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eLearning for knowledge management in collaborative architectural design

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Energy and environment concerns and budget cuts are determining an increasing complexity of requirements, constraints, and regulations in the field of Architecture, Engineering and Construction (AEC), as well as in other domains, such as aeronautics, automotive, and more. As a consequence, the amount of information required to take decisions and for a reciprocal understanding among actors increases accordingly. If the resulting problem of knowledge management is not managed properly, either the design cost grows or a portion of the required knowledge is not taken into account, and the quality of the resulting solution decreases. In order to avoid mutual misconceptions and incomprehension, the actors participating in a collaborative design activity play interchangeable roles of teacher (explaining own methods and necessities) and learner (importing the teaching-colleague's knowledge into her individual settings). In this paper we propose to adopt eLearning methodologies and technologies in order to support knowledge management in collaborative architectural design. Enhancing collaborative design with eLearning would help to break the "symmetry of ignorance", to make the mutual awareness experience more supported and the result of the collaborative work more reusable.

Keywords: collaborative architectural design, eLearning, design methodologies, knowledge management

1 Introduction

With the developments in Web and Web2.0, Computer Supported Collaborative Work (CSCW) and, in general, groupware applications have become increasingly widespread in all branches of research and industry, for both work and learning. Collaboration is nowadays recognized as the key to success in design and implementation of industrial endeavours, fostering productivity and satisfaction. It is subject, though, to those problems deriving by misconceptions, prejudice, ignorance and miscomprehension that can occur in groups working over the internet. CSCW has spread around, in spite of such problems: the main reason is in the increasing complexity of the information to be managed, and of the demand for needed interactions among the members of a project.

In collaborative architectural design there is a common effort of various actors sharing a final goal: this requires exchanging information and knowledge in any stage of the process.[1] Architectural design tackles energy and environment concerns, higher safety demand, and budget cuts: these imply an increasing complexity of requirements, constraints, and regulations. As many disciplines conceive higher and higher standards to the performances of modern buildings, there are corresponding higher expectations and demands by several stakeholders.

The expression "sustainable design" usually concerns the artefact being conceived, but there is evidence that the sustainability of the design process itself is becoming an issue. In fact, together with requirements, there is a corresponding increase of both the amount and fragmentation of information required to take decisions. Hence, in the building industry (as well as in other domains), a more complex design activity involves a larger number of actors, with different expertise and capabilities, each contributing to the final design.[2]

1 **Carrara G.** & **Fioravanti A.** (2007). Collaboration - new media - design: An integrated environment for supporting collaboration in building design. In 5th International Workshop on Challenges in Collaborative Engineering, CCE'07, pp 143–160

2 **Kvan T.** (2000). Collaborative design: what is it? Automation in Construction, 9:4, pp 409–415

3 Kalay Y.E. (1999). The future of CAAD: from computer-aided design to computer-aided collaboration, Proceedings of the 8th International Conference on Computer-aided Architectural Design Futures, pp 14–30
4 Aalst J. van (2009). Distinguishing knowledge-sharing, knowledge-construction, and knowledge-creation discourses. International Journal of Computer-Supported Collaborative Learning, 4, pp 259–287
5 Carrara G. & **Fioravanti A.** (2002). 'Shared Space' and 'Public Space' dialectics in Collaborative Architectural Design, Proceedings of Collaborative Decision-Support Systems Focus Symposium, InterSymp, 14th International Conference on Systems Research, Informatics and Cybernetics, Baden-Baden, pp 27–44
6 Dourish P. & **Bellotti V.** (1992). Awareness and coordination in shared workspaces. In: Mantel M. & Baecker R. eds, Proceedings ACM conference on computer-supported cooperative work, New York, NY, pp 107–114
7 Brusilovsky P. & **Millan, E.** (2007). User models for adaptive hypermedia and adaptive educational systems. In: Brusilovsky P.et al eds, The Adaptive Web: Methods and Strategies of Web Personalization, LNCS 4321, Springer-Verlag, Berlin, pp 3–53
8 IEEE (2002). Learning Technology Standards Committee. Draft standard for learning object metadata, IEEE 1484.12.1-2002
9 Chatti M.A. et al (2007). The future of

If we regard the flow of information among the actors, these are the peers of a communication process underneath the design process. While there is a need for mutual awareness among the peers (sharing each other knowledge and viewpoints), it is not desirable that all the information flowing in the process is uniformly shared among all such actors. First of all, the amount of time required to explore this information would increase accordingly. Secondly, the design of a building is typically undertaken by assembled teams, with experts having conflicting needs and different background:[3] in such competitive environments, people may be not naturally inclined to share knowledge.[4] Rather, a reasonable choice is to have a shared design space with a contribution by all actors and a private design space owned by each single actor.[5]

CSCW research deals with problems of knowledge management in group activities. In particular, group awareness is considered a crucial point to allow all actors for a better grounded and productive collaboration.[6] One key factor is often the application of organization methods based on the working/cultural context in which the collaboration takes place.

One powerful way to avoid misconceptions, though, at least in a context in which collaboration is sought, is in the possibility to have the other party to understand your needs and demands (related to the precise accomplishments of your task); therefore the actor has to *explain* the reasons for such needs and demands, and in short her professional point of view, to the other party. This involves the selection, and the organization, of suitable material, in such a way for it to be effective in communicating certain information goals to the other party (personalizing, to some extent, the actual content of the communication).

