Concurrent Engineering in Research Projects to Support Information Content Management in a Collective Way

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CONCURRENT ENGINEERING: Research and Applications

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Received 7 July 2004; Revised 12 December 2004; Accepted 7 March 2005

Abstract: Innovation has become a factor of competition. In order to increase the production of new knowledge, Concurrent Engineering (CE) could be applied to research activities by improving efficiency and reliability in the communication between the researchers. In the same way, research activities could also profit from approaches such as quality management and knowledge management. To this end, in this article, within a CE integrated team, research activities are analyzed in depth using a sociological study. Approaches harnessing the bibliographical work done by researchers are proposed – ANITA (ANnotation tool for Industrial TeAms) and MICA-Graph. Their associated communication tools are developed and undergo experimentation. The intention is to facilitate research activities by supporting information artifacts (textual and graphical such as sketches). These new and ergonomic groupware prototypes working on PC networks tend to be used to control two kinds of artifact: (1) Semi Structured Information (e.g., reports, etc.) thanks to the ANITA functions, that are based on the attribution of points of view and annotations on artifacts, and (2) Non Structured Information (such as mail, dialogues, etc.), thanks to the MICA-Graph approach, which is intended to support the exchange of messages that concern common resolution of research problems within CE-integrated teams and to capitalize relevant knowledge. It also provides facilities to structure and archive knowledge learned during this process owing to new methods of design sketch retrieval. For both approaches, the main feedback utilized involves manufacturing knowledge in the EADS industrial environment.

Key Words: Concurrent Engineering, research activities management, Semi Structured Information, Non Structured Information, CSCW, knowledge management, sketch design.

1. Introduction

Nowadays, industrial companies need to follow and control the acceleration of technological progress to be able to maintain the market position of their products and services and also to generate the opportunities required to become the market leader. As such, to improve their competitive advantage due to innovation, research activity should be rationalized. This phenomenon originally affected industrial research centers but now also affects academic laboratories.

Research activity implies the management of information and knowledge. Also, the research process could be considered as a knowledge production process [1]. In this context, the process of assembling knowledge involves the combination of knowledge to create new knowledge that could be re-used within another combination. To improve this process, during the last few years, some research organizations have shown an interest in quality management. However, research activities present specificities in terms of goals, resources, practices, and organization, which make them very different from industrial activities, where quality management has been traditionally used, because the knowledge is less concrete than products, parts, etc. Indeed, the matter manipulated by research activities is knowledge. As a synthesis of different definitions dealing with the concept of knowledge [2], it is proposed that 'Knowledge is the result of human experience and reflection based on a set of beliefs and residing as fictive objects in people's mind.' In the context of this work, it is considered that knowledge in people's mind is tacit. Brohm [3] argues that the notion of 'explicit knowledge' is another expression for information, which can be interpreted by receivers by using their expertise. Therefore, explicit knowledge can be considered as information as long as it is possible to interpret this information.

This knowledge production activity, according to the results of research in science sociology [4] and reality observed over several months thanks to certain theses projects, is usually developed in the form of more or less structured research projects that make research activities

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1063-293X/05/02 0135–10 $10.00/0 DOI: 10.1177/1063293X05053798

difficult to harness. Moreover, other characteristics make research activities difficult to manage:

– the diversity of activities, the great quantity of records (digital reports and files in particular) to manage,
– the freedom granted to the researchers for the registering or the traceability of their production, the multiplicity of working methods,
– the large turnover of researchers,
– the multiplicity of activities that have to be developed in parallel, with various time delays, which need to be coordinated to lead to valid results,
– the difficulty in establishing, from the beginning of a project, the goals and the precise characteristics of the research product, which are sometimes hardly measurable (for instance, unexpected wrong results could become good research products, which could be physical or conceptual).

which explains the interest of having support practices during the research process, of capitalizing the history of a project, of setting up procedures for the validation of results, etc. [5]. More reasons to put information in the center of the research activities management problem are: (i) information is the main matter of the input and the output of the knowledge production process; (ii) the difference of time scale between the operational systems (requiring quick answers to their problems) and the research organizations (needing time to undertake their research activities) requires an accurate information management of weak signals, crucial information identification, information validity, knowledge maturity, etc.; and (iii) work in a research project team requires information exchange in a distributed and asynchronous way [6].

The intention of this work is the improvement of the research activities by harnessing information flow that, at the end of the day, should increase knowledge production. To achieve this aim, the Concurrent Engineering (CE) [7] concept could be applied to research activities.

