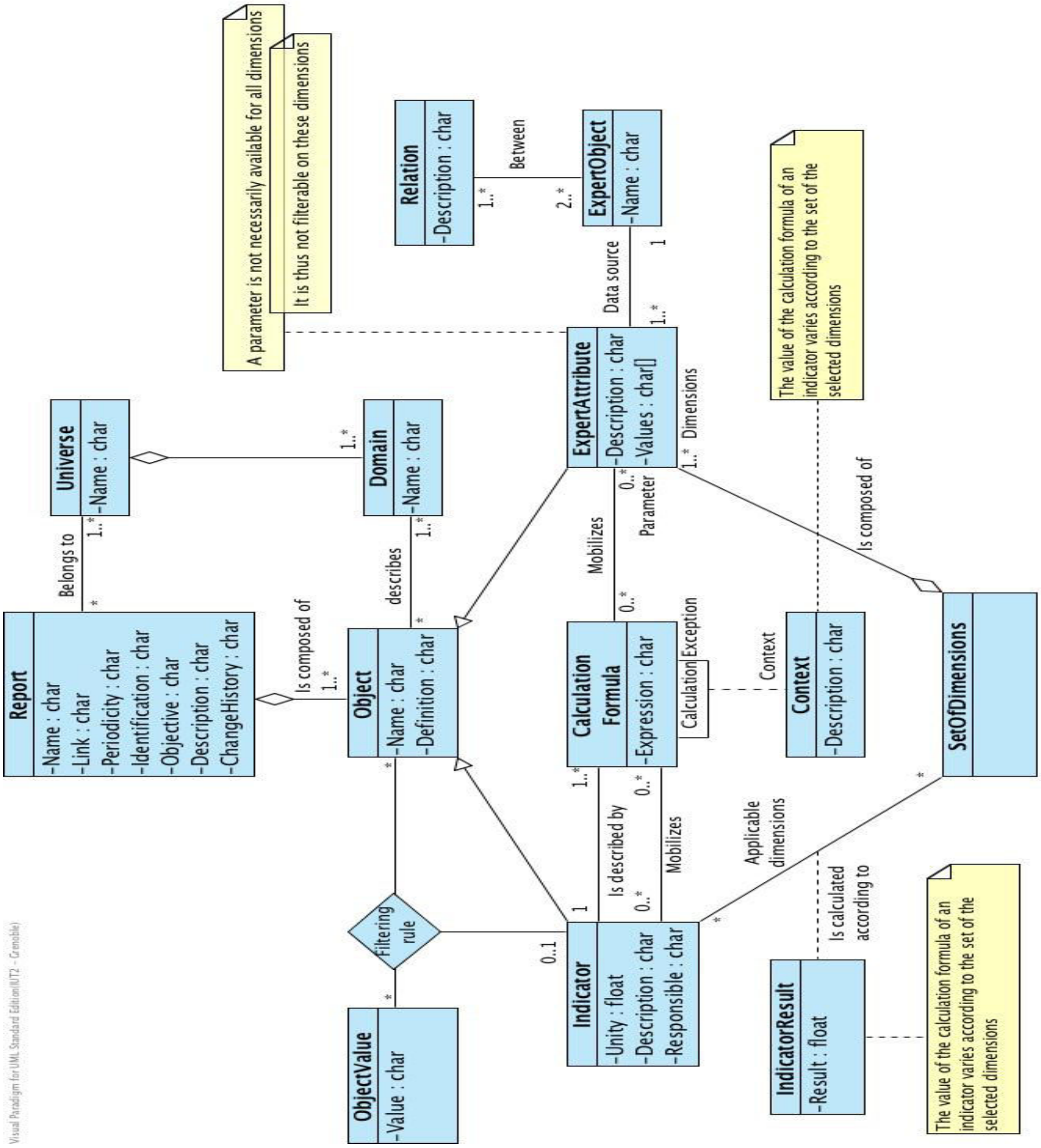


Fig. 4.12. Know *What* representation: *Business Intelligence* process

finished products per month.

Finally, a report could be created for a specific objective. For example, a report measuring rejected products per day needs to be only filtered according to products that were not successfully delivered at the end of the process per day. That requires a filter according to values of products characterizing the failure information. Therefore, the result of the indicator would be different from its result if it is not filtered.

We note, that in the semiconductor domain, expert objects (lots, wafers, machines, etc) are related through several types of relationships such as "one lot is composed of 20 wafers maximum". However, such a dependency has an important impact on the selection of indicators, dimensions and filters composing a report. For example, an indicator could not be associated with a dimension in a report if they do not have functional dependency.

For instance, the indicator's content should be related to the dimension (the number of "wafers" per "lot").

To summarize, through the *Reporting* process, data are manipulated, information is transferred and knowledge is continually created. Depending on the context of use, required knowledge varies. That is in what consists the difficulty of the *Reporting* process. Also, this difficulty increases when knowledge is not effectively represented and formalized for eventual reuse and sharing among users. To this end, proposing such a model will not only facilitate the comprehension of objects interaction but also will guide the way knowledge should be capitalized and shared. To complete knowledge representation, we describe, next, knowledge in its behavioural level, followed by its technical level.

Behavioural Level: *Why* Representation

In this level of representation, we aim at representing the behavioural aspect of knowledge. Relying on knowledge described in the conceptual level through objects interaction in the *Reporting* process, we particularly consider:

- *Why* creating a report?
- *Why* is an indicator differently created? *Why* choosing a formula instead of another to calculate an indicator?
- *Why* an indicator could not be calculated or associated to a specific dimension?

As we have seen in the literature review, several methods [15, 86, 101, 106] have been proposed to deal with the behavioural aspect of knowledge. We mention design rationale (QOC, DRL, etc), expert systems or question answering systems. Relying on the literature, we analysed question types in each representation methods and we focused on methods that closely match the most with our knowledge representation.

As we mentioned above, in our work, we aim at studying the various directions explored during the process, identified alternatives or why certain options have been made (for the calculation of indicators for example). Therefore, in a first stage, we decided to study the QOC (Question-Options-Criteria) model, present our vision of one possible solution, as well as discuss how to deal with the know *What* representation, previously described.

The QOC model provides an analysis of decision making throughout a process. In our research, this corresponds to the behavioural aspect of knowledge, that we represent with its know *Why* characteristic. Therefore, in our work, the QOC model is our solution for representing the understanding of principles behind processes.

To effectively use the QOC model for the know *Why* representation, we believe that it is crucial to base on knowledge described in the know *What* model. We consider therefore its identified concepts and relationships. To proceed, first, the QOC model targets their identified ambiguities and/or exceptions throughout their behaviours. These ones represent the questions in the QOC model. To answer a question, the design space of the considered process is represented by design options. These options are structured as responses to issues raised by the design problems related to the considered objects and their relationships. Finally, criteria are used to select options as solutions to answer the question. Arguments can justify the selection of an option according to a given criterion.

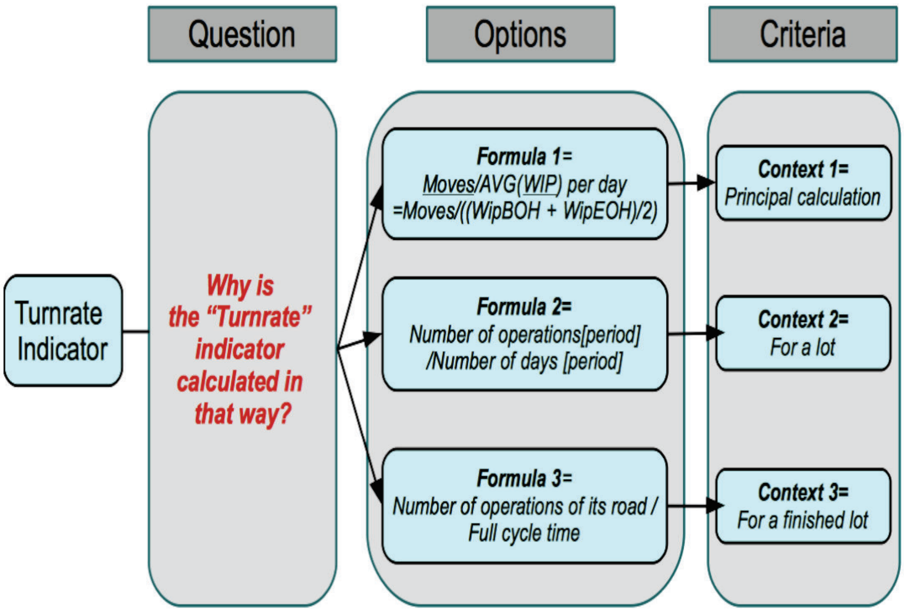


Fig. 4.13. Know *Why* representation with the QOC model

In the following, we take the *Reporting* process as an example of case study. Figure 4.13 shows the know *Why* representation, applied to the *Reporting* process. The model presented in this figure is based on the QOC model (Questions-Options-Criteria). Based on the know *What* model described above in figure 4.12, we aim at demonstrating principles behind the creation or use of manipulated objects through the *Reporting* process. *Reporting* engineers and users are daily confronted to a set of questions when selecting objects (of the know *What* model) to validate a task. For example, *Why* is an object the way it is? *Why* is it calculated in that way?. The response to such questions are important to successfully accomplish their work.

In this context, the example in figure 4.13 treats the indicator object and the principles behind its use. As demonstrated in the know *What* model, an **indicator** (**Turnrate**: The number of operations performed per day for a lot) used to create a report could be calculated by more than one **formula** according to its **context** of use. Therefore, one of the most important questions asked when selecting an indicator is " *Why* is the **Turnrate** indicator calculated in that way?". In fact, the first part the QOC model used in figure 4.13, treats the Question part that corresponds to the Indicator **Turnrate**. Options presents its second part. In our context of use, options provide different formulas calculating the same indicator. For example the indicator **Turnrate** could be calculated by either **Formula 1** or **Formula 2** or **Formula 3**. To each formula, one criterion explains its selection. In our case, contexts of selection of formulas correspond to the criteria in the QOC model. For example, if the user is in the **Context 3** where he/she wants to calculate the **Turnrate** of **a finished lot** then it will select the **Formulas 3** to calculate it. As a result, using the QOC model could meet the problematic of the know *Why* characteristic representation in *Reporting* process.

To summarize, the know *Why* remains an important characteristics that should be effectively represented and capitalized. It involves knowledge on explanations and behaviours behind performed business processes. We believe that the QOC model is an effective solution that helps users to easily represent their knowledge and understand others' one.

Technical Level: *How* Representation

As we have discussed above, the know *How* treats the knowledge integration and configuration in systems throughout processes. Capitalizing such knowledge in industrial contexts is a crucial step since the technology evolves and important configuration process could be quickly lost. Keeping track of technical details facilitates engineers' work and saves time. The IRTV (Information-Roles-Tasks-Views) methodology deals with platform configuration, delivery, extension and improvement [114].

Generally, using the IRTV, we aim at modelling knowledge intensive tasks throughout projects. Being a very generic solution [114] helps its applicability in our proposal. In the same manner as the QOC model for the know *Why* representation, the IRTV model should base on knowledge from the know *What* and *Why* contents. Therefore, it takes into account concepts, their relationships, as well as their behaviours. Thus, the principle behind its use consists in capturing and discussing primary information on concepts characteristics and their behaviours during the early stages of a process. We note, for example, concepts access rights or passwords, according to their behaviour. Such knowledge is included neither in the *What* nor in the *Why* models. Therefore, roles are identified, their information enrich existing one, their tasks are specified and their required views are detailed. Since we use the IRTV for the technical aspect of knowledge, considering technical users is particularly important to deal with processes' and solutions' configuration, delivery, execution, etc. As a result, the IRTV model includes knowledge required to make an operational process.

In the following, the *Reporting* process is considered as a case study on which we apply the IRTV solution for the know *How* representation. In figure 4.14, the IRTV solution is applied to describe the know *How* related to the use of a report (the WIP Status Report) that actually represents an expert object of the know *What* model, as follow:

Information: considers knowledge required for the users to create, to manage or to use a report and knowledge produced by them (inputs and outputs). This is not what we described in the *What* model, but, technical knowledge required by an IT member. For example, to create a report, inputs are passwords, access rights, etc. Outputs are scripts or the final report category and nature.
Roles: represents different users who are confronted with the use of a report (owner, developer and simple user).
Tasks: each role is in charge of specific tasks. For example, as depicted in figure 4.14, a BI expert is in charge of evaluating requests of users (the end user role in the figure, for example) in terms of relevance, priority, gain, etc. He/she needs also to detail data technical specifications (databases, tables, attributes and how to extract them). In addition to documenting these technical knowledge, he/she is in charge of specifying exceptions, alternatives and tests. If needed, he/she has to contact the end user since he/she is the one making the request.
Views: Each role accesses to a specific view. As depicted in figure 4.14, a BI expert performing technical tasks needs to have a technical view which is different from the view needed by an end user. He/she needs to have a clearer view about the environment he/she should work on (platforms, tools, etc.), as well as requirements and specification definition, etc.

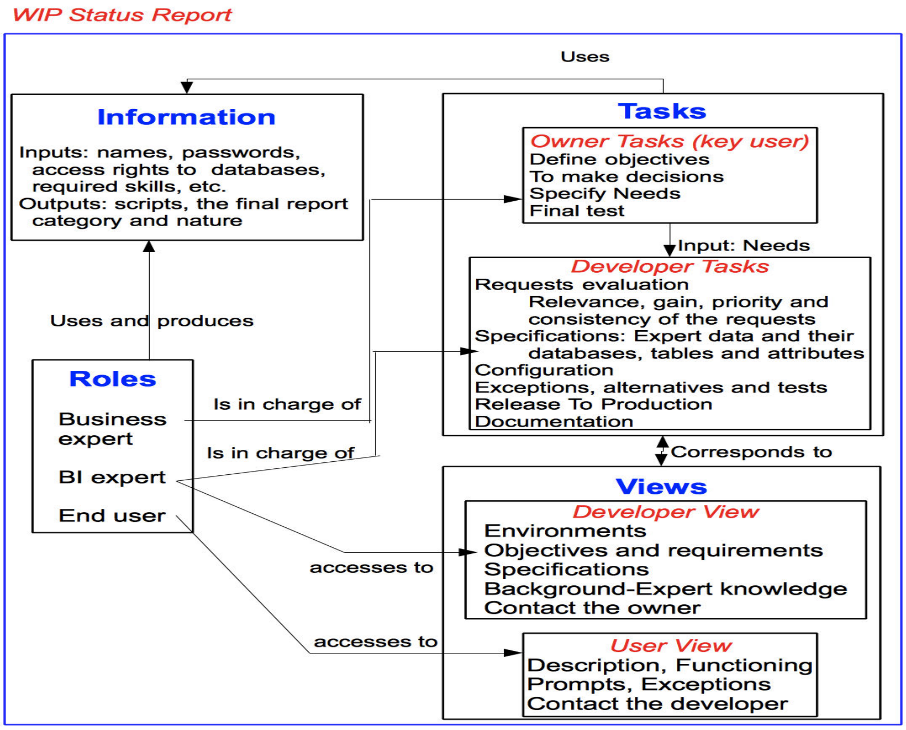


Fig. 4.14. Know *How* representation with the IRTV methodology (the WIP Status Report)

These knowledge need to be capitalized and shared with other users, particularly between the same category, for an effective reuse. Actually, IRTV modelling meets our needs because it involves knowledge on the technical context at a finer granularity. This model completes the know *What* and *Why* models, with knowledge required to technically achieve the required task. In our example, we considered the task of creating reports, according to each role characteristics. However, we believe that involving knowledge on process modelling in the know *How* model will be beneficial to represent the technical knowledge, particularly for complex processes, which is not included in the IRTV solution. In fact, the IRTV solution offers the possibility to integrate other solutions [16]. Consequently, in our case, a process modelling solution can be effectively added to IRTV and complement the know *How* representation.

3.2.7 From Knowledge Representation to Knowledge Sharing

Previously, we suggested to represent knowledge based on its three characteristics "*What*, *Why* and *How*", with three complementary models. In order to integrate them in the capitalization cycle, we suggest a process to make the consistency between knowledge representation and its integration in a wiki. In this work, we consider the *Stiki*. This process consists in transforming the represented knowledge characteristics to shareable ones in order to facilitate access to knowledge and promote its effective reuse. The objective is to split knowledge in several pages according to its characteristics to facilitate and ensure a maximum of reuse. Particularly, in the *Reporting* process, knowledge concerns manipulated and created objects (know *What*), their behavioural aspects (know *Why*) and their technical integration (know *How*).

In fact, structuring pages and information helps writing information, guides information research, improves understanding and unifies the content. Therefore, our idea consists in systematically providing *Stiki* templates for objects, where each template aim to treat all knowledge characteristics (*What*, *Why* and *How*), according to the appropriate models. In figure 4.15, we describe our vision of knowledge sharing through *Stiki* while integrating knowledge characteristics. In fact, the *Stiki* templates (boxes in the figure) represent some classes identified in the know *What* model (indicator, dimension and report for example). The links between the templates represent some relationships between these classes in the same model. The content of each template should include important knowledge represented in the *What*, *Why* and *How* models (For example, the formulas to calculate an indicator and criteria of each one as well as the technical description of a report). The objective is to transform knowledge characteristics representation to shareable *Wiki* pages.

As a result, based on the know *What* model, we obtain templates for: report, universe, indicator, dimension and domain. Each one must include related information within the same model. Thus, in the indicator template, we include its calculation formulas and their contexts description. We include as well expert attributes that constitute each formula. From the know *Why* model, knowledge on justifications behind the selection of indicators formulas are included in the template of indicators, where we treat different questions about the manner it is calculated (For example, *Why* is an indicator calculated in that way?). Thus, we present calculation formulas as well as their contexts of use and calculation exceptions. From the know *How* model, technical knowledge, such as access rights to the indicator must be also included in the indicator template.