Certain aspects of the above evocated problem are actively studied in the field of eLearning, namely, 1) the area of personalized and adaptive eLearning studies the problem of how to select and present learning material suitable for the individual characteristics and traits of each learner,[7] and 2) the management and retrieval of learning material (organized in *learning object*s) can be based on *standards for eLearning*.[8]

In the last decade, eLearning has evolved, together with the web technology and applications, to comprise a wide variety of features: from the (original) dissemination of instructional resources, to the personalization of adaptive delivery of learning content, to the support to social and collaborative learning, summing up in the development of truly knowledge management approaches, for both formal and informal learning and knowledge. One aspect of the eLearning applications, especially those fostering social and group collaboration, is in that they are devised not solely to disseminate (or to implant) information: they actually allow to create new knowledge, by collaboration and combination and known knowledge in the learners' (and teachers') environment.[9] The constructivist approach to instruction, which is supported by modern eLearning, considers that knowledge is recreated and created through experience and by the interaction between learners (and teachers), and their collaboration.[10 11]

Bringing eLearning methodologies and technologies in the field of organized work is quite straightforward. The idea that the organization process of knowledge can't limit just to store and retrieval dates well back in time:[12] that process is in fact deemed to create accommodations and management of available knowledge, and so to the creation of new knowledge. Moreover, an organiza-

tion's knowledge management process should produce competitive advantages, out of such new knowledge creation, and eLearning appears to be a good asset to use towards that aim.[13]
In this paper we discuss how eLearning methodologies and technologies can be used to represent and exchange information among actors involved in a design process. In fact, eLearning comes with powerful methods and tools that are suitable to support relevant aspects of the design process in Collaborative Work Environments. We mainly address design in the context of Architecture, Engineering and Construction, but similar considerations apply in other domains, where concurrent design is a common practice, as well.
In the next sections we discuss facets of eLearning and collaborative work that may provide a suitable support in the design process. In section 4 we discuss the possible role of eLearning beside several concepts that have been proposed by the recent literature in architectural design and propose a role of eLearning by integrating this technology with other approaches to knowledge management.

2 eLearning Methodologies and Technologies

ELearning is the general branch of research and application dedicated to have learning (and teaching) activities organized and executed through the internet. Usually those activities are performed using web browsers and services, and we talk of web-based eLearning.
Through eLearning "teaching users" can produce, organize, exchange learning material, with the aim to build courses out of it, and "learner users" can have their course (possibly personalized), study the content, interact with the teachers and other learners, and perform learning experiences, hopefully as fruitful and productive as the traditional/face to face ones are. eLearning can offer its users opportunities such as studying at one's pace, and at workplace, and sometimes it can be the only available option, when learners cannot be part of a face to face class. While pedagogical aspects are most important in eLearning, there are some technological and organizational features that actually make eLearning possible and we give brief descriptions of some of them in the following.
One first aspect, that is to be cared of when eLearning has to scale up to the level of effective and widespread systems, is the organization and partition of the learning content into Learning Objects (LO). A LO is a *resource*, containing a chunk of learning content and activities and a formal specification for such material. The content will be the actual material taken by the learner during a course and it can be any kind of material suitable to convey a learning experience via web: Java applet, Flash animation, audio/video clip, web page, pdf documents and some more. LOs are organized in repositories, from where they can be selected to make a course, possibly a course dedicated to the single individual student (a *personalized course*). A course is then a collection of LOs, each one providing a part of the overall learning experience, devised for the learner.
A Learning Management System (LMS) is a software (web) application that allows the users (both teachers and learners) to perform the activities relevant for the organization and management of courses (define LOs, build courses, support the enrolment of learners in courses, monitor learners' learning activities and performance, and interact with them). As an example of LMS we may consider Moodle.[14] LMSs are numerous and varied, though: they may be anything from

eLearning: A shift to knowledge networking and social software. International Journal of Knowledge and Learning, 3:4-5
10 Piaget J. (1926). Language and thought of the child, Harcourt, New York
11 Vygotskij L.S. (1978). Mind in society: the development of higher psychological processes. In: Cole M. et al eds, Harvard University Press, Cambridge, MA
12 Nonaka I. (1994). A dynamic theory of organizational knowledge creation. Organization Science, 5:1, pp 14–37
13 Qwaider W.Q. (2011). Integrated of knowledge management and eLearning system, International Journal of Hybrid Information Technology, 4:4, pp 59–70

fully proprietary – commercial – software systems, to open source software. This means that each LMS may in principle support the above mentioned activities, and in particular the delivery of the course and the interaction among users in it, in its own different manners. So a course prepared in a given LMS can be hard to export for giving it through another LMS. Standards for eLearning are a well established answer to the above problems; they have been developed to give an "industrial momentum" to the sector of eLearning, by supporting qualities:

- *reuse* of the same LOs in different courses on different LMS platforms;
- *durability* of the whole eLearning setting of a course (content and procedures to access it); this means that there will be no need to modify the course content, in order to comply with new formats depending on a new software version of the platform;
- *interoperability*, i.e. the possibility to move a course from a platform to another without significant changes in the users' interaction;
- *accessibility*, that is the possibility to exploit the patrimony of LOs produced throughout the world, by having them collected into organized repositories and available to "search and pick" operations by the part of the interested teachers

Besides IEEE, an example of standard for eLearning is provided by the ADL initiative (Advanced Distributed Learning, originally established in 1997 by the US Department of Defense), aiming in fact to integrate several standards, that proposed the SCORM (Sharable Content Object Reference Model) specification.[15 16]

2.1 Personalization, adaptivity and collaboration in eLearning

In the area of web-based distance learning, personalization of the learning experience is one of the key factors to reach good quality and effectiveness. Learners are different in several respects: they may possess different skills, varied knowledge on the subject matter at hand, different learning aims (what should be gained through the course); they may have different and differently firm motivations; cultural aspects may tax, or ease, a learning approach.

