UNIVERSITY
OF TRENTO

DEPARTMENT OF INFORMATION AND COMMUNICATION TECHNOLOGY

38050 Povo – Trento (Italy), Via Sommarive 14
http://www.dit.unitn.it

A SEMANTIC-BASED INFORMATION MANAGEMENT SYSTEM TO SUPPORT INNOVATIVE PRODUCT DESIGN

Giuliana Ucelli, Raffaele De Amicis, Giuseppe Conti,
Fausto Giunchiglia and Stefan Noll

May 2003

Technical Report # DIT-03-020

A SEMANTIC-BASED INFORMATION MANAGEMENT SYSTEM TO SUPPORT INNOVATIVE PRODUCT DESIGN

Dr. Giuliana Ucelli[1], Dr. Raffaele De Amicis[1], Dr. Giuseppe Conti[1],
Prof. Fausto Giunchiglia[1-2] and Dr. Stefan Noll[1]

[1] Fondazione Graphitech
Via F. Zeni, 8 - 38068 Rovereto (Italy)
Ph: ++39 0464 443450
Fax: ++39 0464 443470
E-mail: giuliana.ucelli@graphitech.it
Web sites:
www.graphitech.it
www.inigraphics.net

[2] Department of Information and Communication Technology
University of Trento, Via Sommarive 14, I 38050 Trento (I)

ABSTRACT

International competition and the rapidly global economy, unified by improved communication and transportation, offer to the consumers an enormous choice of goods and services. The result is that companies now require quality, value, time to market and innovation to be successful in order to win the increasing competition. In the engineering sector this is traduced in need of optimization of the design process and in maximization of re-use of data and knowledge already existing in the company.
The "SIMI-Pro" (Semantic Information Management system for Innovative Product design) system addresses specific deficiencies in the conceptual phase of product design when knowledge management, if applied, is often sectorial. Its main contribution is in allowing easy, fast and centralized collection of data from multiple sources and in supporting the retrieval and re-use of a wide range of data that will help stylists and engineers shortening the production cycle. SIMI-Pro will be one of the first prototypes to base its information management and its knowledge sharing system on process ontology and it will demonstrate how the use of centralized network systems, coupled with Semantic Web technologies, can improve inter-working activities and interdisciplinary knowledge sharing.

INTRODUCTION

As in other industrial and manufacturing fields, also in the engineering sector, sustaining and maintaining innovative product design is fundamental to the continue success and competitiveness of small and medium sized enterprises (SMEs), which dominate the market in Europe. This new scenario is pushing engineering companies to concentrate on acquiring new knowledge and competencies and, in particular, to get maximum return out of their already available knowledge.
On this regard, a number of key factors are crucial for success of an innovative design:

- Improved structure of companies' knowledge assets and formation of an enterprise-wide vocabulary to ensure correct knowledge understanding;

- Identification of an appropriate information management model to explicitly represent enterprises' knowledge;

- Easy and fast information sharing and retrieval among the participants of multi-disciplinary design teams;

- Creation of a culture that promotes knowledge sharing among different companies' parties.

Figure 1: Crucial key factors in innovative design.

Unfortunately, often companies lack in efficient systems handling transmission of information among their employees and, in particular, they urge knowledge-sharing environment systems that can provide both industrial designers and product engineers with appropriate and customizable information. Industrial designers and product engineers are in need of accessing different kind of information, at different times, often in different formats and from different sources. The first are concentrated on the style of the product, its shape, originality and nice looking; the latter are concerned with its technical and normative aspects. It is evident from their roles in the production cycle that they are in need of bridging their different backgrounds and languages, often leading to misunderstanding, in such a way that their mutual understanding during the design process could be improved. Further, designers urge a system that allows retrieval of a broad range of data that could inspire the initial concept of the design and could avoid waste of time.

So far software vendors lacked to cover this specific market therefore designers and engineers are not supported by any means of software during their inter-working activities and designers are still guided only by their intuition, artistic skills and drawing ability during the process. As consequence this phase is dominated by lack of standard procedures that prevents from establishing exact time scales for the production cycle.

