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A web-based system for sharing and disseminating research results: the underground construction case study

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ABSTRACT

Researchers often have to go to multiple information sources in order to identify high-quality, time-critical information. Due to the dynamic and unstructured nature of research results, they are faced with such problems as distributed sources and inter-disciplinary differences in terminology that prevent them from accessing the information they need. This paper presents the System for Active Knowledge Management (SAKM), a web-based system that addresses these problems by supporting effective information search and analysis, and by enhancing communication and collaboration among researchers.

The system was implemented in the underground construction field, which has experienced tremendous growth and is facing increasingly complex and challenging research issues.

Preliminary testing suggested that a tool like the SAKM could improve the information transfer of research results. The validation stage confirmed that the system met the requirements of the initially defined scenarios.

Author keywords:

research knowledge management, underground construction

1. INTRODUCTION

Research activities generate innovation and information that can be defined as meaningful data [1]. Reusing information minimises the need to refer explicitly to previous projects, reduces the time and cost of solving problems and improves the quality of solutions [2]. However, organising research results and disseminating them to the community of interest and other parties involved is a complex process [3].

The growth of the Internet has made the communication and sharing of research ideas and results among scientists easier and faster than ever. It has also made available a large amount of information and resources that can be useful for research [4].

While the Internet provides a convenient means for information searching, researchers often find themselves facing the problem of unstructured information. This is the case of non-specific search engines, which are mainly optimised for a general audience rather than for a specialised target and its results are often imprecise [4].

There are a wide variety of information sources on the Internet, including conference proceedings, research journals and technical reports, and their quality varies greatly. Researchers have to go to multiple information sources to obtain the information they need. Each research discipline uses different terminology to describe its findings [6], so the search terms must also be discipline-specific.

Search results are limited by search conditions such as keywords, full texts and the use of natural language, and they mainly do not consider the suitability of the solutions to the problem being faced. Moreover, although a key aspect in research activities is communication and collaboration among researchers, most search engines only provide retrieval solutions that are not connected to communication and collaboration channels [5]. There is therefore a gap between the services provided and the users' needs [5].

Information management systems developed with Internet methodologies differ according to the type of sector. For example, construction is a knowledge-rich industry in terms of the knowledge it generates, the exchange among participants, and the information it absorbs from outside sources [7]. On the other hand, defence research and development (R&D) projects generate knowledge mainly from within the organisation and do not typically exchange knowledge outside the system. Therefore, the necessities and characteristics of a system for sharing and disseminating research results might differ from other existing domain systems.

This paper presents a Web-based system that facilitates the transfer of information generated in research projects by centralising all the information generated in a specific scientific field. The system also interlinks the different information, incorporates specific vocabulary, automatically analyses the suitability of the results, and enhances communication and collaboration among researchers in a specific scientific field.
To test the feasibility of the system, it was implemented in the scientific field of underground construction.

2. LITERATURE REVIEW

2.1. Sharing and dissemination of research results

R&D produces a large volume of results in many fields. R&D activities include EU-funded research projects, nationally funded projects, institutionally funded projects, and even non-funded projects including PhD and company-oriented research projects. Dissemination of results and findings vary according to the funding institution.

Research results are essential to the community of researchers and to industry and society as a whole. Therefore, the EU asks researchers working on officially-funded projects to complete datasheets that indicate how the results of R&D projects will be used and to ensure that the plans are consistent with the original project objectives. For this purpose, researchers fill in a Technological Implementation Plan (eTIP) that includes the results of the project, the potential applications and the dissemination intentions. This information is then archived by the Community Research and Development Information Service (CORDIS), which stores information on EU programmes and funded projects, the individuals and organisations involved, project results, publications, commission documents and news. Typical end users include researchers, engineers, potential project partners, managerial and administrative staff searching for state-of-the-art publications, planned and current projects, and technical documentation. CORDIS uses over 250 fields that provide mainly textual information, including the title, abstract, surname, and general project information [8].

Some national and international projects also define dissemination plans, which consist mainly of journal publications, conference publications, workshops and meetings and Web-page creation. This information is then stored in Web-based, journal-based and even paper-based sources. Specific search engines such as Scirus, Science Direct, and Compendex provide access to specific knowledge and resources (e.g., refereed papers) [9], which users can search by year of publication, information type, file format, content source, subject area and other parameters. Several powerful Internet search engines are available, including Google, Yahoo, Altavista, AlltheWeb, and Teoma, but in general the results are not filtered.

Most research projects have their own Web pages and intranets. The Web pages are used to present the general project information (objectives, expected results, partners, etc.). Intranets are created for project management (on-line meetings, information sharing, emails, planning, etc.) and can only be accessed by project partners. These sources sometimes publish project results, but the search engines required to access them are difficult to find. In general, this information is not well organised, and most of it is lost once the project has been completed because there are no specific search engines that enable researchers to locate and reuse the research results [5].

There are other sources in which to share and exchange research results, such as journal databases, scientific portals, patents, conference articles, sector-specific meetings and debates. The European Construction Technology Platform [10] and other national construction technology platforms are initiatives aimed at addressing major challenges faced by the construction sector in areas such as society, sustainability, and technological development. They provide information on conferences and current construction projects, strategic research agendas, research project priorities, action plans, and other types of information in the field of construction.

There are also several scientific sector-specific Web portals that provide information on events, members, publications and working groups. One such portal is that of ITA-AITES [11], which belongs to the tunnelling and underground construction sector.

Terminology differences and the decentralisation of the sources of research results are examples of the difficulties and hindrances involved in sharing scientific information. However, several other problems affect the information -management process [12]:

- Researchers working on large-scale projects often begin new sub-projects without submitting reports on their previous work due to time constraints.
- Researchers are so busy with routine tasks that they do not have time to store and index information.
- There are very few systematised, ongoing learning processes between projects due to the lack of efficient information transfer.
- A lot of important knowledge resides in the minds of the individuals.
- Many decisions are often neither recorded nor documented.
- Research results can take many forms, including experiences, best practices, lessons learned, drawings and documents.
- Information is often poorly organised.
- Innovation transfer is generally restricted to explicit knowledge, which is often compiled in simple text documents such as deliverables that are frequently overlooked.
- Research experience is often individual and incidental.
- Domain-specific communication is mainly established at conferences.

Therefore, effective management and dissemination of research results can prevent the research community from “reinventing the wheel” and repeating past mistakes, and creates a solid platform for innovation, overall improvement, and sustained competitive advantage.

2.2. Related research work

Various systems have been developed in the field of information management (IM) and knowledge management (KM). Most are project-centred and aim to organise information and knowledge in specific projects.

Regarding R&D knowledge transfer, Barthes and Tacla [13] developed a project portal for project members to manage the knowledge generated in complex R&D projects using a groupware approach for document management, and a cooperative work and multi-agent system for interaction among project participants.

Li and Chang [14] developed a tool for the management of presentational knowledge such as PowerPoint presentations in R&D organisations. This solution is company-centred and only provides a solution for one kind of knowledge support.

Another initiative was the development of VIZCon, a portal for storing and managing the information of a research project [15]. This initiative demonstrates that the use of portal technology increases the overall project reactivity and the ability to achieve the objectives—namely to reduce time, improve decision-making and increase productivity and reliability.

As mentioned above, these initiatives are project-centred, do not provide tools for sharing research results among end users and their focus is not on communication and collaboration among interested parties.

However, other initiatives in different research fields to improve the transfer and retrieve of R&D information among interested parties have been launched.

Chen et al. [16] developed a system for users to search Web pages and other online databases by using an automatic thesaurus and by browsing graphical displays of medical-related topics. Similarly, Chau et al. [4] created a framework for developing integrated Web portals that support information search and analysis for scientific knowledge and implemented the framework on a knowledge portal in the field of nanoscale science and engineering. Both initiatives are based on online information and use automatic spidered Web pages and results from meta-search engines.

Other researchers proposed semantic webs to provide enhanced information access based on the exploitation of machine-processable meta-data [17]. The semantic web is an extension of the current web in which information is accessed based on meaning, better enabling computers and people to exchange knowledge. Ontology is one of the main components of the semantic web. In the context of IM, ontology is a “formal explicit specification of a shared conceptualization” [18] and provides a mechanism to categorize/classify domain knowledge items/information into interrelated concepts. Ontology structures information in the form of concept hierarchies (taxonomies), axioms and semantic relationships. This structuring allows natural language to be presented to computers in an unambiguous manner.

Some studies have adopted semantic web technologies to improve information and knowledge management. Davies et al. [17] developed a methodology to (semi-)automatically support search engines using ontologies and meta-data. This methodology was used to develop a system that automatically classifies browsed web pages against an ontology and allows users to share comments made about these pages with the members of a community.

Focusing on construction, many systems have been developed for organising information and knowledge to enhance productivity and performance levels in certain operations within specific segments of the construction supply chain [19]. The majority are firm-level focused and aimed at sharing and disseminating documents and experiences in construction projects.

Tserng and Lin [20] developed a tool for sharing and reusing knowledge among experts and engineers who take part in the construction phase of a project.