Learning styles may be different as well.[17] If the learning path is personalized with respect to the above individual traits, in both aspects of the content and its pedagogical approach, the content itself might be better comprehensible by the learner, it could be perceived by the learner as more relevant to her, and acceptable; this might increase motivation and active collaboration during the learning activity, and in general originate beneficial effects on learning efficiency and learner's satisfaction. So, given a common subject matter, and possibly common learning aims, the courses taken by the individual learners may differ, according to personal traits. Yet personal traits may change during the course, as en effect of the learning experience that is being conducted by the learner; so the further frontier of personalization is adaptation, that is the process of a course being continuously "adapted" to the changing model that represents the learner in the system, and its content and pedagogical approach being changed "during the course". Such a quality of eLearning is so much attractive and useful, that a great deal of research work is dedicated to methodologies and technologies for automated construction, maintenance and delivery of adaptive eLearning courses.[18 to 20]

Web-based cooperative and collaborative learning can improve eLearning considerably. By the former we mean, traditionally, the interaction in a well-

14 moodle.org
15 IEEE (2002). ibid
16 www.adlnet.gov/Technologies/scorm
17 Felder R.M. & **Silverman L.K.** (1988). Learning and teaching styles in engineering education, Engineering Education, 78:7, pp 674–681
18 Wolpers M. & **Grohmann G.** (2005). PROLEARN: Technology-enhanced learning and knowledge distribution for the corporate world, International Journal of Knowledge and Learning, 1:1-2, pp 44–61
19 Limongelli C. et al (2009). Adaptive Learning with the LS-Plan System: a Field Evaluation, IEEE Transactions on Learning Technologies, 2:3, pp 203-215
20 Limongelli C et al (2011a). The Lecomps framework for personalized web-based learning: a teacher's satisfaction perspective, Computers in Human Behaviour, 27:4, pp 1310–1320

structured framework, mainly with the aim of producing a deliverable, possibly through plain and planned division of the work activity; usually, instead, collaborative learning is related to more loosely structured interactions, in which possibly clear roles and responsibilities are not directly pre organized.[21 22] As a matter of facts the above terms are often mixed and exchanged, and there is a wide set of commonalities between them,[23 24] so in this paper we use the common term of *collaborative eLearning*. As examples of the mentioned commonalities, we may refer to the learner and the teacher being involved in active and sharing experiences, the teacher being in a role of facilitator, the learners standing in a role of co-worker in group activities.

3 Mutual Awareness in the Context of Collaborative Work: a working hypothesis

In computer supported collaborative work the maintenance of group-workspace awareness is crucial in order to make the work effective; awareness here is intended as mutual comprehension of collaborative, cognitive and organizational aspects of the shared activities.

Dourish and Bellotti define group awareness as "an understanding of the activities of others which provides a context for your own activity"; if a good level of awareness is shared, one's activities are well integrated with others' contributions and allow scaling up towards group goals.[25]

As a matter of facts, the interacting project members are usually *different* persons, in particular because they have different backgrounds and ways to express themselves (for one thing, they are specialist each one in their own subject area). Such differences might induce difficulties in mutual comprehension and understanding during the collaboration. In other words, the interaction among members of the group might suffer of contextual unawareness, where the context is the professional and cultural framework that characterizes the individual person.

A solution to such difficulties is in adding to the collaborative environment a subsystem able to let different people to share their knowledge, with the aim to ultimately explain one individual's knowledge and needs/demands in terms comprehensible for the collaborating counterpart.

This solution can be implemented through the services of a modern eLearning system, where:

- information, related to the context and methods of work in the subject area of a group member can be stored as several learning objects in a repository;
- the learning objects may be either defined, or collected out of other repositories, by the member, who, in turn, gives recognition to them;
- learning paths can be built, possibly in an automated and personalized fashion, for the individual member, in order to give her the means to get suitable knowledge about the subject area of the other collaborating member.

In the following we lay down an example, referring to Figure 1, of the interaction occurring between two persons, "a" and "b". The former comes from the disciplinary realm *A*; the *A* world of knowledge is projected into "a"'s personal background, and influences it strongly. For person "b" dual considerations hold (respective to realm *B*). Instructional material, about the realm *A*, is available in repository "*A kb*"; this material is accumulated with the aim to provide answers to a wide span of learning needs, allowing to select learning content adapted to

21 Panitz T. (1997). Collaborative versus co-operative learning: comparing the two definitions helps understand the nature of interactive learning, Cooperative Learning and College Teaching, 8:2, pp 68–74
22 Slavin R. (1990). Co-operative learning: theory, research, and practice, Prentice-Hall
23 Kirschner P.A. (2001). Using integrated electronic environments for collaborative teaching/learning. Research Dialogue in Learning and Instruction, 2:1, pp 1–10
24 Kreijns K., et al (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: a review of the research, Computers in Human Behaviour, 19, pp 335–353
25 Dourish P. & **Bellotti V.** (1992). ibid

the individual learner characteristics, where such characteristics do comprise her professional context (her base disciplinary realm).