In the same manner, in the report template, we mention objects used to create it (indicators and dimensions). Besides, their relationships, represented in models by UML associations, are represented in the *Wiki* by hyper links between pages. For example, the relationship between a report and an indicator "Is composed of" (in figure 4.12) is transformed to a hyper link between their pages. Besides, describing developers, support and users guide in the report page aims at providing technical information about the report creation, which corresponds to the know *How* model. In this way, we include in *Stiki* templates different knowledge about the reports creation, based on knowledge representation.

Therefore, based on knowledge representation, our goal is to effectively capitalize and share knowledge related to reports creation, while providing a comprehensive knowledge representation and a clear reports description in *Stiki*.

3.2.8 Conclusion

In this section, three complementary characteristics know *What*, *Why* and *How* were defined and represented [2]. We demonstrated the importance of integrating all of them together, in order to effectively capitalize expert knowledge. Each characteristic represents knowledge from a different point of view and is represented in an appropriate way. Therefore, we represented the know *What* with a UML model, the know *Why* with the QOC model and the know *How* with the IRTV model. We explained the idea behind their integration into the capitalization cycle. It consists in their transformation to shareable one through *Stiki* templates. Our proposal was applied to the *Business Intelligence* process at *STMicroelectronics*, that we explored, co-designed and validated with involved users.

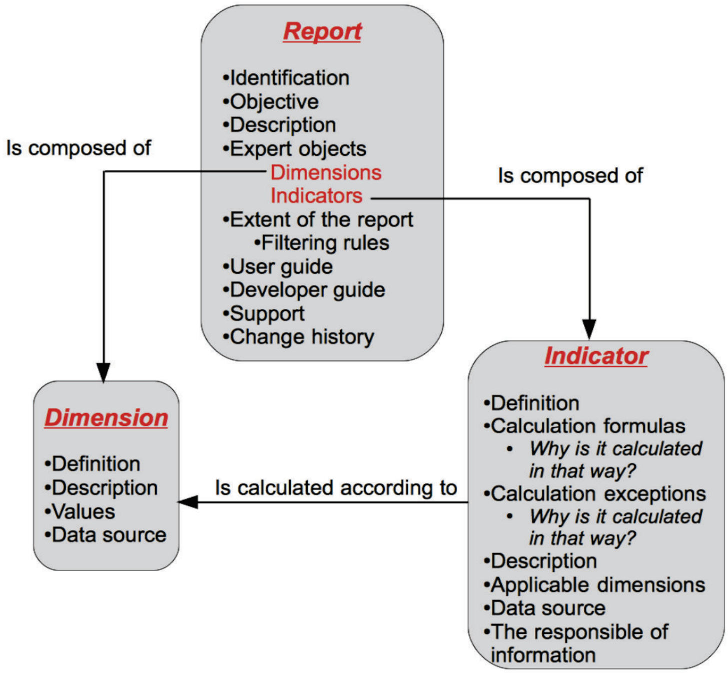


Fig. 4.15. *Reporting* knowledge sharing

4 Knowledge Evolution

4.1 Introduction

Knowledge evolution should allow maintain capitalized knowledge and involved systems according to the evolution of business needs and knowledge. To illustrate our proposal, we take *Business Intelligence* as a case study.

As we discussed in chapter 2, at *STMicroelectronics*, the *Business Intelligence* system acts on many business processes, uses different resources, involves different users' roles and continuously generates knowledge to make new business decisions. All of them are daily evolving requiring a solution for BI knowledge evolution that can allow to take improvement actions. More generally, knowledge evolution can ensure the evolution of used, required and generated knowledge on the system's content, uses, tools and activity. This is the reason why BI knowledge evolution consists of the BI system evolution, while considering its content, uses, tools and activity.

On the one hand, our objective is to quantitatively evaluate, analyse and make decisions on BI knowledge evolution. Since our objective is itself the principle of BI, we aim to develop a BI system for evaluating, analysing and making decisions about the system itself. Such a solution will ensure the BI system evolution involving the evolution of its knowledge.

On the other hand, a user-based evaluation solution will complement our proposal for knowledge evolution. It includes a questionnaire able to assess the BI system knowledge and to identify areas that could evolved. Answers would be likely to come from the BI system's users.

In the following, our global solution is presented, followed by the design and the implementation of our proposal *Business Intelligence* for *Business Intelligence* and the description of the user-based evolution.

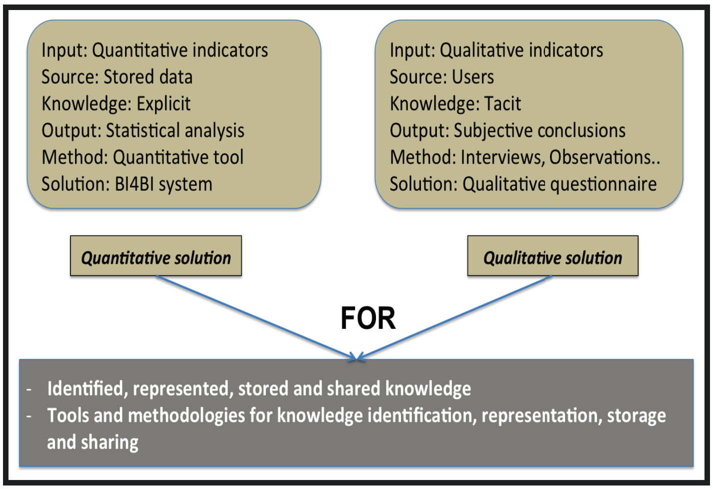


Fig. 4.16. Quantitative and user-based solutions for knowledge evolution

4.2 Global Solution

4.2.1 Objectives

As we discussed above, knowledge evolution involves two complementary solutions, quantitative and user-based. Both are based on indicators. To this end, we identified several BI indicators (presented in appendix B). In total, we identified 29 quantitative indicators, 10 for BO, 9 for Safir, 6 for *Stiki* and 4 for the BlogCrolles300. In addition to quantitative indicators, we identified several user-based ones (with a subjective nature). Those can not be objectively evaluated.

As depicted in figure 4.16, first, a quantitative solution uses quantitative indicators, based on stored data in systems in order to provide statistical analysis. This is why we suggest to use a quantitative tool able to provide quantitative results and help make analysis. Second, a user-based solution uses indicators based on users' opinions and perceptions in order to identify a maximum of their knowledge. The complementarity of our solutions is demonstrated through considering both explicit (stored data) and tacit (users' opinions) knowledge in the process of knowledge evolution. To this end, we propose quantitative and user-based solutions, presented in the following.

4.2.2 Overview of our Proposal

Quantitative Solution: BI for BI

Since the BI system uses, contains and generates business knowledge, we believe that it should be continuously evaluated and analysed while taking into account its use, evolution and maintaining after long time. Therefore, we aim to develop a solution for evaluating, analysing and making decisions about the BI activity and its evolution. Since these are the principles of BI, the developed solution will be a BI system applied to the system itself. We call it a BI4BI system. To this end, our objectives are:

- To define the evaluation criteria in order to identify indicators for assessing BI system
- To measure and integrate them in the BI system
- To model a BI data warehouse with identified indicators and measures

User-based Solution: Questionnaire

A user-based solution helps collect a variety of users' opinions and points of view. It complements the quantitative solution ensured by a BI for BI system, by considering tacit knowledge. To this end, a questionnaire that could be applied face to face or by electronic means helps provide a richer insight mainly about knowledge embedded in the BI system in order to ensure its evolution.

We note that generally, a questionnaire is considered as a quantitative solution because it produces statistical analysis. However, in our work, we consider it a user-based solution because it is based on users' insights required to assess a BI system and knowledge, which can not be achieved by the BI4BI system.

As a part of the design cycle of the Design Science Research (figure 1.5), both solutions design are based on two entries:

- First, we based on defined business needs, presented in chapter 2, where we explored *STMicroelectronics*' current practices in BI, users' expectations and needs from BI, advantages and limits of existing solutions of evaluation and desired improvements.
- Second, we based on a literature review on BI evaluation criteria and their integration in the system, as well as on existing design techniques and artefacts. This is presented in chapter 3 as a part of the rigour cycle of Design Science Research, ensuring innovation for our proposal.

In the following, *Business Intelligence* for *Business Intelligence* solution followed by the questionnaire are detailed.

4.3 Our proposal: *Business Intelligence* for *Business Intelligence*

4.3.1 The Design Process for our Proposal

The first part of our proposal aims at providing a quantitative solution able to analyse and make decisions on the evolution of embedded knowledge in existing systems. These objectives are themselves those of *Business Intelligence* on which we decided to base to achieve our proposal. The main goal of our solution is to develop a BI system, to:

- access to systems' content and identify embedded knowledge to be analysed
- measure its behaviour and integration, based on indicators, measures and dimensions
- allow to analyse the considered systems and therefore their knowledge
- use decision tools to make decisions on systems and knowledge evolution

In this work, we take the case of BI knowledge evolution at *STMicroelectronics* as a case study.
As depicted in figure 4.17, at *STMicroelectronics*, a production system generates data describing the evolution of the activity. A BI system bases on these data to communicate, measure, evaluate and analyse the production activity in order to generate knowledge and make business decisions. We note that at *STMicroelectronics*, the BI system is composed of BI tools as well as communication tools (Stiki, Safir and the Blog). Fundamental elements constitute the base of BI tools, for example, indicators, dimensions, reports, etc.

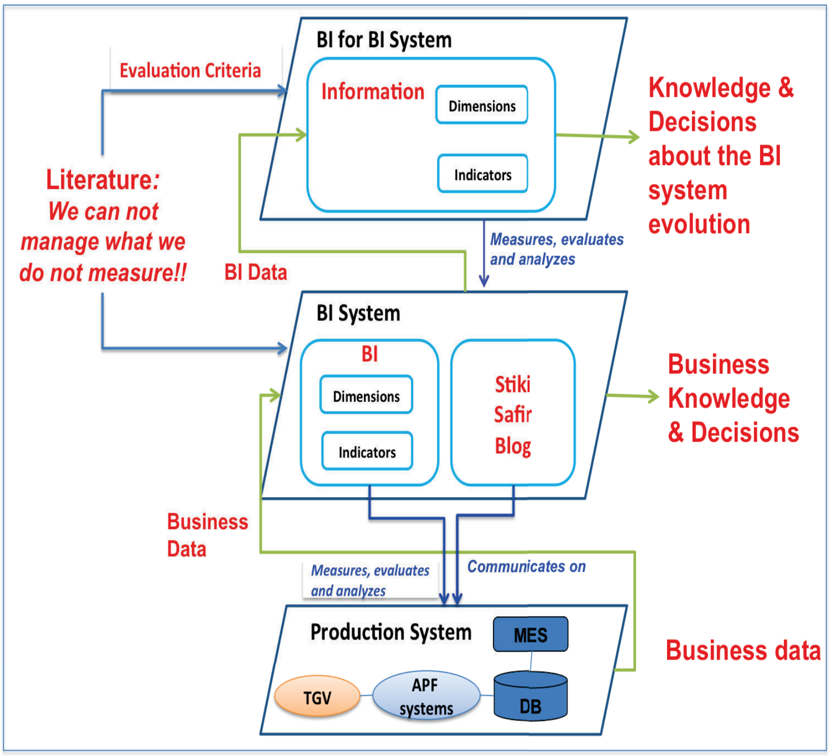


Fig. 4.17. BI for BI system

In addition, in this thesis, a BI for BI system applied to the current BI system is developed (figure 4.17). It consists in using as well BI elements and techniques as follows:

- To define indicators and dimensions
- To define an architecture of the BI for BI system
- To model the dimensional data warehouse

The BI for BI system will be used to analyse the current BI system behaviour and to make decisions about its improvement actions. Monitoring the BI system will promote its activity, ensuring, consequently, making the right business decisions and its knowledge evolution. For example, at *STMicroelectronics*, as part of a migration project, engineers have to migrate existing BI objects to a new data warehouse. First, they need to know which BI objects to migrate. To this end, analysing the uses and relationships between BI objects will help to decide which objects are useful and should be migrated. This will prevent the overloading of the new data warehouse with useless objects and ensure an effective system's evolution. Based on this principle, we detail in the following how we design our solution.

4.3.2 Specification of the BI4BI Solution

As part of our solution's design, BI modelling uses two main concepts, indicators and dimensions. It consists in modelling the relationships between them while providing an effective and simple representation of the activity. This is the core of a BI modelling solution.

Indicators Analysis and Measures Identification

In BI, an indicator corresponds to the aggregation of data, generally quantitative, called measures. We note that we are searching for indicators to measure the BI activity. The particularity of our indicators is that are applied to the BI activity and its objects, for example, to the business indicators or dimensions. They may even reuse some existing ones, for example, a business indicator monitoring the production activity may be reused to monitor the reporting activity. We note that reusing BI techniques for BI systems is the core of our proposal.

In a first stage, we base on a literature review to identify evaluation criteria, as a part of the rigour cycle of the design science methodology. As we discussed in the state of the art (chapter 3), [127] based on ISO 25000 family to evaluate his BI system from three points of view: quality in use, external quality and internal quality. To base on formal specifications described in international standards is very interesting and this justifies our choice of the ISO model to select the evaluation criteria. ISO 25000 provides quality characteristics to evaluate the properties of a software product [129]. The product quality model defined in ISO 25000 comprises the eight quality characteristics and their sub characteristics, for example functional suitability, performance efficiency, compatibility or usability, etc. In order to measure the level of quality for each sub characteristic, appropriate indicators and measures should be assigned.

To construct *STMicroelectronics*' BI for BI system, among identified ISO characteristics, we first focus on the functional suitability and its sub characteristics in order to identify their associated indicators. Actually, despite the importance of the rest of characteristics, we classified them with users according to the BI evaluation's needs. We consider that the functional suitability is the characteristic that distinguishes the most the systems from each other, since it considers the degree to which the system provides specific functions that meet implied needs. The functional suitability is composed of the following sub characteristics:

- Functional completeness: degree to which the set of functions covers all the specified tasks and user objectives
- Functional correctness: degree to which a product or system provides the correct results with the needed degree of precision
- Functional appropriateness: degree to which the functions facilitate the accomplishment of specified tasks and objectives.

To proceed, we use the definition of characteristics and sub characteristics provided by ISO in order to define indicators, their measures and later corresponding dimensions. Users' experiences and expertise in the domain at *STMicroelectronics* helped to enrich our findings from their points of view. As a result, our solution refers to various categories of indicators and measures. As shown in figure 4.18, they concern:

- Involved BI users (figure 1.4): for example, "the number of subscribed users" on the Blog to evaluate "its notification support" indicator
- Used BI objects: for example, "the number of duplicated or similar objects" in BO to measure "the objects coverage" indicator

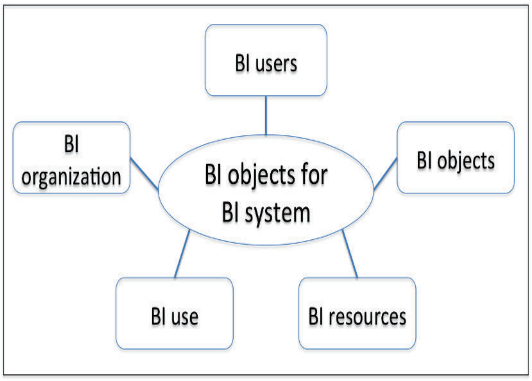


Fig. 4.18. Identified indicators categories

- Used BI resources: for example, "the number of distributed licences" of BO to measure "the resources uses" indicator
- Content BI uses: for example, "the number of contributions per Stiki page" to measure "the content uses" indicator
- Organization in the BI system: for example, "the ease of access to a report" measure to evaluate "the access to information" indicator

As a result, evaluation criteria, indicators and measures are defined for each tool for the functional suitability, in our case (appendix B). For example, to evaluate the functional completeness for BO, we suggest to measure its objects coverage as well as its activity evolution. To this end, a set of measures is proposed for each one. To measure objects coverage, with users, we think that it is important to measure the number of BI objects uses, the number of covered domains, the number of duplicated BI objects, etc. Each measure could be subjective, based on the subjective judgement of a user, or objective, based on quantification where objective measures may vary according to a set of dimensions that we detail in the following.

Dimensions Identification

A dimension is an element constituting the context of an indicator. In BI, they are grouped into meaningful sets for users and decision makers. In BI, dimensions represent business concepts and we often talk about a hierarchy of dimensions that could be geographical (cleanroom, town, etc), temporal (year, month, day, etc) or of products. For example, at *STMicroelectronics*, in the BI system we have as product dimensions: equipment, operation, lot, step, etc.

In our proposal, we do not talk about business dimensions but about dimensions to apply to identified measures analysing the BI activity (described in the previous section). To this end, with users, for each objective measure, we select appropriate dimensions. Our findings were validated with the questionnaire. As a result, we identified four sets of dimensions presented in figure 4.19.

- Date dimension hierarchy: one or more time dimensions are often required. In BI, since we use objects to create reports and make decisions, the time dimensions could vary between the year to the day level.
- User dimension hierarchy: this hierarchy is composed of three levels:

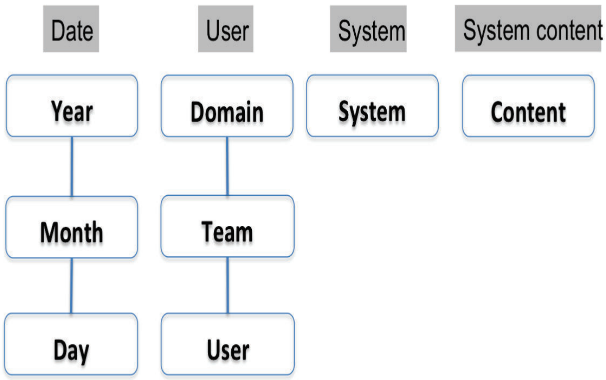


Fig. 4.19. BI dimensions

- Domain dimension: BI system could be used for different domains within the organization. This is why, the domain is one dimension for some identified indicators. For example, at *STMicroelectronics*, domains could be: IT, finance, communication, etc.
- Team dimension: in a domain, the BI system could be used in different teams within the organization. This is why, the team is one dimension for some identified indicators. Each team belongs to one domain. This is why team is a sub dimension of domain. For example, in IT at *STMicroelectronics*, teams could be: local architecture, manufacturing execution systems, process control and automation, etc.
- User dimension: different users use the BI system in the organization. This is why several indicators are measured according to users. Each user works in one team. This explains why user is a sub dimension of team.

