Knowledge in Construction Processes

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Abstract: The growing complexity of the construction sector – due to the proliferation of products, techniques, and needs related to side, not secondary, aspects of objects (environmental impact, energy efficiency, durability, safety, etc.) – means that the current management styles in construction processes are no longer appropriate to their context. Therefore, the construction sector faces an inevitable process of growth in which knowledge is an indispensable resource. The purpose of this paper is to show how knowledge associated with construction processes can be represented using Knowledge Management techniques. The analysis of such knowledge uses a mixed top-down and bottom-up approach, which can formalize it and make it ready for easy access and search. The underlying goal is the rational organization of large amounts of data using the knowledge that characterizes the various stages of a construction process. Elementary Products could be the core concepts that can group the objects associated with such process, guiding the management of relevant information and knowledge involved in construction processes. The formalization was used to define a prototype implementation of the Knowledge Management System using DSpace.

1 INTRODUCTION

The amount of information needed by all the operatives involved in a construction process to work properly and successfully is always growing. For this reason, construction processes – while still largely relying on intuition and experience – need to be rationalized through new procedures and tools for a strict formulation and implementation of efficiency criteria.

The purpose of this paper is to show how Knowledge Management (KM) techniques may be one of those tools, supporting those activities through a rational organization of the large quantity of data/information and a capitalization of consolidated knowledge.

KM is described as follows: "The Knowledge Management is the systematic, explicit and deliberate organization, application and renewal of a company internal knowledge, aiming at maximizing the effectiveness of the cognitive ground and of the related advantages" (Wiig, 1999).

This definition makes it easy to understand why including a KM policy in an organization means considering knowledge as a key resource to develop, capitalize, and share, that will determine the future of its operating strategy. "Knowledge is the information that changes and modifies the organization, making the agent capable of new and/or effective actions" (Drucker, 1996).

Introducing a KM policy into a company means making knowledge into a key wealth, to develop, capitalize, and share, and to use as a base for a company's operational strategy. The aim of KM is, in fact, to express, making it accessible to the entire company, all the knowledge that every operative has gained with their work, so that the company can gain an advantage both economically and from a service quality point of view. An increase in performance and competitive advantage are the main benefits of KM; this is the reason why more and more effort and resources are being spent to define and implement knowledge management policies into

companies (Alavi and Leidner, 1999; Firestone, 2001).

Some of the applicative uses of this research may involve third-party inspection services (verification and validation of the project, technical control of the building) in the construction sector. In fact, tools that can manage elementary products as defined are the foundation of good quality in project validation for public works, thus being vital for a systematic approach by contracting authorities.

One of the instruments of KM is its knowledge base (a knowledge base is an information repository that provides a means for information to be collected, organized, shared, searched and utilized): developing a knowledge base means rationalizing and clearly conveying the dynamics and know-how structure of a company (Malhotra, 1998; Stankosky, 2005; Maier, 2010).

This work sought a rational organization of large amounts of data using the knowledge that characterizes the various stages of a construction process. The approach used to formalize the knowledge is based on the top-down and bottom-up analysis.

The first step to implement a KM system is to define its base content, schemes, and structures, in order to enter and offer the knowledge collected by all the participants to a project. We suggest the concept of elementary product, described further below, as the basic unit needed to create the knowledge base of a construction project.

The paper is structured as follows: in Section Two we present an overview about the state of the art and in Section Three we propose the research questions, the knowledge base, the analysis method and the prototype implementation using KMS. In Sections Four and Five we describe the top-down and bottom-up analysis. Lastly, Section Six includes the conclusion and reasoning about the future evolution of the work.

2 RELATED WORK

According to some researches, knowledge exchange in the construction industry is based on non-developed models (Egbu and Suresh, 2008), and studies for the application of Knowledge Management techniques to the sector were developed only recently, as proven by (Alsakini et al., 2008) and (Loforte Ribeiro, 2008).

An essential aspect of that is the development of tools to support management of variables in construction processes (Argiolas and Quaquero, 2008).

Tools are being defined that could make the flow of information pertaining a construction project more efficient and univocal, outlining a new model that includes both a qualitative description of the work and its production.

It means structuring projects so that the information they contain can flow efficiently, without letting construction site the option of inferring things that could cause substantial changes. The research starts from the development of preliminary concepts, described also in (Argiolas, 2008), functional to the innovative approach introduced above. Limiting the chances of inferring, in fact, is giving an objective value to the project, which now can register all those reasoning the designer does not report for brevity's sake but that would offer a univocal interpretation to all the other professionals (designers, commissioners, builders).