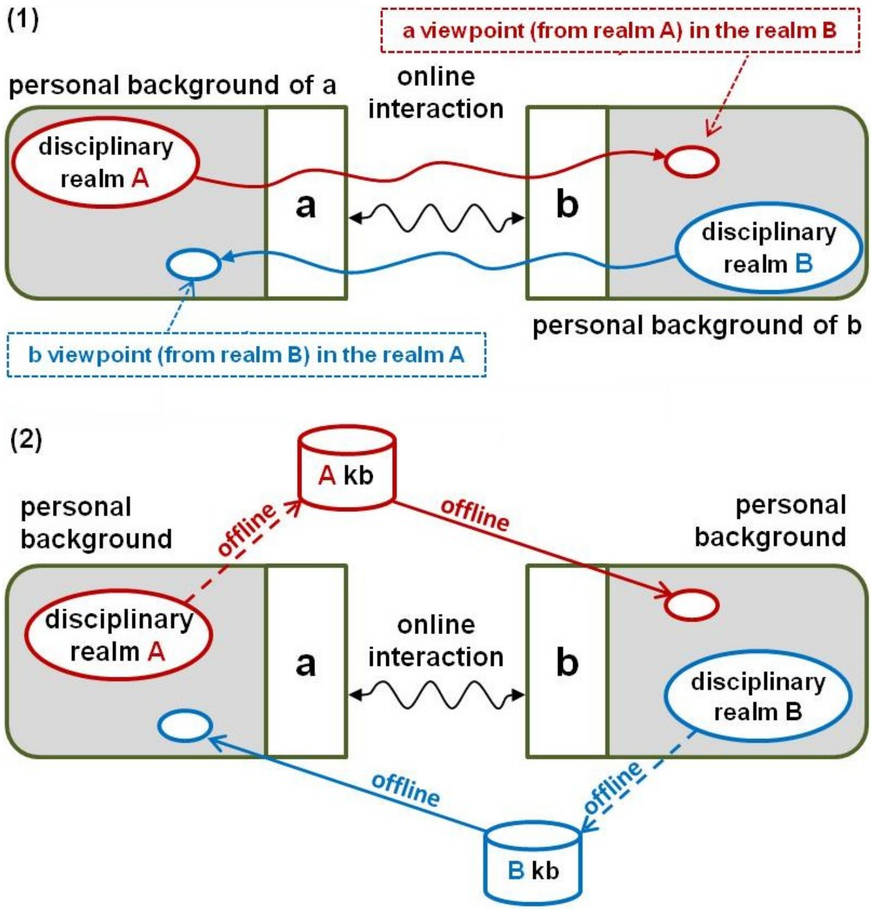

Figure 1 Enhancement of mutual awareness between "a" (member of the disciplinary realm "A"), and "b" (from realm "B"). In the situation (1) no support is given to the development of mutual awareness: "a" and "b" can exchange and understand knowledge about each other realm, by interacting online. Such interaction, if it is sufficiently consistent, allow the actors to develop each one's viewpoint of the other's realm. In the situation (2) an eLearning based support is assumed: the learning activities are personalized also with respect to the base realm of the learner: for instance "a" learns about the realm "B", not only on the basis of interactions with "b" (that could just be absent) yet having suitable learning material selected automatically for her, on the basis of her personal skills, characteristics and disciplinary realm.

The process of collaboration in a common working design environment comprises interactions between the actors "a" and "b" and must involve phases of mutual exchange of information and instruction (that is teaching and collaborative learning activities). There are in fact many "disciplinary realms" involved in the whole design work, yet, for the sake of simplicity, we here take into consideration only "a" and "b", as members (representatives) of two of such many realms. So "a" and "b" share the need to expound and understand the specification of what they require of - and must provide to - each other.
In this process, "b" is supposed to explain her needs and demands also in terms that are familiar to the recipient of such requests ("a"). Having such ability implies that "b" has knowledge of what and how something can be expected by "a". In turn, the acquisition of such knowledge should have taken place according (and adapting) to the professional background of "b". Similar considerations can be done about "a". Indeed this process of support to mutual understanding and

awareness implies features of high adaptivity and personalization, ranging from the "usual" individual characteristics (such as knowledge and learning styles) to the professional context of learner's prior knowledge.

If no previous knowledge is available, it is the raw interaction between "a" and "b" that provides each one with a viewpoint of the other's disciplinary realm. This is what happens in part (1) of Figure 1, where no eLearning support is supposed to exist. There are disadvantages in this approach: interaction, for one, has to happen; that means that "a" and "b" must be available to meet and discuss with the purpose of giving each other a viewpoint of their own disciplinary realm, and they must be able and willing to interact. Moreover, this process has to be repeated by each one for all the project members they have to keep in touch with.

Part (2) of Figure 1 depicts the situation once an eLearning support is available. In this case it is expectable that each one of our project members has contributed to the definition of a repository of learning material, from where the other can get the information useful to build her viewpoint in the other disciplinary realm. It is not actually important to state how the repository *A.kb* has been built: it is most likely that it has been defined by someone else than "a", yet "a" might have participated in establishing it, or enriching it. What is really important here, is that "a" has recognized *A.kb* as a suitable means to help "b" to understand some part of the realm *A*, and that communication between "a" and "b" will be better after this training has taken place.