Kivrak et al. [21] developed a knowledge platform for contractors to capture and store tacit knowledge accurately and in a standard format, avoiding significant additional costs, additional workloads, and violation of copyright and contract conditions.

The only system developed for an area similar to underground construction is the project-knowledge management framework for tunnel construction developed by Tsern and Chang [22], in which practical experiences can be gradually accumulated, stored, used and disseminated. This system adds orientation to searches by using attributes, and provides more narrowly targeted solutions to problems.

One step forward is the Web-based prototype for live capture and reuse of construction-project knowledge called Caprinet [23], which facilitates the collective learning of the participants involved in a project and can be reused during or after the project. Similarly, Moses et al. [24] examine the issues involved in moving project data between two different instances of collaborative software in order to improve the exchange of information among project partners.

Woo et al. [25] developed a Web-based knowledge navigator called the Dynamic Knowledge Map that searches for experts in the field of architecture, engineering and construction (AEC) and facilitates communication with those experts through Internet Technology (IT).

To solve the problem of terminology, EI-Diraby and J. Zhang [26] developed a taxonomy and a prototypical ontology for building construction that was a first attempt to present building construction knowledge in a semantic way. They also developed a framework for an agent-based system for supporting the semi-automatic generation of reports. Several research projects are underway to formalize a set of construction ontologies (see for example, Katanushkov et al. [27], who developed an ontology in the engineering domain, and EI-Diraby and Kashif [28], who developed an ontology in the infrastructure highway domain). Both are based on the e-COGNOS ontology [29]. The e-COGNOS project developed an infrastructure for creating, classifying, indexing, retrieving and disseminating knowledge, which ensures effective knowledge management and incorporates learning into the working processes and practices of construction companies [29].

To conclude, most existing systems are company-level and are basically used for transferring project knowledge and information internally. In this context, communication is mainly among colleagues of a company. However, communication among researchers is mainly among experts from the same scientific domain but from different research centres or universities. Lee et. al [5] analysed the context of R&D teams to develop KM systems and concluded that communication and collaboration is a key aspect in R&D activities.

On the other hand, existing information and knowledge management systems are domain-specific. They are not suitable for sharing and transferring research results because information sources differ greatly. Information on construction projects is mainly taken from project and company documentation and from project team meetings [21], whereas sources for sharing R&D results are external, including journal articles, research project reports, patents, PhD theses, conference articles, meetings and workshop presentations [4].

Moreover, a number of initiatives are being developed to automatically search for information on the Internet. Some of them are so generic that they cannot be used for specific scientific domains. Others do not provide retrieval results analysis and focus only on searching for information on the Internet rather than enhancing communication and collaboration among researchers.

Thus, the particularities of the system presented in this paper are:
- It is an open system for sharing research results information on the Internet among the entire community of interest rather than having company or project restricted access like the majority of information and knowledge management systems.
- The system is generic for any R&D domain but implemented in the underground construction field. Therefore, a domain-specific taxonomy and ontology based on the existing thesaurus and standardised metadata models is developed. So far, no ontology has been created in this field.
- The system will combine search and retrieval functionalities with communication among the community of users by linking the domain knowledge map, which facilitates domain-specific searches, with a forum to enhance communication in specific areas of interest.
- The information stored in this system will be restricted. Information retrieval will be limited to the codified information stored in the system and the authorised research databases (such as domain research journals) rather than to the entire web like most of the systems displayed above.
- An information manager and a group of experts, who will review, correct and update the information stored in the SAKM, will guarantee the quality of the information included in the SAKM. However, the community of users will be in charge of the codification and incorporation of information.

3. THE SAKM APPROACH

The user requirements were analysed in order to define the SAKM approach. Firstly, user groups and community profiles were identified. Selected end users were then asked to answer a survey on the transfer and dissemination of research results with a view to defining the user requirements. Finally, the main functionalities of the system for sharing and disseminating research results were defined.

3.1. End-user identification

The end users of research results are usually researchers, organisations, R&D departments and academics. End users of the SAKM act simultaneously as information users and information creators.

Since research results are the main source of information, one of the main groups of end users are the **researchers and organisations** involved in research projects. Many researchers from different centres, companies and universities work simultaneously on similar topics. In some cases, different end users carry out complementary research that could be of mutual benefit but they do not realise this until they see presentations prepared by the other end users. The SAKM will thus ensure that all researchers are aware of the work being carried out in previous and current research projects belonging to the same scientific domain.

Other end users of the SAKM include **academics**. The system is aimed at bringing them closer to research advances and improvements with a view to promoting research activities.

Finally, the SAKM is intended to act as a **community of interest** in specific research fields. Its potential users include researchers, organisations, and individuals interested in the scientific domain, who will be able to incorporate new information, and search and retrieve information from other researchers.

3.2. System requirements

To define the SAKM specifications, selected end users were asked to answer a survey on the transfer and dissemination of research results. Once the prototype was developed, the same end users participated in the evaluation of the system.

For each question, participants were asked to tick the box that best represented their assessment on a scale of 1 (poor) to 5 (excellent). Test participants included 12 academics and 10 industrial partners involved in research projects. The survey contained 7 questions about the functionalities of existing tools for transferring research results. Table 1 illustrates the survey results.

Functionality	**Mean**
1. Research results are easy to organise and disseminate	2.1
2. Non-specific search engines are useful for searching for research results	0.5
3. Retrieved research results from different sources are structured	2.2
4. Existing sector-specific web portals are useful for searching for research results	1.5
5. Existing search engines are terminology-oriented according to the scientific domain	1.2
6. Existing search engines include suitability solutions (personal information from other researchers)	1.4
7. Existing tools for communication among researchers are useful	1.1

Table 1. End-user questionnaire

All test participants thought that research results are difficult to organise and disseminate, and that there are too many research sources. They stated that neither non-specific search engines nor existing sector-specific Web portals are useful for searching for research results and that they are not optimised for a specialised target. Nearly all test participants thought that information on the Web is overloaded and unstructured. Most stated that terminology differences are an important problem when one is searching for research results on the Web, and that search engines are limited by search conditions. They also considered that existing search engines do not provide content analysis capabilities, or proper retrieval options (each source is limited by search conditions). Finally, nearly all test participants said that existing tools do not provide proper solutions for communication among experts.

Therefore, the main objective of this research was to create a system for transferring and disseminating research results and enhancing communication among researchers.
The main requirements from the user's side were as follows:

- The system must cover R&D results.
- The system must save time when searching for R&D results.
- The system must be generic but adaptable to specific research sectors.
- The system must include an analysis of the suitability and content of the results.
- The system must combine information retrieval and communication and collaboration among researchers.
- The system must act as a central channel for gathering existing sources of research results.
- The system must be accurate.
- The system must be easy to use.

Thus, the system proposed in this research implements two general approaches:

- **The Codification approach.** This approach aims to solve the problem of disseminating and transferring explicit research results that can be codified, collected, stored and disseminated. Research results from existing sources are captured, structured and codified to be used by others to improve their research investigations. This approach is based on different knowledge maps to structure the information and some metadata to characterise it. The main sources for the codification approach are journal articles, research project reports, patents, PhD theses, conference articles, meetings and workshop presentations.
- **The Personalisation approach** [30]. This approach aims to solve the transfer of information and knowledge that resides in the minds of the persons and improve communication and collaboration among researchers. To this end, a personalised forum is directly linked to the codified information. The system registers the main interests of end users and of the expert that has captured the information. End users can then go to the forum to contact the expert researcher, and thus create communication among interested parties. The connexion between the codification and personalisation approaches is the vocabulary structure (knowledge map) that is used to organise each scientific domain. Furthermore, the system provides user metadata fields in which end users can comment on the quality and suitability of the retrieved information and give a satisfaction score.

The codification and personalisation approaches are implemented in the same Web-based system used to access and retrieve the results generated in a specific research domain. To this end, the SAKM enables research results to be captured, structured, shared, transmitted, reused and maintained.

Figure 1 shows the four main processes on which the SAKM is based: capture, share, reuse and maintain. Following these main processes are explained in depth.