It actually means borrowing the approach from the techniques of Project Management: it starts from the description of the building through a multi-level tree structure (i.e., creating a Project Breakdown Structure, PBS). This approach allows for a description where components are listed in detail, down to the most basic ones.

Currently, many international researches have been developed, using different approaches: the use of Knowledge Management techniques and the theorization of virtual models suggested that knowledge sharing and the ability to manage the whole cycle of knowledge is indispensable for the process, so that no knowledge is lost.

A hierarchical knowledge structure is defined in (Beckman, 1999), starting from information and applying it to a specific context. Contextualization of information is one of the pre-requisites of the construction sector, so approaches to safety during manufacturing (Argiolas et al., 2008), and timing and budgeting algorithms (Rigamonti, 2001; Bove, 2008), were developed with that focus.

Knowledge Management is based on information tools and cutting-edge technologies, defined and developed in the last 15 years, where knowledge has become the real added value, and as such, the real competitive advantage for those companies that choose to organize it (Tronconi, 2005).

3 RESEARCH DESIGN

Our proposed approach for knowledge formalization and management, gathered in an annotated

electronic corpus in an IR based on the OAI model, will be described below.

3.1 Research Questions

The research questions are:

RQ1: How can we manage knowledge in a construction process? Which information can be formalized?

RQ2: What types of information are more suitable as metadata, useful for search? Can these types of information be managed with a KMS?

A construction process is a very complex process, with many legal constraints and technical elements, like plans, design, construction site pictures, product data sheets, construction notes, etc.

Each construction project has many associated objects: a simple house construction project could produce 100 different objects. A more complex construction project, like that of a hospital, could produce 1,000-2,000 different objects during its life. Many of those objects are multimedia objects.

3.2 The Knowledge Base

The knowledge base started from the experience in building projects of the Department of Civil Engineering and Architecture team, which had information and objects from many real building projects. We selected for the analysis a representative subset of that project for different kinds of buildings: Hospitals, Primary Schools, Houses, University Departments, etc.

3.3 Analysis Method

We used an approach that mixed top-down, to formalize already well-defined knowledge, and bottom-up to extract information embedded in the objects produced in the construction process (Civi, 2000; McKeen and Zack, 2006).

The top-down phase started by splitting this process into subprocesses in an iterative approach, in order to define the elementary components and objects involved in the process. The analysis can work orthogonally with a breakdown process of the building objects in sub-elements.

The bottom-up phase analyzed the objects created in the construction process and the information associated to them. The objects are varied and with different kinds of information.

We started from the Knowledge Base described above, which contained several thousands of elementary objects and 80 building projects. For example, a data sheet is a document summarizing the performance and other technical characteristics of a product, component, material, in sufficient detail to be used by a design engineer to integrate the component into a system. Depending on the specific purpose, a data sheet may offer typical values, tolerance, colors. Specific materials have technical data in individual sheets, such as Ethanol: this includes subjects such as structure and properties, thermodynamic properties, spectral data, vapor pressure, etc.

We had too many basic objects to manage and we had to organize them for knowledge management purposes. Using the mixed approach, we could group the objects analyzed during the bottom-up phase in elements with a semantic meaning based on the Elementary Product concept defined in the top-down phase.

3.4 Prototype Implementation using KMS

The formalized knowledge could be managed using a KMS, using defined metadata and the multimedia objects as defined with the analysis method introduced above. Our choice has fallen on DSpace, because we had to manage many multimedia objects and we wanted to promote availability of that information also for maintenance purposes. DSpace is an open source software package developed in 2000 in the context of a joint project of the MIT2 Massachusetts Institute of Technology with Hewlett-Packard. It is a very efficient tool easy to use, customizable and flexible to allow the management, the classification and the storage of a vast amount of knowledge, as proven, for example, by University of Cagliari in the context of an industrial project that aimed to create the Analytic Sound Archive of Sardinia (Pani et al., 2012). DSpace is designed as a central storage facility able to collect various types of digital resources: text, images, video, audio, articles, technical reports, working papers, datasets, etc.

4 TOP-DOWN ANALYSIS: DEFINING THE ELEMTARY PRODUCT

The top-down phase started from the theory to split the construction process in subprocesses in a logic that uses an iterative approach, to define the Elementary Products (EP) and objects that are

involved in the different phases of the building process. We proceeded with an orthogonal breakdown of the building objects in sub-elements.