2. Research Activities Characterization

2.1 Research Activities Context

Most of the time, a single researcher does not have all the skills required to respond to research objectives, which is why formal/informal or multidisciplinary/unique-competence teams are created. In this context, the researchers share their knowledge across these different teams in order to be able to produce new research products in a communal manner. According to studies [8], research activities could be characterized by an objective-oriented research process framework structured in three phases: to investigate, to focus, and to deploy (Figure 1): (i) the aim of the investigation phase is to elaborate states of the art; (ii) the role of the focus phase is to experiment and illustrate new technologies and methods with prototypes; (iii) the aim of the deploy phase is to transfer research results and knowledge directly to the operational units.

Concurrent Engineering could be applied to each phase and also between the three phases of investigate, focus, and deploy. Indeed, team project work enables the exchange of information intra- and inter-phases. According to Dunbar [9] 'many researchers have noted that an important component of science is the generation of new concepts and modifications of existing concepts.' By scientific concepts the author means the constructions based on previous scientific knowledge and supporting data, that undergo an evaluation procedure to verify their ability to explore, explain,

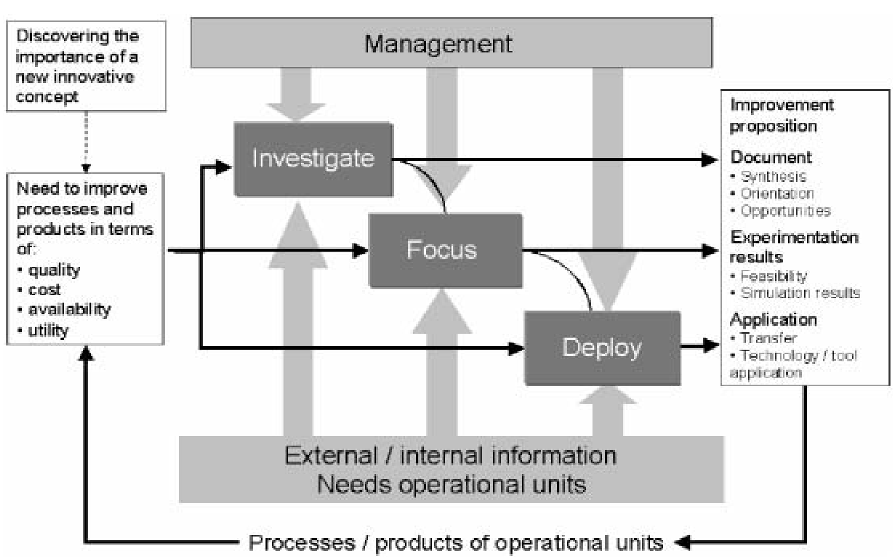

Figure 1. Objective-oriented research process framework [8].

describe, predict, or influence a phenomenon. The investigation phase could be the main framework to this generation of scientific concepts, and more particularly the bibliographical work which includes all activities: from the research of available knowledge in written documents (articles, theses, etc.) or owned by other people, to the production of new knowledge with the writing of documents or by interaction with other people [10]. Results from research projects are already capitalized thanks to existing valorization mechanisms (articles, theses, etc.), however, all the knowledge produced throughout the research process and which form part of the construction of the final result is barely tracked. Nevertheless, it could be profitable to exploit this richness to benefit from the latest improvements and not to repeat the same failures. The idea is to support the researcher in the realization of his bibliographical work, and by this way to capitalize, at least, part of the knowledge acquired and produced during this phase.

To this end, supporting bibliographical work should not be restricted to the management of document references as objects and should embody the scientific concepts, which are part of the bibliographical sources content. To keep track of this content, the artifact notion seems useful. Indeed, an artifact is an element having a material form (speed chart, paper-board, indicator on a data-processing screen, or a measuring apparatus, etc.) or a virtual form (as it can exist in computer system), which can convey a part of the knowledge held by its author if a receiver knows the context in which the artifact was conceived and if he has the necessary knowledge to interpret it. The notion of artifacts, is a reflexive one (a document artifact could be composed of section artifacts, which could be composed of figure artifacts, etc.). Thus artifact capitalization could be a means to capitalize at least part of the knowledge resulting from the realization of research projects. Moreover, Groleau [11] says that 'the possibility of increasing the effectiveness of work within organizations greatly depends on the configuration of information sources offered to workers in that environment, the vision they offer, and the competence of workers to act upon it.' So, researchers can benefit from artifact supports in their way of working.