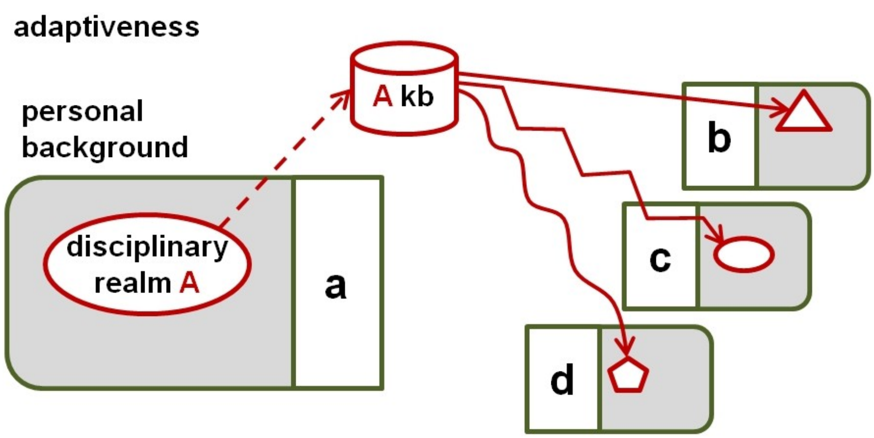

Figure 2 The repository A kb, of learning knowledge for the disciplinary realm A can comprise learning material devised and/or endorsed by the project members joining in that realm. This material can be suitably redundant, allowing to cover the needs for learning coming from members of several realms other than A. Once a "b", from another realm, is deemed to learn about A, the learning material suitable for the creation of "b"'s viewpoint about A can be selected (possibly automatically) from A kb, and build a learning path that is tailored over "b"'s personal characteristics, also those derived by her professional realm.

So, the informational (learning!) needs of "b" ("a") about the realm *A* (*B*) could be accomplished by having a suitable course prepared from the *A kb* repository and properly served to "b" ("a"): the whole process can be supported by eLearning methodologies and technologies; the course can be built and administered offline (outside of the actual performance of collaborative work), and it is even possible that parts of the course are administered, during the work span time, when the occasion demands for it. Then, any further communication between "a" and "b" can be 1) facilitated by the underlined share of mutual awareness, and 2) fruitfully dedicated to the project work themes, rather than to earlier instructional aims. In this way, what is expected is that the actual interpersonal relationships

and collaboration would be more efficient, with lower probability of mutual misconceptions to hold, and misunderstandings to happen.
One further advantage of the above described scenario is in the possibility of *re-use*, which is implied by the eLearning approach: the learning material collected in the repository, say *A kb*, can be a varied collection of learning objects, each subset of them suitable for different "target realms". So, whenever a new project member "c" is coming to interact with "a", having background knowledge in the realm *C*, (s)he can be helped in developing a viewpoint on the realm *A* by selecting, possibly automatically, a set of learning objects from *A kb*, appropriate to realm *C* and to the related different learning needs (Figure 2).

4 eLearning and Knowledge Management in Architectural Design

ELearning has become a mature discipline where established methodologies, technologies and standards provide convenient support for *delivering* knowledge. In this section we will show how eLearning can support knowledge *management* within collaborative working environments, with an exemplification on the eminent area of AEC. We figure out a scenario – with no experimental result – where eLearning can leverage toward the final goals of a design activity: more effectiveness (better quality of the final result), more efficiency (fewer resources required for the given target).
ELearning has been proposed as an instructional tool in architectural design. In particular it has been used in order to capture events and choices in a (pseudo)real design process and – later – to bring the learners in the context of a typical design activity. Collaborative games have been devised in order to challenge students with choices in a collaborative design environment.[26]
Software tools supporting a teaching-training design methodology have been explicitly considered in order to enhance the quality of the architectural design.[27]
ELearning techniques are adopted together with other interactive and collaborative methods in order to set up "blended learning" environments.[28 29]
Rezgui et al provide a critical overview of knowledge management approaches in the AEC industry, and highlight the potential impact of ICT and KM on projects and innovation in this sector.[30]
A discussion concerning Cooperation, Coordination, and Collaboration in a design activity is proposed in.[31] Collaboration implies a joint problem solving, with shared goals. In a complex design activity participants teach and instruct each other.[32]
Marshall et al observe that educational systems and knowledge management systems are similar, in the sense that both involve the creation of useful knowledge from the available resources; in particular, they use eLearning tools in order to visualize a knowledge representation: hence, interestingly, they exchange the roles of goal and tool that we propose in the present paper.[33]
In their seminal paper analyzing new educational models for superior education, Scardamalia et al discuss the notion of knowledge-building communities.[34] They observe that these determine a situation of a second-order environment: in this case "learning is not asymptotic because what one person does in adapting changes the environment so that others must readapt [...]; continued adaptation requires contributions beyond what is already known, thus producing non-asymptotic learning". We observe that, in a truly creative design activity, new

26 Carrara G. & **Fioravanti A.** (2006). A Game of Collaborative Architectural Design: The Birth of c-House, InterSymp, International Conference on Systems Research, Informatics and Cybernetics, Focus Symposium on Advances in Intelligent Software Systems, Baden-Baden, Germany
27 Fioravanti A. (2008). An eLearning Environment to Enhance Quality in Collaborative Design, 26th eCAADe Conference Proceedings, Architecture 'in Computro', Antwerp, Belgium, pp 829–836
28 Spigai V. & **Stefanelli C.** (2005). Collaborative eLearning in architectural design, knowledge sedimentation in atelier activity and virtual workshop, IUAV - experimentation 2002-2004, CIB W78, 22nd International Conference on Information Technology in Construction
29 Hu W. et al (2010). Collaborative web-based e-learning environment for information security curriculum. International Journal of Human and Social Sciences, 5:7, pp 468–471
30 Rezgui Y. et al (2010). Generations of knowledge management in the architecture, engineering and construction industry: An evolutionary perspective, Advanced Engineering Informatics, 24:2, pp 219–228
31 Kvan T. (2000). ibid
32 Fischer G. (2000). Symmetry of ignorance, social creativity, and meta-design. Knowledge-Based Systems, 13:7-8, pp 527–537
33 Marshall B. et al (2003). Convergence of knowledge management and eLearning: The

knowledge is being built: this is the definition of a new artefact. In this view, a heterogeneous design team falls within the notion of "knowledge-building community". We remark that the considerations above apply regardless of the support of information technologies.