Describing the building object as a tree structure with several levels, following the top-down technique (Nepi, 1997), lead to a representation that defines all of its components down to the most elementary ones. The building object was resolved into three elements, called macro products. They were further subdivided into products and by-products, progressively less complex, to the level of desired breakdown. Such a procedure allowed us to work on smaller and smaller portions, more easily controllable and manageable, coordinated by a production simulation. The levels at the base of that hierarchical tree showed an in-depth and detailed definition of the work needed for the final product; moreover, they had an identification code that highlighted their sequential order in the structure.

The object is broken down into less complex units, until it reaches an optimal level: it is possible to operate on smaller and simpler portions (the so-called "elementary products"), coordinated through a production simulation. The optimal breakdown level appears to be the one where the elements are: flexible, interchangeable with other elementary products of different quality; identifiable, and assigned to a manager; manageable: of a determinable duration and cost; misurable in their results; significant and interfaceable in their specific requirements.

Should we make an example, it is easy to understand how destructuring and performing PBS (through production simulation) a building leads to mark the elementary products as pillars. They are included into the structure as a group of vertical elements, placed in a given position, with a given dimension, made with formwork, etc. All these pieces of information, despite belonging to the same elementary product, are not to be conveyed to every person involved in the project, but are organised in a structure through which each person can access them differently.
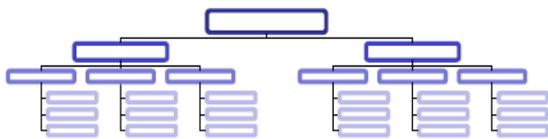

Figure 1: Tree-like breakdown (P.B.S.).

The creation of the PBS and its efficacy in a process are directly influenced by the level of accuracy used to identify all the parts of the building object. The breakdown process finishes when the
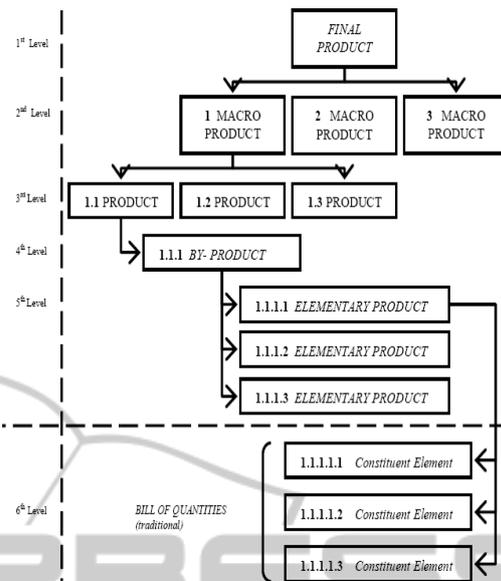

Figure 2: Hierarchical breakdown diagram (P.B.S.).

required level of appropriate accuracy is reached. It is important to remember that the breakdown level varies according to the characteristics of the work to carry out. In fact it is correct to say that the PBS can be divided into any number of levels, according to the intervention complexity. Nevertheless, if the destructuring is extreme, it is difficult to keep track of the general state of the work, particularly if it has a long-term planning. The products that belong to the lowest level of the breakdown are called elementary products (Argiolas et al., 2011).

The breakdown level, which the elementary product belongs to, allows for an effective management and control of the process in regard to the economic, time, and quality properties. So the project becomes the conception of a building object in relation to the production possibilities and methods, and to its employment and maintenance.

The elementary product, which represents the basic unit of the knowledge base, is configured as the sum of four basic knowledge units, defined as follows:

EPd: elementary design product;
EPe: elementary executive product;
EPc: elementary constructional product;
EPm: elementary managerial product.

According to the four views of the EP, the building process is divided into four phases:

1. Definition of architecture;
2. Project engineering;
3. Construction;
4. Management.

Phase 1: Definition of Architecture

Based on a set of needs expressed by the customer, the designer defines the architecture of the building object, that is broken down and described as a set of elementary design products (EPd) related to each other. In order to meet both the constraints and the needs, the technical and performance characteristics are specified. Therefore, at this stage EPds are structured as a real storage of architectural design data, information and knowledge.

Phase 2: Project Engineering

After capitalizing on the information and the knowledge about the object in terms of EPd, each identified elementary product is defined, and as a consequence, the building itself is interpreted in terms of production techniques, technologies, resources, activities, etc. EPes are structured to contain all data, information and knowledge related to this stage.