2.2 Artifact Characterization

To deepen the research project analysis where artifacts are produced, a research project representation inspired from the Structured Analysis Design Technique (SADT) modeling is proposed (Figure 2). Indeed, some added proposed formalisms allow the differentiation of the activities performed – between routine activities, semi-routine activities, and intellectual activities and to differentiate the outcomes obtained – between main results (state of the art, report, etc.), secondary results (author list, conference list, result table, etc.), and un-used results (articles not in the scope, etc.). The model is purposely general and centered more in the arrows (artifacts produce and potentially exchanged between researchers) and less in the boxes (activities).

During sociological observation [5], more than a hundred artifacts were identified, which could be classified into two typologies:

- Purpose typology:
  - Bibliographical artifacts: publications, reports, books, etc.
  - Project management artifacts: project plan, meeting reports, etc.
  - Intermediate result artifacts: software and hardware developed for a project, data gathered and treated, etc.

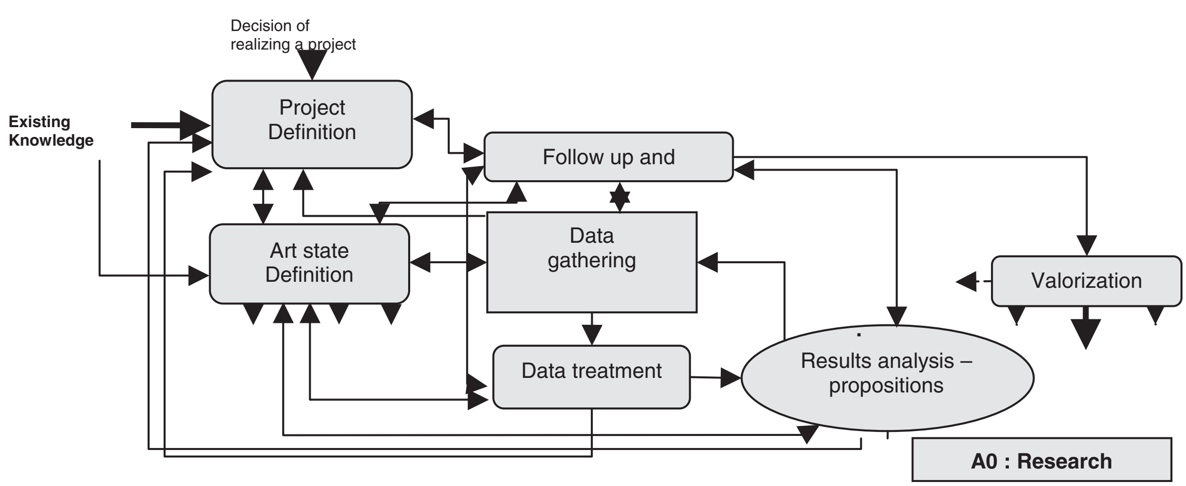

Figure 2. Example of SADT representation with.

- Control typology, characterized by [12]:
  - Structuration that consists of linguistic components (that bring significance by instructions or formalisms) and rhetorical components (that bring meaning by contextual elements),
  - Sharing by the ability of 'pushing' information,
  - Accessing by the ability to 'pull' information,
  - Capitalization by the ability to store and process information for interpretation and later re-use, as suggested by the knowledge management cycle model [13]: identify, acquire, structure, combine, share, distribute, use, preserve, and eliminate.

With respect to this Control typology, artifacts could be characterized as [14]: (i) Structured Information (SI) (e.g., an industrial design), which will barely be dealt with in this article, because they are rather well controlled by actual quality management; (ii) Semi Structured Information (SSI) (e.g., reports/minutes, articles, etc.); and (iii) Non Structured Information (NSI) (mail, dialogue, etc.), which can relate to the resolution of common research problems within teams.

To study the bibliographical work description in more depth, a functional analysis was carried out [5] (Figure 3). The following functions were identified:

- F1: To locate and analyze interesting information in the external information sources.
- F2: To choose and to analyze interesting information available in the internal information sources.
- F3: To bring relevant information to a project in progress.
- F4: To allow the enrichment of the information available in the internal information sources.
- F5: To share the bibliographical information collected and produced.
- F6: To support the writing of publications.

These functions have been also defined in a greater level of detail, by taking into account the bibliographical artifacts already identified [5]. There are two main possible ways of fulfilling the definition of bibliographical work management and capitalization functions: methodological and software tools.