Today, the companies' current sources of information are proprietary, in-house databases, off-line and on-line catalogues, and the World Wide Web (the Web). Although these sources have proved to be difficult to use efficiently, they are poorly integrated and do not address the sharing of knowledge among designers and engineers, yet they are the most common approach to knowledge management. On this regard modern Product Data Management (PDM) systems [1,2] are indeed a more effective answer to the companies' request of shortening product development time and knowledge sharing but they are not used in the initial phase of the process.

Software that could cover the existing gap in conceptual design should aim at actively support the industrial designers' and product engineers' inter-working activities and concurrently it should facilitate sharing of knowledge during the design of a new product. On this regard

previous research work carried by Ucelli et al. [3] gave the opportunity to identify the significant role of dedicated media and software in allowing communication and especially collaboration among different parties of the design process.

THE SIMI-PRO SYSTEM

Current authors' research efforts are made to demonstrate how the use of knowledge management systems [4,5,6], coupled with Semantic Web technologies [7], can improve inter-working activities and interdisciplinary knowledge sharing. In particular the aim of these efforts is the development and test of a Semantic-based information management system, called SIMI-Pro (Semantic Information Management system for Innovative Product design), to be used by teams of industrial designers and product engineers. This offers the unique occasion to investigate the capabilities of modern knowledge management systems in combination with emerging Semantic Web technologies and to employ the associated standards and tools currently under development [8,9]. The final outcome will be a system capable to answer efficiently the demands of industrial designers and product engineers involved in product design, and ultimately capable to improve the result of the final product.

More specifically the main final goals are:

- To significantly improve the effectiveness and efficiency of innovative product design by the identification of specific communication deficiency;

- To support differences in cultures, backgrounds and working methodologies of both industrial designers and product engineers by allowing retrieval of customizable data and information typology;

- To actively enhance effective knowledge sharing and inter-working communication through the implementation of a system capable of:

    - Easy and fast collection of data from multiple sources (web, in-house repositories systems, databases and PDM systems);

    - Intelligent customized searching capabilities for the retrieval of information and data;

    - Customisable and standardisable visualization of data retrieved from multiple sources;

The system will finally address an actual and pressing problem faced by several companies in the engineering sector. Furthermore it will act as a benchmark for the use of Semantic Web technologies eventually contributing to the identification of possible developments. This way technology will be exploited by SMEs to boost up product innovation and efficiency.

FOCUS ON THE SPECIFIC COMMUNICATION PROBLEM

Any communication problem among different participants to the design process can be considered a knowledge management issue and obviously the best solution would be a common language at work. On this regard Davenport and Prusak, two of the fathers of Knowledge Management (KM), state that "people can't share knowledge if they don't speak a common language" [4].

Although the identification and agreement upon a common language would be the simplest solution, in practice this is not always achievable. In fact, industrial designers and product engineers, due to their different education, training, and working practices, tend to develop different working approaches. This brings the two groups to form substantially different points of view on product design and, not surprisingly ultimately, to think and talk using

different languages when speaking about designing of products. This is the result of the fact that industrial designers and product engineers are embedded in different cultures.

Effective sharing of knowledge, however, does not necessary require the two parties to speak a common language. In fact it would be sufficient a mutual understanding of each other's language while speaking their own: this will minimize the effort and waste of human resources since it would not require both groups to adopt a different language.

Starting from this assumption, the concept behind the development of SIMI-Pro is to provide an active information management and knowledge sharing system specifically targeted for both industrial designers and product engineers. The system will support inter-working by effectively helping the two groups understand other parties' languages and methodologies. It will facilitate the communication among different professional profiles to ultimately deliver a better product result.

APPROACH: SEMANTIC INTERNET TECHNOLOGIES TO SUPPORT INNOVATIVE PRODUCT DESIGN

Ontologies are "consensual, shared and formal descriptions of the concepts that are important in a given domain"[8]. The research community is expressing growing interest towards them in many scientific fields and nowadays they are emerging as crucial ingredients in Semantic Web applications. Multiple ontologies, together with domain thesauri, will set the foundations of SIMI-Pro. In particular, to effectively automate the combination and coordination of multi-language and cross understanding supports, the system is based upon ontology of the design process. This, in turn, is based upon an existing Knowledge Level theory of design [10,11], which identifies, at a general level, the different kinds of knowledge used and generated in design, the roles they play in the process as a whole, and the relationships between them.