Phase 3: Construction

Thanks to the capitalization of all the information on the specific products and materials selected and used to meet performance and requirements declared in EPe, EPe evolves in EPc during the accomplishment of the building process.

Phase 4: Management and Maintenance

EPcs are reliable and updated storages of information and knowledge, and a starting point to run and maintain the building object. Building deterioration, due to time, requires a planned ordinary and/or extraordinary maintenance, and consequently it is essential to record all information related to the life of the building and to its elementary products. The EPm is the basic unit to capitalize on the information and the knowledge concerning the building management and maintenance.

The building process gradually progresses, and EPd first becomes EPe, then EPc and finally EPm. Such a development is the integration of the information and the knowledge acquired during the Project Engineering and Construction stages. The EP is the outcome of the four structures defined above. Therefore, the EP has to keep track of all information and knowledge of a specific building process, including As Built documents and feedbacks on use. With respect to this aspect, in Italy, as in most European countries, authorities require drawings of the object to be built immediately after the design phase, while as-built drawings are not mandatory after construction. However, many changes occur during the construction phase, and a lack of information on such changes makes maintaining and/or renovating existing buildings particularly difficult and onerous. Moreover, the lack of users' feedback is an obstacle to innovate and develop new and more appropriate products and/or construction criteria for future building activities.

During the whole building process, EP is the basis for all parties involved. In fact, at any time they can dialogue and cooperate, and be kept up to date about the evolution of the process in terms of elementary products. Moreover, each involved actor can modify and/or add data, information and knowledge concerning each EP. Each Elementary Product is analysed from different aspects (EPd, EPe, EPc, and EPm), that are complementary, since they represent different development stages of a specific building process.

5 BOTTOM-UP ANALYSIS: THE BUILDING OBJECTS

The BU analysis started from the objects produced in the construction process and the information associated to them. These objects are varied and rich in many kinds of information. We start to analyze these very different objects. We have many different kind of objects gathered during the different phases of the construction process, such as designs, pictures, technical sheets/specifications (tables 1 and 2), notes, etc.

Table 1: Brick wall - Technical data sheet (example).

Density	DIN 53420	Av 33 kg/m3
Compressive Strength 10% 25% 50%	ISO 3386	0.024 N/mm2 0.043 N/mm2 0.100 N/mm2
Compression Set (22h,25%, 230C) ½ Hr recovery 24 Hr recovery	ISO 1856	14% 6%
Tensile Strength	ISO 1798	0.25 N/mm2
Elongation at Break	ISO 1798	100%
Tear Resistance	DIN 53575	1.28 N/mm
Thermal Conductivity	ASTM C-177	0.038 W/mK
Water Absorption 28 days immersion	DIN 53428	0.8 vol %
Water Vapour Transmission 230C (0-85%rh)	DIN 53429	23 μg/(m2s)
Permeability	ISO 1663	10 ng/(Pa.sm2)

Table 2: PVC window - Technical data sheet (example).

Density	
(lb/in³)	0.048
(g/cm³)	1.38
Tensile Strength (psi)	10,200
Tensile Modulus (psi)	425,000
Tensile Elongation at Break (%)	36
Flexural Strength (psi)	14,000
Flexural Modulus (psi)	425,000
Compressive Strength (psi)	12,000
IZOD Impact Notched (ft-lb/in)	0.52
Coefficient of Linear Thermal Expansion (x 10-5 in./in./°F)	7.0
Heat Deflection Temp (°F / °C) at 264 psi	138 / 59
Vicat Softening Temp (°F / °C)	152 / 67
Max Operating Temp (°F / °C)	130 / 54
Surface Resistivity (ohms/square) at 50% RH	10^6- 10^8
3mm Transparent Clear Transmittance - Total (%)	69
Haze (%)	6

The analysis shows that we have a knowledge base with too much very heterogeneous associated information, multimedia information, design information, products attributes (as thermal resistance, insulating capability, etc.) and other information. All of this information can be represented using metadata, but and their number changes depending on the object which we are analyzing, as shown in the data sheets in table 1 and table 2.

The main goal of the study is to make available the knowledge also for searching purpose in a smart mode. Make a system that manage all these information can be a solution for a database of all the element involved in the construction process, but can't be a solution to manage the knowledge using a knowledge management approach. We need to manage the information at a higher level, we have to group this information in a single object and manage it as knowledge element. We use the semantic concept of Elementary Products to aggregate this information and make available the information using this level of abstraction.