- Regarding the methodological aspects, many works exist [15], however, they do not address content management.
- Regarding software tools, an automated search and web intelligence solution (Google alert) during a two-month period (July–August, 2003) was applied. This allowed the identification of more than 50 firms, offering more than 200 tools, which could be classified according to their main functionalities: – project management, data management, and bibliography management (mostly about reference management and visualization references). The supply is very rich and diverse. Nevertheless, there is still a lack of tools adapted to the basic research activity, focusing on the control of artifacts supporting content and consequently scientific concept.

In order to build system specifications to support researchers through the realization of the bibliographical work related to the manipulation of scientific concepts, a modeling system with Unified Modeling Language (UML) was carried out (Figure 4).

These different models (SADT (Figure 2), Functional Analysis (Figure 3) and UML (Figure 4)) lead to define two approaches to support: (i) SSI by ANnotation tool for Industrial TeAms (ANITA) functions and its prototype, which are based on attribution of points of view via index and annotations [8]; (ii) Non Structured Information (NSI) that tend to be supported by the MICA-Graph approach and its prototype and to capitalize a part of the produced knowledge [14]. Thereafter, the ANITA and MICA-Graph prototypes were developed and evaluated in the environment of the Common Research Center, European Aeronautic Defence and Space Company (EADS). This work was undertaken in close cooperation with EADS during the last six years via two theses [8,14] and

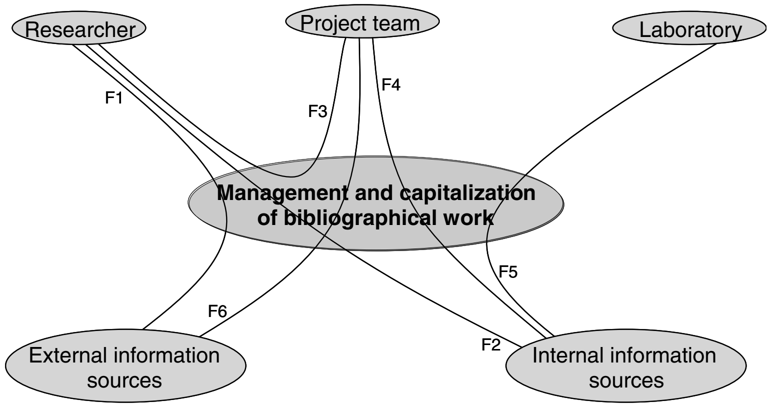

Figure 3. Functional analysis of a system for managing and capitalizing bibliographical work within research projects.

