KNOWLEDGE MANAGEMENT IN BUILDING PROCESS

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ABSTRACT

Over the last few years, the management and organizational aspects of the construction process have undergone a profound reflection that is closely linked to the development and the clear changes in the market. Such market is characterized by a rapid change, a strong growth in technology, and by a widespread and transparent information. International character, knowledge and innovation are key elements to win an increasingly exasperated competition.
Moreover, the growing complexity of the construction sector - due both to the rapid proliferation of products and innovative technical solutions, and to the need to take into consideration side, but not secondary, aspects of the object (environmental impact, energy efficiency, durability, safety, etc.) - points out that present management patterns of the construction process are no longer appropriate to the context in which one operates. Therefore, the construction sector faces an inevitable process of growth in which knowledge is an indispensable resource.
The present article aims at showing how Knowledge Management techniques (KM) might represent a possible tool to assist in achieving such goals through a rational organization of large amounts of data and through a corporate use of the knowledge that characterizes the various stages of a building process.

Keywords: knowledge management, building process, interoperability, collaborative design.

1. INTRODUCTION

The amount of information and knowledge that all the involved characters need in the construction process to properly and successfully perform their duties, is always growing. For these reasons, both the logics, and the tools must be constantly updated in order to deal with the increasing complexity of the market. The building process, while still largely relying on intuition and human resources' experience, has to be rationalized through procedures and new tools that allow a strict formulation and implementation of efficiency criteria.
There is less and less time for the necessary information to reach the target. The variable *time* is becoming more and more critical and essential in managing business. Therefore, using, and systemically structuring all the information and the knowledge involved in the specific process, is fundamental in order to allow all involved subjects to easily track and use them, at any time.
From this point of view, in the management of the building process, strategies, KM, and most of all, classification elements acquire a wider range of action. Thanks to a rational organization of large amounts of data/information, and to a corporate use of consolidated knowledge, such approaches allow the implementation of a protocol to communicate and coordinate the involved subjects.
The development of a KM policy in the building process supports the decision-making process in designing, implementing and managing. In addition, KM tools favour the definition of a code and, of a complementary interface used by all the stakeholders involved at the different levels of the process.

2. STATE OF THE ART

Classification

In the first place, in order to effectively use and manage the information and the knowledge involved in the building process, it is necessary to efficaciously organize them. Classification orders the wide variety of information and, grouping each piece of information in classes, effectively employs it. "*beginning to study any problem, always try to classify what you are observing in a functional*

group of categories or general concepts which you usually relate your own opinions to" (Ciribini 1995).
All the objects to be classified have to belong to a given **domain of knowledge** and are allocated in suitable **containers** that may have single or multiple links among each other. The containers are defined in different ways: classes, sections, categories, etc..
There are three stages in classifying the knowledge of a given domain:

- selection of the classification type to use, namely the definition of the principles to employ in implementing categories;
- structure of the categories;
- application of the classification system, namely assigning a class to each object in the domain.

Faceted classification as part of the building process
The best suited classification model to manage the building process appears to be faceted analysis, since its peculiarities lie in being an open and adaptive model and, in ensuring a flexible and multi-dimensional access to information and knowledge.
Ranganathan, who created the system thanks to his Colon Classification (CC), defines *facet* any part of a composite object (Ranganathan 1967). In English *facet* is a very common word that means *aspect*. Considering that the *facet or faceted analysis* is the decomposition of a subject into different coordinates, each of which expresses one aspect, *faceted classification* could also be translated into *multi-dimensional classification,* since reality is broken down, analyzed, and classified from different points of view, even if the final object of the research is always the same (Gnoli 2004, Denton 2005). Attributes are called **facets** and possess the following characteristics:

• do not change from a semantic point of view;
• provide an open set, so it is always possible to add new facets to existing ones;
• in a search, there can be single or combined search keys/attributes.