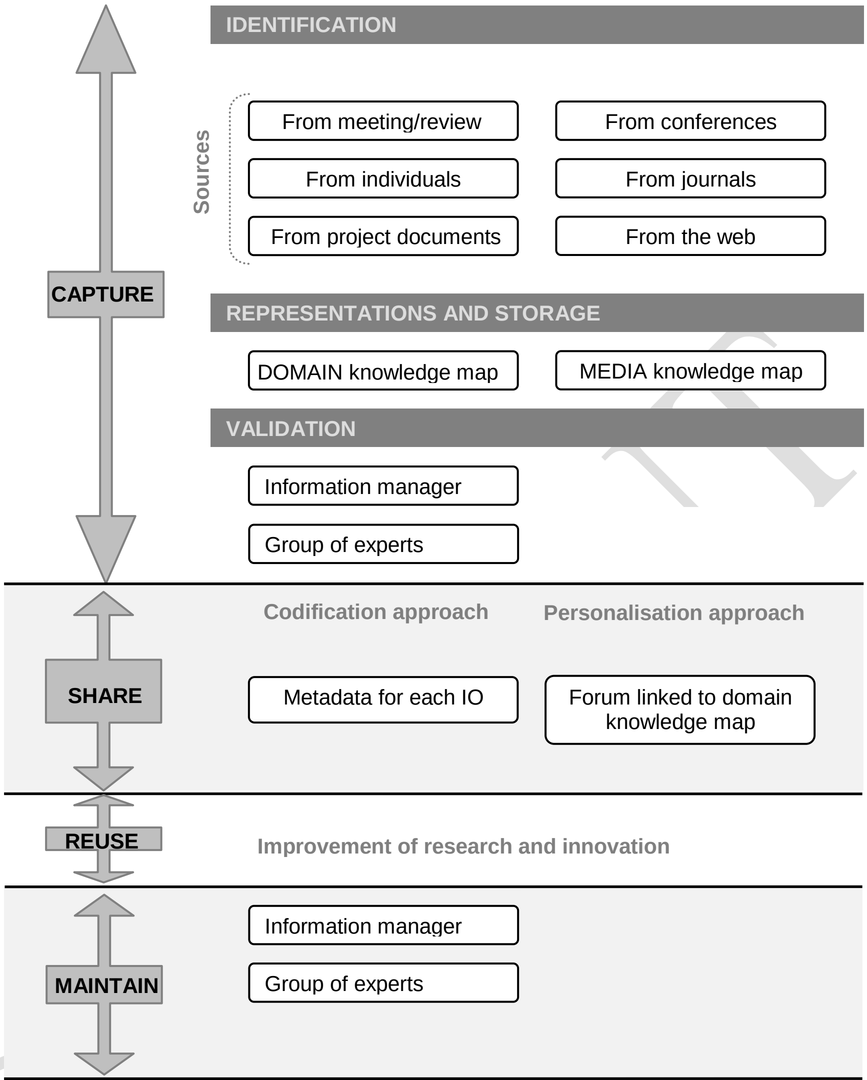

Figure 1. Information management processes in SAKM

3.3. Capture and structuring of research results

The capture and structuring of research results involve identifying the types/categories of information to be managed and locating learning situations, representing information (indexing, organising and structuring information into themed areas) in the format standard specified, and validating it to ensure the credence of captured information [31]. There are well-known information organisation systems such as taxonomy, thesauruses, ontology, topic maps and metadata, most of which are designed to organise as many relevant topics as possible. Some domains have already developed their specific ontologies and can be used in SAKM. Others have not and the taxonomies will have to be developed in order to implement the system in these R&D domains.

3.3.1. Knowledge map development

Since each research discipline encompasses differences in terminology and vocabulary to describe its findings, user search terms may differ according to the research field.

The vocabulary and terminology problem is solved in the SAKM by using knowledge maps. A knowledge map is a diagrammatic and graphical representation of knowledge that illustrates the relations between knowledge and knowledge attributes [32] and helps users to find the required information easily and effectively. Knowledge maps have two principal advantages over other knowledge structures: they can be displayed clearly in the KM system, and their mapping methodology helps users to identify the most critical and easily available knowledge areas in the project. [32]. Knowledge maps can be represented as file cabinet knowledge maps, cognitive maps, knowledge networking charts, scatter charts, contour charts, list charts, category maps, topic maps, and concept maps [33].

The SAKM uses two knowledge maps to organise, classify and describe each information object (IO), which is the basic textual and graphical information that forms the basis for consistent content generation.

- The DOMAIN knowledge map shows the basic characteristics of the IO. In SAKM, research results are structured using IO to enable the information to be reused and to provide maximum flexibility for the dynamic generation of online information.
- The MEDIA knowledge map describes the typology of the IO.

Then, two concept maps are used to represent the knowledge maps. Both maps are stored in CSV format and in separate files, which accelerates the independent PHP code update process.
These maps are active, which means that end users can incorporate and/or delete new terms according to their requirements.

3.3.2. Metadata

In addition to the knowledge maps, each piece of identified information is clearly characterised, completed and represented using metadata.

Metadata, defined as “data about data”, are used to organise, classify and describe information [34]. Firstly, taking into account the user requirements, end users search for research results by their content and attributes (format, size, creation date, etc.), so these metadata must be included in the system. Since some end users may be academics, it is important to include educational metadata such as the difficulty level or the type of learning object. In addition, it will be necessary to include copyright metadata once the system is made available to the user community.

Secondly, the system incorporates different domain-specific repositories or database systems. Therefore, an existing normalised and standardised metadata model should be used. There are many initiatives that promote the normalised and standardised use of metadata to describe information, including Metadata Resources for Digital Libraries [35], the Dublin Core Metadata Initiative [36], and Learning Object Metadata (LOM) [37].

After analysing different standards, the LOM standard with adaptations and extensions was considered the most suitable for the requirements of the SAKM because it includes content and formal metadata, and learning metadata. Furthermore, the extended use of LOM in similar repositories provides interoperability with other sources and/or repositories.

Table 2 shows the metadata used in the SAKM, including the LOM metadata and some adaptations and extensions. The metadata are divided into seven categories:

- **General:** The general information that describes the IO as a whole.
- **Lifecycle:** The history and current state of the IO and those entities that have affected the IO during its evolution.
- **Technical:** The technical requirements and characteristics of the IO.
- **Educational:** The key educational or pedagogic characteristics of the IO.
- **Rights:** The intellectual property rights and conditions of use of the IO.
- **Relation:** The relationship between this IO and other IOs, if any.
- **Classification:** The position of the IO within a particular classification system. This category is used if IOs are described using extensive classifications. In the SAKM, this category includes both knowledge maps.

Metadata fields	**Explanation**
General	
identifier	A globally unique label that identifies the IO.
catalogue	The name or designator of the identification or cataloguing scheme for the entry. A namespace scheme.
entry	The value of the identifier within the identification or cataloguing scheme that designates or identifies the IO. A namespace specific string.
title	Name given to the IO.
language	The primary human language or languages used within the IO to communicate with the intended user.
description	A textual description of the content of the IO.
keyword	A keyword or phrase describing the topic of the IO.
structure	The underlying organisational structure of the IO.
aggregation level	The functional granularity of the IO.
Lifecycle	
version	The edition of the IO.
status	The completion status or condition of the IO, e.g., draft, final, etc.
contribute	Those entities (i.e., people, organisations, etc.) that have contributed to the state of the IO during its life cycle (e.g., creation, edition, and publication).
role	The type of contribution relative to the IO, extending the value space with specific roles in underground construction, e.g., author, editor, etc.
entity	The identification of and information about entities (i.e., people, organisations, etc.) contributing to the IO.
date	The date of the contribution.
source	The project from which the IO is taken.
Technical	
format	Technical data type(s) of (all the components in) the IO.

size	The size of the digital information object in Kbytes.
location	A set of metadata fields that is used to locate the object.
requirement	The technical capabilities needed to use the IO.
installation remarks	A description of how to install the IO.
duration	The time that the IO takes when played at the intended speed.
Educational	
interactivity type	The predominant learning mode supported by this learning project.
learning resource type	Defines the specific kind of information object. The predominant kind is first. Describes the learning type of the information object, i.e., whether it is a building, a project, etc.
interactivity level	The degree of interactivity of the IO. Interactivity in this context refers to the degree to which the learner can influence the appearance or behaviour of the information object.
semantic density	The degree of concision of an IO. The semantic density of an information object can be estimated in terms of its size, span, or—in the case of self-timed resources such as audio or video—duration.
intended end-user role	Principal user(s) for which the IO was designed, predominant first.
context	The principal environment in which the learning takes place and for which the IO is intended.
typical age range	The age of the typical intended user.
difficulty	How hard it is to work with or through the IO for the typical intended target audience.
typical learning time	The approximate or typical time it takes the typical intended target audience to work with or through the IO.
description	Comments on how the IO is to be used.
language	The human language used by the typical intended user of the IO.
Rights	
cost	Whether use of the IO is subject to payment.
copyright	Whether copyright or other restrictions apply to the use of the IO.
description	Whether copyright or other restrictions apply to the use of the IO.
Relationship	
kind	The nature of the relationship between the IO and the target IO. For example, "is part of", "is a format of", "references", etc.
catalogue	The name or designator of the identification or cataloguing scheme for this entry. A namespace scheme.
entry	The value of the identifier within the identification or cataloguing scheme that designates or identifies the target information object. A namespace specific string.
description	The description of the target IO.
Classification	
source	The name of the classification system. This data element may use any recognised “official” taxonomy or any user-defined taxonomy. Two sources are defined for the SAKM: domain knowledge map and media knowledge map.
keyword	The keyword of the IO defined in the source.

Table 2. Metadata fields in the SAKM

In most information and knowledge systems, search results are limited by search conditions such as keyword, full text and natural language, and they do not consider the suitability of the solutions to the problem being faced. There is a gap between the services provided and the users’ needs [4].

To ensure that search results match the search criteria, Tseng and Chang [22] suggested that a suitability attribute could be defined for directing users to the most relevant information for their specific problem.