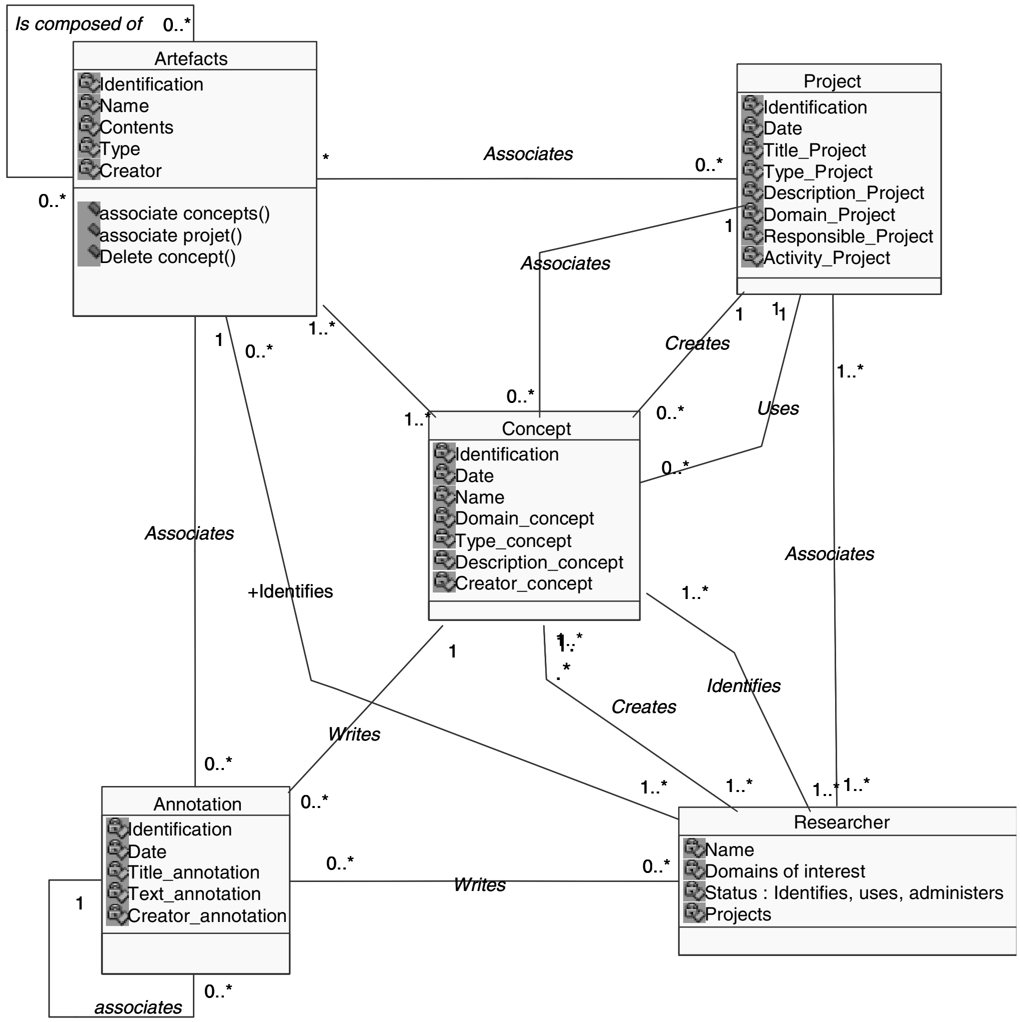

Figure 4. Example of bibliographical research activities UML model.

gave rise to three other theses still in progress. The ANITA and MICA-Graph approaches will be described in Sections 3 and 4, respectively.

3. ANITA Approach and Prototype

By ISO standards, the document references in project teams are clearly identified however their contents are not characterized in an explicit way, so relevant facts in these SSI could be lost.

An indexation describing the context could be a way to characterize the content. It could be supplemented profitably and accurately by free text annotation. The annotation could be considered as high added value information insofar as it represents the expert time required to read the document and to index/annotate. According to research [8], traditional paper annotation is mostly a personal exercise (or dedicated to a very limited group) because of the difficulties of sharing information written on paper. Also the software annotation tools on the market do not offer enough possibilities in terms of structuration, access, sharing, and capitalization [14]. So, for the SSI harnessing, the ANITA approach and its prototype allow us to index information content description with contextual meta-data and to attach annotations to artifacts.

3.1 Information (SSI) Structuring in the ANITA Approach

In order to identify a contextual index, which can add structure to the content enclosed in SSI (cf Section 2.2), parts of the CIMOSA framework [16] could be used. From studies [8], it was proposed to use specifically the 'instantiation principles' with its three levels that could be concretized by: generic level (the 'objective-oriented research process framework' (Figure 1) is re-used), partial level (the 'knowledge management cycle model' [13] (Section 2.2) is proposed), and particular level (domain ontology indexation [17] and free text annotations could be used). These three levels provide the basis for a proposal of a general model framework for industrial research activities with a three-layer architecture [18] (Figure 5), which represents a SSI structural framework.

3.2 Information (SSI) Access in the ANITA Approach

To access artifacts with their content description, a retrieval module and full text search engines are applied on the document itself and also on the index and annotation.

3.3 Information (SSI) Sharing in the ANITA Approach

The researchers should also be able to visualize the different artifacts according to cross sets of index [8].

3.4 Knowledge Capitalization with the ANITA Approach

Thus, in the assembly module studied, the researcher could use the sharing module to elaborate new documents with existing artifacts and content descriptions in new documents, which could potentially help to create new knowledge by combining scientific concepts [11].

3.5 ANITA Prototype

From a technical point of view, the ANITA prototype is based on Adobe Acrobat, technologies of XML [19] for the indexing, on PHP for the annotations, and the platform of MySQL for the representation of the research results and document navigation [20].

In the context of the ANITA prototype the experiment showed that distributed and asynchronous bibliographical work can be facilitated owing to this structurable, accessible, sharable, tracked, and thus capitalizable indexation and annotation. Moreover, with this new communication tool, researchers can express themselves more freely (doubts, astonishments, etc.) because annotation is not considered as 100% validated and because there is no review process. This tracked indexation and annotation could become a way of detecting partially tacit knowledge during an ongoing project and of supporting elaboration of new research results by easing artifact juxtaposition and, as a result, the combination of scientific concepts.