Research efforts in the identification of ontologies, their use and construction were originally included in the domain of Knowledge Engineering methods. CommonKADS [12], and various other ontology specification languages were developed with the specific purpose of building domain ontologies. More recently, due to ontologies' increasing role as essential components of the Semantic Web, we have witnessed a convergence of efforts of Web based specification languages and ontology specification languages. This convergence enriches the development of SIMI-Pro of important theoretical stimuli and it gives the chance to use the emerging standards and tools in this area. XML and XMLS [13], RDF and RDFS [14], together with OIL (Ontology Inference Layer) [9] and DAML (DARPA Agent Markup Language) [15], currently being combined into the DAML+OIL language, will be adopted as languages to implement the Semantic system. Furthermore the tools that have been developed to use these languages, such as OILed [16], FaCT (Fast Classification of Terminologies) [17], Ontoedit from Ontoprise [18], and its related products Ontoannotate and Ontobroker, and eventually Protégé-2000 [19] are currently evaluated for use in the implementation phase of the system.

The SIMI-Pro system is at its initial phase when preliminary research is carried out in order to build its foundations and to investigate relevant issues. These include:

- Identification of appropriate navigational mechanisms and interfaces to be offered to the users. These can be based on presentation modality information [20], on some navigation structure [21] or they can be personalised according to user provided data [22].

- Dynamic adaptation of contents that in turn can depend on:

    - Preferences explicitly declared by users;

- The response of automatic mechanisms for profiling user behavior;

- The devices and bandwidth available to the users;

- The environment where the user is located (e.g., if the user is outdoor, he/she might prefer to exploit vocal menus instead of the usual visual navigation bars).

These issues will be investigated and then addressed through adoption of information filtering techniques, of meta-data based upon user profiling and profile analysis using business rules [23], or using artificial neural network techniques [24], or collaborative filtering [25], or eventually considering a combination of these approaches.

- Customization of search mechanisms for specific information retrieval. In most knowledge management systems a number of elements are already predefined at the time the knowledge base structure is defined, as for instance, the way a search is accomplished, the information sources to be visited, the policy to terminate the search and to present the results. SIMI-Pro pursues an alternative approach according to which the users will be provided with information request mechanisms that are mostly independent from predefined categories. This issue is currently studied within the IST project OPELIX (www.opelix.org) and a preliminary solution, that will be extended and adapted to the current project, can be found in [26], where searching agents receive user requests, interpret them, query multiple information sources, and combine the obtained results in a way that depends on the user's request [5,6].

SIMI-Pro will be implemented in Java™, a programming language that in previous authors' experiences, developing network-based collaborative environments [27,28], has proved to be powerful and offered great flexibility. This choice allows compatibility with Web tools and already available PDM applications, the possibility to use built-in functionalities and libraries related to database management, and last but not least hardware independence, network capabilities and application portability. These are key factors when various parties have to employ the software from a multitude of different computer configurations through a network system.

In terms of software architecture the system consists of two main parts: a flexible core and the domain-specific extensions that serve as test applications and as proof-of-concept. The following two paragraphs will show their peculiarities.

THE CORE SYSTEM

The core of SIMI-Pro is structured in three layers representing different kinds of information: a *content layer*, a *semantic* or *meta-layer* and the *user-interface layer*. Each layer has its own purpose and handles different information elements:

– The *content layer* deals with the creation of a database and a related query interface. In particular the primary objective of the database is to store the content of information required by the user. Agents feed it from Semantic Web Sites, local databases and PDM systems. In order to allow access and interaction mechanisms for semantic search engines and web sites, it is based on XMLS and RDFS languages, open standards to be used by provider companies. Moreover, within this layer, a dedicated interface to the upper levels will be implemented. This layer hides specific data originated by the use of ontologies, such as the origin of information (internet, PDM or local database) and the implicit structure of the information objects. Eventually the content layer takes care of extending the existing meta-data system of the database in order to address semantic aspects for retrieval. Thus, it is closely related to the meta-data system of the next layer.