In addition to knowledge maps and extended LOM metadata, the SAKM incorporates a user or social metadata field to help users to find the most suitable IO for their requirements. This metadata field contains feedback information that users add to an IO once they have consulted it. The information is essentially a satisfaction score, but it may also include comments, notes, and the number of times the IO has been downloaded. This user metadata field is one of the strategies used for transferring tacit knowledge. End users incorporate their comments on the specific IO of research results and other end users can profit from this information and incorporate or complete this field by writing their own comments.

The SAKM organises the results according to the suitability metadata score and users can access comments and notes by other end users.

3.3.3 Communication system

A forum has been created for end users to share their opinions and to enhance communication and collaboration. Although the system's end users are domain-specific, each research area is very broad and sub-areas of interest are created.

When end users retrieve specific research results, a link to the sub-area of the forum is provided. Therefore, users with specific queries can post them in the corresponding forum and an email is sent to all other users in the sub-area in order to generate a discussion in which different points of view, examples and solutions are presented.

The forum is organised using the same domain knowledge map from the codification of the IO.

3.4. Sharing and transmitting research results

The aim of sharing and transmitting research results is to provide the right information to the right person at the right time. According to Markus [38], this process can be passive, such as publishing a newsletter or using a information repository for users to browse, or active, such as using an electronic alert to send information to those who require it. However, information is also shared through face-to-face meetings and through information and communication technology (ICT) systems.

Once the information results are captured, structured and gathered in a single point, the system provides tools for sharing and transmitting this information:

- Using the domain and media concept maps and the metadata, specific research results can be retrieved and transmitted to interested parties (**passive sharing**).
- The system also provides **active sharing** by sending an email to interested end users when new knowledge is added in a specific area. In order to differentiate end-user

interests, when they register into the system, users are asked to specify the areas in the main content knowledge map in which they are expert or interested.

3.5. Reuse and maintenance of research results

The process of reusing research results includes reapplying information and adapting or integrating it for innovative purposes. An information manager is in charge of maintaining the technical aspects of the SAKM, as well as reviewing, correcting, updating and refining research results to keep it up to date and preserving and removing obsolete knowledge.

A group of experts made up of researchers, organisations and academics in the specific domain field help the information manager to analyse the quality of the information included in the SAKM.

In SAKM, knowledge maps are not static. When developing and updating ontologies, automatic tools are not suitable and human intervention and guidance is required [17]. Therefore, the group of experts offers the information manager support on the suitability of including new terms in the domain and media knowledge map.

To maintain the information included in the SAKM, the information manager examines the IOs with bad satisfaction scores and analyses the reason for the results. The group of experts then checks the possibility of eliminating the IOs from the SAKM.
Although it is time-consuming to maintain such a system, an information manager is essential. Other prototypes include automatic tools for this purpose but results are poorly refined and organised.

4. SYSTEM DEVELOPMENT

4.1. Architecture description

The system architecture must facilitate the transfer of research results and the coordination and collaboration between end users (knowledge providers and retrievers). Given the nature of the framework defined above, a Web-based system was adopted. The system architecture is implemented in a server that uses Internet protocols to transmit knowledge. The system is a centralised, accessible, and reliable tool for transmitting and storing research results. The information is stored on a server that authorised members can access using a standard Web browser.

SAKM has been implemented using a three-tier architecture composed of three logical layers (Figure 2): the user layer, the application layer and the database layer.

The **user layer** provides system security and restricted access, firewall services, and system administration functions. This layer is connected to the server through the application layer, which is in turn connected to the database layer.

The **application layer** defines various applications for adding, managing, updating, codifying, searching and retrieving information and end-user communication. This layer uses PHP language to generate dynamic content from the database in order to produce standard Web pages in the system. PHP is a simple scripting language that can be embedded in specialised tags in HTML information. PHP was selected because it is a widely used open-source scripting language that is particularly suitable for Web development; it can be embedded into HTML and enables Web designers to write Web pages quickly; it is compatible with many operating systems, such as Linux, Unix, Microsoft Windows, MacOS X and RISC OS; it is supported by many Web servers, such as Apache, Microsoft Internet, Information Server, Personal Web Server, Netscape and iPlanet servers; and it is supported by a wide range of databases, including Adabas D, dBase, Empress, MySQL, Oracle, Postgres and Solid.

The **database layer** consists of an SQL Server database. A GNU/Linux Red Hat Enterprise operating system was installed in the software environment. It is an open-source system based on the Unix operating system and it is internationally recognised in the field of server management and large-format applications. This system has several possible applications, but it is particularly suitable for managing databases in PostgreSQL, which is the language that was used to develop the SAKM database.

The SAKM is supported by a Dell PowerEdge 1950 server, which is a high-performance small-format server that can be installed in rack to reduce the amount of space and energy it requires. The server contains two Intel Xeon 5300 processors with a speed of 2.66 GHz that provide high calculation power, which is ideal for Web systems that need to access data and applications with high-response performance and capacity. For a large and flexible storage capacity, the server was integrated in a SAN store net infrastructure that provides a flexible data storage capacity of 600 Gb. The server was also connected to an external backup system for the system data and for the application and storage data, with a lower recovery time of 24 h. This system guarantees the stability and security of the database.

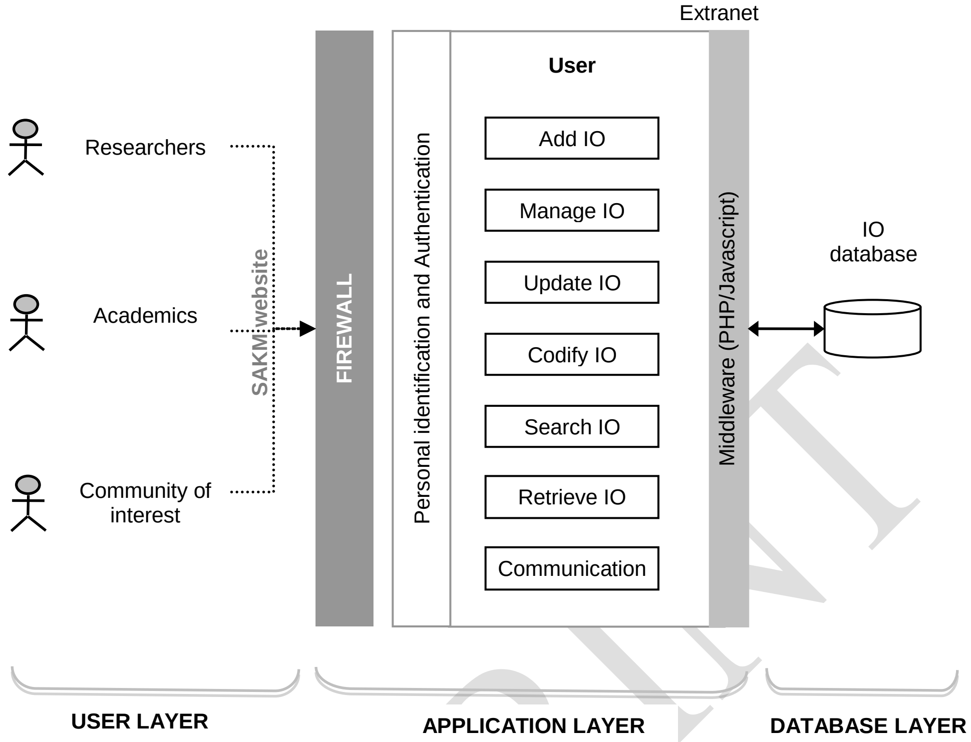

Figure 2. System architecture (adapted from Udeaja et al. [23])

4.2. System description

The SAKM access is currently restricted to registered users. Figure 3 shows the user navigation process within the system. The main page displays information about the research domain, useful links, and the system characteristics. Users are given two options: A) data introduction; B) content search. The steps in the knowledge capture process are numbered A1-A5 and are initiated from the Web browser. The sequence is shown below:

A1. A login page appears when users select the "data introduction" option. Once the authentication has been verified, the user is allowed to access the following pages. If the authentication is unsuccessful, the user is prompted to register. During the registration process, users are asked to specify the areas of the main content knowledge map classification in which they are expert or interested. This information will be used in the system personalisation approach, which will enable the system to send emails when new information in a specific area is added and provide access to forums when users request specific information.

A2. If the user (in this case the content provider) chooses to capture new research results, the user should "upload" the IO to the server by browsing it in the PC or entering the link to the Website on which the IO is located.

A3. The content provider should then edit all of the metadata of the IO. Required data are marked with an asterisk (*). Each metadata field has a help link indicated by the following icon (?). When users access the help link, a screenshot containing a description of the information in this metadata is displayed. A JavaScript function was included so that certain fields such as the calendar could run more quickly. Other fields such as format and size are automatic, and the remaining fields are to be filled in by the content provider.

A4. Once the metadata have been completed and submitted, the system stores the captured research result or the link in the database. Content providers of specific IOs can add, delete and edit metadata fields from the IOs that they created at any time.

A5. Finally, the system sends emails to every registered member in the area of the content knowledge map classification to which the new information belongs.