4. MICA-Graph Approach and Prototype

In the context of the research project teams, SSI is not agile and flexible enough to handle conversation and to allow quick synchronization between researchers about, for instance, scientific concept via: dialogues/sketches

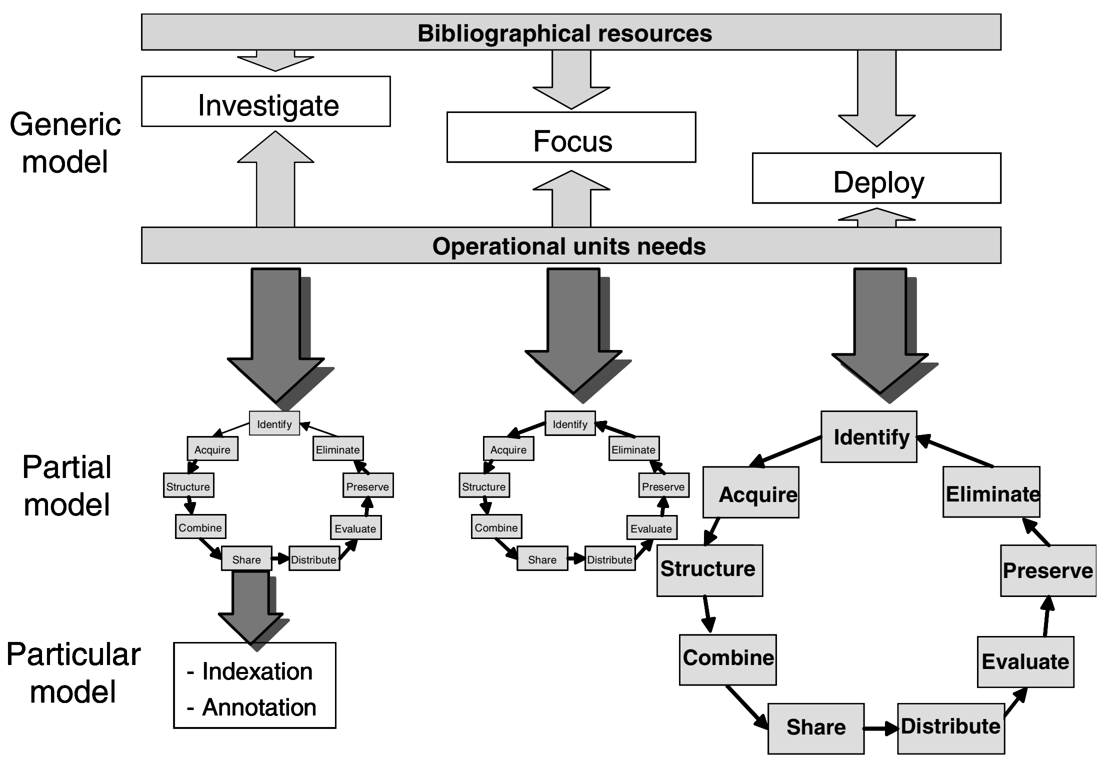

Figure 5. Knowledge management architectural framework for industrial research activities.