In a multidimensional classification system, single elements are not organized in a hierarchical structure, such as in traditional classification systems, but each of them is associated with a number of characteristics that identify him through various points of view. Then a selection of these particular characteristics will point out the item or group of items to the user. In this way, the user reaches a single object not through a defined path, but thanks to several possible questions that mirror different possible points of view (Gnoli, Marino and Rosati 2006).
The faceted classification system develops more horizontally than vertically, since it doesn't lengthen the hierarchical chain, but it adds descriptive characteristics to the objects. Therefore, it is possible to infer that the facet analysis has the following characteristics:
• multidimensionality: it allows a variety of accesses and logical searches;
• order: facets are presented according to a suited and fixed sequence;
• Expandability: it allows the creation of new sections, areas and documents without forcing the organizational structure;
The faceted classification is the appropriate system to use in the following conditions:
• specific and consistent contents;
• large amount of knowledge and information;
• need to provide multiple accesses and points of view to specific contents.
Such a classification system is particularly propitious in processes that involve great dynamism and considerable changes, which are typical of the current building process; in fact, this type of classification prevents changes that can negatively affect the organization of information.
Classification in the building process
The building process focuses on the implementation of the *building system*, a structured set of elements that meet an allotted function as a whole, but each for its part. The *building system* is made up of parts correlated by a set of relations that guarantee the operation unity as regards the overall task, while allowing each part to perform its specific function in order to achieve the general objectives of the system. This means that we can consider the building structure as a domain in which elements are classified on their specific functions and mutual relations. There are already some classification systems made for this specific domain that present different structures and widening. The two most popular classification systems are: UNI 8290 and SfB system (Scapicchio 2009).

At the moment, UNI 8290, though published in 1981, is still an important point of reference in Italy, where it is extensively widespread. The purpose of such a standard has been to unify the terminology used in prescriptive, planning, designing, and operational activities that involve the building structure. This standard provides a hierarchical-enumerative classification based on a graduated decomposition of the building in: *classes of technological units, technological units, classes of technical elements.*
The SfB is an example of faceted classification, designed in Sweden after the Second World War, and spread in some northern European countries. In 1958, the IBBC (International Committee for the Classification of Construction), after taking into consideration a number of building rating systems, recommended the adoption of SfB in those cases that aim at achieving a better coordination of all the different activities and resources involved in the building process. Then the CIB, that is the advisory body of the UN, undertake the task to internationally promote the SfB. This classification system has not been used on a large scale because of its complexity while dealing with non-computerized applications. In fact, during its development, the data processing structure of classification plans was little spread. SfB system identifies some basic principles of the construction process in building activities that produce, as a result, parts of a building defined in quantities and locations. This means that its main characteristic is taking a building or a project apart. In addition, each part is examined from several points of view: elements, labours, materials, natural and building environment, activities, and requirements.
After analyzing the main types of classification systems, limiting the field of investigation to the systems that focus on building processes and structures, we have been able to evaluate advantages and disadvantages of current methodologies. The classification based on UNI 8290 immediately shows the rigidity of its hierarchical system. The sole link to a system does not allow a clear organization of the information and the knowledge related to unconventional structures. UNI 8290 cannot easily and unequivocally be applied to building structure that do not meet its model, since some elements could not be defined by any classes, and some others could suit more classes. When dealing with contemporary structures, it is problematic to classify modern housing systems since they can involve structural, closing, and plant functions. The faceted structure, as that of PC/SfB, can be more widely applied. Thanks to the implementation and the spread of data processing systems, it is possible to use a facet system to structure the knowledge involved in building processes.
Over recent years, there have been many efforts to classify and record information belonging to the architectural context. The MACE project (www.mace-project.eu) is an example of a European research that aims at creating an innovative search engine that can look for architectural contents on the Web (Zambelli, Janowiak and Neuckermans 2008). Starting from this example of excellence, our work presents a further development of the classification of knowledge and information produced during **all phases** of a specific process, and it facilitates interoperability and cooperation among the involved subjects.

3. KNOWLEDGE MAPS IN BUILDING PROCESS

The present work presents the meta-project of a knowledge map (Wiig 1999), in which relevant information and knowledge involved in the construction process are rationally organized and structured in progress. The work originates from the outcomes achieved and presented at the Symposium CIB W102 in 2009 (Argiolas, Melis and Quaquero 2009), which refer to a model that makes use of relevant and significant knowledge and information involved in major public construction. In this model, information and specific knowledge of a public building process are employed in three different maps, each linked to the specific operators of the construction process (the designer, the company, and the final user). The basic unit of all knowledge maps linked to all different actors of the public building process is the elementary product (EP), defined as follows (Argiolas and Sanna 2008):
Elementary products (EP) are obtained by analysing the building object through a Project Management planning technique (Nepi 1997) known as Product Breakdown Structure (PBS). According to a top-down technique, the building object is broken up into small components, to the most elementary ones. The resulting output is a representation of the object as an upside-down tree structure with different levels. The bottom levels of the hierarchical tree (elementary product levels) offer a deeper

and more detailed description of the work and have an identification code that highlights their sequential order within the structure.