- The *meta-layer* contains the design process ontology at the base of the system. It coordinates and controls the data flow between the information management and knowledge sharing system. It provides the tools needed to construct, maintain, and access the domain-specific and user-types ontologies. It deals with the meta-data construction and the implementation of access mechanisms. Moreover, within this layer, tools to build and maintain domain and application thesauri will be provided to the user. These are important to transfer and share knowledge among different expert groups, since words interpretations can lead to misunderstanding. By these means the meta-level adds the semantics to the content layer and it ensures that information from other language domains sources are also considered in the retrieval process.
- The *user-interface layer* contains both graphic user interface (GUI) and the tools for editing and extending the system's navigation structure by developers and users. The information filtering and visualization mechanisms are realized within this layer. Finally, it provides the dynamic interface adaptation mechanisms needed to adapt the system to the type of user, activity context and to the design stage. These functionalities provide the user with a source of information easily customizable and with an information space flexibly adaptable to a specific user.

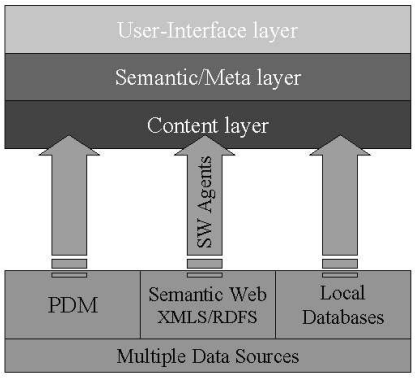

Figure 2 : The Content layer provides a dedicated interface hiding the origin of the information.

DOMAIN-SPECIFIC EXTENSIONS

Domain-specific extensions will be also added to the core system according to specific industrial scenarios. One of these, a concrete working-situation, will provide the appropriate environment to evaluate and verify the usability of the system, thus proving the robustness of the SIMI-Pro architecture.

This scenario depicts the early stages of the design process and the typical working behavior of industrial designers and product engineers in the context of automotive industry. Stylists use mostly natural language opposed to the technical language typical of the engineers. This language is originated by the stylists' need to express feelings and sensations rather than quantitative data, and the words used are difficult to translate into technical terms. Starting from this basic observation, SIMI-Pro will allow the following scenario:

> *A stylist needs to start from scratch the design of a new sport car with a retro feeling. He/She uses SIMI-Pro to gather suggestions and types in the sentence: "I want something aggressive with a look from the sixties, sporty, powerful and muscular".*

SIMI-Pro, knowing from the profile that the user is a car designer, starts its agents to search for information.

As result the designer obtains data on cars of the sixties from the company's database, as well as pictures from the internet showing not only cars but also aggressive animals, athletes running, sixties design and fashion items, all things that can give him valuable hints for his job.

The same system is useful for an engineer who is meanwhile looking for technical data, based on the experience of previous projects, carry-over solutions and technical norms.

In other words:

- Industrial designers can retrieve information from the Internet or from an existing local database using their own language and terms. Retrieved data is of various type including images that might inspire the shape of the new car.
- The system deals with different users' profiles and provides the means for improving inter-department communication inside the automotive company. For instance, a query about "round headlamps" carried out by a stylist would gather as results examples of headlamp design with round shape, while the same query performed by an engineer would result in the retrieval of documents containing norms about headlamp illumination or headlamp glass feasibility.