- System dimension: a system dimension could be any of *STMicroelectronics*' BI tools (BO, Safir Reporting Portal, Stiki or the Blog).
- System content dimension: for each system a content dimension is identified. For example, for BO, we identified its objects (Indicators, dimensions and reports). For Safir, indicators could be measured according to published reports or according to categories classifying these reports.

As depicted in figure 4.20, a BI system could be BO, Safir, Stiki or the Blog. Each one has its own content type. For BO, objects could be: indicators, dimensions, universes or reports. The content type of Safir could be: reports or its categories. These objects constitute actually the BI dimensions represented in figure 4.19.

For example, for BO, "the number of objects uses" measuring the "Object coverage" indicator is measured according to the following dimensions: time, domain, BO objects, user (appendix B).

Above, indicators and dimensions required for our proposal are presented. In the following, we detail how they are integrated and used in the data warehouse modelling that is considered as the core of BI systems.

BI Data Warehouse Modelling

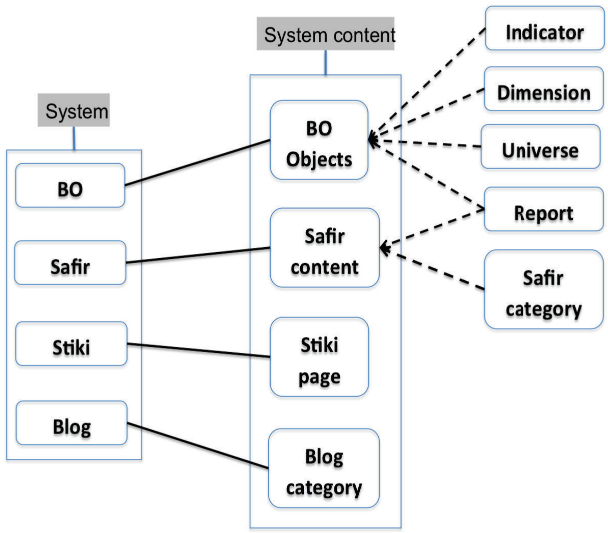


Fig. 4.20. BI system content

As we discussed previously, data modelling in a DWH is different from a classical modelling in a transactional database (Entity-Association). Two main rules are considered, first, the intelligibility of data that must be understandable, meaningful and in an appropriate granularity, second, performed analysis must be interactive and response time must be minimized. To this end, dimensional modelling attempts to overcome these two problems. It considers two key concepts, indicator and dimension (more details are given in chapter 3).

In order to demonstrate how the BI could be applied to the BI system activity, in this section, we suggest an example of a BI data warehouse modelling based on identified indicators, measures and dimensions previously presented:

In the decisional solution section, BI experts would like to analyse their BI system activity and particularly the way objects are used in order to clean the system of unused objects. To this end, following objectives are identified:

- To track the BI objects' uses in BO
- To track the shared reports uses and users
- To track the documented reports uses and users

To address these issues, we elaborate the relationships between indicators and dimensions previously identified with a bus matrix. We present an example in table 4.21 where we determine the measures for the solution and decide which individual element to include with each dimension.

Based on these findings, in the following, we review the design of the dimensional model using the Snow Flake schema. In this example, we made the choice of using a Snow Flake schema because it is more detailed and explicit than the star schema.

	Date	System			Content				User
	Month	BO	Safir	Stiki	Indicator	Dimension	Report	Stiki page	User
The number of indicators	X						X		
The number of dimensions	X						X		
The number of created reports	X				X	X			
The number of accesses	X		X	X			X	X	X
The number of users	X		X	X			X	X	

Fig. 4.21. Bus matrix

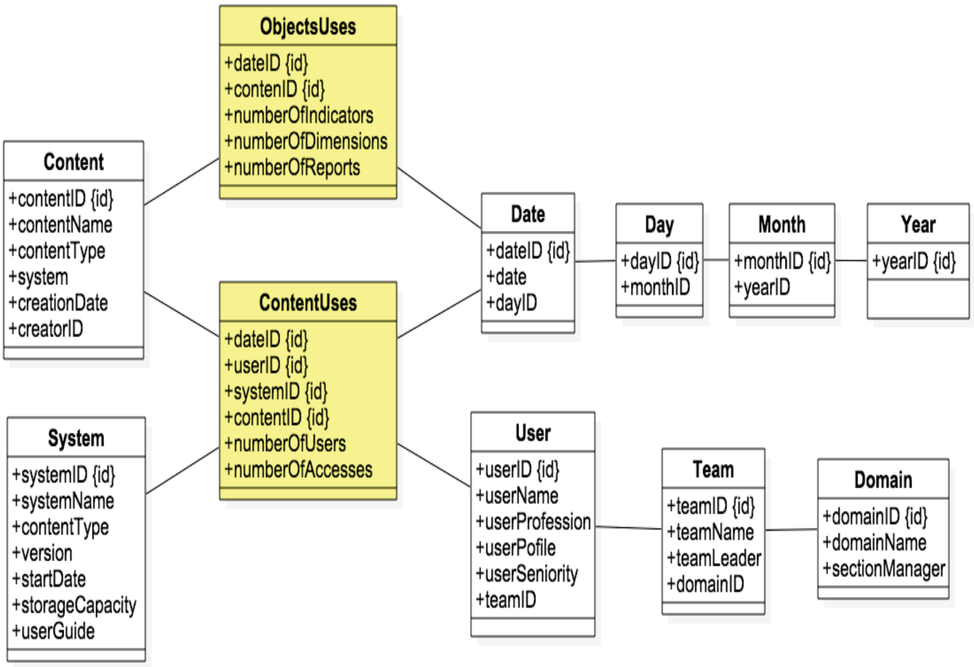


Fig. 4.22. Snow flake schema

In the snow flake schema, presented in figure 4.22, two types of tables are identified, fact tables (ObjectsUses and ContentUses) connected to dimension tables (Date, Month, System, Content, User). These tables are identified based on the bus matrix previously described in figure 4.21, where we model, first, the fact table "ObjectsUses" used to track the BI objects' uses particularly indicators, dimensions for creating reports and the second one used to know if shared and documented reports are used or accessed, and by how many users.

For example, as a result of the development of the "ObjectsUses" table, we will be able to report:

- How many indicators and dimensions used per report
- In how many created reports, each indicator or dimension is used

Such findings will help engineers to determine the usefulness of the objects.

Up to now, we described how BI could be applied to BI based on its own techniques and particularly the data warehousing modelling, as a first part of BI knowledge evolution. In the following, we proceed with its implementation (section 4.4). Next, the user-based solution, as the second part of BI knowledge evolution, is detailed (section 4.5). We end this section with presenting both solutions as a single full proposal for knowledge evolution (section 4.6).

4.4 Our Proposal BI4BI Implementation

A *Business Intelligence* for *Business Intelligence* system is actually a BI solution able to analyse and make decisions about an existing system. At *STMicroelectronics*, it is applied to the production system. However, in our research, it is actually applied to a BI system (figure 4.17). As we mentioned above, we base on a classical BI architecture and techniques to implement our proposal, as follows.

Technical Architecture
To build our system, a BI architecture plays an important role in organizing data, information and technology components that are used throughout the development and implementation decisions.

As depicted in figure 4.23, we choose a very classical BI architecture based on relational OLAP paradigm. The data components of the system architecture include the data sources, that in our case, correspond to BO, Safir Reporting portal, Stiki and the Blog databases. They include data describing each tool's activity. Next, by ETL -Extract, Transform and Load- processes, data from the four tools databases are extracted, transformed and loaded into the data warehouse, where data is stored in a suitable format for their decisional analysis. APF and Oracle Data Integrater (ODI) constitute our ETL solution that are known to be relevant systems according to *STMicroelectronics* experience.

The target data warehouse is based on Oracle database as our object-relational database management system. We call it BI4BI DWH, where a multidimensional representation should help interactive analysis. To this end, OnLine Analytical Processing (OLAP) technique is used to represent data in a OLAP cube. Such a representation leads to conceptually straightforward operations to facilitate analysis. Typically, OLAP data is stored in star schema or snow flake schema. In our case, we use the snow flake schema to represent data in the data warehouse as described in the following. To effectively use data presented in the OLAP cube and generate information, different BI tools are used for reporting, analysis or data mining. BusinessObjects (BO) is our OLAP application solution for analysing, mining and reporting the BI activity, since it is used and known by the organization's users for its effectiveness.

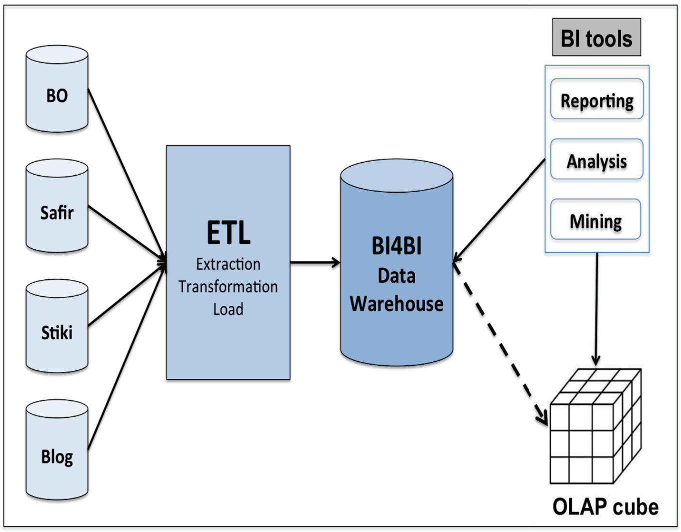


Fig. 4.23. The data warehouse technical architecture

We note that the existing BI system on what we will apply our solution is composed of different tools: BO, Safir, Stiki and the Blog Crolles300. To implement our BI4BI system, we decided to work on two stages. First, only one source among BO, Safir, Stiki and the Blog databases is considered. Second, a more advanced development will consider the remaining bases.

Application

We present an example of application, where the objective is to analyse reports uses in Safir (reports users, uses and likes). Therefore, we detail needs definition, data extractions and transformations, data loading, data warehouse modelling, reporting analysis results and results exploitation.

1. **Needs definition:**

   Based on these objectives, the database, its tables and data are analysed in order to identify required data. Figure 4.24 presents the current schema of the database of Safir.

   Among tables and their attributes included in Safir database, for our analysis, only some of them are required:

   - PORTAL_REPORT: presents a published report in Safir.
   - PORTAL_REPORT_HIERARCHIES: presents the hierarchy to which the published report is assigned. For example, the "Products_Cycle_Time" report is assigned to the "Cycle Time" hierarchy.
   - PORTAL_HIERARCHY: presents the higher hierarchy of a given one. For example, the "Cycle Time" hierarchy belongs to the "Lots" hierarchy, which belongs in its turn to the "Functional View" hierarchy.
   - PORTAL_REPORT_STATS: presents information on accesses to Safir.

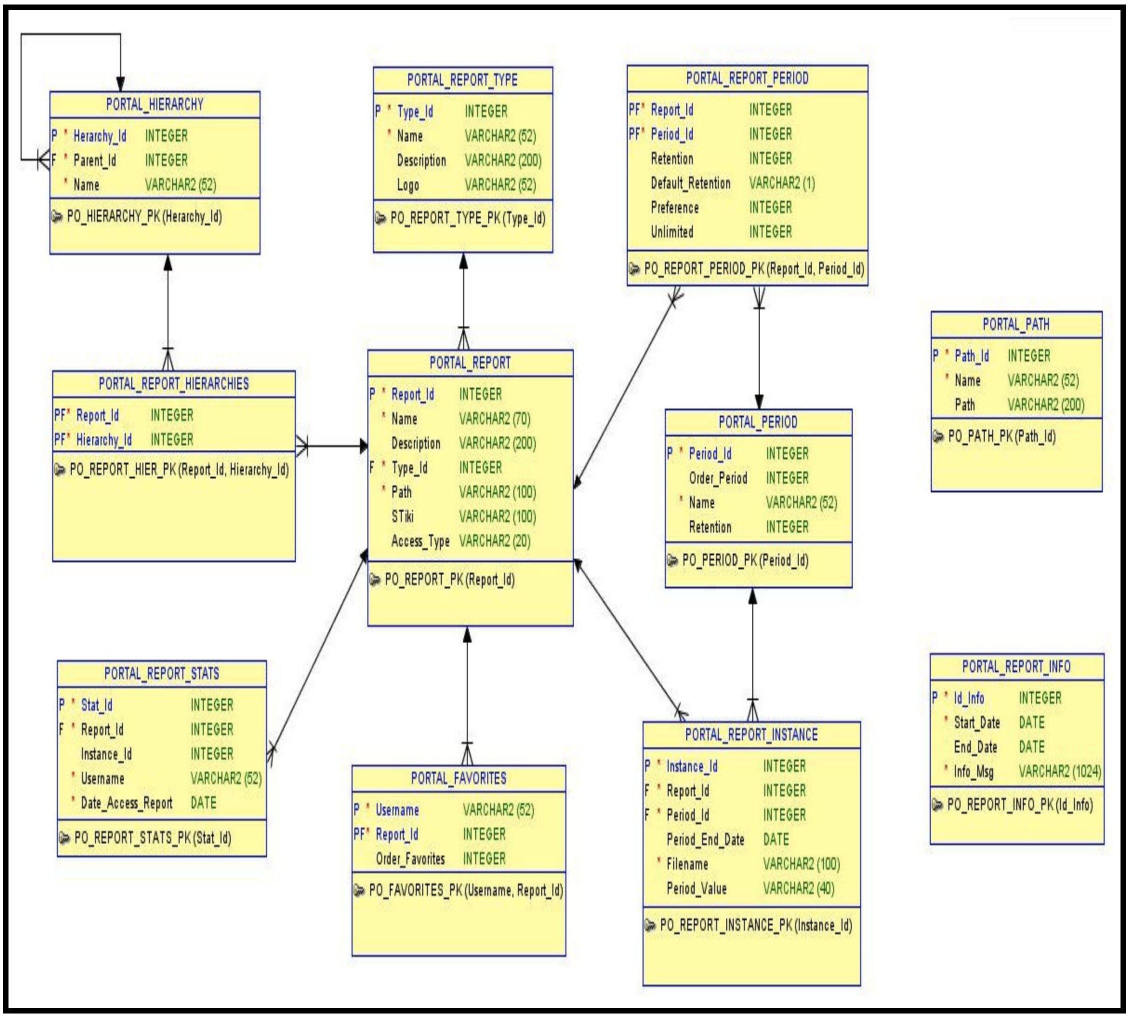


Fig. 4.24. SAFIR database

- PORTAL_FAVORITES: presents information on liked published reports.

2. **Data extractions and transformations:**

   Once data is identified, we proceed with its extraction and transformation, as part of the ETL process. To this end, we use Advanced Productivity Family (APF) [63], an industrial standard software for data collection and transformation.

   Briefly, APF is a software system allowing retrieve production data in real-time, insert it into a repository and exploit it throughout the creation of reports on this repository. Its objective is to discharge the source database (usually an operational production database) from analysis and querying, while offering a high level of responsiveness thanks to its real-time functions.

   A example of extraction and transformation is presented in figures 4.25. It shows a simple extraction process without transformations of two columns REPORT_ID and USERNAME from the table PORTAL_FAVORITES from safir database.

APF is also in charge of creating workflow-based jobs in order to automate extractions and transformations in real time. This is performed using a series of linked blocks, each representing an activity. Figure 4.26 shows and example of a job execution to automatically extract data from PORTAL_REPORT table. Extracted data is finally stored in text files, in a particular format required by the loader.

We note that APF offers rule deployment without the need for complex programming or extensive recompilations, making it easy to adapt to changing conditions as they occur [63]. It is based on event and schedule-driven execution control, icon-based job-development environment, automated exception handling logic, etc.

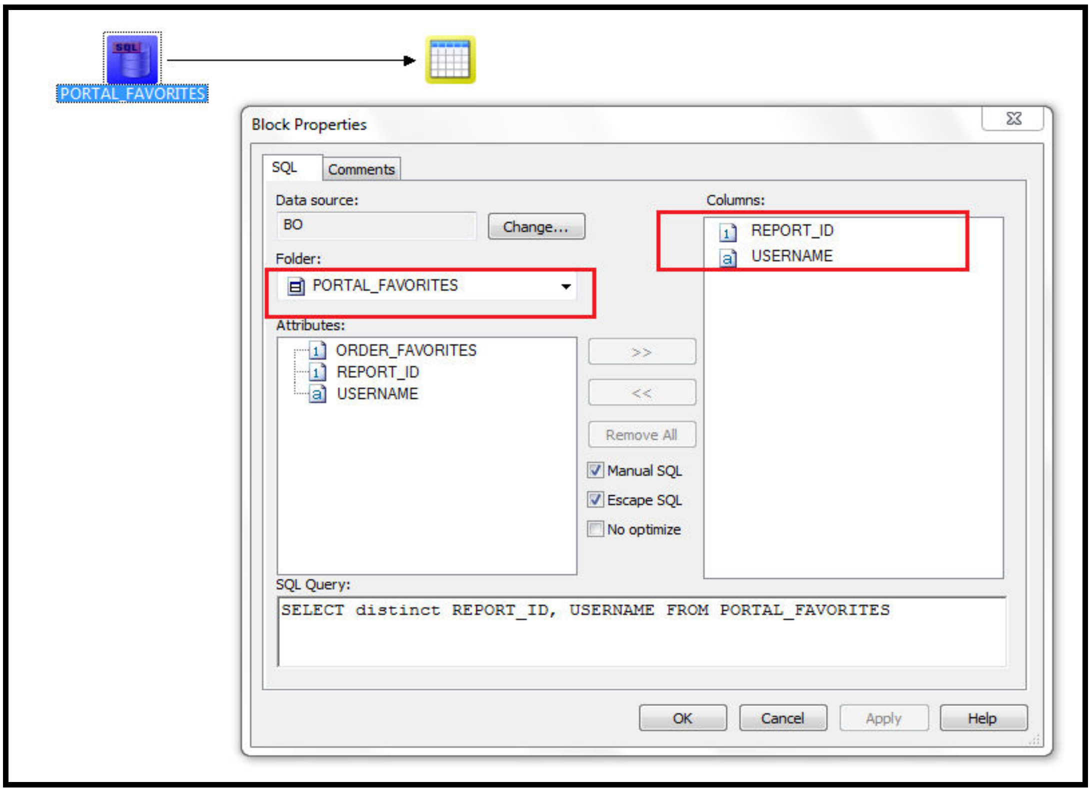


Fig. 4.25. Extraction from PORTAL_FAVORITES table

A simple extraction process without transformations of two columns REPORT_ID and USERNAME from the table PORTAL_FAVORITES from Safir database.