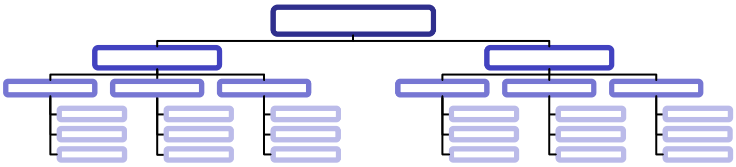

Figure 1: **T**ree-Like Decomposition (P.B.S.)**.**

Although the basic unit of the map of each operator involved in the building process is always the same (the elementary product as defined above), different types of knowledge, concerning different aspects of the same basic product, are recorded and accumulated within each map in order to fulfil different needs (Argiolas, Melis and Quaquero 2008).
The following diagram clarifies what defined above:

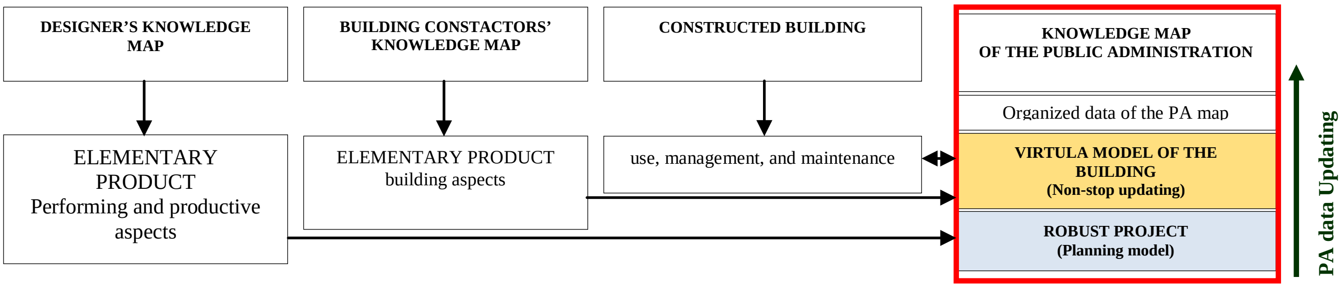

Figure 2: the contents of the organized data in the PA map

In detail:

- **The designer's knowledge map** includes the elementary products defined in their performing and productive aspects;
- **The building contractors' knowledge map** includes the elementary products solely defined in their building aspects. In fact, the building contractors aim at associating each elementary product to the activities linked to its accomplishment, in order to rationalize both resources and time and to capitalize the knowledge related to the outcomes;
- **The knowledge map of the PA** is structured on elementary products as well. It supports queries related to the decision-making stage, the project evaluations, and the control of the procedures to select the building contractors and the construction of the building. Further queries also allow to track management and maintenance aspects of the building in use.

The graph shows that, thanks to the progress of the public building process, the PA map progressively grows richer and richer of contents, registering:

- the defined requirement table;
- the preliminary documents for designing;
- what defined by the robust project (organized in a virtual model of the building);
- what capitalized during the carrying out process, and according to the virtual model updating;
- data, information, and knowledge required to the effective management and maintenance of the building;
- knowledge related to interventions carried out on the building after the accomplishment of the construction.

From these outcomes, the present article defines the development of the research developed in this area. The elementary product - the basic unit of knowledge maps of the different actors involved in the construction process – has undergone a deep evolution. It is now acquiring a new dimension, as vector that connects the knowledge maps of those involved in the specific building process. Therefore, the elementary product is configured as the sum of four basic knowledge units, defined as follows:

- EP_d: elementary design product
- EP_e: elementary executive product
- EP_c: elementary constructional product
- EP_m: elementary managerial product

Therefore, the elementary product (EP) allows four different, but complementary, points of view that all aim at implementing interlaced knowledge maps.