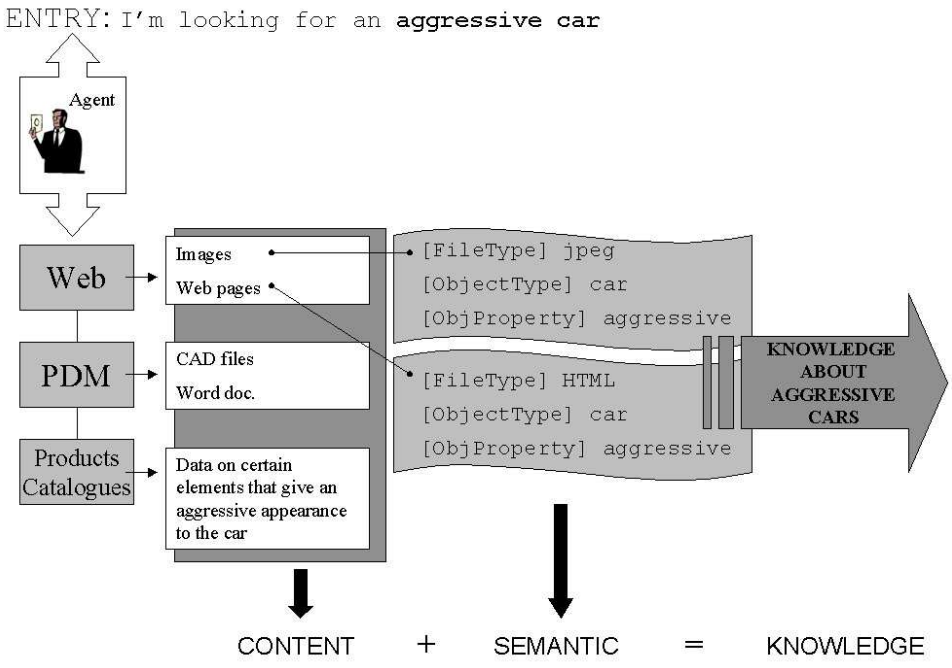

Figure 3: A Semantic search mechanism provides broad information from a multitude of sources.

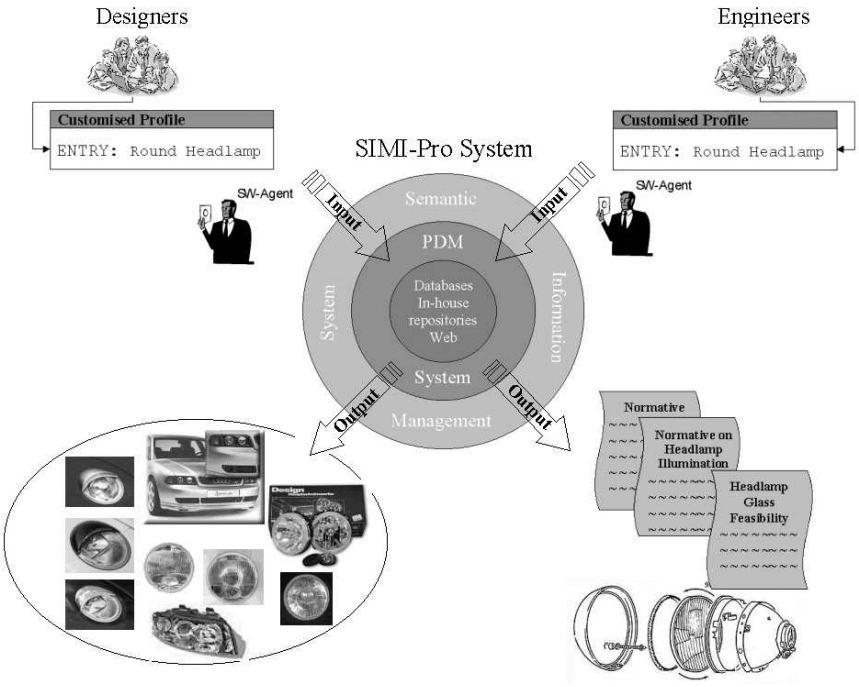

Figure 4: SIMI-Pro provides customised entry and retrieval of data.

INNOVATION IN SIMI-PRO

SIMI-Pro brings four important innovations to the industrial design domain:

- It bases its functioning mechanisms on ontologies, thus pushing their application in the industrial domain
- It enriches the design process ontology of notions from existing general theory of design
- It relies on emerging Semantic Web technologies
- It supports information management and knowledge sharing in multi-disciplinary design teams, without forcing different parties "to speak a common language".

Ontologies define which entities are included in a certain domain, what kind of properties they have, and how they are related. They are intended to support both human interpretation of information and machine processing and they are the means by which automated machine processing of information can come closer to human reasoning. Ontologies have been created for many different applications and purposes, but they all were intended for very specific domains. The idea of using them to define a process, rather than a domain, is relatively new and not much studied. SIMI-Pro will be one of the first projects to base its information management and its knowledge sharing system on ontology of the process. (So far, to the best of the authors' knowledge, only few attempts have been made, one being a recently proposed EU-IST project that uses ontologies in an e-business application [29]).

Ontology of the design process will define the different kinds of information that are generated during the design activities, together with their roles and relations. This will be then used by the system to identify what kind of information has been requested, used, added, shared among the users, and if it is relevant to the current design activity. The perspective is to give to the information management and knowledge sharing system some hints of the nature of the process they are intended to support, so that to improve their effectiveness as design decision support system.