Along the years, several authors have considered together eLearning and knowledge management. Many of these contributions pay attention to the study of knowledge creation and transformation in collaborative design environments proposed in.[35] In their vision, analyzing the effectiveness of the design activity in Japanese industries, knowledge can be either tacit ("how-to") or explicit (suitable of a computer-based representation). They propose a cyclic "SECI" model with four knowledge-processing stages:

- Socialization (where tacit information is exchanged among the actors)
- Externalization (tacit information is translated to explicit)
- Combination (of explicit information), 4. Internalization (explicit information is translated to tacit).

Starting from this model, Woelk and Agarwal,[36] and – more explicitly –Woelk,[37] discuss the adoption of eLearning for knowledge management, and show how this has an impact on the business performances of organizations.

Simon discusses how organizations learn in these terms: "all learning takes place inside individual human heads; an organization learns in only two ways: (a) by the learning of its members, or (b) by ingesting new members who have knowledge that previously the organization did not have".[38] The transmission of information from one organizational member or group of members to another is a crucial issue. Starting from these considerations, we argue that if an organization could rely upon an explicit representation of the knowledge of its members, then this is a possible way to make it permanent (so that it can be transferred to others, at any time – i.e., "offline").

This brings us to what kind of design-related knowledge can be effectively managed. Recording activities of design meetings has been one of the motivating goals for adopting IT technologies in Collaborative Working Environments. But the birth of ideas and decisions does not take place necessarily in the meeting where those ideas and decisions are officially presented. In many cases, as observed in Lilley et al, "Meetings can thus be highly strategic affairs, with participants engaged in skilled rhetorical performances to secure their own objectives".[39] Even in the best case, where an inspiring business meeting was actually the source of a good idea (an example of social learning), a recording of that meeting may have its intrinsic value, but it could be not the best source of knowledge for those who need to understand and learn that idea. For sure, a recording lacks the adaptability to different learning needs.

The adoption of *ontologies* has been devised as a base for knowledge sharing.[40] Basically ontology is a collection of words, relationships, meanings: a representation that must be both readable (for humans) and formally defined (for computers). Ontology contains all the terms relevant to a given domain, and grows as new concepts are defined, based on existing concepts and on relationships among them. From the human side, ontologies are navigated by means of simple tools, adopting both textual and graphic metaphors which allow the user to navigate, inspect and possibly edit the content. From the computer side, the connection that allows machines to use and exploit ontologies is constituted by the

getsmart experience, Joint Conference on Digital Libraries, IEEE Computer Society, Los Alamitos, CA, USA, pp 135–146

34 Scardamalia M. & **Bereiter C.** (1994). Computer support for knowledge-building communities, The Journal of the Learning Sciences, 3:3, pp 265–283

35 Nonaka I. & **Takeuchi H.** (1995). The Knowledge-creating Company: How Japanese Companies Create the Dynamics of Innovation, Oxford University Press

36 Woelk D. & **Agarwal S.** (2002). Integration of eLearning and Knowledge Management. In: Driscoll M. & Reeves T. eds, Proceedings of World Conference on eLearning in Corporate, Government, Healthcare and Higher Education, Montreal, Quebec, Canada, pp 1035-1042

37 Woelk D. (2004). eLearning Technology for Improving Business Performance and Lifelong Learning. In: Singh M.P. ed, The Practical Handbook of Internet Computing, Chapman Hall & CRC Press

38 Simon H.A. (1991). Bounded rationality and organizational learning, Organization Science, 2:1, pp 125–134

39 Lilley S. et al (2004). Representing organization: knowledge, management, and the information age, Oxford University Press

40 Gruber T.R. (1995). Toward principles for the design of ontologies used for knowledge sharing, International Journal of Human-Computer Studies - Special issue: the role of formal ontology in the information technology

metadata, such as the tags that labels tables and fields in any data collection.
Far to be alternative to ontologies, eLearning can be considered an exploitation tool for ontologies: as an example, some authors have considered eLearning as a possible user interface to explore ontologies.[41]
Ontologies are a static detailed representation of information and, far better than a flat glossary, may provide a valuable reference, but – again – are not suitable as a unique source to learn a topic.

4.1 Managing the complexity of the design process

In the design of a complex artefact, such as in the building industry, it has been argued that we have an increasing complexity of the resulting product and hence a corresponding increasing complexity of the design process. Beautiful pages by Herbert Simon discuss the *bounded rationality* of individuals;[42] this notion provides evidence that the processing capability of human mind does not grow with the needs. Hence, a more complex design context requires more knowledge than a single person can process, and results in a corresponding growth of the *"symmetry of ignorance"*.[43]
The Building Information Model (BIM) has been proposed by leading CAD firms; a BIM model defines geometry and attributes of a building and its parts throughout its life cycle - hence the reference to "4D", where the fourth dimension is time. Another relevant achievement for collaborative architectural design has been provided by the Industry Foundation Classes (IFC), an object-oriented open standard introduced by the International Alliance for Interoperability (IAI), aiming at improving the interoperability among software tools. These models allow the design team to assemble very complex representations of building and all its physical details but – still – there is the problem of how to manage such a large collection of information.
Divide et Impera is a very general paradigm to deal with complexity. This has been successfully applied to the increasing complexity of the design process. Following this strategy, the design team becomes wider and more heterogeneous. The knowledge to be managed can be partitioned as well: for example Carrara et al discuss how this can be split along more dimensions: one of these allow us to discriminate Project-Dependent from Project-Independent knowledge.[44] Any design activity grows both these: the former is the immediate goal of the design process, including its requirements, details, motivations, and so on – the latter represents an accumulation of experience of the activity. The increment of knowledge is larger as the innovative content of the project at hand. Note that a large portion of the knowledge to be used in a design process is not strictly produced for the project at hand – i.e., it is Project-Independent – but it is related: pieces of this must be required by some actor of the design team in order to investigate about origin and motivations of a given design choice. On the negative side we have that the knowledge supporting a design process is increasing with the complexity of the requirements. On the positive side we have that (1) no actor needs to have access to all this knowledge, (2) the responsibility of gathering this knowledge is split among various specialists, (3) this knowledge is largely reusable for further projects.