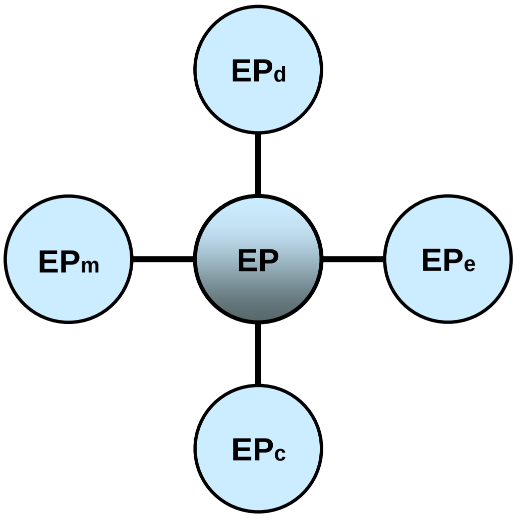

Figure 3: the four dimensions of elementary products

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

Step 1: Definition of architecture

Based on a set of needs expressed by the client, the designer defines the architecture of the building object, that is broken down and described as a set of elementary design products (EP_d) related to each other. In order to meet both the constraints and the expressed needs, the technical and performance characteristics are specified. Therefore, at this stage EP_ds are structured as a real storage of architectural design data, information and knowledge. The use of EP_d , during this specific phase of the construction process, besides allowing the capitalization of some significant knowledge, simplifies and clarifies the dialogue between designer and client.

Step 2: Project Engineering

After capitalizing on the information and the knowledge about the object in terms of EP_d, each identified elementary product is defined, and as a consequence, the building itself is interpreted in terms of production techniques, technologies, resources, activities, etc. EP_es are structured to contain all data, information and knowledge related to this stage. The use of EP_e, besides allowing the capitalization of relevant knowledge of the process, guarantees an effective integration and cooperation among all the designers involved, at various levels, in the definition of technical and technological components of the building object.

Step 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 $EP_{e.,}$ EP_e evolves in EP_c during the accomplishment of the building process.

Step 4: Management and Maintenance
EP_cs 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 EP_m is the basic unit to capitalize on the information and the knowledge concerning the building management and maintenance.
The building process gradually progresses, and EP_d first becomes EP_e, then EP_c and finally EP_m. 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. The knowledge, that is currently lost, appropriately fits into the knowledge maps implemented in the present work.
During the whole building process, EP is the basis for all parties involved. In fact, at any time they can dialogue and cooperate among each other, and be brought up to date about the evolution of the process in terms of elementary products (Argiolas, Dessì and Meloni 2006; Argiolas, Dessi and Fugini 2008). Moreover, each involved actor can modify and/or add data, information and knowledge concerning each EP. Classifying information and knowledge in the building process by defining elementary products in their four dimensions, is an effective implementation of *faceted classification model*. Each Elementary Product is analyzed from different aspects(EP_d, EP_e, $EP_{c,}$ and $EP_{m)}$, that are complementary, since they represent different development stages of a specific building process.

4. META-PROJECT OF AN INTERACTIVE KNOWLDGE MAP

The work starts from a classification of the significant knowledge and information involved in a building process. The information and the knowledge acquired during the four steps of the building process are recorded, stored, and organised in the following sections and categories:

- **EP_d** (elementary design product) **Section**

*SEC.: **DEFINITION OF ARCHITECTURE***
CATEGORY A_1:: ***building object under review***
CATEGORY $A_{2:}$ ***typology***
CATEGORY $A_{3:}$ ***hierarchical structure: identification of EP_d coding***
CATEGORY $A_{4:}$ ***requirements of identified EP_d***
CATEGORY $A_{5:}$ ***boundaries and relations among identified EP_ds***

- **EP_e** (elementary executive product) **Section**

*SEC.:**PROJECT ENGENEERING***
CATEGORY $E_{1:}$ ***production techniques***
CATEGORY $E_{2:}$ ***production technologies***
CATEGORY $E_{3:}$ ***production activities*** (including cost and time information)
CATEGORY $E_{4:}$ ***links between EP_es***
CATEGORY E_5: ***resources***

- **EP_c** (elementary constructional product) **Section**

*SEC. :**CONSTRUCTION***
CATEGORY $C_{1:}$ ***identification of the EP_cs in the market that meet the specifications of the EP_es***
CATEGORY $C_{2:}$ ***time***

CATEGORY $C_{3:}$ ***costs***

- **EP_m** (elementary managerial product) **Section maintenance**

*SEC.: **MANAGEMENT AND MAINTENANCE***
CATEGORY $M_{1:}$ ***description of maintenance***
CATEGORY $M_{2:}$ ***date of maintenance***
CATEGORY $M_{3:}$ ***techniques of maintenance***
CATEGORY $M_{4:}$ ***technology of maintenance***
CATEGORY M_5 : ***user's feedback***

Each elementary product (EP) is described and determined through a faceted analysis that defines suitable categories concerning its aspects/components (**EP_d**, **EP_e**, **EP_c**, **EP_m**). Such categories may be used as single or multiple search keys when querying and/or handling consolidated knowledge to manage new building projects.