Further, ontologies built so far were essentially empirical constructions while SIMI-Pro offers the possibility to use a theory at the base of the definition of its ontology. In fact, it will be based upon an existing Knowledge Level theory of the design process, which has been specifically developed to support the knowledge engineering of design support systems.

Very few application examples involve the use of emerging Semantic Web technologies. The choice of using them as the base of the system is a challenging and serious test for the tools available. SIMI-Pro will thus pioneer the way towards the use of these technologies in industrial applications.

SIMI-Pro will enable the users to gain centralized access to knowledge from the industrial design and engineering area. Knowledge about the project can be deposited in the database of the system and all participants can use it, anywhere, at any time like a de-localised office. The flexibility of the content level allows to store and to retrieve information from various sources falling into a multitude of categories, such as:

- Best practice examples
- Products
- Technology and material
- Research & development
- Market information
- Job-Exchange
- Events
- Addresses

The user can freely navigate among these categories searching through content structured in such a way to easily lead the user to the relevant information. Moreover the free-term search reacts to experts' terminology and provides information that enhances creativity processes intuitively.

Finally SIMI-Pro provides designers and engineers with an easy and effective mean of interaction. It facilitates the retrieval of customised information and improves the existing search mechanism on the web. It allows engineers to quickly provide designers with the technical constrains they need and it enhances the exchange of information and notions during the early phases of the design process resulting in a shortening of the design cycle and the design of a better product.

CONCLUSIONS

Research in Knowledge Management (KM) has been recognised essential for enhancing competitiveness in the market of business companies [4,5,6]. Hence software applications, such Product Data Management (PDM) systems, following a KM approach, tent to embrace the integration of all the aspects of the companies' knowledge assets [1,2] providing the users with an integrated software platform and a common environment for easy transfer of information and knowledge. However existing PDM systems have failed to provide industrial designers with suitable tools for conceptual design.

New research efforts, such as Semantic Web technologies, are paving the way towards a more effective approach on knowledge management, and ontologies are considered to be among the crucial ingredients of this emerging technology. They are now widely recognised as important notions in a number of fields from knowledge representation, to natural language processing, databases, information retrieval, knowledge management and multi-agent systems, to name but a few. They are essential to the implementation of mechanisms for handling machine understandable content and to the development of intelligent systems that support active information management and knowledge sharing.

SIMI-Pro takes advantage of current state-of-the-art technologies, providing an innovative application for the design context and an original contribution for the advancement of the technology.

AKNOWLEDGEMENTS

The authors would like to thank the Department for Industrial Applications (A2) of the Fraunhofer Institut Graphische Datenverarbeitung (IGD) in Darmstadt for valuable support and collaboration indispensable for the advancements of the SIMI-Pro project.

REFERENCES

[1] Kenneth Crow, 2002: Product Data Management/Product Information Management, See <http://www.npd-solutions.com/pdm.com> [Last accessed 15.8.2002]

[2] Samir Mesihovic and Johan Malmqvist, 2000: Product Data Management (PDM) System Support for the Engineering Configuration Process, Proceedings of the 14th European Conference on Artificial Intelligence ECAI 2000, Configuration Workshop, August 20-25, 2000, Berlin, Germany.

[3] Giuliana Ucelli, Giuseppe Conti, Malcolm Lindsay and Gerard Ryder, 2000: From "Soft" to "Hard" prototyping: A Unique Combination of VR (Virtual Reality) and RP (Rapid Prototyping) for Design, Proceedings of 7th VRSigUk conference, Glasgow, 2000, pp. 1--9.

[4] Thomas D. Davenport and Laurence Prusak, 1997: Working Knowledge: How organizations manage what they know, Harvard Business School Press.

[5] Brigitte Koch, Marianne Koch, 2000: An Internet-based information service to support the product development process in design offices, Proceedings FAIM, Maryland, pp. 77-82.

[6] Brigitte Koch, Uwe Jasnoch, 2001: DEPOT-an Internet-Based Knowledge Management System for Design, Engineering and Production, Proceedings ISE, Las Vegas, pp. 49-51.

[7] Tim Berners-Lee, James Handler and Ora Lassila, 2001: The Semantic Web -- A new form of Web content that is meaningful to computers will unleash a revolution of new possibilities, Scientific America, May 2001.