archive, 43:5-6, pp 907–928

41 Demo B. & **Angius A.** (2007). Database and Expert Systems Applications, 18th International Workshop on Database and Expert Systems Applications, DEXA, IEEE Computer Society, Regensburg, Germany, pp 222–226

42 Simon H.A. (1996). The Sciences of the Artificial, 3rd Edition, MIT Press, Cambridge, MA

43 Fischer G. (2000). ibid

44 Carrara G. et al (2009). Knowledge-based Collaborative Architectural Design. International Journal of Design Sciences & Technology, 16:1, pp 1–16

4.2 Organizing knowledge bases as a collection of Learning Objects

In particular, each actor is supposed to collect information in a standard format in a private design workspace. This workspace can be nourished either by adding resources that are directly authored by the actor, or by joining resources found in other workspaces, that (s)he considers sufficiently close to represent her knowledge in her professional context. These workspaces are actually organized as standard repositories of learning objects. Through eLearning methodology and techniques such repositories can be

- used by the actor herself, in order to prepare a selection of learning objects that can be used to communicate and explain her professional needs and demands to other members of her design team; since personalization is possible in the eLearning framework, the selection would be tailored to the others' individual characteristics and professional traits, and would be adaptable to the possible changes in such individual characteristics;
- used by the other members in the design team, in order to independently browse the actor professional knowledge base and gain, independently as well, a better awareness of the professional peculiarities and motivations of the actor.

As an example, a given feature of the artefact, corresponding to a design choice, can be constrained (or determined) by a combination of requirements, norms, and standards. If this is the case, the supporting explanation is a collection of knowledge items connecting the considered feature with the "source" motivations (requirements, norms, and standards). These knowledge items might be fully in the shared workspace or – possibly in part – in private workspaces, and available for browsing only to entitled users. What is important is that the details can be explored by each actor based on subjective needs, and may be very different according to the different design needs, or the different background and understanding of the problem. The "knowledge on demand" is a feature that makes eLearning very effective as the needs of the various actors are very heterogeneous.

4.3 The crisis of a communication pattern

We will show as the resulting flow of knowledge to be exchanged among the actors involved in a design process with increasing number and heterogeneity of participants changes the rationale of the communication pattern.

A "many-to-many" communication pattern, as in a meeting (or a virtual meeting) is an effective form of communication when there are a relatively small number of participants, with similar needs and relatively homogeneous background: there must be a shared set of concepts and terminology. In the current scenario of an articulated design team, there are several factors that make this model not fully satisfactory. In particular, there is a higher number of actors, and a more differentiated specialist profile of these: this implies a quite heterogeneous need of information by the several actors involved in the project, according to the different background.

Let us consider a single unidirectional flow of information between two specific actors. Each actor, regarded as a learner, does need specific information from this specialist, playing the role of the teacher. The level of detail and the content itself of this information may heavily depend on the background and the role of the learner. In this situation, a more suitable communication pattern would be

peer-to-peer. Unfortunately the burden of this pattern for each “teacher” increases linearly with the number of “learners”, unless each additional access after the first one is performed with a marginal cost for the “teacher”, as in eLearning.
We claim that an approach based on eLearning hinges on concrete economics. In the design of a complex artefact, such as in the building industry, we have argued that we have an increasing complexity of the requirements, the design process and the resulting products. On the other side, the team might be formed on a temporary base. As a consequence:

- the number of actors required in a large project increases: these have different profiles and different roles; this creates a very heterogeneous “audience” with different needs in terms of required details; on the other side, each of them is owner of a “specialist knowledge base” that is not necessarily willing to share with the others in full;
- the required knowledge to be managed in a design process is fragmented among various actors;
- the details required in order to fully explain and motivate the choices by each actor increases;
- a relevant portion of the knowledge supporting the design process is Project-Independent, and it may be required in order to support other users: if this information is not explicitly represented, it may be a burden in further interactions.

In the following section we will show how the adoption of eLearning can improve the performances of any business based on the interaction among knowledge workers.

4.4 Towards an eLearning-supported collaborative design environment

In this section we have considered available concepts and techniques that have been conceived so far in the context of collaborative design, providing some evidence of how eLearning can coexist with them, possibly enhancing the considered features. In the previous sections we have discussed features of eLearning environments that make the corresponding solutions appealing tools for knowledge management in a design process. We suggest that eLearning techniques may be adopted by assembling them together with existing tools, in order to build very effective environments. We present a possible scenario, to be used as requirements for defining an eLearning-supported collaborative design environment:

- each actor (or organization) maintains a representation of the Project-Independent knowledge, where each piece of information has possibly different “versions” with different levels of detail;
- when a design activity is undertaken, each actor contribute as required by her/his role to the process, by authoring a portion of the project in the shared workspace together with updates to the current collection of learning objects;
- beside contributing to the shared workspace, each actor, regarded as a teacher, may provide other’s access on demand to her “knowledge base”, or can import a portion of this knowledge base into the shared workspace;
- each actor, regarded as a learner, can browse the shared workspace following the learning path best suited to her needs, possibly supported by the adaptive features of the available Learning Management System;

- there can be links from the shared workspace to learning objects in the private workspace of any actor: following these links might be subject to access policies.