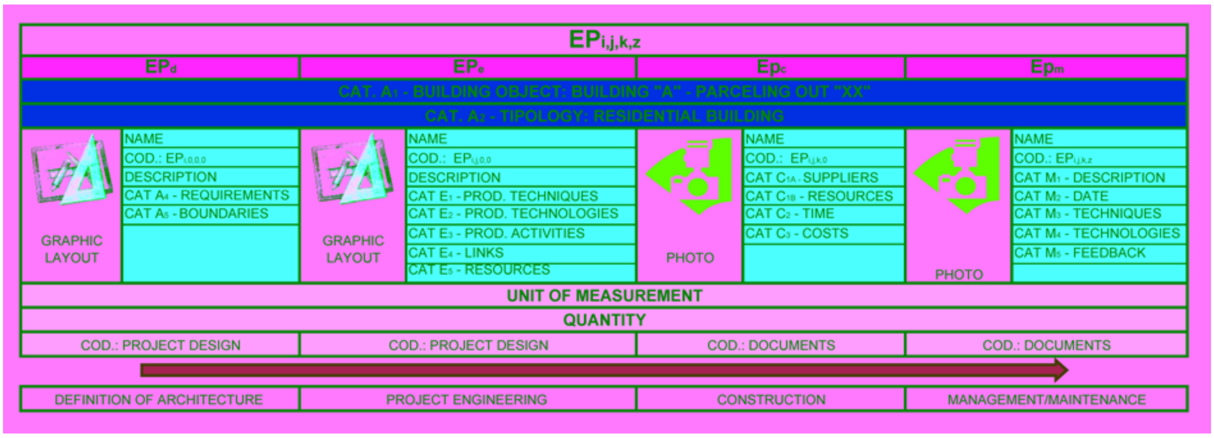

Figure 4: faceted classification of elementary products

The ability to treat and process information and knowledge used and implemented during the development of a building project, and the ability to capitalize and reuse them, are key elements to develop effective managerial forms in processes (Argiolas and Quaquero 2004). Using *Best Practice* models, the operators of the building process can rely on presumptive knowledge. In the past such practices led to successful outcomes (Argiolas, Melis and Quaquero 2008).

We now aim at defining the capitalization procedure of the different phases in the building process. We first assume that in order to carry out a building object, it is necessary to simultaneously develop the design and the construction on the stocks. Since the architectural definition stage focuses on identifying shapes and requirements of the building object, a PBS (Product Breakdown Structure) has to be implemented during it. The object is represented as an upside-down tree hierarchical structure, and therefore, as a set of elementary products. In this phase of the building process, various and different solutions for each elementary product are implemented and proposed in order to meet the client's need. All solutions are recorded in the knowledge map as valid answers, even if only one will be chosen. The implemented EP_ds are represented by a code, and only the null index is the first one (Example: EP $_{2,0,0,0}$). In the next phase (project engineering), the actors involved in the technical and technological definition of each elementary product, implement one or more possible solutions, each satisfying - in different ways - EP_d specifications. Therefore, all defined solutions are recorded in the knowledge map, even if only one is carried out. EP_es - basic elements of the project engineering phase - are identified by a code, and only two are *null*: the EP_d of origin and the second one (Example: EP $_{2,3,0,0}$). During the construction phase, the elementary product is enriched with all the basic information and knowledge to be carried out on the stocks. The EP_c records all the involved knowledge and information to implement an elementary product that complies with the EP_d and EP_e prescriptions of the previous stages. The EP_c code has three null indexes: the first and the second respectively match the EP_d and the EP_e of origin while the third univocally identifies the specific EP_c

(Example: EP $_{2,3,1,\,0}$). After the construction phase, the operation and management/maintenance phase of the building object begins. At this stage, the elementary product records the types, the chronology and the feedbacks of ordinary maintenance over time. Therefore, the final user's knowledge map appears to be an ordered list of actions, performed on each elementary product of the final building object. In this stage, EP_ms are recorded in the map as four null indexes: the first three respectively match the EP_d, the EP_e, and the EP_c of origin, while the fourth refers to the chronological sequence of a specific maintenance intervention on the elementary product (Example: EP $_{2,3,1,1}$).