[8] Frank van Harmelen and Ian Horrocks, 2000: Questions and answers on OIL: the Ontology Inference Layer for the semantic web, IEEE Intelligent Systems, December 2000, pp 69--72.

[9] Dieter Fensel, et al, 2001: OIL: An Ontology Infrastructure for the Semantic Web, IEEE Intelligent Systems, March/April 2001, pp 38--45.

[10] Tim Smithers, 1996: On knowlege level theories of design process, in J S Gero and F Sudweeks (eds), {\it Artificial Intelligence in Design '96}, Kluwer Academic Publishers, Dordrecht, pp 561--579.

[11] Tim Smithers, 1998: Towards a knowledge level theory of design process, in J S Gero and F Sudweeks (eds), {\it Artificial Intelligence in Design '98}, Kluwer Academic Publishers, Dordrecht, pp 3--21.

[12] Guus Schreiber et al., 1999: Knowledge Engineering and Knowledge Management: The CommonKADS Methodology, The MIT Press, Cambridge, Mass.

[13] See <http://www.w3.org/XML> for the current definition of XML and related discussion documents, and http://www.xml.com/XML for a technical introduction to XML. [Last accessed 09.10.2002]

[14] See <http://www.w3.org/RDF> for the current definition of XML and related discussion documents, and <http://www.xml.com> for a technical introduction to RDF. [Last accessed 24.04.2003]

[15] See <http://www.daml.org> for a technical explanation of DAML, and its current status. [Last accessed 24.04.2003]

[16] See <http://img.cs.man.ac.uk/oil/> for a technical description, status, and availability of the OILed editor. [Last accessed 24.04.2003]

[17] See <http://www.cs.man.uk.ac/~horrocks/FaCT> for a technical explanation and pointers to related publications. [Last accessed 09.10.2001]

[18] See <http://www.Ontoprise.de>. [Last accessed 24.04.2003]

[19] N F Noy et al, 2001: Creating Semantic Web Contents with Protégé-2000, IEEE Intelligent Systems 16(2), pp 60-71. Or See <http://www-smi.stanford.edu/pubs/SMI_Reports/ SMI-2001-0872.pdf> [Last accessed 09.10.2001]

[20] T. Joerding, Intelligent Multimedia Presentation in the Web: Fun Without Annoyance. Proc. Of 7th World Wide Web conference (WWW7), Brisbane, Australia, 1998.

[21] L. Calvi, Multifunctional Hyperbooks: a Cognitive Perspective On The User's Side. Proc. of Adaptive System and User Modeling on the World Wide Web, CHIA, Italy, 23-30, 1997 (http://www.cs.usask.ca/UM99/w4.shtml).

[22] R.Dale, S. Green, M. Milosljevic, C. Paris, Dynamic Document Delivery: Generating Natural Language Text On Demand. Proc. DEXA '98, Wien 1998.

[23] S.Ceri, P.Fraternali, S. Paraboschi: Data-Driven, One-to-One Web Site Generation for Data-Intensive Applications. Proc. of VLDB'99, Edinburgh, Sept. 1999, pp. 615-626.

[24] A. Jennings, H. Higuchi, A User Model Neural Network For a Personal News Service. User Modeling and User-Adapted information, 3(1), 1-25, 1993.

[25] U. Shardanad, P. Maes. Social Information Filtering: Algorithms for Automating "Word of Mouth. Proceedings of the Conference on Human Factors in Computing Systems, 210-217. Denver, CO, ACM Press, 1995.

[26] Elisabetta Di Nitto, Carlo Ghezzi, Maurizio Sabba, Paolo Selvini, Using Agents in Performing Multi-site Queries. Proceedings of CIA 2001, Modena, Italy, 2001.

[27] Giuliana Ucelli and Giuseppe Conti, 2002: Real Experiences of Virtual Worlds, Proceedings of International Design Conference - DESIGN 2002 -, Dubrovnik, Croatia, 2002, pp. 561--566.

[28] Giuseppe Conti, Giuliana Ucelli and Jelena Petric, 2002: JCAD-VR: A collaborative design tool for architects, Proceedings of ACM Collaborative Virtual Environment 2002, Sept. 30-Oct.2, 2002, Bonn, Germany, pp. 153-154.

[29] J M H Akkermans, Personal communication, June 2001.