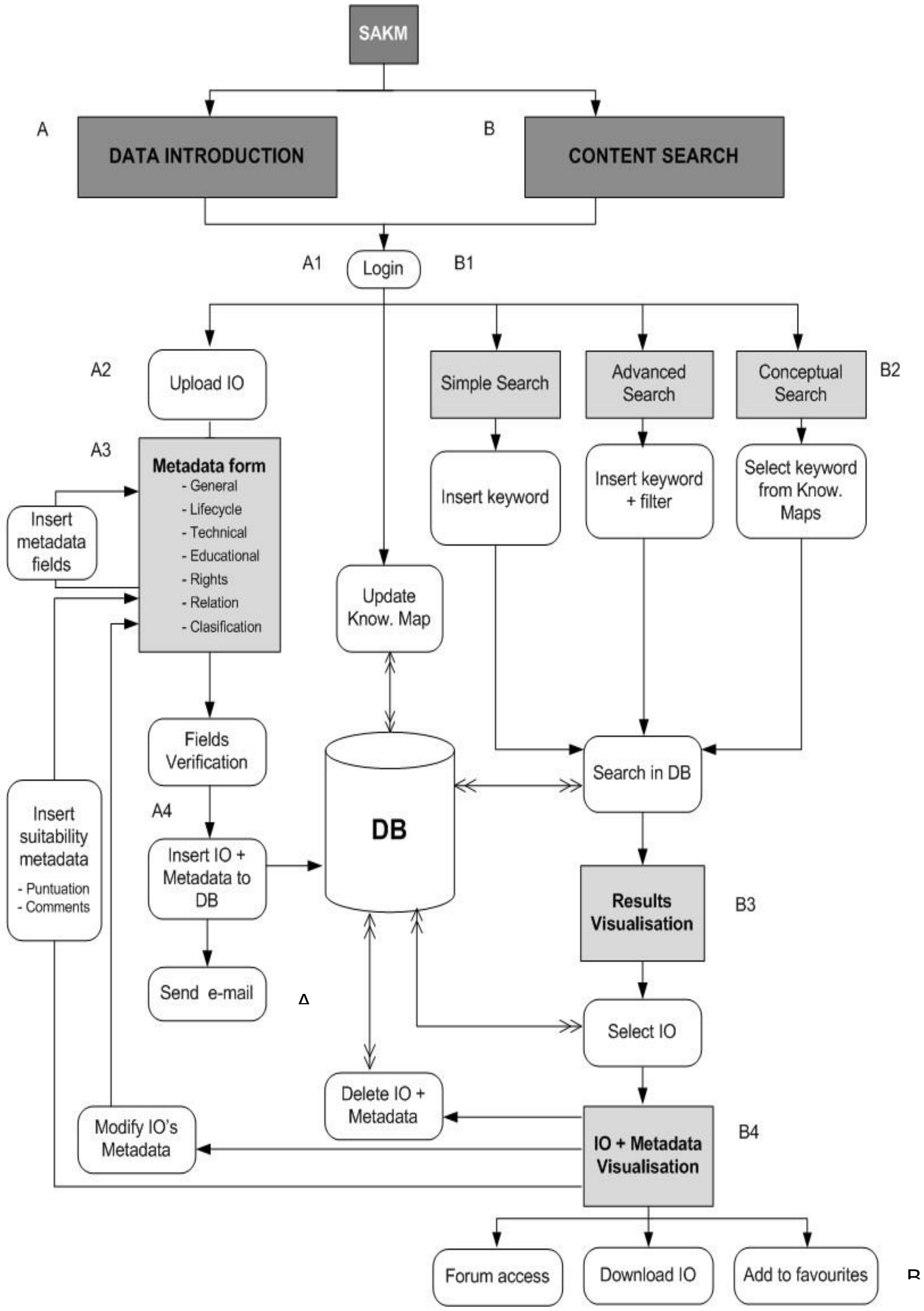

Figure 3. User navigation process

The sequences of interactions for information retrieval are numbered B1-B5 and are initiated through the Web browser (see Figure 3). The sequences are described below:

B1. When users select the "content search" option, a login page appears. Once the authentication has been verified, the user is allowed to access the following pages. If the authentication is unsuccessful, the user is advised to register and asked to provide the same information as requested for the knowledge capture option.

B2. Users can retrieve knowledge in one of the following three ways:

   a. Simple search. The user can search for a term included in a title, a description, or a knowledge map (domain or media). While the user is typing a term, the system suggests matching words found in one or both of the knowledge maps, although the search is performed even if the term is not found in either one.

   b. Advanced search. This search enables users to combine different fields such as the IO source, language, date, and terms from both knowledge maps.

   c. Conceptual search. Specific scientific domains are highly specialised fields, so it can be difficult to obtain results when the same term is used in a search and for information capture. Many synonyms for specific terms were included when the content knowledge map was defined, but the conceptual search also enables users to search for words directly by navigating through the concept maps. This option provides users with a broad map of the conceptual structure of the information stored in the system. In this case, the user can search both concept maps simultaneously. If the desired term is very specific, the user can search directly in the most detailed category in the knowledge map (for example, materials-concrete-polymeric), but if the information is more general, for example regarding "concrete material", the user only needs to search the general level. The system retrieves all of the IOs in this subcategory regardless of the type of concrete. Therefore, users can search all of the category levels of the concept maps (see Figure 4).

B3. Once the user has completed the required information, the system displays the title, description, source, date, punctuation, comments and number of visits of each IO that matches the search criteria. The results can be sorted by format, date, source or punctuation (see Figure 5). Users can access the IO directly by clicking on the icon.

B4. When users select an IO, the system retrieves all of the associated metadata, such as the title, description, language, version, state, source, date, size, format, copyright, related documents, classification, punctuation, comments and number of visits.

   The "classification" section shows the concept map structure in which the IO is classified.

   The "related documents" section links the selected IO to other IOs. The system considers the following relationships, among others: "is required by", "requires", "has format", "is format", and "is based on". This section provides the name and description of all related documents and retrieves a user-friendly display of these relations (see Figure 6). The user can then select one or more of the related IOs to access its content and attributes.

The "comments" section provides the punctuation that other end users give to the specific IO and comments on the quality, value and possible uses of this IO, which improves the content and results analysis.

B5. Once users have obtained the search results, they can access the forum to request additional information or to clarify certain points. The system uses the information provided during the registration process to define "sub-areas of interest". Therefore, users with specific queries can post them in the corresponding forum and an email is sent to all other users in the sub-area to generate a discussion in which different points of view, examples, and solutions are presented.

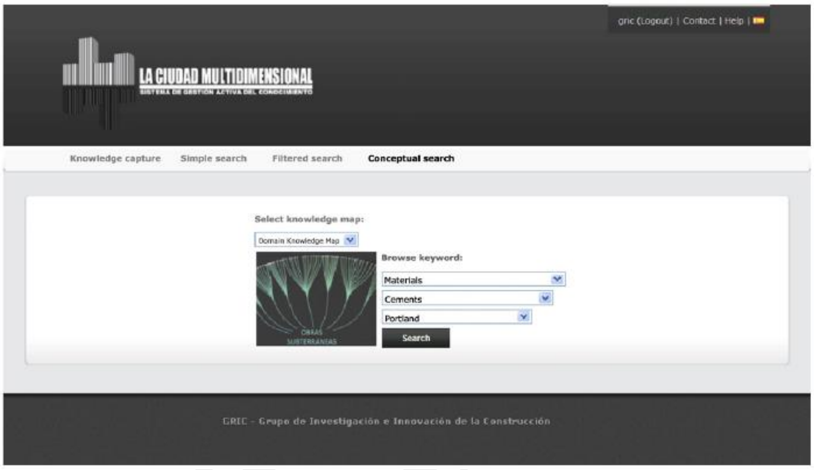

Figure 4. Screenshot of SAKM: example showing conceptual search for knowledge retrieval.

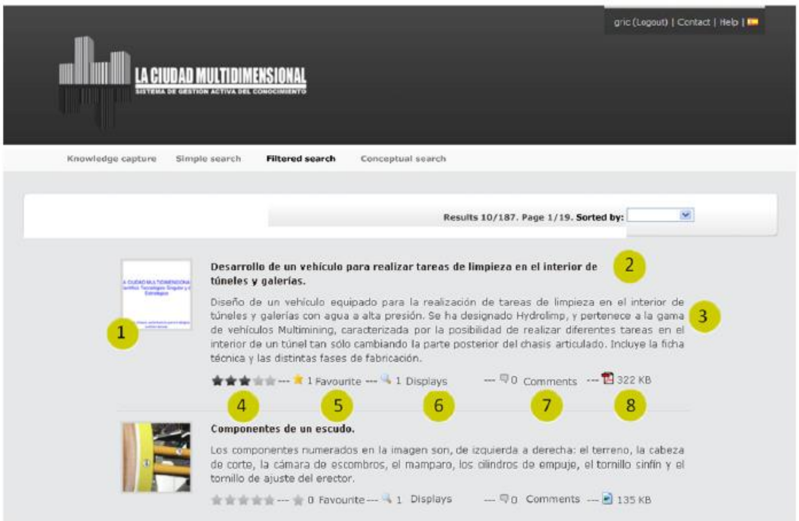

Figure 5. Screenshot of SAKM: example showing search results for knowledge retrieval, 1. Preview, 2. Title, 3. Description, 4. Score, 5. Statistics of favourite, 6. Statistics displayed, 7. Number of comments, 8. Format and size.