3. **Data loading:**

As a part of the ETL process, loading consists in importing extracted data into the target data warehouse (DWH). In this work, we use Oracle Data Integrator (ODI) [64] as a data loader. It is a data integration platform. It covers moving extracted data in real time with the possibility to make advanced transformations that could not be done before by APF. We note for example, filtering, conversions, inserts, etc. This step requires several actions that we summarize in the following and presented in figure 4.27.

In a first stage extracted data is inserted into Operational Data Store (ODS) tables (initially stored in text files). Actually, ODS is a database that we use to make further

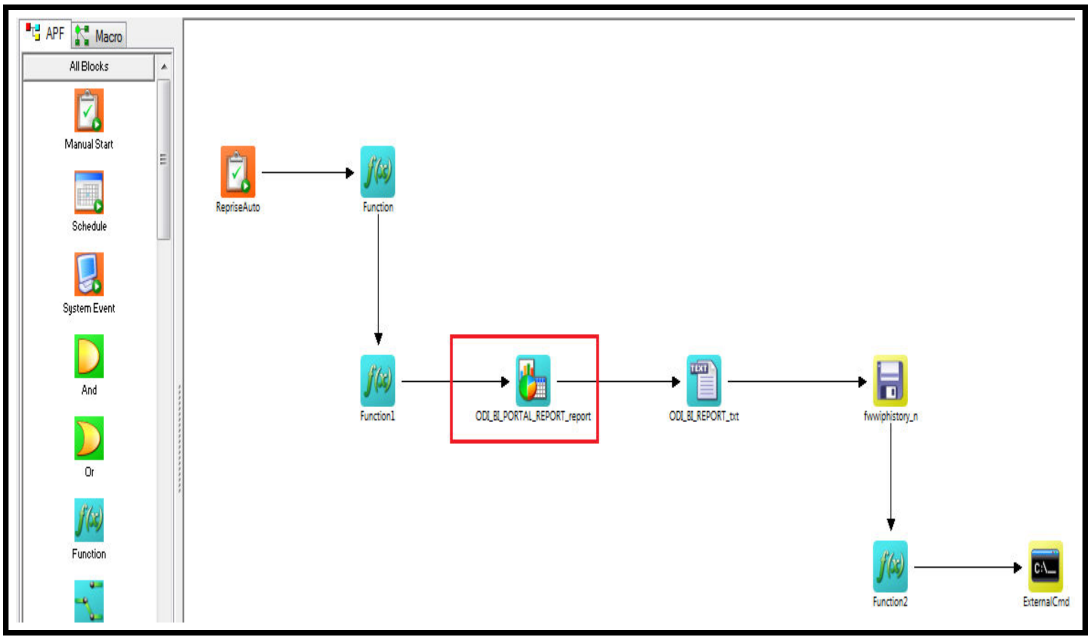


Fig. 4.26. APF job to extract data from PORTAL_REPORT table in real time

operations, such as filtering, conversion, constraints, etc. In our case, data is stored in tables named: ODI_BI_REPORT, BI_REPORT_ACCDATE, BI_REPORTFAV, BI_REPORTHIER and BI_REPORT_USED.

Once all operations are achieved on the ODS tables, they have exactly the same structure and the same constraints as those of the DWH. However, this process presents different advantages. First, we are able to make all wished and required treatments and transformations on ODS tables until the final desired results without affecting and disturbing the DWH activity. This is required especially because, unlike ODS, only selection queries can be performed in a DWH. Third, storing on ODS tables is required in our context because extracted data quickly evolve. In our case, it concerns the BI system uses. In that way, we can be sure that extracted data at a given moment is the same found in the DWH.

To ensure the efficiency of loading data into ODS tables, we complete our ODS tables with complementary fields. For example, ID_LOADING is the identifier of the current loading into the DWH that is incremented for each new one. It allows affirm the success of loadings by comparing ID_LOADING in both tables, ODS and the DWH. As a result, for the same ID_LOADING, data stored in the DWH is the same in ODS.

Once treatments on data stored in ODS are completed and finalized, it is copied into the DWH having the same structure and constraints using the ODI platform. Figure 4.28 shows an example of copying ODI_BI_REPORT content from the source ODS table into the target DWH table.

4. **Data warehouse (DWH) modelling:**

   Figure 4.29 presents the complete DWH modelling applied to our example. We identified:

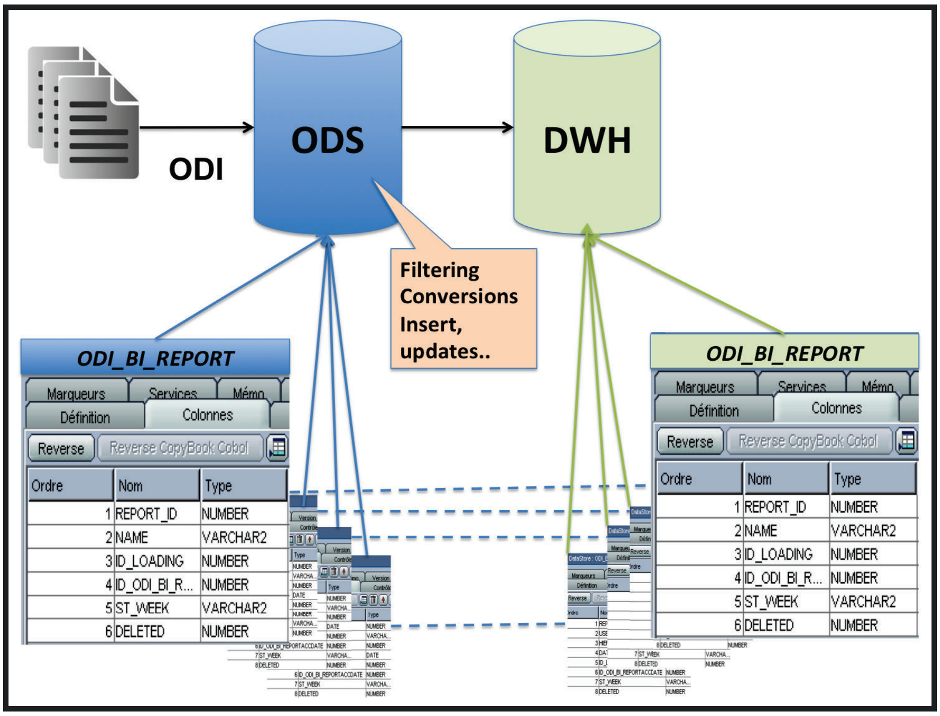


Fig. 4.27. Data loading with ODI process

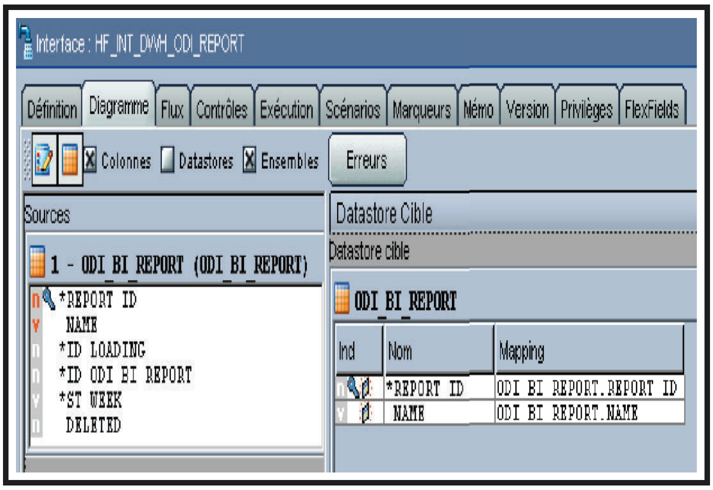


Fig. 4.28. Loading data from ODS into the DWH

- Fact table: BI_REPORTACCDATE, containing three measurable indicators:
  - *NumberOfUsers*: measures the number of Safir reports users.
  - *NumberOfUses*: measures the number of Safir reports uses.
  - *ReportLikes*: measures the number of favorite Safir reports.
- Three dimension tables, containing different dimensions:
  - ODI_BI_REPORT: contains dimensions related to reports. For example, number of users could be measured per REPORT_ID or the report NAME.
  - BI_HIERARCHY: contains dimensions related to reports hierarchies. For example, number of uses could be measured per HIERARCHY_ID, NAME or the hierarchy PARENT_ID.
  - ST_CALENDAR: contains temporal dimensions. To standardize temporal

results of our analysis with existing ones at *STMicroelectronics*, we decided to reuse the calendar used in its systems. Indicators therefore could be measured per ST_YEAR, ST_WEKK, etc.

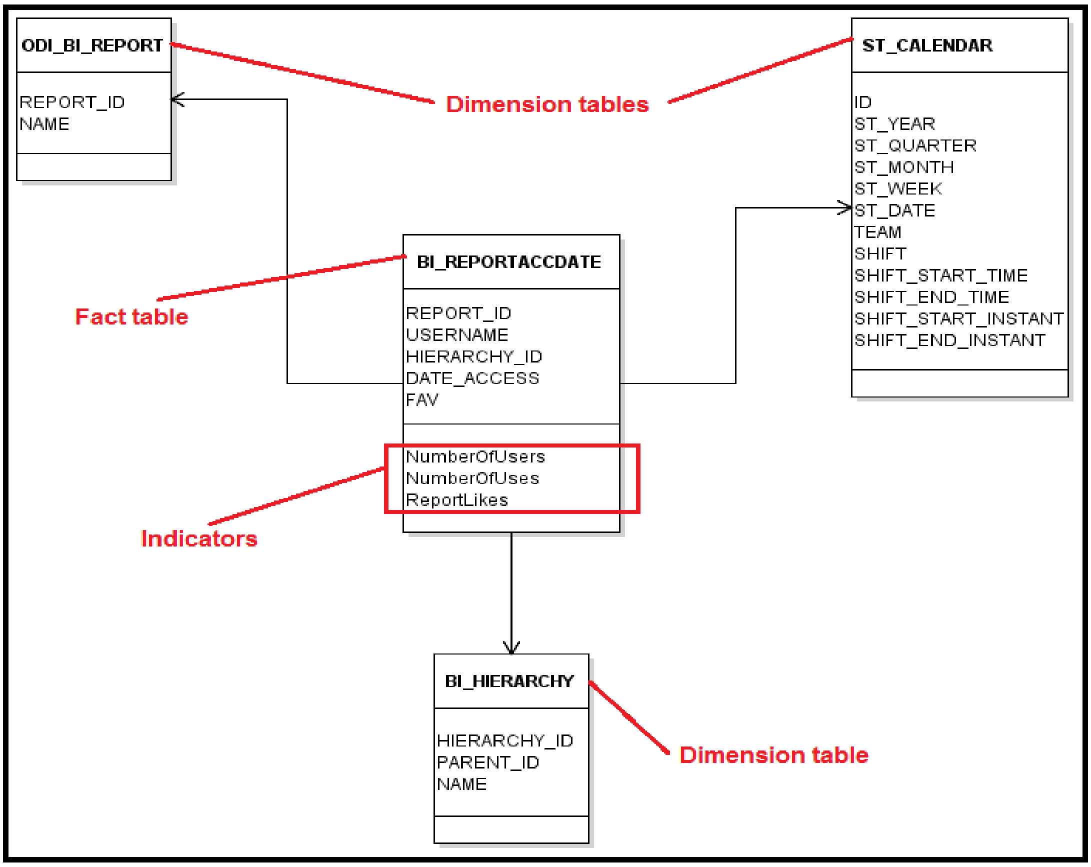


Fig. 4.29. DWH modelling

5. **Reporting analysis results:** Once the DWH objects are defined, reporting results of our analysis is our objective. To this end, we use the reporting tool Business Objects (BO). Figure 4.30 shows the interface used for our analysis where we note three different work areas. On the left, BO presents the defined objects of the DWH (indicators and dimensions previously described). On the top left, selected objects are shown. Finally on the bottom left, filters could be done on selected objects.

   Applied to our analysis, we select for example, the number of uses and the number of users after 2013. The output is therefore a report (figure 4.31) of wished results about the number of Safir reports users and uses.

6. **Results exploitation:** *Business Intelligence* aims at helping its users to make business decisions. Applied to our context, a BI for BI system aims at making decisions about the current BI system. As an output of an example of analysis, we were able to report the number of Safir report uses and users (figure 4.31). This report uses two indicators, "Number of users" and "Number of uses", where:
   $Number\ of\ users$ = count(distinct USERNAME)
   $Number\ of\ uses$ = count(distinct DATE_ACCESS)
   They are measured according to the report dimension, based on the attribute "REPORT_ID" from the dimension table "ODI_BI_REPORT" (figure 4.29).

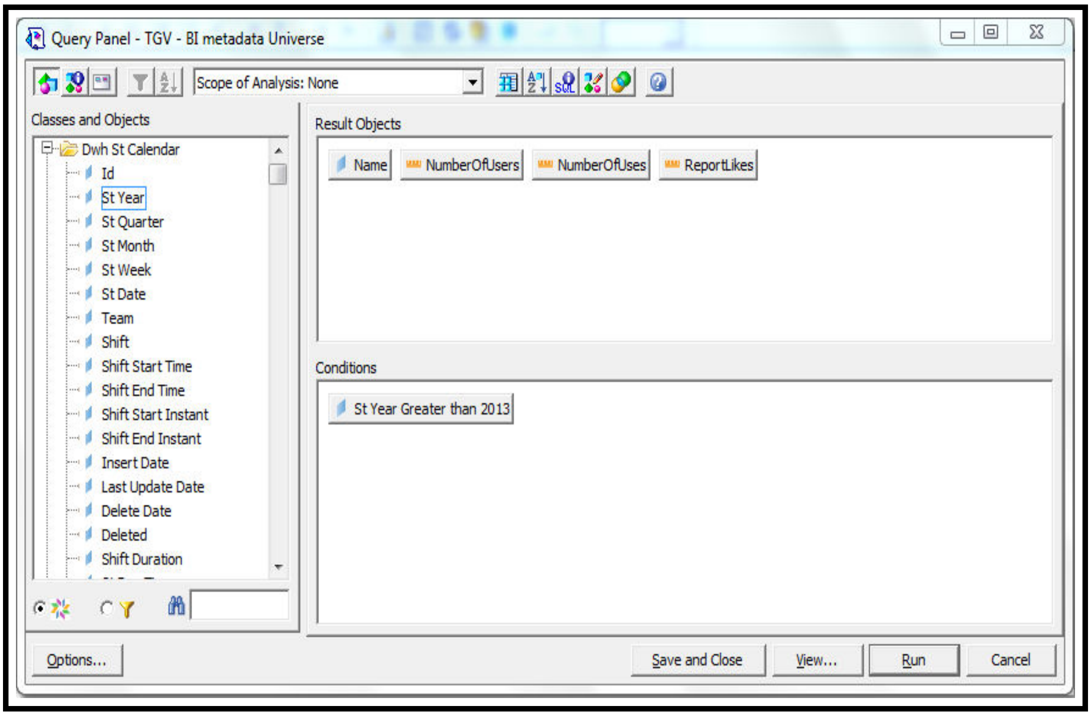


Fig. 4.30. Business Objects (BO) for reporting results

We note that our main objective using a BI system is to help make decisions on its evolution. In our example, such a report could be an entry for removing unused reports. Currently, thanks to made analysis of our example, we were able to identify 286 unused reports in Safir among 512 existing ones. Unused reports are defined as those which were used less than one time and which were accessed the last time before 2013.

Discussion

We note that the development and the use of the BI4BI system do not imply more recommendations and technical skills than any other BI system. Actually, BI4BI targets different categories of users who yet use a BI system or similar technologies, as experts or simple users. The development of the BI4BI system can be actually easier, particularly due to the fact that a data warehouse already exists. Therefore, the data warehouse used in the existing BI system can be also reused for the BI4BI system. It is applicable also for the rest of BI technologies (ETL, Reporting tool, etc.). Consequently, in addition to facilities provided by *Business Intelligence*, we believe that a BI4BI system's development and use remain accessible to BI experts as well as its end users.

To summarize, in this section, we presented the implementation of our proposal *Business Intelligence* for *Business Intelligence* that aims to quantitatively analyse the current BI system behaviour and to make decisions about its improvement actions. In the following, we present the second side of our knowledge evolution solution, based on user-based analyses.