The fig. 3 shows Elementary Product (as part of WBS) PVC window, which can contain the information in the data sheet of a PVC window in table 2 and brick wall which can group all the information in the table 1.

Moreover, each EP keeps, together with its attributes, different data gathered during the
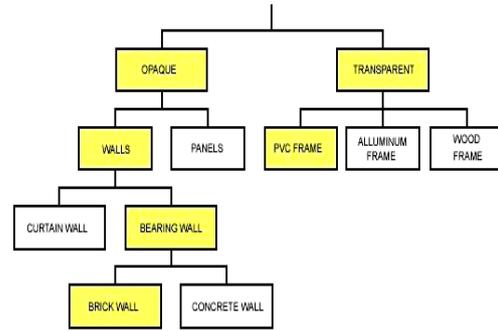

Figure 3: The Elementary Products PVC window and brick wall.

different phases of the construction process, such as designs, pictures, technical sheets/specifications, notes.

An analysis on which kind of information is actually described is then necessary. Properties, considered as attributes, which could be searched in the context are stored in two bulk metadata fields called "General Description" and "Technical Description", where the information is not managed as structured metadata, but with a free logic like in Folksonomies (what is considered more interesting is tagged). The technical sheet becomes then the tool through which information is not transformed into structured metadata but left as information belonging to an object, so that is can be searched according to the most peculiar attributes of that same object. We select only two important, according with the semantic of the Elementary Products, metadata for searching purpose: "ProjectName" and Phase. This information qualifies the Elementary Product as the Elementary Product associated with a Project Phase of a specific project, qualifying the single EP for a specific project. The other important information has to be stored in the bulk metadata fields 'General Description' and 'Technical Description'. The experts storing the objects decide which kind of information has to be stored in these fields as folksonomies.

Where "thermal resistance" is important, it is marked with a proprietary tag (like in Folksonomies) inside the general description, while most other attributes are stored inside the object. Naturally, important attributes vary depending on each case, and on each EP, so the description could show "designer name", "planning supervisor name", etc.
A simple management system is thus created, where knowledge elements are classified following Folksonomies logic, instead of structured information, but are available also full text search in these fields.

6 CONCLUSIONS

In this section we discuss the validity threats and the information gained with the analysis by providing answers to our research questions.

6.1 Threats to Validity

In the following, threats to internal (whether confounding factors can influence the findings), construct validity (relationship between theory and case study) and external (whether results can be generalized) are illustrated.

As for internal validity, we analyzed the objects and verified the structure, and the factors were all well defined and analyzed. There is no analyzed element. Regarding the external validity, the knowledge base that we used is very big and representative of the general knowledge. The analysis can be replicated on different data. Regarding the construct validity, it was assumed that breakdown of building products in the top-down phase and the analysis of objects in bottom-up phase had been applied in the case study. The results are compliant with the general theory of mixed approach to analyze knowledge.

6.2 Research Questions

RQ1: How can we manage knowledge in a construction process? Which information can be formalized?

The breakdown process of building components in Elementary Products defines the reference elements that can manage the multimedia objects.

The Elementary Product:

- is a classification that can be used to define formalized metadata;
- groups all the multimedia objects in a single semantic object;
- has associated users select information in form of Folksonomies tag;
- can be connected with other concepts like Designer, Project Manager, etc.

The Elementary Product is the core concept of this knowledge; every instance of a single building project and the construction process can be managed using this semantic concept.

The formalized information is the metadata defined for the Elementary Product.

All other information, like technical data or data sheet (a PVC window), is present in the multimedia objects associated with the Elementary Product, and the interesting information regarding the project can be represented as a Folksonomy tag.

RQ2: What type of information is more suitable as metadata, useful for search? Can this type of information be managed with a KMS?

The structural information of the Elementary Product is represented as metadata, as well as the "Project Name", "Technical description" and "General Description" where the relevant information of the project selected by the user can be found. With this approach and formalization we can manage all the relevant and embedded information using DSpace.

6.3 Discussion

The management of very complex knowledge is a big problem in Knowledge Management research; the proposed approach reaches its main goal to find a rational organization of such large amounts of information. The technical and multimedia information are very various and contain interesting information embedded. The solution proposed is based on the very interesting concept of Elementary Product, which guides the organization of the knowledge. The implementation of this formalization in a KMS like DSpace demonstrates that this knowledge base can be represented using this formalization. Further studies could analyse the results of the use of this system and the result of the experience could be used to define further interesting information that can be formalized as metadata associated with the Elementary Product.