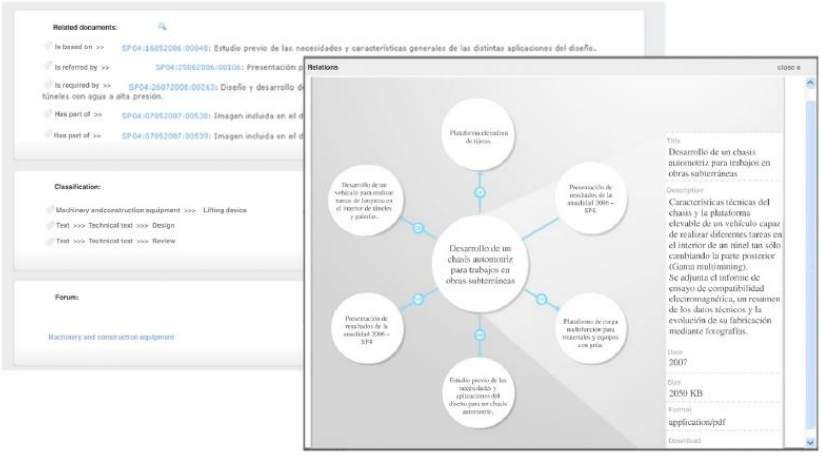

Figure 6. Screenshot of SAKM: example showing the visualisation of the "related documents" of an IO.

5. CASE STUDY

To test the feasibility of the system, it is implemented in the specific research domain of underground construction, which is a knowledge-rich industry in terms of the knowledge it generates, the exchange among participants, and the information it absorbs from outside sources [39].

The system presented in this article is generic for any research domain, and only domain and media knowledge maps should be defined for each specific sector.

Several attempts have been made to develop an effective representation of construction concepts. At the beginning, the main focus was to categorize terms through classification systems and thesauruses. Object-oriented features were then included to create taxonomies such as IFCs with the aim of using semantic web technology in the construction industry [29]. Currently, many research projects are underway to formalize a set of construction ontologies [27] but none focus on underground construction and disseminating and transferring research results.

Many glossaries and thesauruses are developed in the field of underground construction [40, 41, 42]. Therefore, to generate the domain knowledge map, which was the representation of underground construction concepts, the various construction classification systems, taxonomies, ontologies and underground glossaries and thesauruses were analysed.

Thus, the domain knowledge map describes the content of each IO using field-specific underground construction terminology and has a very large, multi-level tree structure divided into four category levels. Figure 7 shows the main structure and some of the categories (some are too extensive to be represented here).

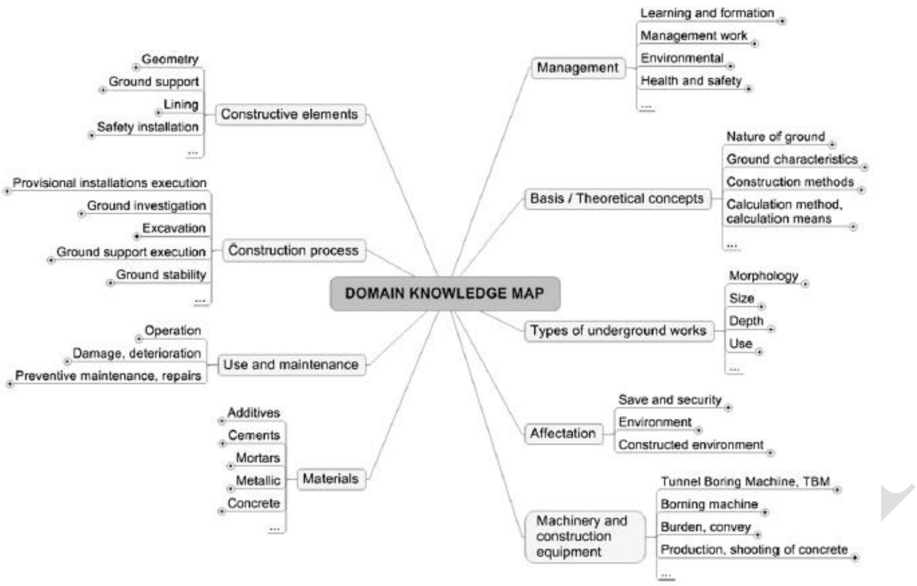

Figure 7. Main structure of the domain knowledge map.

The media knowledge map is used to describe the type of IO. It is important for the system because researchers often search for specific types of information, such as regulations or specifications. The multi-level structure of the media knowledge map was defined based on the study of different thesauruses and research projects [43], [44]. Figure 8 shows the structure of this map.

Once the knowledge maps are developed for the specific domain, Figure 9 shows the ontology of the overall system including the different metadata to the IO, such as related documents, social metadata and domain knowledge maps linked to the forum.

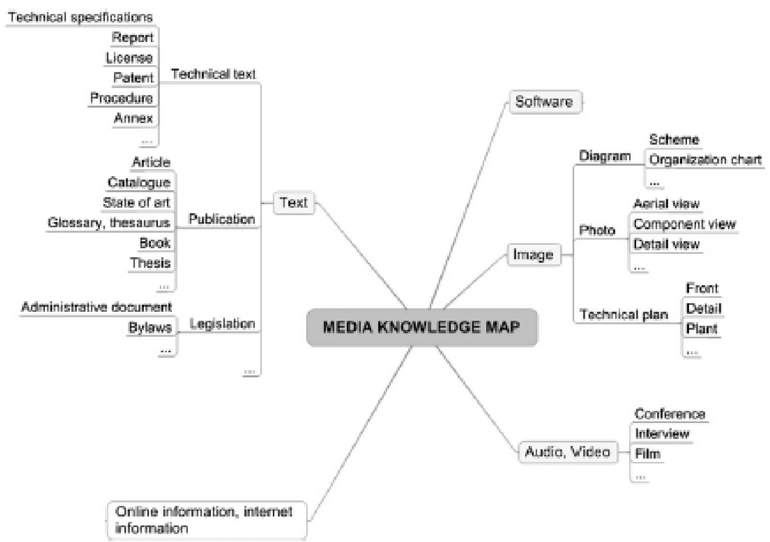

Figure 8. Main structure of the media knowledge map.

When the system was adapted for underground construction, a pilot test was conducted by making the SAKM available to researchers from centres, companies and universities involved in underground construction research. All 22 case participants took part in an R&D project called The Multidimensional City [45], which is a multi-disciplinary research project that promotes the development and implementation of Spanish technological innovation in underground construction. It is a strategic scientific-technological project funded by the Spanish Ministry of Science and Innovation and endorsed by the Spanish Construction Technology Platform. The project's five strategic lines of research—underground construction, cities and buildings, health and safety, sustainable construction, and cultural heritage—are intended to promote increased efficiency, productivity, safety and environmental awareness in the Spanish construction sector. The project started in 2005 and the partners involved possess not only direct engineering experience and technical know-how but also the research capabilities and conceptual innovation of the academic sector. The Multidimensional City project is divided into ten subprojects.

At the first annual meeting, the partners were shown presentations by the other groups and realised that some were carrying out complementary research that could have been used to help others. Therefore, a tool like SAKM could improve the dissemination of the results of this research project and the sharing of information during the project and among involved researchers.

The SAKM was made available to the Multidimensional City partners one year after the start of the project. During this period, the information manager took on the role of the end user:

- Results were acquired from underground research projects, repositories and databases related to underground construction, associations, journals, Web information, etc.
- Information was obtained from the Multidimensional City project, including documentation, presentations made by project partners, project team meetings, intranet/extranet, and personal libraries from 2005 and 2006.
- IOs were created from the acquired information.
- IOs were codified: general, lifecycle, technical, educational, rights, relation and classification metadata fields were inserted.
- IOs were captured using the SAKM.

Approximately 800 IOs were acquired, codified and captured. They included experimental test results, states of the art, graphical simulations, photographs, videos, links to the results of the TunConstruct European tunnelling research project [46], journal articles, reports, etc. Apart from the general information about underground construction, the SAKM included information from many results and reports that were already obtained from the Multidimensional City project.