Uses and users of Safir reports

Reports	Number of users	Number of uses
0_C2_ProductConfig.xls	26.00	52.00
0_C2_ProductUsage.xls	17.00	47.00
0_C2_R2R_Configuration.xls	17.00	116.00
0_C2_RouteConfig.xls	26.00	42.00
0_C2_RouteUsage.xls	16.00	28.00
0_C2_Transmask_C020.xls	2.00	2.00
0_C2_Transmask_C028.xls	6.00	10.00
0_C2_Transmask_C040.xls	8.00	31.00
0_C2_Transmask_C045.xls	4.00	11.00
0_C2_Transmask_C055.xls	9.00	43.00
0_C2_Transmask_C065.xls	12.00	25.00
0_C2_Transmask_C090.xls	7.00	9.00
0_C2_Transmask_C110.xls	4.00	4.00
0_C2_Transmask_C120.xls	3.00	3.00
0_C2_Transmask_C12A.xls	5.00	7.00
0_C2_Transmask_F90F.xls	10.00	21.00
0_C2_Transmask_F90U.xls	3.00	4.00
0_C2_Transmask_I140.xls	10.00	20.00
0_C2_Transmask_I175HP.xls	1.00	1.00
0_C2_Transmask_I175.xls	4.00	4.00
A80 Uptime Variability	13.00	16.00
ACTIMACH	500.00	25,904.00
Activity analyser	81.00	421.00
Activity Per Eqp Capability	24.00	59.00
ACTI WIP TURN FE/BE	21.00	80.00
all_products_attrs.txt	15.00	26.00
AntiSlow	30.00	172.00
apc_planlist.xls	4.00	7.00
APC_Step_Config	17.00	42.00
APF_Automation_StepsTrend_internal	5.00	9.00
APF_Automation_StepsYesterday_internal	6.00	9.00
APF_Automation_StepsYesterday.xls	21.00	24.00
A.R.A.M.I.S.	23.00	139.00
Archives	30.00	166.00
Assemble Product Config	12.00	47.00
A.T.H.O.S.	9.00	14.00
AutomatedStepsLotInfo.xls	11.00	13.00
Automation Hold	27.00	80.00
AUTOM_HOLD	30.00	106.00

Fig. 4.31. An example of a report results

4.5 User-based Knowledge Evolution

The identification of user-based indicators was a part of our process for the BI system evaluation. We note that users' experiences and expertise in the domain at *STMicroelectronics* helped to enrich our findings from their points of view. Among identified indicators, quantitative ones were integrated in the BI4BI system, and the user-based ones in the questionnaire, presented in this section. As a result, identified user-based indicators are about, content relevance, content correctness, content manipulation, ease of access and use, adequacy to business needs and tools functionalities.

This questionnaire is presented in appendix C. It contains several questions on the BI system. They are almost containing the same number and types of answers (Very easy/satisfied, Fairly easy/satisfied, Neither easy/satisfied nor not easy/satisfied, Not very easy/satisfied, Very difficult/Not at all satisfied). This choice has been made for two reasons. First, having the same format makes it easy to answer and to continuously integrate it in the evaluation process. Second, this format of questions and answers facilitates a lot its integration within our continuous improvement cycle, particularly into the BI4BI system. This step is detailed in the following.

4.6 User-based Knowledge + BI4BI

4.6.1 Solution Specification

Knowledge evolution involves two complementary solutions, quantitative and user-based. In this section, we demonstrate how both of them can be considered together and provide a unified solution for knowledge evolution.

Our idea consists in integrating results of the questionnaire within the BI4BI system. Such a solution will help to analyse and make decisions on the evolution of embedded knowledge not only in existing systems but also in users' minds. Therefore, both explicit and tacit knowledge will be considered in knowledge evolution. Besides, combining both results will allow more effective knowledge evolution on the BI system.

Actually, by integrating the results of the questionnaire in the BI4BI system, we will be able to measure and evaluate users' opinions on the BI system. Consequently, here, we talk about users' centred evaluation, since it is initially consisting of the questionnaire results. However, with the results of the BI4BI system based on statistics on the BI system use, we talk about data centred evaluation.

To proceed, as usual in a BI system, it consists in identifying indicators and dimensions. Stored in a data warehouse, they help measuring and making decisions on the system. This process is detailed in sections 4.3 and 4.4. In the following, we demonstrate our solution in an example measuring the relevance of reports' content in Safir. This example is the continuity of results of previous sections.

We consider that the content relevance can be measured as follows:

Safir Content Relevance = Average (Safir Reports Relevance , Safir Reports Uses)

Where,

- *Safir Reports Relevance* is based on the questionnaire results. It consists in evaluating the adequacy of Safir reports with users' needs. In the questionnaire (section 4.5), two questions target this need: (1) Considering the last 5 used Safir reports, are they informative? and (2) Are reports' content well structured?
- *Safir Reports Uses* is based on the BI4BI system. We base on measuring reports users and uses. This part is developed in section 4.4. This indicator is an average of the evolution of uses of Safir reports over time. It considers the reports uses, their users and the favourite ones.

4.6.2 Technical Architecture

Combining both results, we are be able to provide one indicator measuring the content relevance in Safir. Previously, we demonstrated how to measure the reports uses in Safir with the BI4BI system. In this section, we focus on the integration of the user-based part of our solution in the BI4BI system. Figure 4.32 shows the BI4BI technical architecture, including the results of the questionnaire in addition to the Safir data base data.

To proceed, the questionnaire results are initially stored in a text file. They include data on the two questions, users (20 participants) and their responses. To proceed, we

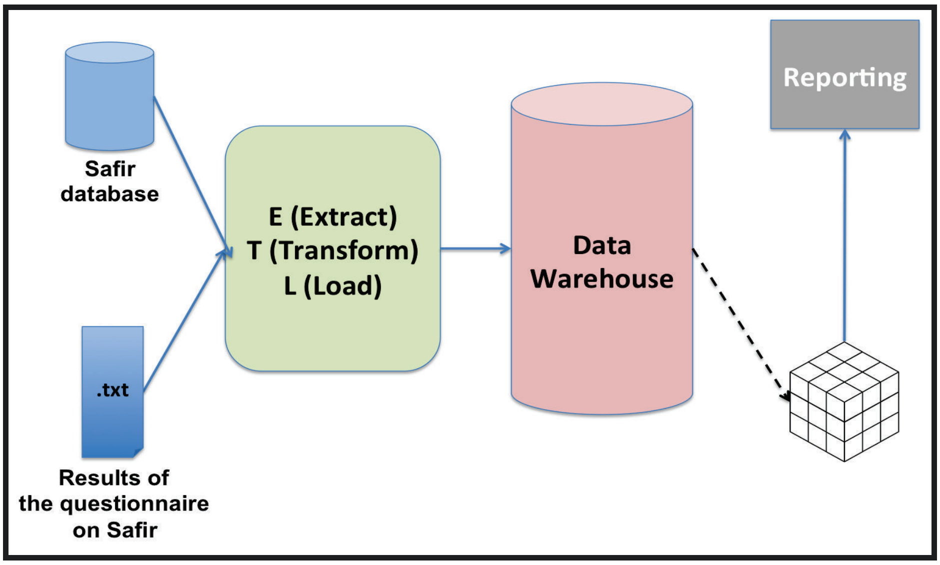


Fig. 4.32. Integration of the questionnaire results in the BI4BI system

extracted, transformed and loaded them into the data warehouse, in the form of indicators and dimensions. Indicators are the "Level Of Information" and the "Level Of Structuring". Their overage imply a third one which is "Safir Reports Relevance", where:

- The "Level Of Information" indicates if the report is informative for its users according to their points of view.
- The "Level Of Structuring" indicates if the report is well structured according to users' points of view.
- The "Safir Reports Relevance" indicates if the report is quite relevant according to users' points of view. It is based on the "Level Of Information" and the "Level Of Structuring" results.

Their results are between 0 and 1, where 0 is the worst score (not all informative, structured, relevant) and 1 is the best one. Dimensions could be the "User" and/or the "Question". Figure 4.33 presents the data warehouse modelling, where, in addition to the BI4BI modelling, it includes the questionnaire modelling (the red square).

4.6.3 Results Exploitation

Using the Reporting tool (Business Objects), reports are created. An example is shown in figure 4.34 that presents the level of information in Safir reports according to the results of the questionnaire.

Finally, based on the results obtained from the B4BI system on Safir content relevance (questionnaire results), we obtain the following findings:

Safir reports relevance = Average (Level Of Information , Level Of Structuring) =
Average (0.88 + 0.84) = 0.86

This result can be eventually completed with the an indicator on "Safir Reports Uses". A result combining both Safir content relevance (Safir database results) and Safir content uses (questionnaire results) will provide an overview that helps to assess and make decisions on the evolution of Safir content.

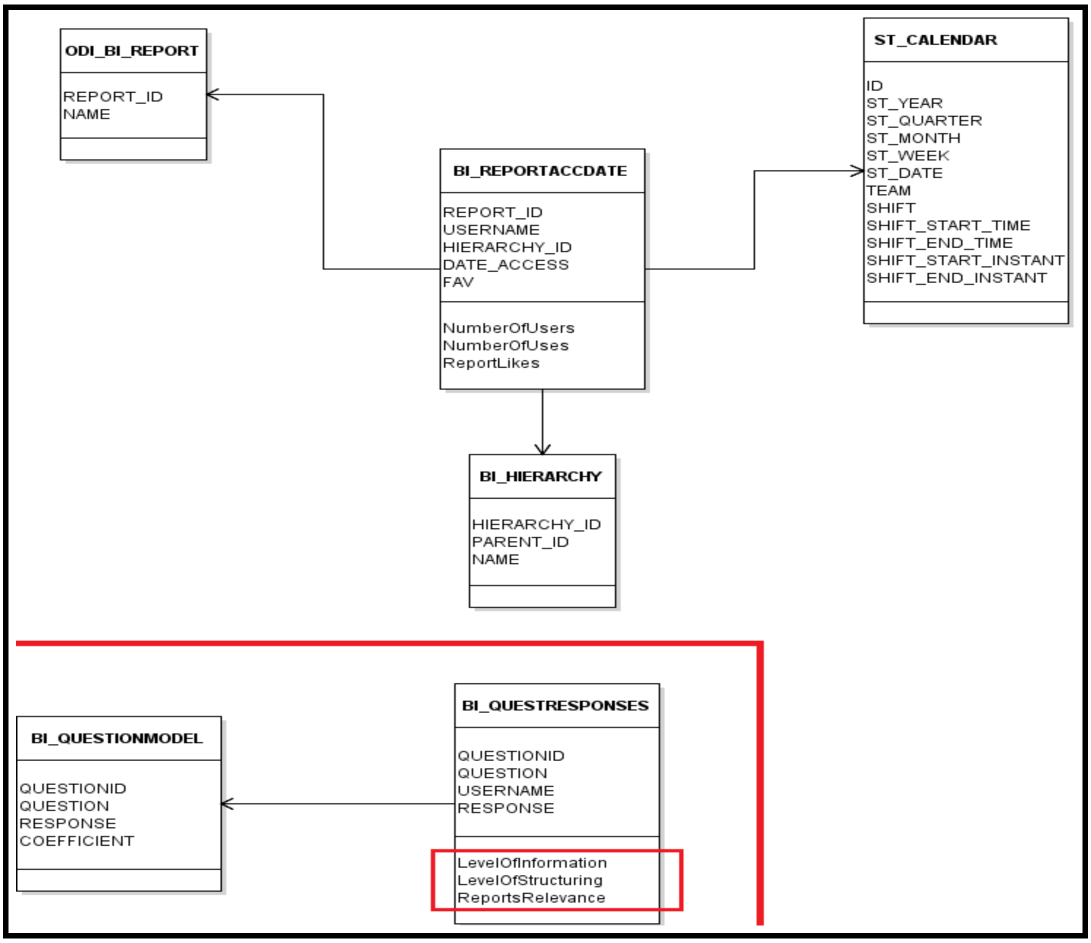


Fig. 4.33. BI4BI modelling + questionnaire modelling

To summarize, in this section we integrated the results of the questionnaire within the BI4BI system. Respectively, they allow to gather tacit and explicit knowledge throughout our continuous improvement cycle, as a part of BI knowledge evolution.

4.7 Conclusion

In this section, our BI knowledge evolution proposal is presented. It includes two complementary solutions. On the one hand, a data centred solution is based on a *Business Intelligence* for *Business Intelligence* system. It aims at evaluating, analysing and making decisions about the BI activity and its evolution, ensuring therefore its knowledge evolution. Its design process, specification and implementation are detailed. On the other hand, a user-based solution complements our proposal for knowledge evolution. It is based on the results of the questionnaire evaluating the BI system and its users' points of view. Together, the data centred and user-based solutions help evolve BI knowledge.

5 Summary

This chapter presented our solution for BI knowledge capitalization as a part of the design cycle of the Design Science Research. We described the different solutions for each considered step of the knowledge capitalization cycle. First, made evolutions and areas of progress on *Stiki* for knowledge sharing are presented and their integration in the tool are evaluated. Second, we suggested a knowledge representation solution considering three

Level Of information in Safir Reports

Are the reports informative

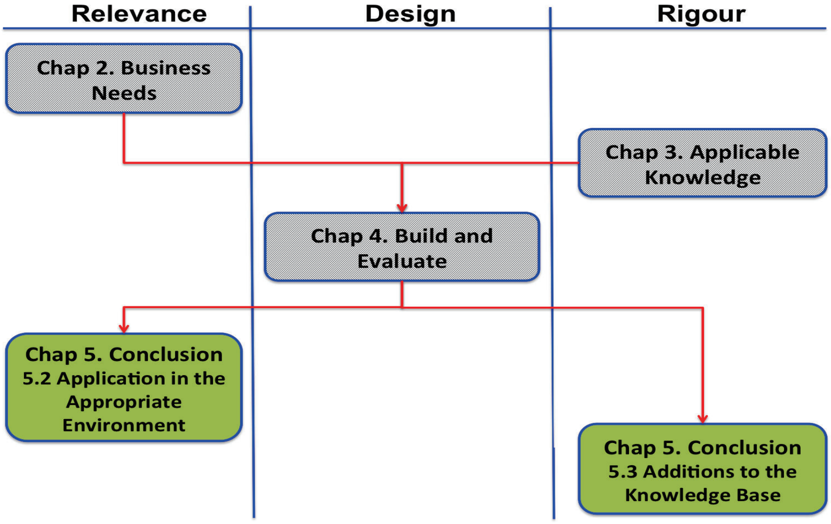
Username	Response	Level Of Information
aa67	R1	1.00
ay7	R2	0.75
ce7	R1	1.00
cg51	R2	0.75
ci11	R1	1.00
cr46	R2	0.75
df89	R2	0.75
gs27	R1	1.00
hj11	R2	0.75
hj43	R2	0.75
mm11	R2	0.75
mp58	R1	1.00
pe33	R1	1.00
re28	R2	0.75
rr13	R1	1.00
sj12	R2	0.75
sj41	R1	1.00
vf15	R1	1.00
vr1	R2	0.75
zt1	R1	1.00
	Level of information	**0.88**

Fig. 4.34. Example of a report about the level of information in Safir reports

complementary characteristics, know *What*, *Why* and *How*, differently represented and applied to BI. Such a solution ensures the completeness, relevance and organization of knowledge, that we demonstrated its feasibility by its results integration in *Stiki*. Finally, BI knowledge evolution proposal is presented. It includes two complementary solutions. First, a quantitative one based on a BI4BI system aiming at evaluating, analysing and making decisions about the BI activity and its evolution. Here, we talk about a data centred evaluation solution. Second, a questionnaire allows assess the BI system's knowledge from its users' points of view. Here, we talk about a user-based evaluation solution. Finally, combining both of them is discussed. It allows to involve at the same time explicit and tacit BI knowledge.

Chapter 5

Conclusion and Perspectives



1 Introduction

This chapter presents at the same time a conclusion for this thesis, while including also two important steps of the Design Science Research: application in the appropriate environment as well as additions to the knowledge base. These ones describe our contributions [5]. We end this chapter with some perspectives.

2 Application in the Appropriate Environment

"Most often, the contribution of design science research is the artefact itself. It must enable the solution of heretofore unsolved problems" [5]. Design tools and prototype systems are examples of such artefacts. This section demonstrates how our research contributes to the appropriate environment, i.e *STMicroelectronics*.

In our research, three proposals have been improved, suggested and developed as part of our knowledge capitalization solution: first, *Stiki* for knowledge storage and sharing; second, the *Business Intelligence* for *Business Intelligence* (BI4BI) system for knowledge evolution; third, the questionnaire for knowledge evolution. In the following, we describe the development of these solutions and their application in the environment, in our case at *STMicroelectronics*.

2.1 *Stiki*'s Improvement

Thanks to the evaluation of *Stiki*'s use for knowledge sharing (presented in chapter 2), several issues have been identified and a set of areas of progress have been recommended, in order to promote its use and to accomplish its objectives. Consequently, several improvements have been achieved, for example, a rating functionality for reviewing its content, expanding its scope of application, etc. In addition, structuring pages' content has been promoted thanks to our knowledge representation proposal. Our solution for improving *Stiki*for knowledge sharing at *STMicroelectronics*, has several strengths. First, an appropriate user centred approach allowed to target the real problems encountered by users throughout their daily activities at work. Second, collaboratively improving them ensures the relevance and usability of the improvement proposals and therefore the effectiveness of our solution. Third, it is a way to make them aware of the importance of knowledge sharing.

As a result, performed evolutions have contributed to its success for knowledge sharing, which were demonstrated throughout its effective use. Thanks to its evolution, today, *Stiki* is considered the main tool for knowledge sharing at *STMicroelectronics* and constitutes therefore an important contribution effectively integrated in the work environment.

2.2 BI4BI System Development

As one first stage of knowledge evolution, we implemented a *Business Intelligence* for *Business Intelligence* system. It is actually a BI solution able to analyse and make decisions about the existing BI system, in our case, at *STMicroelectronics*. Our solution included several modules required for its development:

- ETL (Extract-Transform-Load) tools
- A data warehouse
- The reporting tool "Business Objects"

We demonstrated the feasibility and applicability of our system through different application examples on the existing BI system at *STMicroelectronics*. Consequently, one clear contribution of our research is the development of the BI4BI system for a continuous improvement cycle for knowledge capitalization. Our proposal has practical added values to the considered environment. At *STMicroelectronics*, it provides interests for people, technology and organization. First, the developed BI4BI system helps BI users evaluate, assess and make decisions on their own produced knowledge evolution based on their own uses, which makes them feel more comfortable with obtained results. Second, we note that, in the case of *STMicroelectronics*, our proposal BI4BI system is actually based on a yet used technology in the organization. Therefore, its integration was adequate and suitable to the existing technological environment. Third, our proposal fits with the strategy of the organization to provide a continuous improvement cycle for business knowledge capitalization, in a first stage, applied to the BI process. We highlight that this work has been published, as well in the IEEE Ninth International Conference on Research Challenges in Information Science [4].