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REFERENCES

Alavi, M. and Leidner, D. E. (1999). Knowledge management systems: issues, challenges, and benefits. *In Journal Communications of the AIS*, Vol. 1, Issue 2es, Article No. 1.

Alsakini, W., Kiiras, J. and Huovinen P. (2008). An integrated information system of a virtual construction management service company, *Joint CIB Conference W102 Information and Knowledge Management in Building W096 Architectural Management*, ISBN: 978-951-758-492-0.

Argiolas, C. (2008). Raccontando il dettaglio: ricerca e sperimentazione nel processo di produzione e management edilizio, *Lithos Grafiche Editore*, Cagliari, ISBN: 978-88-95398-04-4.

Argiolas, C., Melis, F. and Quaquero, E. (2008). Knowledge Management as a safety management strategy in building sites, *Joint CIB Conference W102 Information and Knowledge Management in Building W096 Architectural Management*, ISBN: 978-951-758-492-0.

Argiolas, C., Melis, F. and Quaquero E. (2011). Knowledge management in building process, *Joint CIB Conference W078-W102 Computer, Knowledge, Building*, Sophia Antipolis, France, ISBN: 978-90-6363-068-3.

Argiolas, C. and Quaquero, E. (2008). L'elaborazione dell'offerta economicamente più vantaggiosa. In Argiolas, C. (a cura di), L'edilizia disegnata dal Decreto Legislativo n.163 del 2006: Analisi dei punti critici per gestire la complessità, *Lithos Grafiche Editore*, Cagliari, pp. 119-147, ISBN: 978-88-95398-03-7.

Beckman, T. (1999). The current state of Knowledge Management, *Knowledge Management Handbook*, J. Liebowitz (Editor). CRC Press LCL, Boca Raton (FL).

Bove, A. (2008). Project Management: la metodologia dei 12 step, Hoepli.

Civi E. (2000). Knowledge management as a competitive asset: a review, Marketing Intelligence & Planning, Vol. 18, Issue 4, pp.166-174.

Drucker, P. F. (1996). Il grande cambiamento, Sperling & Kupfer.

DSpace, http://www.dspace.org

Egbu, C. and Suresh, S. (2008). Knowledge Mapping Techniques Within The Construction Industry: An Exploratory Study, *Joint CIB Conference W102 Information and Knowledge Management in Building W096 Architectural Management*, ISBN: 978-951-758-492-0.

Firestone, J. M. (2001). Key issues in knowledge management. In Knowledge and innovation, 1(3), pp. 8-17.

Loforte Ribeiro, F. (2008). Knowledge management in construction sites: a comparative case study, *Joint CIB Conference W102 Information and Knowledge Management in Building W096 Architectural Management*, ISBN: 978-951-758-492-0.

Maier, R. (2010). Knowledge Management Systems: Information and Communication Technologies for Knowledge Management, Springer London, ISBN: 3540714081, 9783540714088.

Malhotra, Y. (1998). Knowledge Management for the new world of business. *In Journal for Quality and Participation*, pp. 58-60.

McKeen, J. D. and Zack, M. H. (2006). Knowledge Management and Organizational Performance: An Exploratory Survey. *In Proceedings of the 39th Annual Hawaii International Conference on System Sciences (HICSS '06)*, Vol. 7.

Nepi, A. (1997). Introduzione al project management. Che cos'è, come si applica, tecniche e metodologie, Edizioni Angelo Guerini e Associati.

Pani, F. E., Lunesu, M. I., Concas, G., Stara, C. and Tilocca, M. P. (2012). Optimization of Knowledge Availability in an Institutional Repository, *International Conference on Knowledge Engineering and Ontology Development, KEOD 2012*, Barcelona, Spain.

Pani, F. E., Lunesu, M. I., Concas, G., Stara, C. and Tilocca, M. P. (2012). Knowledge Formalization and Management in KMS, *International Conference on Knowledge Management and Information Sharing, KMIS 2012*, Barcelona, Spain.

Rigamonti, G. (2001). La gestione dei processi di intervento edilizio, UTET.

Stankosky, M. (2005). Creating the Discipline of Knowledge Management, Elsevier, Burlington, MA.

Tronconi, O. (2005). Tecnologie informatiche e imprese di costruzioni, Il Sole 24 Ore.

Wiig, K. (1999). Introducing Knowledge Management into the Enterprise. *In Knowledge Management Handbook*, J. Liebowitz (Ed.), CRC Press LCL, Boca Raton (FL).