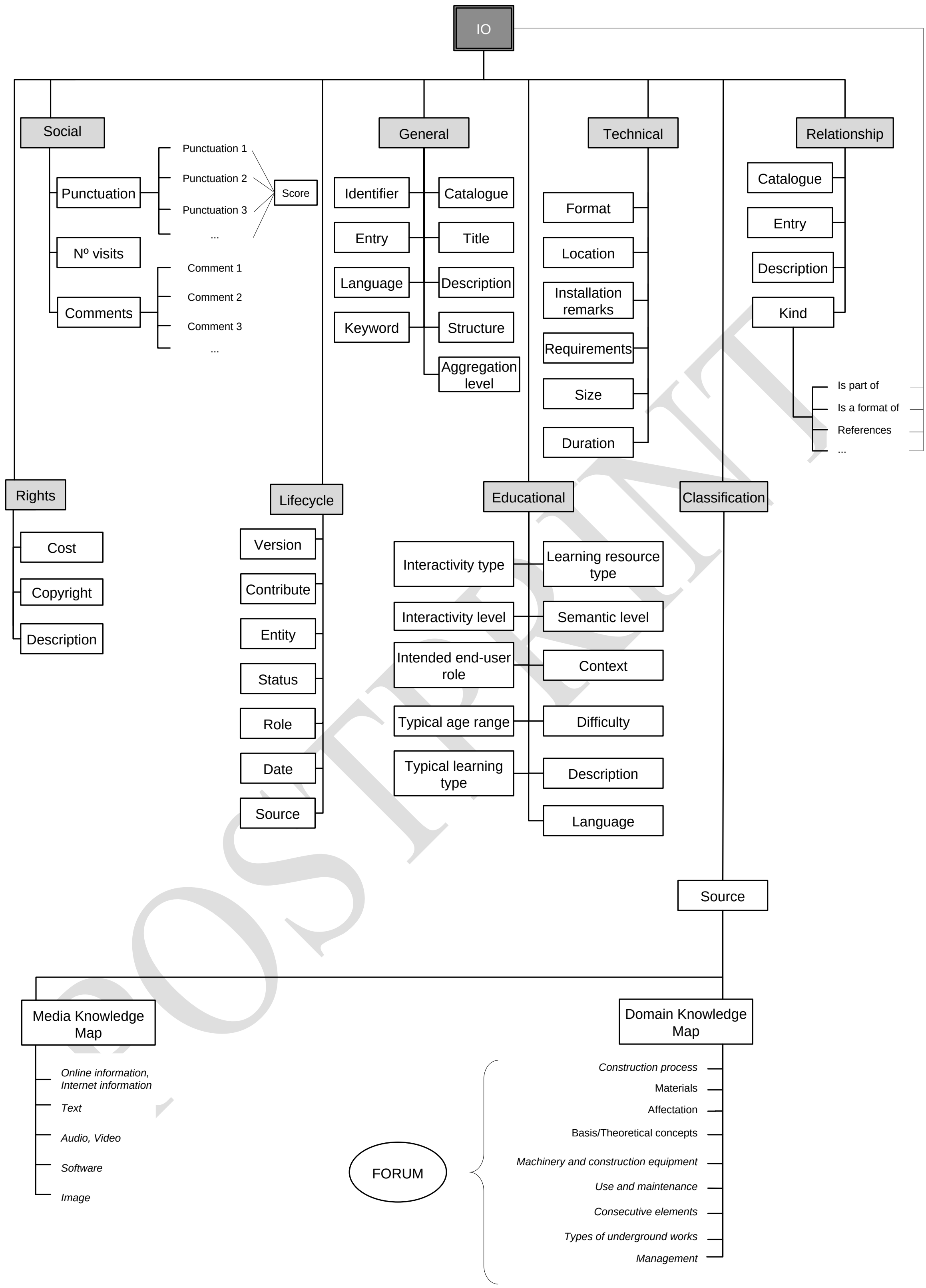

Figure 9. SAKM ontology (implemented in the underground construction field).

Table 3 presents the details of various stages of implementation of the SAKM in a case study in which a company involved in the Multidimensional City project is preparing the basis of a research project on advanced modelling methods in underground construction and wants to obtain information and previous research results in this area. Instead of looking online, in journal articles, intranets, European project results, etc. the company carries out a conceptual search in the SAKM and realises that there is another project that focuses on the same issue. The company can then use the forum to get in touch with the person responsible for the IO obtained by the SAKM.

Step / Phase	**Scenario**
Knowledge capture	
Collect information	The information manager collects information from existing underground databases, journal articles, web information, etc.
	Engineer 1 involved in *Development and control of new integrated constructive processes* from the Multidimensional City project collects the agreements of the first subproject meeting.
	Engineer 2 involved in *Tunnelling guidance and control systems* from the Tunconstruct project collects the results of an experimental test.
Edit information	The information manager creates IOs from existing underground databases, journal articles, web information, etc.
	Engineer 1 creates IOs from the agreements of the first subproject meeting.
	Engineer 2 creates IOs from the results of an experimental test.
Codify information	The information manager codifies IOs by inserting general, lifecycle, technical, educational, rights, relation and classification metadata fields.
	Engineer 1 codifies IOs from the agreements of the first project meeting by inserting general, lifecycle, technical, educational, rights, relation and classification metadata fields.
	Engineer 2 codifies IOs from the results of an experimental test. When defining the classification of the IO, engineer 2 realises that the areas included in the initial classification do not fit with the IO to be codified.
	Engineer 2 proposes a new term to include in the classification domain knowledge map by filling in a form, including the reason for creating a new term and the possible location in the knowledge map.
	The information manager receives the notification of a possible new term to be included in the domain knowledge map and delivers this information to a group of experts formed by three researchers involved in underground construction researches.
	The group of experts checks the necessity to include a new term in the domain knowledge map and if 2/3 of the group accept it then the information manager includes this term in the SAKM.
Submit information	The information manager captures IOs using the SAKM.
	Engineer 1 captures IOs using the SAKM.
	Engineer 2 captures IOs using the SAKM.
Validate information	The information manager and a group of experts review, correct, update and refine IOs submitted in the SAKM by end users.
Knowledge sharing	
Search knowledge	Engineer 3 is preparing the basis of a research project on *Advanced modelling methods in underground construction* and wants to obtain information and research results on this area.
	Instead of looking on the Web, in journal articles, intranets, European project results, etc., the engineer searches in the SAKM using the conceptual search.
	Engineer 3 obtains many research results on this area and realises that future work from the Multidimensional City project are to be included in the possible objectives of the project he is aiming to submit. He then decides to

	get in touch with the person in charge of the IO with the related information. He looks for the metadata of the IOs related to the agreements of the first project meeting and then he can choose between sending an email to Engineer 1 or connecting to the forum related to the "*construction process*" and asking the people involved in this field of research about possible collaborations.
Collect feedback	Engineer 3 assess the IOs consulted by associating a satisfaction score (from 0 to 5) with each IO and commenting on the relevance of the IOs and the suitability of the location of the IOs in the domain and media knowledge map.
Knowledge maintenance	
Analyse feedback	The information manager lists IOs with a score of less than 2 and obtains the relevance comments and analyses the reason for the results. The information manager delivers this information to a group of experts formed by three researchers involved in underground construction researches.
Remove non relevant knowledge	The group of experts check the possibility of eliminating the IOs from the SAKM and if 2/3 of the group accept it then the information manager eliminates these IOs from the SAKM.
Updating knowledge	The information manager search for all the results from the second meeting of the Multidimensional City project. If there are some results that have not been included in the SAKM, the information manager looks it up in the intranet of the project, the Web, journals, national database project results, etc. and links or uploads the information to the SAKM. The information manager updates IOs by searching for new underground databases and linking them to the SAKM, updating research results published in journals, etc.

Table 3. Scenario description for the Use Case

6. SYSTEM EVALUATION

Verification and validation tests were performed to ensure that the system conforms to the outlined functional requirements. Verification determines whether the system operates correctly and behaves according to the design and specifications, while validation assesses the usefulness of the system. The primary interest in evaluating the SAKM was to demonstrate that the system works as intended and meets the requirements specification in terms of functionality and performance. The specific objectives of the evaluation were to:

- Demonstrate that the end-user requirements were achieved
- Demonstrate the functionality of the system
- Demonstrate the use of the system
- Demonstrate that the SAKM will facilitate the sharing of knowledge of research results in the field of underground construction
- Obtain comments and recommendations to guide future development
- Identify and correct any system inconsistencies

To achieve the above objectives, the same end users who answered the user requirements survey (12 academics and 10 industrial partners) were asked to use the SAKM system and then provide feedback by answering a questionnaire and commenting on what they particularly like about the system and how they think it can be improved. All test participants were experts in the field of underground construction.

The questionnaire contained 18 questions about the functionality, adaptability and use of the system. For each question, participants were asked to tick the box that best represented their assessment on a scale of 1 (poor) to 5 (excellent).
Table 4 illustrates the system testing results.