2.3 User-based Questionnaire

As part of BI knowledge evolution, we suggested a questionnaire to complete our quantitative system BI4BI. It is able to assess the use of the BI system and its knowledge, from its users' points of view. The conception of the questionnaire was based on BI users involvement to select the most appropriate user-based indicators to take into account.

The suggested questionnaire presents a real interest and effectively integrated within the work environment at *STMicroelectronics*. On the one hand, our proposal for regularly launching the questionnaire to assess the knowledge system helps involving more and more users in knowledge capitalization, while its integration in the organizational practices. On the other hand, the proposed questionnaire is well integrated in the technological system at *STMicroelectronics*. It is actually developed with a regularly used application by the company for surveys. Besides, obtained results could be easily forwarded to other used applications, in our case, to the BI4BI system.

3 Additions to the Knowledge Base

"Effective Design Science Research must provide clear contributions in the areas of the design construction knowledge (i.e., foundations), and/or design evaluation knowledge (i.e., methodologies)" [5]. This section demonstrates how our research contributes to the knowledge base.

On the one hand, according to [5], the creative development of novel, appropriately evaluated constructs, models, methods, or instantiations extend and improve the existing foundations. In our thesis, they present the development of novel and evaluated models, and instantiations that improve the existing foundations in the knowledge representation field. Therefore, we proposed modelling knowledge according to three characteristics, *What*, *Why* and *How*. In addition, in our research, a continuous improvement cycle for knowledge evolution has been proposed. Its principle is, in fact, based on a creative and novel methods, involving a user based solution (questionnaire) in addition to a data based solution (BI4BI). These contributions' application at *STMicroelectronics* is detailed in section 3.1.

On the other hand, according to [5], the creative development and use of evaluation methods and new evaluation metrics provide design science research contributions. In our research, it consists, first, in the use of innovative evaluation methods and indicators throughout the evaluation of the use of *Stiki* for knowledge sharing. Second, it includes the identification of the BI4BI system's indicators and measures as part of the continuous improvement cycle for knowledge evolution. Both contributions are detailed in section 3.2.

3.1 Foundations

According to [5], modelling formalisms, ontologies, problem and solutions representations, design algorithms and innovative information systems are examples of foundations. In this work, main foundations are demonstrated throughout our proposal for expert knowledge representation with the know *What*, *Why* and *How* models (presented in chapter 4). In this section, these foundations are highlighted.

3.1.1 Knowledge Representation: *What*, *Why* and *How* Models

As one stage of the knowledge capitalization cycle, knowledge representation consists of defining knowledge characteristics, know *What*, *Why* and *How* [2, 3]. Applied to the *Business Intelligence* process at *STMicroelectronics*, each one describes knowledge in a different level and should be modelled in an appropriate way, where:

- Know *What* corresponds to the conceptual level representing manipulated objects during the process and their relationships. It is modelled by a class diagram.
- Know *Why* corresponds to the behavioural level representing explanations and justifications behind processes. It is represented by the QOC model (Questions-Options-Criteria).
- Know *How* corresponds to the technical level representing knowledge integration, implementation and exploitation in systems. It is represented by IRTV modelling (Information-Roles-Tasks-Views).

Defining and representing BI knowledge characteristics allowed the use of well-designed models that are useful in a real organizational setting. To validate our proposal, with a user centred approach, we explored, co-designed and validated our models based on users' points of view (end users, managers and engineers). Consequently, our complementary models for knowledge representation are themselves a foundation. On the other hand, this work has been published in two international conferences in two different domains (information systems and industrial engineering): IEEE Eighth International Conference on Research Challenges in Information Science [2], as well as, International conference on Advances in Production Management Systems [3].

3.1.2 A continuous Improvement Cycle

In our research, a continuous improvement cycle has been proposed for knowledge evolution. It includes a BI4BI system and a questionnaire. Their objective is to evaluate, analyse and make decisions about BI knowledge. Their design process, specification and principle constitute creative novel methods for evaluating BI knowledge. But also, being generalizable makes them applicable not only on BI knowledge but also information systems' knowledge in general and in different contexts.

3.2 Methodologies

According to [5], methodologies include the creative development and use of evaluation methods (e.g., experimental, analytical, observational, testing, and descriptive) and new evaluation metrics. In our work, different methodologies have been applied. First, we note that one main strength of our proposal is the use of user centred approaches to conduct our research. To proceed, a user centred evaluation approach is applied to *Stiki* in order to assess its use for knowledge storage and sharing at *STMicroelectronics* (presented in chapter 2). Second, the development of the BI4BI system and the questionnaire (presented in chapter 4) required the identification of a set of evaluation criteria and measures to assess a *Business Intelligence* system. In this section, these two main methodological contributions are highlighted.

3.2.1 Knowledge Storage and Sharing: *Stiki*'s Evaluation Methodology

A user-centred approach was developed to assess the use of a Wiki for knowledge sharing at *STMicroelectronics*, that we reflected on the possible validity threats to its generalizability to other settings. Our experimental evaluation approach is complete, as it includes qualitative and quantitative methods ensuring representative results and uses different evaluation criteria, where two aspects have been considered, social and technical (detailed in chapter 2). It aims at understanding how a Wiki is used, by collecting users' opinions about its advantages, limits and areas of progress. It takes into account current practices and considers users as the main source of information.

On the one hand, involving practitioners throughout our evaluation approach supports their professional values and roles, where they need to recognize how others can benefit from such a process. On the other hand, it will be particularly relevant for researchers to focus on studies and approaches of joint working, to develop ways of identifying and qualitatively and quantitatively evaluating its outcomes for users and to understand organizational phenomena. Thus, applying such an approach, involving users in systems' use evaluation, enables researchers and practitioners to understand and address the problems inherent in developing and successfully implementing systems within organizations and then bridge the gap between theory and practice. Consequently, our user centred evaluation approach is itself a contribution to design science, that has been published in the international Journal of Knowledge Management [1].

3.2.2 Knowledge Evolution: Evaluation Methodology, Indicators and Measures

Among stages of the continuous improvement cycle, defining BI indicators and measures according to a set of evaluation criteria was a crucial step in the development of the BI4BI system and the questionnaire. In a first stage, based on the product quality model defined in ISO 25000, we identified evaluation criteria required to assess the properties of a software product. Second, relying on previous findings, we based on users' experiences and expertise in the domain to define indicators and measures for assessing a BI system (detailed in chapter 4). Those ones are of several categories and natures, and could be generalized to make them applicable not only for assessing a BI system but also information systems in general and in different contexts. These findings constitute an important contribution to the design science research knowledge base.

4 Perspectives

In terms of perspective, our aim is to expand the continuous improvement cycle not only for *Business Intelligence* but also for information systems in general. To this end, two parts are involved: first, to extend the knowledge capitalization cycle to a knowledge management cycle; second, to consider it for any information system (IS).

4.1 Knowledge Management Cycle

In order to extend our solution to a knowledge management cycle, we aim in a fist stage to improve our proposal, mainly for knowledge representation. Next, we aim to complete it other steps, such as, knowledge reuse.

Knowledge representation:

We aim to improve the What, Why and How characteristics representation, taking into account the relationship between them. To this end, we will study how the QOC Model can be adapted to deal with the confusion problem in the know Why representation. As well, we will investigate if it could be applied to other objects of the What model or if it has to be completed with other methods. Then, the representation of the know How will be improved in order to involve both process modelling and control mechanism.

Finally, applied to *STMicroelectronics*, the relationship between knowledge representation and its sharing in *Stiki* will be achieved. The idea consists in providing, automatically through proposed models, *Stiki* templates for objects, where each one treats all knowledge characteristics, according to the concerned models. Eventually, we will discuss how new users can search for information while learning existing vocabulary. At *STMicroelectronics*, such an approach for knowledge capitalization could be generalized to other contexts.

Knowledge reuse:

We aim at studying knowledge reuse as another stage of our capitalization cycle, through which, we will discuss how capitalized knowledge could be reused in an effective way by users, and eventually discuss how new users can search for information while learning existing vocabulary. To this end, an expert system can be developed. It is based on the construction of a knowledge base, where users can reuse knowledge based on their needs. Commonkads is one of the most known methodologies for developing expert systems [25].

4.2 IS Knowledge Management

In order to extend the knowledge management cycle for all information systems, the main challenge will be about IS knowledge evolution. It is considered as the more critical and difficult to realize. This will be discussed in a first stage. Next, throughout our proposal for knowledge capitalization and evolution, we based mainly on structured data, that is stored in internal databases. At this stage, we aim to consider not only unstructured data, but also data stored in different and heterogeneous types of databases. These perspectives lead us to explore the domain of Big Data.

Knowledge Evolution:

Identified indicators and measures for BI system evaluation will be evolved to make them platform independent, which is not discussed in this work. Actually, in our current work, indicators have been identified for each tool of the BI system (BO, Stiki, Safir and the Blog). As a result, our identified indicators are system-oriented. For example, the way "content uses" is measured for BO is not the same for Safir. Therefore, our idea is to propose a more suitable indicators for all considered systems. Consequently, we will make them independent from the system that should be evaluated. In that way, they will not be restricted to the type of the concerned system. Such a generalized solution makes it applicable not only for monitoring a BI system but also information systems in general and in different contexts.

BIG Data:

In the context of *STMicroelectronics*, the *Business Intelligence* domain has been considered for its knowledge capitalization. However, it could also be interesting to generalize our solution to be applicable and applied to different domains and contexts. As a result other requirements would certainly appear. We note, for example, the necessity to base on structured and unstructured data, such as presentations, stored in different and disorganized types of databases, which makes its volume more important and heterogeneous.

Actually, each application domain does not produce, manipulate and store neither the same volume of data nor in the same manner. Nowadays, due to the proliferation of systems that continuously produce data (social networks, mobile applications, electronic sensors, etc), the volume of data and information produced every day is exponentially growing and data sources are various and very different [134]. Complementary to BI, Big Data is seeking to navigate this avalanche of data in order to identify in real time relevant and useful information. We identified three characteristics of Big Data, that can applicable in our research: the considered sources, their structures and data quantity.

First, as shown in figure 5.1, the range of data used in big data projects varies from internal companies' operational data extended with archives, logs and transactional data, to external public data. For example, most organizations, such as *STMicroelectronics*, are subscribed in social media (facebook, twitter, etc). Extracting data coming from these external platforms could help to identify consumers perception about using their products.

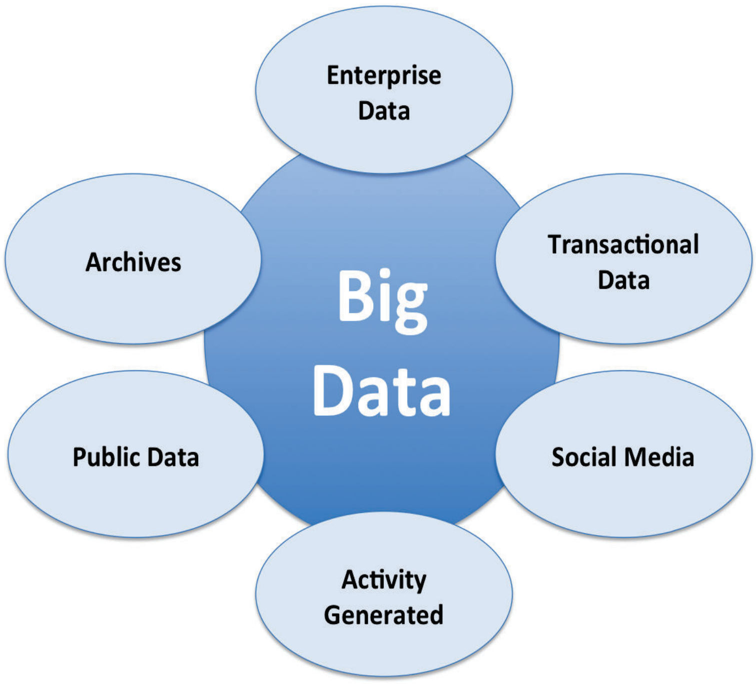


Fig. 5.1. Big Data sources

Second, developers prefer work with flexible solutions easily adapted to any new type of data, while not being disrupted by its content structure changes [135]. Actually, current data is often unstructured and semi-structured requiring, therefore, an effective database for its storage. This is why, today, organizations are adopting the NoSQL technology that means Not only SQL. For example, at *STMicroelectronics*, unstructured data is present in regular presentations, shared folders, logs, etc. Big Data provides, therefore, a more flexible, schemaless data model, better adapted to an application's data organization.

Third, Big Data adds to traditional BI systems a new dimension, which is to exploit huge volumes of data at the finest detail. This is the case in most large organizations. At *STMicroelectronics*, for example, records on executed tests on wafers are daily multiplied. Consequently, Big Data is able to explore a huge amount of interrelated data and to emerge significant findings and to identify new relevant information and knowledge [136].

To summarize, a big data system is capable to generate complex processes and deeper business insights than existing data warehouse and *Business Intelligence* systems. This is the reason why, we believe that our vision fits in well with the Big Data field.

Appendix A

Questionnaire for *Stiki* Evaluation

The use of Stiki: frequency and type of use

Stiki is used for searching for information	1-Everyday / 2-Once a week / 3-Once a month / 4-Less than once per month
If you use it one a month or less, you do not use it because	You do not have enough time Other reason, specify You do not find an interest for using Stiki You thing that it is not easy to use
Otherwise specify	
You contribute in Stiki (for update or page creation)	1-Everyday / 2-Once a week / 3-Once a month / 4- Never
If you do not contribute, it is because (multiple choices ctrl+clic)	You do not have enough time Other reason, specify You do not find an interest for using Stiki You thing that it is not easy to use
Other reason, specify	
Within your team, Stiki is used to access information	1-Everyday / 2- Once a week / 3-Once a month / 4-Never
You usually use Stiki to store your own job information	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree
Eventually, which other sharing tools do you use?	

Usability and usefulness of Stiki

Stiki is a knowledge sharing tool	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree
In order to use Stiki, it has to present an interest for users	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree
Access	
For access, I think that Stiki is easy to use	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree
For access, I think that I need help	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree
For access, I think that most people are able to quickly learn using Stiki	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree
For access, I feel confortable using Stiki	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree
Contribution	
For contribution, I think that Stiki is easy to use	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree
For contribution, I think that I need help	1-Agree / 2-Somewhat agree / 3-Somewhat disagree / 4-Disagree

For contribution, I feel confortable using Stiki	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
For contribution, I think that most people are able to quickly learn using Stiki	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
For contribution, I think that page structuring is easy to follow	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
I realize that Stiki is a collaborative tool	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Stiki can be used to train new recruits	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Stiki can serve not IT users	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Interest of knowledge sharing	
Knowledge sharing is a daily need	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Knowledge sharing saves time	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Stiki is currently the reference tool for knowledge sharing	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Stiki is currently the reference tool for knowledge storage	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Stiki has to be part of the project life cycle	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Knowledge structuring	
I know the existing templates of Stiki	1-Yes 2-No
Structuring helps in writing information	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Structuring helps searching for information	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Structuring helps unifying the content	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Structuring promotes understanding	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Following the structuring instructions seems to be	1-Easy 2-Rather easy 3-Rather difficult 4-Not easy
I think that existing structuring is easy to adapt to special cases	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Knowledge quality and relevance	
Stored information in Stiki is	1-Very useful 2-Rather useful 3-Rather not useful 4-Not useful
I can trust the information stored in Stiki	1-Yes 2-No
Otherwise, why	
Knowledge stored in Stiki is	1-Very relevant 2-Rather relevant 3-Rather irrelevant 4-Irrelevant
Knowledge stored in Stiki is	1-Updated 2-Rather updated 3-Rather obsolete 4-obsolete
I think there is much inconsistencies in knowledge stored in Stiki	1-Agree 2-Somewhat agree 3-Somewhat disagree 4-Disagree
Areas of progress	
For each functionality, give a mark on a scale of 1 to 10, where 1: not important and 10: very important	
More user-friendly interface	

Advanced search	
Selecting favourite pages	
Expanding the scope of application of Stiki	
Others, specify	
Training should be regularly established for the use of Stiki	1-Very important 2-Somewhat important 3-Not very important 4-Not at all important
Knowledge in Stiki should be regularly evaluated	1-Very important 2-Somewhat important 3-Not very important 4-Not at all important
Any other suggestions to improve Stiki	

Analysis (optional)

How old are you?	1-Under 25 years 2-Between 25 et 30 years 3-Between 30 et 40 years 4-Over 40 years
You status or profession at STMicroelectronics	IT Co-contractor Not IT
Seniority in the company (number of years)	
Seniority within the team (number of years)	