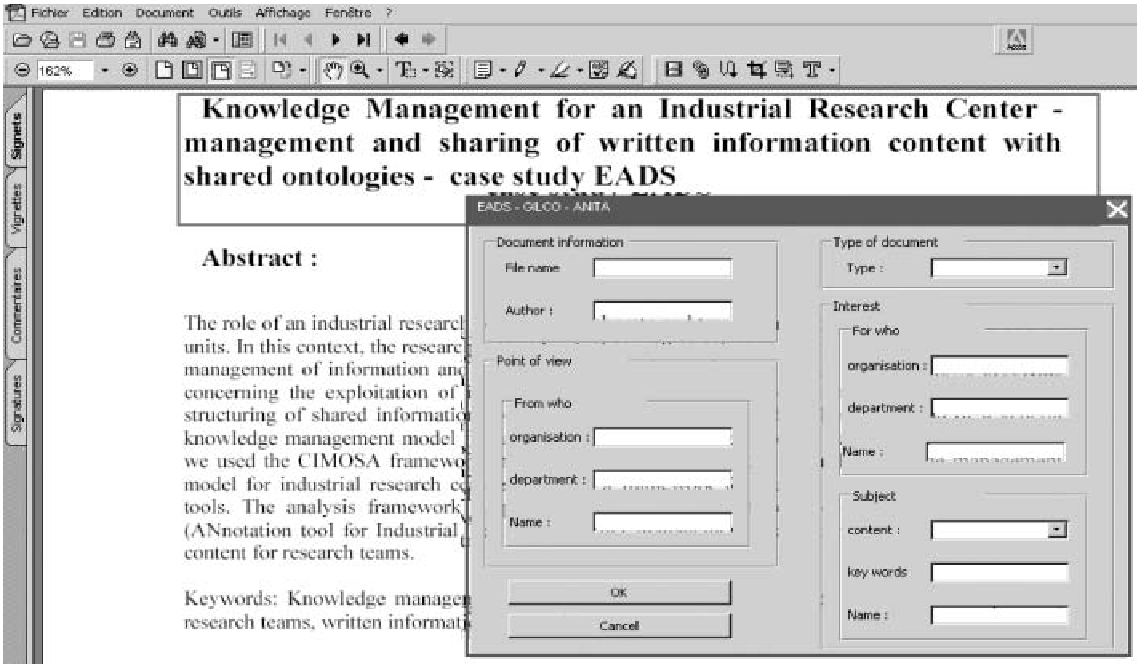

Figure 6. User interface for the attribution of points of view with contextual meta-data.

or NSI. With the intention of harnessing NSI, as in the previous section, a framework is first built and a software prototype called MICA-Graph [14] is then produced according to four main points of view (cf Section 2.2): structuration, access, sharing information, and knowledge capitalization [21].

One difficult NSI part is the graphical one, that is to say: sketches; which is less structured than textual information because the linguistic components or formalism are not predefined (the shape significance is built in the action) and the contextual components, most of the time, are verbal and thus volatile [12]. The MICA-Graph approach hypothesis is to give enough elements to allow sketch interpretation in a distributed and asynchronous way to such an extent that it would be possible to partially understand a sketch without being involved in the sketch-building process.

4.1 Information (NSI) Structuration in the MICA-Graph Approach

Information structuring in MICA-Graph should rely on two considerations (cf Section 2.2):

1. for the linguistic components, the natural language formalism is used;
2. for the rhetoric or contextual components, the ANITA ontology indexation (cf Section 3.1) could be re-used. However, this is not sufficient to interpret NSI, such as dialogues segments like 'continue as planned.' To add relevant contextual components, the CIMOSA approach [16] is partly used again for the problem at hand with the views model concept. For instance, for a technical research environment, four main views could be defined, namely cooperation, resource, product, and process views.

The Cooperative View makes it possible to take into account interactions. It was decided to gather all the NSI concerning the same negotiation in one form [22], called MICA-Graph form. It is made of three sections symbolizing three negotiation states: initial, negotiation, and final. And these sections are made of free fields and pre-defined fields characterizing the context [21].

For graphical information or sketches, to symbolize the various possible design choice processes, a tree structure is used to keep the designer/researcher's intention which facilitates sketch interpretation: the sketch modification could be characterized with the renamed Fergusson's proposition [23] (thinking, talking, and prescriptive into private, public, and prescriptive) and Goel's [24] point of view: lateral transformations (from one idea to a slightly different idea) and vertical transformations (from one idea to a detail or an extract of it). To create a new sketch the actor is able to choose from among any of the previous sketches in the tree structure the most suitable one for the context of his or her purpose (Figure 7) or to create a new root by using a blank paper, industrial design, photography, etc.

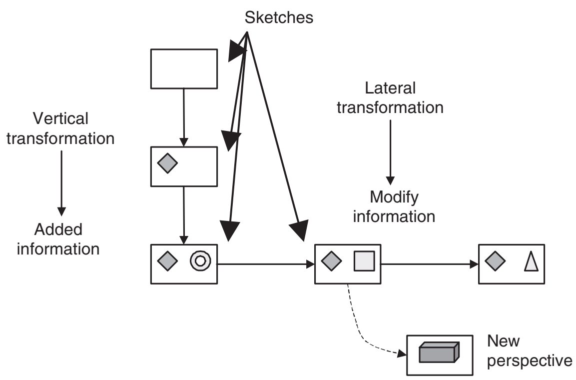

Figure 7. Historical tree structure of sketches: representation of steps of the sketch building process.

The other resource, product, and process views complete the context characterization by specifying added pre-defined fields.

4.2 Information (NSI) Sharing in the MICA-Graph Approach

All researchers of a project can have access to, but not modify, the existing NSI.