	Mean
Functionality	
1. Ease of capturing knowledge	2.8
2. Ease of codifying knowledge	2.3
3. Ease of knowledge retrieval	4.2
4. Accuracy of the codification fields	4.0
5. Accuracy of the knowledge retrieval results	4.3
6. Usefulness of the system	3.2
7. Usefulness of the forum	3.8
8. Usefulness of the relation field between IOs	3.5
9. Usefulness of the suitability attribute: satisfaction score on an IO	2.6
10. Usefulness of the suitability attribute: comments on an IO	2.5
Adaptability	
11. Adaptability of the classification fields: Content knowledge map	4.2
12. Adaptability of the classification fields: Media knowledge map	4.1
13. Adaptability of the codification fields	3.8
14. Applicable to research results in the field of underground construction	4.2
15. Compatibility with other systems	3.4
16. Comprehensive	3.8
Use	
17. Ease of use	4.0
18. System interface / Visual interaction / User friendliness	3.8

Table 4. System test results

Functionality:

In general, all test participants found the SAKM useful (average score of 3.2 to question 6), although they considered that capturing and codifying all their research results without assistance from information experts would be very time-consuming and difficult (average score of 2.8 and 2.3 to questions 1 and 2). This confirms the importance of the information manager. The information manager will not only be in charge of maintaining the technical aspects of the SAKM but also of reviewing, correcting, updating and refining knowledge to keep it up to date, and preserving and removing obsolete knowledge. On the other hand, a high percentage of the test participants found the knowledge retrieval easy (average score of 4.2 to question 3).
Although the codification of the IOs is time-consuming, test participants found both the codification fields and the knowledge retrieval results accurate (average score of 4.0 and 4.3 to questions 4 and 5). As regards the usefulness of different areas of the SAKM, test participants found the forum for exchanging comments and contacting experts and interested researchers very useful (average score of 3.8 to question 7). In addition, the relation field between IOs was considered to be very useful in terms of achieving extra information from the results obtained (average score of 3.5 to question 8).

Test participants gave an average score of 2.5 and 2.6 to questions 9 and 10 on the suitability attribute. These scores indicate that participants were not quite convinced that the attributes for evaluating the suitability are relevant for the SAKM. Furthermore, given that the system is not yet available to all possible end users, only test participants enter suitability attributes in the results of their retrievals. Therefore, few IOs had suitability scores and comments, and the results for questions 9 and 10 could not be extrapolated to the situation when all end users have access to the system.

Adaptability:

Domain and media knowledge maps were developed by a group of experts (4 academics working in the field of underground construction). They were then checked and verified for discrepancies and errors through the submission of the knowledge maps for criticism and evaluation by 10 practitioners. Comments and suggestions on the terminology and the main underground construction areas were compiled and implemented in SAKM. Afterwards, the system was evaluated by the test participants.
Nearly all test participants considered that the organisation of the information (domain and media knowledge maps, codification, etc.) is adaptable and applicable to research results in the field of underground construction and very useful for searching and retrieving information (average score of 4.2, 4.1, 3.8 and 4.2 for questions 11, 12, 13 and 14).
Although the system uses the LOM standard to codify the IOs in order to improve interoperability with other systems, access restrictions to repositories make it difficult to visualise the results (average score of 3.4 to question 15).

Use:

Finally, the test participants found the system easy to use (average score of 4.0 to question 17) thanks to the help information resource. The system provides two types of help information. Firstly, each metadata field has a *Help* option that provides a specific description of the metadata when users upload information. Secondly, the main page of the SAKM contains a link to a *User's Guide* that provides complementary information to help users with specific questions. The guide was reviewed for clarity and ease of use and to make sure that it provided comprehensive details of system requirements, system error messages, and problem-solving procedures.
Test participants gave an average score of 3.8 to question 18 related to the system interface. User friendliness is the key factor in overcoming any minor drawbacks in the system and ensuring that users are satisfied with its functionality. The menus, windows and explanations in this prototype are easy to access and simple to use. Graphic elements such as screen colours, typefaces, and figures were chosen to create an attractive system interface.

Participant's comments:

Test participants were also asked to make comments on the SAKM and they provided the following feedback. Some of the project partners were reluctant to include their research results in a tool like SAKM because they consider that codifying all IOs is very time consuming. Other test participants argued that they prefer to use traditional methods for disseminating their results, such as conferences because they have always used these methods and were reluctant to change. On the other hand, all test participants were very interested in the SAKM as a tool for searching for specific research results. These results strengthen the need to encourage participation. Raybourn et. al. [47] suggest that there is no recipe or standard format for encouraging participation, nor should any one cultural perspective be forced on a community. However, Kings et al. [48] suggest that a sense of history and a user's reputation are prerequisites for the development of a shared community purpose. Therefore, when interested parties notice the great value of the codified information of SAKM and the importance of sharing research results, then the community of users will increase and start providing their research results in order to make their research groups visible to the community. If users can benefit from codifying their research results they will start doing so. To determine whether the software is built correctly and checks for technical errors, consistency, technical integrity, database correctness and normalisation, tests were conducted on robustness, maintenance and security.

Consistency:

We checked the consistency of all system components that were subsequently built by verifying the logic of sets of input data (scenarios). The system was run more than 100 times using a combination of inputs. The output of each run was examined and the corresponding rules and logic were changed until the intended results were obtained.

Technical integrity:

Integrity is guaranteed because the system uses a standard metadata classification (LOM). The classification was adapted to the KM for underground construction, although there are some implicit restrictions on creating tables and inserting and updating data in the relational database to guarantee the integrity of the database.

Database correctness and normalisation:

These aspects are guaranteed by using the appropriate classification standard and a suitable integral database design. The SAKM is implemented in the normalised PostgreSQL language, which is compatible with the restrictions designed to ensure technical integrity.

Robustness:

The maximum and minimum parameters are defined by the operating system in which the application is run. In this case, PostgreSQL in a GNU/Linux Red Hat operating system is a consolidated and effective combination in database management.

Maintenance:

End users are not required to perform any type of maintenance, but the system administrator can modify and update information and migrate all contents and input data using MySQL.

Security:
We guarantee the security of the system by incorporating standard protection measures for Web environments, including password-controlled access and https protocol encryption.

6. CONCLUSIONS

In this paper, we report the design of a Web-based system to support the sharing and dissemination of effective research results and to enhance communication and collaboration among researchers, academics and other interested parties. To validate the approach, the prototype was implemented in the research field of underground construction.

Although the technical capabilities of Web-based knowledge sharing and dissemination systems are improving, they are not yet advanced enough to handle research project results due to unstructured information, vocabulary differences, distributed sources and the poor content analysis of the available systems for scientists and researchers.

The system presented in this paper provides an integrated approach to Web-based information capture and retrieval that incorporates various techniques and functionalities that include domain-specific knowledge maps, standard metadata to make the system interoperable with existing databases, keyword suggestion based on the knowledge maps, content analysis techniques to determine the suitability of the results obtained, and a subsector-specific forum for enhancing communication and collaboration among researchers through the knowledge maps.

The key feature of the SAKM is the simultaneous implementation of two approaches: the codification approach, which is designed to transfer and share research results, and the personalisation codification, which enhances communication by creating a direct forum and suitability metadata linked to specific IOs. Therefore, the domain and media knowledge maps and the end-user metadata are used to retrieve required information easily and effectively, and the metadata structure based on the standard LOM provides possible interoperability when different repositories are incorporated into the system. The suitability metadata indicate whether the searched IOs match the desired target.
The layered architecture design also allows developers to maintain the system, revise the user interface, and add new components easily.

Because the techniques employed are not domain-specific, only minimal effort would be required to apply the architecture to different areas of research such as electronics, computer science, engineering, energy, technology, etc. All functionalities are developed to share and disseminate research results among researchers and organisations working on similar research topics, give academics access to research results and innovation so that they can be incorporated in the classroom, and offer the opportunity to the entire community of users to add and retrieve specific research information and communicate with other researchers with a view to working together in the future. The SAKM can be used in any R&D domain by defining the domain and media knowledge maps and incorporating them into the system.

Information management systems can only work well if they receive sufficient input from experts. A Web-based system such as the SAKM should be capable of meeting the increasingly complex demand for research result sharing among scientists. The case study and the validation presented in this paper demonstrate that the SAKM helps users to share research results. The analysis also shows that it is important to foster an information-sharing mentality among researchers. The time and cost benefits of this system can only be achieved if researchers and interested parties (end users) create a culture of information sharing and encourage all parties involved in research projects to share the information they possess.

Currently, the Spanish Association of Underground Construction, which has a huge amount of data on their members, is interested in exploiting the system. The association will ask their members to incorporate the information related to their R&D departments. When the members of the association realise the value of the codified information of the SAKM and the importance of sharing research results, then they will be more inclined to provide their research results in order to make their research groups more visible to the community. If users can profit from codifying their research results they will start doing so.

At first, the information manager will give support to the members of the association and subsequently to the entire community of users.

7. LIMITATIONS AND FUTURE RESEARCH

The main limitation of the SAKM is its efficiency. Although end-user capture and codification guarantee the success of the retrieval results, the evaluation of the system demonstrated that end users have no time to codify their results unless they receive some sort of benefit. At present, it is only a prototype. The information manager assumed the role of the end users and codified the research results obtained from different end users, domain-specific databases, journal databases, Web portals, etc. Currently, more information is being codified by the Spanish Association of Underground Construction that will make the system visible to its members and to the community of users. However, once the system is made available to the members of the association, it will be evaluated again in order to obtain more accurate feedback from end users.

On the technical side, we are improving the visualisation of the results and planning to include several databases with existing metadata with the aim of testing the interoperability of the system with other existing systems.

Future research may be directed towards using automatic information searches through predefined and existing databases, and improving the quality of the retrieved information of these search engines.

8. ACKNOWLEDGEMENTS

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