Thank you for your participation in this study

Submit

Appendix B

BI System Indicators, Measures and Dimensions

BO: Functional suitability criterion			
Sub-criterion: Functional completeness			
Indicators	Measures	Types of measures	Dimensions
Objects coverage	Number of BI objects uses	Objective	time, domain, BO objects, user
	Number of covered domains by BI in the organization	Objective	domain
	Number of available reports in BO	Objective	time
	Number of duplicated or similar BI objects	Objective	domain, BO objects
Activity evolution	Number of reports created after BI modelling	Objective	time, domain, report, user
	Number of requests for creating objects	Objective	time, domain, BO objects, user
	Cycle time of reports creation	Objective	time, domain, report, user
	Number of requests for correcting BI objects	Objective	time, domain, BO objects, user
	Number of participants in creating a report	Objective	time, domain, report, user
Sub-criterion: Functional correctness			
Indicators	Measures	Types of measures	Dimensions
Objects relevance	Adequacy of BI objects to users' needs	Subjective	
	Number of changes after the BI modelling	Objective	time, domain, BO objects
	Number of different BO objects providing the same result	Objective	time, BO objects
Objects uses	Number of BI objects (indicators and dimensions) uses in personal reports	Objective	time, domain, BO objects, user
	Number of reports uses (in public and personal folders in BO)	Objective	time, domain, report, user
	The number of unused instances of reports running on BO	Objective	time, domain, report, user
Objects correctness	The accuracy of BO objects results	Subjective	
Objects availability	Number of available BI objects at the scheduled time	Objective	time, domain, BO objects
Objects freshness	Number of available objects updated at the required business time	Objective	time, domain, BO objects
	Number of incidents for reports problems	Objective	time, report, domain
Sub-criterion: Functional appropriateness			
Indicators	Measures	Types of measures	Dimensions
Objects manipulation	Objects identification	subjective	
	Objects organization	Subjective	
	Objects exploitation	Subjective	
	Objects documentation	Subjective	
Exporting format	Graphics rendering	Subjective	
Resources uses	Number of trained people	Objective	time, domain
	Number of distributed licences	Objective	time, domain
	Number of licences used for consultation and for contribution	Objective	time, domain, BO objects, user
	Number of connections to BO	Objective	time, users

Safir: Functional suitability criterion			
Sub-criterion: Functional completeness			
Indicators	Measures	Types of measures	Dimensions
Reports management	Number of accesses to historized reports	Objective	time, domain, report, user
	Number of historized reports	Objective	time, domain, report
Safir coverage	Number of covered workshops	Objective	time, domain
	Number of new reports	Objective	time, domain, user
Access to information	How to access to a report for the first time	Subjective	
Sub-criterion: Functional correctness			
Indicators	Measures	Types of measures	Dimensions
Reports obsolescence	Number of unused reports	Objective	time, domain, user
	Number of unused categories	Objective	time, domain, Safir categories
Reports relevance	Adequacy of reports with users needs	Subjective	
Content uses	Number of reports in "Favourite" folders	Objective	time, domain, user
	Number of documented reports	Objective	time, domain
	Number of used/unused reports	Objective	time, domain, BO, user
	Number of reports uses	Objective	time, user
Sub-criterion: Functional appropriateness			
Indicators	Measures	Types of measures	Dimensions
Reports manipulation	Reports identification	Subjective	
	Reports organization	Subjective	
	Reports exploitation	Subjective	
	Reports documentation	Subjective	
Exporting format	Graphics rendering	Subjective	
Categories organization	Number of categories	Objective	time
	Number of reports in right categories	Objective	SAfir categories
	Adequacy of categories with the organization structure	Subjective	

Stiki: Functional suitability criterion			
Sub-criterion: Functional completeness			
Indicators	Measures	Types of measures	Dimensions
Content coverage	Number of documented objects	Objective	domain, BO objects
Activity evolution	Adequacy of changes in Stiki with changes in the whole BI system (they have almost the same evolutions of changes)	Objective	time, system
Sub-criterion: Functional correctness			
Indicators	Measures	Types of measures	Dimensions
Content relevance	Adequacy of the content with users' needs	Subjective	
	Number of pages' likes	Objective	time, Stiki page
Content uses	Number of users	Objective	time, Stiki page, user
	Number of consultations	Objective	time, Stiki page, user
	Number of contributions	Objective	time, Stiki page, user
	Number of contributors	Objective	time, Stiki page
Sub-criterion: Functional appropriateness			
Indicators	Measures	Types of measures	Dimensions
Content manipulation	Pages identification	Subjective	
	Pages location	Subjective	
	Search means	Subjective	
Content organization	Number of hyper links between Stiki pages	Objective	Stiki page
	Number of pages having an objective description	Objective	Stiki page
	Number of pages respecting defined templates	Objective	Stiki page

Blog: Functional suitability criterion			
Sub-criterion: Functional completeness			
Indicators	Measures	Types of measures	Dimensions
Notificaion support	Number of subscribed users	Objective	time, blog category
	Number of unsubscribed users	Objective	time, Blog category
	Number of resubscribed users	Objective	time, Blog category
	Number of "Alert me" in the Blog categories	Objective	time, Blog category, user
Sub-criterion: Functional correctness			
Indicators	Measures	Types of measures	Dimensions
Content relevance	Number of "Likes"	Objective	time, Blog category, user
	Number of accesses to the blog via mails notifications	Objective	time, user
	Content information completeness	Subjective	
Sub-criterion: Functional appropriateness			
Indicators	Measures	Types of measures	Dimensions
Information manipulation	Adequacy of the title and the location	Subjective	
	Reports historic	Subjective	
Content organization	Number of categories respecting the template	Objective	Blog categories

Appendix C

Questionnaire for the Qualitative Knowledge Evolution

This study is addressed to the *Business Intelligence* (BI) system's users and is designed to assess its use and evolve its knowledge. The following questions cover different tools used in your work and constitute today the BI system: Business Object (BO), Stiki, Safir the reporting portal and the blog Crolles300.

If you do not know the answer to a question, you can just move to the following one. Your participation is voluntary. We ensure that all collected information will remain confidential.

1. ***Ease of use of:***

	Very easy	Fairly easy	Neither easy nor not easy	Not very easy	Very difficult
Search engine of Stiki					
Exploiting a BO report results					
Exploiting the Blog Crolles300 report results					
Exploiting Stiki pages' content					

2. ***Documentation quality:***

- Author

	Always	Often	Rarely	Never	I do not know
Considering the last 5 used indicators and universes, their authors, are they identified?					
Considering the last 5 used reports, their authors, are they identified?					
If authors are mentioned, is there information on their profiles?					

- Content

	Very informative	Fairly informative	Neither informative nor not informative	Not very informative	Not at all informative
Considering the last 5 used BO objects (report, indicator, dimension and universes), are they informative?					
Considering the last 5 used Safir reports, are they informative?					
Considering the last 5 used Blog Crolles300 pages, are they informative?					
Considering the last 5 used Stiki pages, are they informative?					

  - Are reports' content well structured?
    - Totally agree
    - Agree
    - Somewhat agree
    - Somewhat disagree
    - Disagree
  - Considering the last 5 used Stiki pages, how do you evaluate writing quality?
    - Very good quality
    - Good quality
    - Neither good nor bad quality
    - Not very good quality
    - Very bad quality
  - In general, do you trust information in BO?

1

      * Always
      * Often
      * Rarely
      * Never
      * I do not know
   - In general, how do you think about information structuring in BO?
      * Very good structuring
      * Good structuring
      * Neither good nor bad structuring
      * Not very good structuring
      * Very bad structuring

3. ***Considering the last 5 used Stiki pages, what do you think about the level of detail of their content?***
   - Very detailed
   - Fairly detailed
   - Neither detailed nor not detailed
   - Not very detailed
   - Not at all detailed

4. ***Considering the last 5 used the Blog pages, what do you think about the level of detail of their content?***
   - Very detailed
   - Fairly detailed
   - Neither detailed nor not detailed
   - Not very detailed
   - Not at all detailed

5. ***Search for information***

	Very easy	Fairly easy	Neither easy nor difficult	Not very easy	Very difficult
Assess the ease of identifying reports with their titles					
Assess the ease of identifying a dimension with its name					
Assess the ease of identifying a universe with its name					
Assess the ease of identifying a Stiki page with its name					
Assess the ease of identifying a Blog page with its name					
Assess the ease of locating reports					
Assess the ease of locating indicators					
Assess the ease of locating dimensions					
Assess the ease of locating Stiki pages					

6. ***The legibility of the category tree in tools (BO, Safir, Stiki and the Blog)***

2

	Very satisfied	Fairly satisfied	Neither satisfied nor not satisfied	Not very satisfied	Not at all satisfied
Specify you level of satisfaction of the category tree naming					
Specify you level of satisfaction of the relevance of hierarchies in the category tree					
Specify you level of satisfaction of the number of hierarchies in the category tree					
Specify you level of satisfaction of the the category tree in BO					
Specify you level of satisfaction of the the category tree in Safir					
Specify you level of satisfaction of the the category tree in Stiki					
Specify you level of satisfaction of the the category tree in the Blog					

7. ***Considering the last 5 used objects, assess their adequacy to your needs***

	Very adequate	Fairly adequate	Neither adequate nor not adequate	Not very adequate	Not at all adequate
Report					
Indicator					
Dimension					
Universe					
Stiki page					
Blog page					

8. ***Considering the last 5 used objects, assess their accuracy (right results)***
   - Very accurate
   - Fairly accurate
   - Neither accurate nor not accurate
   - Not very accurate
   - Not at all accurate

9. ***Further information***
   (a) Are you?
   - Woman
   - Man

   (b) How old are you?

   (c) What is your job?
   - Engineer
   - Technician
   - Manager
   - Other, please specify

   (d) Do you practice managerial functions? Yes No

   (e) In which year were you recruited at *STMicroelectronics*?

   (f) What is your current level of expertise in the BI field?
   - Expert
   - Advanced
   - Intermediate
   - Beginner

Thank you for your cooperation.

3

Bibliography

[1] M. Brichni, N. Mandran, L. Gzara, S. Dupuy-Chessa, and D. Rozier, "Wiki for knowledge sharing, a user-centred evaluation approach: a case study at stmicroelectronics," Journal of Knowledge Management, vol. 18, pp. 1217–1232, 2014.

[2] M. Brichni, S. Dupuy-Chessa, L. Gzara, and C. Jeannet, "A user centred approach to represent expert knowledge: A case study at stmicroelectronics," IEEE Eighth International Conference on Research Challenges in Information Science (RCIS), 2014 IEEE Eighth International Conference on, pp. 547–558, 2014.

[3] ——, "Manufacturing reporting knowledge representation: A case study at stmicroelectronics," International Conference on Advances in Production Management Systems, pp. 34–41, 2014.

[4] M. Brichni, S. Dupuy-Chessa, L. Gzara, N. Mandran, and C. Jeannet, "Business intelligence for business intelligence: A case study at stmicroelectronics," IEEE Ninth International Conference on Research Challenges in Information Science (RCIS), 2015 IEEE Ninth International Conference on, pp. 239–249, 2015.

[5] A. R. Hevner and S. T. March, "Design science in information systems research," MIS Quarterly, pp. 75–105, 2004.

[6] N. Matta, J. L. Ermine, G. Aubertin, and J. Y. Trivin, "How to capitalize knowledge with the mask method," IJCAI'01 Workshop on knowledge Management an Organizational Memories, vol. 6, pp. 700–717, 2001.

[7] A. Boury-Brisset and N. Tourigny, "Knowledge capitalisation through case bases and knowledge engineering for road safety analysis," Knowledge-Based Systems, pp. 297–305, 2000.

[8] S. Mathieu, "Knowledge management appliqué à la rénovation d'une unité de production de produits biologiques," Ph.D. dissertation, Faculté de pharmacie de Grenoble, 2012.

[9] H. Busch, "Towards the reuse of dynamic industrialization knowledge processes: Case study in the microelectronic domain," Ph.D. dissertation, Laboratoire Gestion Industrielle, Logistique et Conception, 2002.

[10] V. Bombardier, P. Lhoste, and C. Mazaud, "Expert knowledge modeling and expert knowledge integration for defect identification by fuzzy linguistic rules," traitement du signal, vol. 21, 2004.

[11] E. Younesi, A. Malhotra, M. Gündel, P. Scordis, A. T. Kodamullil, M. Page, B. Müller, S. Springstubbe, U. Wüllner, D. Scheller, and M. Hofmann-Apitius, "Pdon:

Parkinson's disease ontology for representation and modeling of the parkinson's disease knowledge domain," Theoretical Biology and Medical Modelling (2015), pp. 1–17, 2015.

[12] M. Page, J. Gensel, C. Capponi, C. Bruley, P. Genoud, and D. Ziebelin, "Representation de connaissances au moyen de classes et d'associations : le systeme arom," LMO, 2000.

[13] T. Ebadi, M. A. Purvis, and M. K. Purvis, "A collaborative web-based issue based information system (IBIS) framework," University of Otago Department of Information Science, Tech. Rep., 2009.

[14] J. Lee, "Decision representation language (DRL) and its support environment," MIT Artificial Intelligence Laboratory, Tech. Rep., 1989.

[15] A. Gracia-Frey, "Quality of human-computer interaction: Self-explanatory user interfaces by model-driven engineering," Ph.D. dissertation, Laboratoire d'Informatique de Grenoble, 2013.

[16] A. K. M. A. S, "Visual solution development," pp. 1–81.

[17] M. ollo and S. G. Winter, "Deliberate learning and the evolution of dynamic capabilities," Organization Science, vol. 13, pp. 339–351, 2002.

[18] D.-N. Chena and T.-P. Liang, "Knowledge evolution strategies and organizational performance: A strategic fit analysis," Electronic Commerce Research and Applications, vol. 10, pp. 75–84, 2011.

[19] G. Lahrmann, F. Marx, R. Winter, and F. Wortmann, "Business intelligence maturity: Development and evaluation of a theoretical model," in System Sciences (HICSS), 2011 44th Hawaii International Conference on, 2011, pp. 1–10.

[20] A. Popovič, R. Hackney, P. Simões Coelho, and J. Jaklič, "Towards business intelligence systems success: Effects of maturity and culture on analytical decision making," Decision Support Systems, vol. 54, pp. 729 – 739, 2012.

[21] O. Isik, M. C. Jones, and A. Sidorova, "Business intelligence success: The roles of BI capabilities and decision environments," Information & Management, vol. 50, pp. 13 – 23, 2013.

[22] S. Rouhani, M. Ghazanfari, and M. Jafari, "Evaluation model of business intelligence for enterprise systems using fuzzy TOPSIS," Expert Systems with Applications, vol. 39, pp. 3764 – 3771, 2012.

[23] S.-L. Yan, Y. Wang, and J.-C. Liu, "Research on the comprehensive evaluation of business intelligence system based on BP neural network," Systems Engineering Procedia, vol. 4, pp. 275 – 281, 2012.

[24] L. Michel, "Méthodes socio-statistiques pour l'aide à la décision en milieu industriel : Application à la gestion des capacités d'un système d'information en industrie micro-électronique," Ph.D. dissertation, Ecole Nationale Supérieure des Mines de Saint-Etienne, 2013.

[25] G. Schreiber, Knowledge engineering and management. MIT Press, 2000.

[26] P. Bera, "Knowledge requirements analysis: A case study," Ph.D. dissertation, The University of British Columbia, 2002.

[27] T. P. L. Grace, "Wikis as a knowledge management tool," Journal of Knowledge Management, pp. 64–74, 2009.

[28] T. Haasea, W. Termathb, and M. Martsch, "How to save expert knowledge for the organization: Methods for collecting and documenting expert knowledge using virtual reality based learning environments," Procedia Computer Science 25, vol. 25, p. 236 – 246, 2013.

[29] (2014) Knowledge proliferation. http://c2.com/cgi/wiki?KnowledgeProliferation.

[30] N. Samoilenko and N. Nahar, "It tools for knowledge storage and retrieval in globally distributed complex software and systems development of high-tech organizations," Proceeding of PICMET: Technology Management for Emerging Technologies, pp. 1353–1369, 2013.

[31] E. Dubois and A. Rousseau, "Service science: A service system design science research method?" Lecture Notes in Business Information Processing, vol. 143, pp. 100–113, 2013.

[32] A. Mili, "Vers des méthodes fiables de contrôle des procédés par la maîtrise du risque," Ph.D. dissertation, Laboratoire des Sciences pour la Conception, l'Optimisation et la Production, 2009.

[33] (2015) SWOT analysis. [Online]. Available: Available at: en.wikipedia.org/wiki/SWOT_analysis

[34] C. Jooste, J. Van Biljon, and J. Mentz, "Usability evaluation for business intelligence applications: A user support perspective," South African Computer Journal: SAICSIT 2013, vol. 53, pp. 32–44, 2014.

[35] J. Kaufmann and P. Chamoni, "Structuring collaborative business intelligence: A literature review," in System Sciences (HICSS), 2014 47th Hawaii International Conference on, 2014, pp. 3738–3747.

[36] V. Panos, "A survey of extract-transform-load technology," IJDWM, vol. 5, pp. 1–27, 2009.

[37] M. D. Sano, "Business intelligence as a service: A new approach to manage business processes in the cloud," WETICE Conference (WETICE), 2014 IEEE 23rd International, pp. 155–160, 2014.

[38] I. Hilgefort. (2011) Selecting the right SAP businessobjects BI client product based on your business requirements for SAP BW customers. [Online]. Available: http://www.scn.sap.com

[39] X. Boucher, E. Bonjour, and B. Grabot, "Formalisation and use of competencies for industrial performance optimisation: A survey," Computers in Industry, vol. 58, p. 98–117, 2007.

[40] M. Gardoni, C. Frank, and F. Vernadat, "Knowledge capitalisation based on textual and graphical semi-structured and non-structured information: case study in an industrial research centre at {EADS}," Computers in Industry, pp. 55 – 69, 2005.

[41] X. Daniela, F. Morán, F.-F. Rubén, and P. Gonzalo, "Modelling knowledge strategy for solving the dna sequence annotation problem through commonkads methodology," Expert Systems with Applications, pp. 3943–3952, 2013.

[42] P. Clarysse, F. Frouin, M. Garreau, J. Rousseau, D. Sarrut, and C. Vasseur, "Knowledge integration and modelisation in medical image processing," Elsevier SAS, pp. 139–149, 2004.

[43] J. Xu, R. Houssin, A. Bernard, and E. Caillaud, "Systemic modeling of knowledge for innovation in design," CIRP Journal of Manufacturing Science and Technology, pp. 1–12, 2013.

[44] A. Garcia-Perez and R. Ayres, "Wikifailure : the limitations of technology for knowledge sharing," Electronic Journal of Knowledge Management Volume, pp. 43–52, 2010.

[45] B. Montero-Fleta and C. Pérez-Sabater, "Knowledge construction and knowledge sharing: a wiki-based approach," Procedia - Social and Behavioral Sciences, pp. 622–627, 2011.