4.3 Information Access in the MICA-Graph Approach

Concerning textual information, a search engine is used for full text analysis or search criteria based on pre-defined fields only [25]. Moreover data-mining tools dedicated to the recognition of sketch shape are in development [26].

4.4 Knowledge Capitalization with the MICA-Graph Approach

Thanks to the MICA-Graph software, parts of NSI exchanged during the project could be tracked; it becomes possible to treat them, especially by applying data-mining to extract parts of knowledge from large quantities of linguistic data. Concerning sketches, three possible interaction mechanisms are possible: (i) utilizing sketch annotations; (ii) identifying important symbols that support shared knowledge; and (iii) providing new means of accessing MICA-Graph forms through content-based sketch retrieval, which hold the promise of retrieval of a similar sketch from the sketch based on drawing similar sketches as input [26].

Thus, the MICA-Graph prototype offers, as the ANITA approach, a support to ease working in an asynchronous and distributed way by allowing NSI structuration, access, sharing, and capitalization from tracked NSI. As in the ANITA approach, experimentations are in progress.

5. Experimentations and Prospects

In order to validate the ANITA and MICA-Graph approaches, prototypes were programmed and experimented upon by industrial users. Evaluation of the effectiveness of this kind of prototype is difficult. They offer a support for information exchanges required by research project teams and, thus, we can assume an improvement in the research activities process. However, we cannot confirm that it increases knowledge production activity because knowledge creation, in other words the generation of new scientific concepts, is a human activity. This makes it technically impossible to measure increases in knowledge creation. Even if knowledge creation increases, there may be no links between the generation of new scientific concepts and the use of the ANITA and MICA-Graph, which harness artifacts representing content. However, if researchers use the ANITA and MICA-Graph prototypes then there must be aspects, which interest them. Nevertheless, we have to assess the advantages and drawbacks of the ANITA and MICA-Graph prototypes compared with other existing tools. According to studies based on interviews, the shared structuration of the information content is the main point of interest because it allows individual treatments of information content to be re-used collectively. Experimentation of the ANITA and MICA-Graph is still in progress. It had already been identified that opposition to their use was caused partially by the transition from oral expression to writing practice, the nonexistence of a common ontology, the transparency of information, the fear caused by the elicitation of knowledge, etc. However, day-to-day use with the ANITA and MICA-Graph prototypes has been shown to alleviate this opposition and to create links between the researchers which crystallized their work, leading to significant growth in results.

From a practical point of view, several areas could be explored for further research work:

- experimentation of the ANITA and MICA-Graph prototypes in other environments and within large teams with the difficulty of managing several domain ontologies,
- the use of new technologies such as handwritten annotations via interactive screens or with oral annotation or character recognition through voice recognition,
- identification of the SSI captured by ANITA and the NSI tracked with MICA-Graph with a capture rate and a study of the information relevance,
- aggregation of various information management systems for SI, SSI, and NSI (in particular, the use of MICA-Graph and ANITA together).

From a theoretical point of view, other areas of exploration indicate several crucial points which could be dealt with:

- 'rebuilding' the decision-making process and especially in the sketch-design process,
- identification of ANITA and MICA-Graph Return of Investment,
- assessment of the improvement of knowledge management and of the increase of knowledge production,
- the way quality management and other CE concept applications [7] could improve knowledge management, etc.

These two topic lists are not exhaustive, however, these areas could be considered preferential to other experiments and generalization attempts of the ANITA and MICA-Graph approaches.

6. Conclusions

Quality management could be considered as a means to support the research process, however, current approaches only address administrative activities. Based upon sociological studies which help to model the research activities through an adapted SADT model which allows the identification of more than a 100 artifacts, we focussed on one aspect of research activity: the bibliographical work. In this context, a functional analysis highlights the importance of the content management, which are conveyed by artifacts. According to research, neither methodological nor software tools are efficient in controlling these artifacts according to CE concepts [7]. With this in mind, a UML model enabled us to elaborate the basis of two software prototypes specification of the ANITA and MICA-Graph approaches to harness SSI and NSI, respectively. Moreover, methodological and organizational approaches should be implemented to accompany the utilization of ANITA and MICA-Graph tools, to this end a sociological approach, with a deeper look at human behavior, is still in practise.

To sum up, new collaborative working tools are being experimented and the capitalization of ongoing projects starting from SSI and NSI is in progress. The ANITA and MICA-Graph approaches offer new avenues of research, which remain to be explored.

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