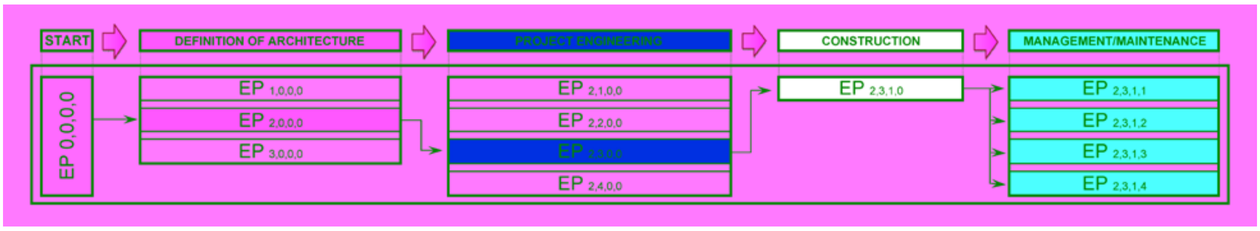

Figure 5: EP evolution during building processes and record of the involved information and knowledge

The distinctive feature of the present work depends on the fact that, unlike the achievements presented at the Symposium CIB W102-2009, the knowledge maps of the different actors involved in the specific building process are interlaced. The elementary product operates as a key element that allows the communication and the connection of different maps. And, for example, this enables the architectural design of an EP_d map to acquire further information and knowledge on a product, not only in terms of basic requirements and performances, but also in terms of technical and technological solutions already developed and successfully implemented (best practice). In other words, each operator of a specific building process has free access to all sections of the involved operators' knowledge maps, since they detail and explain complementary aspects of the product that he himself contributed to achieve.

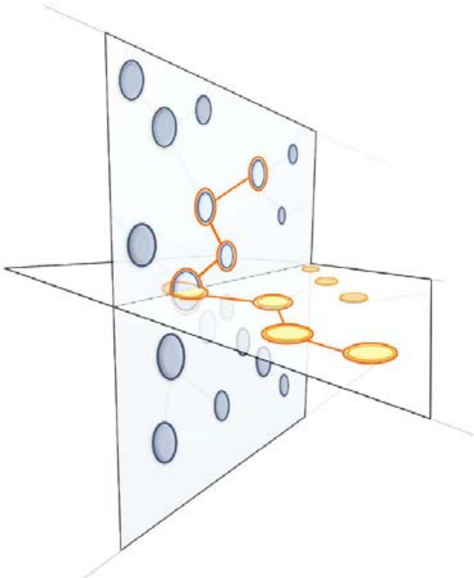

Figure 6: **I**nterlaced Knowledge Maps

Interlaced maps bring significant advantages, not only tracing - thanks to the review of previous building projects – useful information and knowledge to deal with new projects; but also during the development of a specific intervention. In fact, map-connections favour a great synergy among the operators themselves, since they can benefit from an effective communication channel.

CONCLUSIONS

Although at the moment there are many efforts to rationalize, list, and classify architectural domains, such efforts mostly focus on classifying information and knowledge on the finished building object. The current work aims at integrating different approaches: structuring knowledge maps in order to record, classify, and capitalize on the significant information and knowledge involved in **all** phases of the process.

In details, the benefits of the present work are:

- The implementation of an effective coordination of all the various operators involved in the construction process, and the clear identification of areas of actions and responsibilities;
- Supporting management, while dealing with a new intervention, with a free access to a historical database of successful interventions;
- optimizing and tracing processes. The partial outcomes of the different stages of the process are structured, organized, and capitalized during the process itself and, in case of non-conformity, it is easily possible to track causes and responsibilities down.

Being construction operators and domain experts, our work focuses on structuring the contents of the knowledge maps, leaving to developers and programmers the implementation of the related software parts. In fact, the EPs, developed and codified thanks to ICT tools, can be configured as carriers of information and knowledge throughout the whole building process, providing a comprehensive interface, that is not only concise, but also univocally interpretable by all the involved parties.

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