[46] L. Chen and P. S. Fong, "Evaluation of knowledge management performance: An organic approach," Information & Management, pp. 431–453, 2015.

[47] C. Yuh-Jen and C. Yuh-Min, "Knowledge evolution course discovery in a professional virtual community," Knowledge-Based systems, pp. 1–28, 2012.

[48] B. Inmon. (2014) Evolution of business intelligence. [Online]. Available: http://www.forestrimtech.com/evolution-of-business-intelligence

[49] I. Lykourentzou, K. Papadaki, D. J. Vergados, D. Polemi, and V. Loumos, "Corpwiki: A self-regulating wiki to promote corporate collective intelligence through expert peer matching," Information Sciences, pp. 18–38, 2010.

[50] M. Krebs, M. Ludwig, and W. Müler, "Learning mathematics unsing wiki," Procedia Social an Behavioral Sciences, vol. 2, pp. 1469–1476, 2010.

[51] R. Ramanau and G. Fawei, "Researching the use of wikis to facilitate group work," Social and Behavioral Sciences, pp. 2620 – 2626, 2009.

[52] R. MacManus. (2006) ebay wiki-world's largest commercial wiki launched. [Online]. Available: Available at: www.readwriteweb.com

[53] A. Conte, I. Hassine, J. P. Giraudin, and D. Rieu, "Agap: un atelier de gestion et d'application de patrons," Actes du XIXème Congrès INFORSID, 2001.

[54] M. Sandelowski, "Focus on qualitative methods: using qualitative methods in intervention studies," Res Nurs Health, pp. 359–364, 1996.

[55] ——, "Des lettres et des chiffres : vers la troisième génération du qualitatif en sciences de gestion," Revue Science de Gestion, pp. 179–206, 2003.

[56] M. Fonteyna and S. Bauer-Wu, "Using qualitative evaluation in a feasibility study to improve and refine a complementary therapy intervention prior to subsequent research," Complementary Therapies in Clinical Practice, pp. 247 – 252, 2005.

[57] J. Brooke. (1996) A quick and dirty usability scale, s.l.: Usability evaluation in industry.

[58] K. Selhorst, "Putting library 2 . 0 into practice : the process of setting up a wiki as a tool for knowledge sharing in a public library," Online Information, pp. 1–6, 2008.

[59] S. Chaudhuri and U. Dayal, "An overview of data warehousing and olap technology," SIGMOD Rec., vol. 26, pp. 65–74, 1997.

[60] R. Freitas Paixao, "La business intelligence est-elle adaptée au mode des pme?" Ph.D. dissertation, Haute Ecole de Gestion de Genève HEG-GE, 2006.

[61] H. Luhn, "A business intelligence system," IBM Journal of Research and Development, vol. 2, pp. 14 – 31, 1958.

[62] H. Morris, H. Liao, S. Padmanabhan, S. Srinivasan, P. Lau, J. Shan, and R. Wisnesky, "Bringing Business Objects into Extract-Transform-Load (ETL) Technology," 2008 IEEE International Conference on e-Business Engineering, pp. 709–714, 2008.

[63] A. Materials. (2015) Apf. www.appliedmaterials.com.

[64] (2013) Oracle data integrayor. www.oracle.com.

[65] D. Cardon. (2014) Database vs data warehouse: A comparative review. https://www.healthcatalyst.com/database-vs-data-warehouse-a-comparative-review.

[66] S. Chaudhuri, U. Dayal, and V. Narasayya, "An overview of business intelligence technology," Communication of the ACM, vol. 8, pp. 88–98, 2011.

[67] I. Gam El Golli, "Ingénierie des exigences pour les systèmes d'information décisionnels: concepts, modèles et processus - la méthode cadwe," Ph.D. dissertation, Université Paris I - Pantheon- Sorbonne, 2008.

[68] D. Barone, T. Topaloglou, and J. Mylopoulos, "Business intelligence modeling in action: A hospital case study," Advanced Information Systems Engineering, vol. 7328, pp. 502–517, 2012.

[69] X. Dai, N. Matta, and G. Ducellier, "Knowledge discovery in collaborative design projects," APMS Advances in Poduction Management Systems, pp. 330–336, 2014.

[70] M. Alavi and D. Leidner, "Knowledge management and knowledge management systems: Conceptual foundations and research issues," INSEAD Working Paper Series, pp. 1–79, 1999.

[71] P. Cooper, "Data, information, knowledge and wisdom," Anaesthesia and intensive care medicine, vol. 15, pp. 44–45, 2001.

[72] D. Bellinger, Gene andCastro and A. Mills. (2004) Data, information, knowledge, and wisdom. www.systems-thinking.org/dikw/dikw.htm.

[73] A. Frost. (2013) Defining knowledge, information, data. www.knowledge-management-tools.net/knowledge-information-data.html.

[74] I. Nonaka and H. Takeuchi, "The knowledge creating company," Oxford University Press, pp. 1–304, 1995.

[75] J. Barthes, Livret d'introduction au knowledge management. edition 2000, Paris: IIIA Groupe de Travail Méthodologie, 2000.

[76] M. Polanyi, The tacit dimension. Garden City, N.Y., 1967.

[77] D. Skyrme. (2011) Tacit and explicit knowledge. http://www.skyrme.com/kmbasics/ktacit.htm.

[78] R. G. Best, S. J. Hysong, C. McGhee, F. I. Moore, and J. A. Pugh, "An empirical test of nonaka's theory of organizational knowledge creation," E-journal of Organizational Learning and Leadership, vol. 2, pp. 1–19, 2003.

[79] G. Petrash, "Managing knowledge assets for value," Knowledge-Based Leadership Conference, pp. 18–38, 1996.

[80] S. Denning. (2009) What is knowledge. www.stevedenning.com/knowledge-Management/what-is-knowledge.aspx.

[81] B. Schmid, P. Schubert, and D.-M. Lincke, "A global knowledge medium as a virtual community - the netacademy concept," Proceedings of the Americas Conference of AIS, pp. 618–620, 1998.

[82] M. H. Zack, "A global knowledge medium as a virtual community - the netacademy concept," Sloan Management Review, vol. 40, pp. 45–58, 1999.

[83] R. McQueen, "Four views of knowledge and knowledge management," Proceedings of the Fourth Americas Conference on Information Systems, pp. 609–611, 1998.

[84] S. Carlson, O. ElSawy, I. Eriksson, and A. Raven, "Gaining competitive advantage through shared knowledge creation: in search of a new design theory for strategic information systems," 4th European Conference on Information Systems, vol. 40, pp. 90–111, 1996.

[85] S. Ranganathan. (2011) Are you speaking with your knowledge or capability? www.modernghana.com/news/349006/1/are-you-speaking-with-your-knowledge-or-capability.html.

[86] W. Regli, X. Hu, M. Atwood, and W. Sun, "A survey of design reational systems: Approaches, representation, capture and retrieval," Engineering with computers, pp. 209–235, 2000.

[87] C. ACT-NET CONSORTIUM, "The active databasemanagement systemmanifesto: a rule- base of adbms features," SIGMOD Record, pp. 40–49, 1996.

[88] R. Garud, "On the distinction between the know-how, know-why and know-what," Advances in strategic management, pp. 81–101, 1997.

[89] M. Z. Ouerteni, "Depnet: A methodology for identifying and qualifying dependencies between engineering data," The 17th CIRP International Design Seminar, pp. 1–10, 2007.

[90] K. Efthymiou, K. Sipsas, D. Mourtzis, and G. Chryssolouris, "On knowledge reuse for manufacturing systems design and planning: A semantic technology approach konstantinos," CIRP Journal of Manufacturing Science and Technology, vol. 8, pp. 1–11, 2015.

[91] T. Gruber R, "A translation approach to portable ontology specifications," Knowledge Acquisition, p. 199–221, 1993.

[92] S. Grimm, P. Hitzler, and A. Abecker, "Knowledge representation and ontologies," Logic, Ontologies and Semantic Web Languages, pp. 37–87, 2007.

[93] E. Benaissa, I. Charfeddine, S. Bendriss, and A. Benabdelhafid, "Ontological model for knowledge capitalization in multimodal transport domain," International Conference on Advanced Logistics and Transport Ontological, pp. 4799–4839, 2014.

[94] T. Edgington, T. Raghu, and A. Vinze, "Knowledge ontology: A method for empirical identification of 'as-is' contextual knowledge," Proceedings of the 38th Hawaii International Conference on System Sciences, pp. 1–10, 2005.

[95] J. Zhou and R. Dieng Kuntz, "Manufacturing ontology analysis and design: Towards excellent manufacturing," Industrial Informatics, pp. 39–45, 2004.

[96] M. ZGORZELSKI and Z. ZALEWSKI, "Fuzzy NIAM for real world data modelling," I.S.A.T.A. 29th International Symposium on Automative Technology and Automation, 1996.

[97] P. Bradley. (2007) Introduction to symbolic models. http://www.mind.ilstu.edu/curriculum/turing_machines/symbolic_models.php.

[98] W. J. Black, "Acquisition of conceptual data models from natural language descriptions," Proceedings of the Third Conference on European Chapter of the Association for Computational Linguistics, pp. 241–248, 1987.

[99] P. Van Gorp, H. Stenten, T. Mens, and S. Demeyer, "Towards automating source-consistent uml refactorings," The Unified Modeling Language. Modeling Languages and Applications, pp. 144–158, 2003.

[100] W. R. King, "Knowledge management and organizational learning," Springer US, pp. 3–13, 2009.

[101] A. MACLEAN, R. YOUNG, V. BELLOTTI, and T. ANDMORAN, "Questions, options and criteria: Elements of design space analysis," Human-Computer Interaction, pp. 201–250, 1991.

[102] J. Conklin and M. L. Begeman, "gIBIS: A hypertext tool for team design deliberation," Proceedings of the ACM Conference on Hypertext, pp. 247–251, 1987.

[103] A. Brice. (1994) Design rationale management (drama). http://www.quantisci.co.uk/drama.

[104] D. McCullough, T. Korelsky, and M. White, "Information management for release-based software evolution using emma," Software Engineering and Knowledge Engineering, 1998.

[105] J. Penalva, "Sagace, la modélisation des systèmes dont la maîtrise est complexe," ILCE, EC2 (Ed), 1994.

[106] J. Lee and K.-Y. Lai, "What's in design rationale?" Human-Computer Interaction, p. 251–280, 1991.

[107] M. Klein, "Capturing design rationale in concurrent engineering teams," Computer, vol. 26, pp. 39–47, 1993.

[108] N. Matta, O. Corby, and M. Ribiere, "Méthodes de capitalisation de mémoire de projet," pp. 330–336, 1999.

[109] E. Céreta, S. Dupuy-Chessa, G. Calvaryc, A. Front, and D. Rieu, "A taxonomy of design methods process models," Information and Software Technology, vol. 55, pp. 795–821, 2013.

[110] M. Benabdellatif, “Process modelling analysis: comparison between activity-oriented models, product-oriented models and decision-oriented models,” Data Mining II, p. 251–258, 2002.

[111] C. Rolland, “L’ingénierie des méthodes : une visite guidée,” E-revue en Technologies de l’Information (e-TI), 2005.

[112] ——, “From conceptual modeling to requirements engineering,” Conceptual Modeling - ER 2006, pp. 5–11, 2006.

[113] (2009) Object management group: Business process modeling notation (BPMN). http://www.omg.org/spec/BPMN/1.2/.

[114] I. Marthinusen, “The active knowledge modeling approach-to configurable product and process design,” Ph.D. dissertation, Norwegian university of science and technology, 2011.

[115] B. Montero-Fleta and C. Pérez-Sabater, “Knowledge construction and knowledge sharing: a wiki-based approach,” Procedia-Social and Behavioral Sciences, pp. 622–627, 2011.

[116] B. Gee-Woo, Z. Robert W, K. Young-Gul, and L. Jae-Nam, “Behavioral intention formation in knowledge sharing: Examining the roles of extrinsic motivators, social-psychological factors, and organizational climate,” MIS Q., pp. 87–111, 2005.

[117] G. Avram, “At the Crossroads of Knowledge Management and Social Software,” The Electronic Journal of Knowledge Management, pp. 1–10, 2006.

[118] M. Buffa, F. Gandon, G. Ereteo, P. Sander, and C. Faron, “SweetWiki: A semantic wiki,” Web Semantics: Science, Services and Agents on the World Wide Web, pp. 84–97, 2008.

[119] K. Selhorst, “Putting Library 2 . 0 into practice : the process of setting up a wiki as a tool for knowledge sharing in a public library,” Online Information 2008, pp. 7–12, 2008.

[120] Wikipedia. (2015) Enterprise 2.0. https://en.wikipedia.org/wiki/Enterprise_2.0.

[121] R. Parker Kevin and T. Chao Joseph, “Wiki as a teaching tool,” Interdisciplinary Journal of Knowledge and Learning Objects, vol. 3, 2007.

[122] B. Lamb, “Wide open spaces: Wikis, ready or not,” EDUCAUSE Review, vol. 5, pp. 36—48, 2004.

[123] A. Wichmann and N. Rummel, “Improving revision in wiki-based writing: Coordination pays off,” Computers & Education, pp. 262–270, 2013.

[124] Stmicroelectronics. www.st.com.

[125] R. Ramanau and F. Geng, “Researching the use of wiki’s to facilitate group work,” wiki Social and Behavioral Sciences, pp. 2620–2626, 2009.

[126] M. Bieber, D. Engelbart, R. Furuta, S. Roxanne, H. John Noll, J. Preece, E. A. Stohr, M. Turoff, and B. Van De Walle, “Toward virtual community knowledge evolution,” Journal of Management Information Systems, vol. 18, p. 11–35, 2002.

[127] J. Polańska and M. Zyznarski, "Elaboration of a method for comparison of business intelligence systems which support data mining process," Ph.D. dissertation, School of Engineering Blekinge Institute of Technology, 2009.

[128] C. Dell'Aquila, F. Di Tria, E. Lefons, and F. Tangorra, "Evaluating business intelligence platforms: a case study," in Proceedings of the 7th WSEAS International Conference on Artificial intelligence, knowledge engineering and data bases (AIKED'08), 2008, pp. 558–564.

[129] (2014) Iso 25000 software product quality. [Online]. Available: http://www.iso25000.com

[130] P. Mo John, B. Cees, and S. Arvind, "12-continuous improvement," Engineering Systems Acquisition and support, pp. 205–212, 2015.

[131] F. Goundo Camara, "Retours d'expérience sur la conception centrée valeur de cocoon: vers des arbres de vie," Ph.D. dissertation, Laboratoire d'informatique de Grenoble, 2013.

[132] S. BusinessObjects, "Guide de l'utilisateur de l'outil de conception d'univers sap businessobjects business intelligence platform 4.0 feature pack 3," SAP AG, Tech. Rep., 2012.

[133] A. S. Maniatis, "Olap presentation modeling with uml and xml," Proceedings of the 1st Balkan Conference in Informatics, 2003.

[134] Big data pour doper la BI traditionnelle. http://www.cxp.fr/content/forum-news/big-data-pour-doper-la-bi-traditionnelle.

[135] Couchbase. Why nosql http://www.couchbase.com/nosql-resources/what-is-no-sql.

[136] C. Bucur, "Using big data for intelligent businesses," Proceedings of the Scientific Conference AFASES, vol. 2, pp. 605 – 612, 2015.

RÉSUMÉ

À *STMicroelectronics*, l'équipe de *Business Intelligence* est confrontée à exploiter quotidiennement des données et des informations pour créer des rapports d'activité afin de superviser la production. Dans une telle organisation industrielle, les produits changent régulièrement et les données peuvent rapidement devenir obsolètes. Par conséquent, au fil du temps, le nombre de rapports crées est de plus en plus important, tandis que les connaissances sur leur création sont perdues. Ceci est illustré dans une évaluation qualitative et quantitative de la partie principale du système de connaissances à *STMicroelectronics*. Ainsi, des problèmes d'obsolescence, de duplication, de non-centralisation et de prolifération continuent à surgir. Ce travail doit, donc, répondre à la question de recherche générale suivante:

Comment assurer une capitalisation continue des connaissances métier?

Pour répondre à cette question, un cycle d'amélioration continue pour la capitalisation des connaissances est proposé. Son objectif est de capitaliser efficacement et en permanence les connaissances, tout en ciblant les besoins métier et assurant une solution évolutive. Un système de *Business Intelligence* pour la *Business Intelligence* (BI4BI) est proposé. Comme la connaissance est intégrée non seulement dans les systèmes et les outils, mais aussi détenue par les humains et leurs pratiques, notre solution de capitalisation de connaissances proposée implique aussi les utilisateurs et les organisations: elle propose de recueillir les points de vue des utilisateurs pour les intégrer dans la représentation des connaissances et dans notre système BI4BI.

MOTS-CLÉS *Capitalisation des connaissances, reporting décisionnel, Design Science Research, cycle d'amélioration continue.*

ABSTRACT

At *STMicroelectronics*, the *Business Intelligence* team is daily confronted to exploit data and information to create reports about manufacturing activities in order to supervise it. In such an industrial organization, products change regularly and data can quickly become obsolete. Consequently, over time, the number of created reports is highly growing, while knowledge about their creation is lost. This is shown in a qualitative and quantitative evaluation of the main part of the *STMicroelectronics*' knowledge system.
As a result, problems related to knowledge obsolescence, duplication, non-centralization and proliferation continuously arise. Therefore, this work addresses the general following research question:

How to ensure a continuous expert knowledge capitalization?

To answer this question, a continuous improvement cycle for knowledge capitalization is proposed. Its objective is to effectively and continuously capitalize expert knowledge while targeting business needs and providing an evolving solution. It is based on a *Business Intelligence* for *Business Intelligence* system (BI4BI). Since knowledge is embedded not only in systems and tools, but also in human minds and practices, our proposed knowledge capitalization solution also involves people and organizations: it proposes to collect users' feedbacks and insights to integrate them in knowledge representation and in our BI4BI tool.

KEY WORDS *knowledge capitalization, Business Intelligence, Design Science Research, continuous improvement cycle.*