Three distinct representations coexist in a software architecture integrating the features described in this section, (Figure 3):

- a project, that is one or more files which are viewed and edited by means of the CAD-software tools: these representation contains a collection of objects
- an ontology, with a collection of concepts and relationships
- a collection of learning objects, to be used as source for personalize learning experiences.

Links among entities in the different representations are to be supported, so that a user who is inspecting an “object” in a CAD environment can follow links connecting it to a learning object played within a browser, in order to access to explanations, motivations and roles, and possibly follow further links connecting terms in ontology.

We remark that both eLearning environments and ontologies have a modular and navigational nature. Therefore, both are suitable to be connected each other across the borders of modular collections, thus preserving the combination (and separation) of project dependent and project independent knowledge bases, as well as of private and shared work spaces.

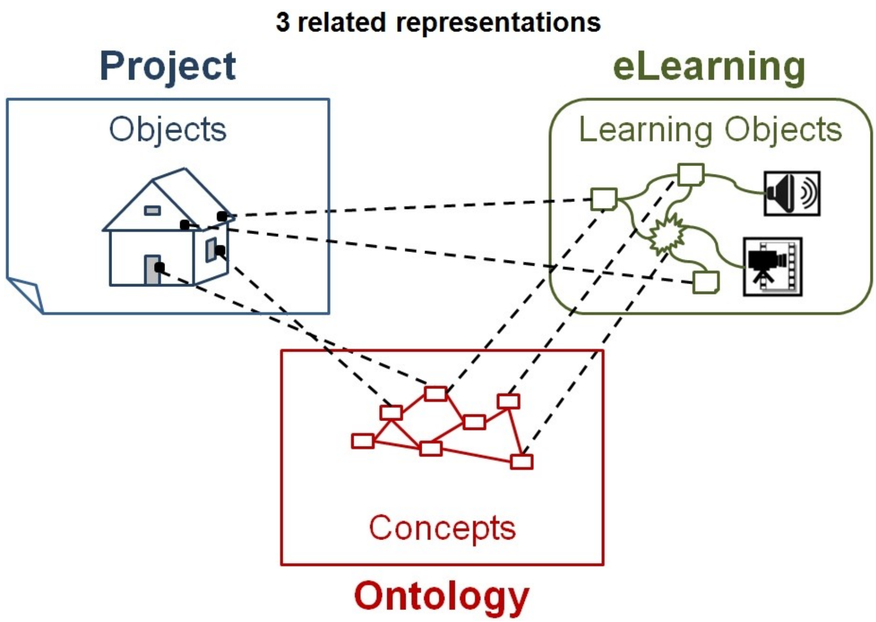

Figure 3 The three representations, the objects in the project files, the concepts within the ontology, and the learning objects are linked: any of the visualizing environments supports the browsing of the related entities.

5 Conclusions

In this paper we have discussed the use of eLearning methodologies and technologies as a ground base for collaborative communities. In this context, where each member may need knowledge provided by the others, the problem of contextual unawareness might be significantly addressed by means of eLearning.

Traditionally, these have been primarily directed towards pedagogical and instructional aims, yet they have found already application to provide operational support in other fields, such as touristic tours,[45] or within a complex project, (Freightwise, funded by EU-DG-TREN).[46] Moreover methods to enrich the provision of learning objects in a local repository, under the specifications given by a teacher (or an interested user) are under study and provide initial promising results.[47]

In particular, eLearning provides intriguing and promising features in term of personalization and adaptivity, and even for supporting social collaborative learning, are not yet in a final phase of exploitation. For instance, there are no widely adopted commercial LMSs that offer such capabilities, which can be found in experimental prototypes supporting social collaborative learning[48 to 50] or, more specifically, adaptive learning in group activities.[51]

The research endeavour reported in this paper is meeting two main challenges: on one side we are investigating on the possibility of enhancing a Learning Management System for supporting Knowledge Management in collaborative design; secondly, we are proposing an innovation within the process of collaborative architectural design by introducing an offline accumulation and exploitation of knowledge with the target of reducing the burden of the online interaction among larger and more heterogeneous design teams. In both cases, we are developing strategies and exploiting features that still lay on the frontier of the research work in the area.

Our proposal is currently a conceptual construction that, although based on realistic features, such as (1) functionalities of a social collaborative eLearning system, and (2) cross-platforms links among objects in different software environments, still lacks a comprehensive implementation in software. The constituents of this conception are, however, already quite clear:

- a Learning Management System, allowing for the definition of Learning Objects and the maintenance and combination of repositories, supporting the definition of customized learning experiences for the project members, in order to have them trained over the aspects of their colleagues' disciplinary realms that they deem relevant;
- a cross-platform integration connecting a LMS with (1) a software environment for architectural design, (2) an ontology; this integration has to support links connecting objects in the different environments.
- Beside these implementation challenges, we need to define an experimental setting for testing the design process using the new tools; in particular we have to define:
- a group of designers representing different disciplinary realms in the context of architectural design;
- the "learning outcomes", i.e. a description of the measurable results of the users learning activities (to see what the users should have learnt after the training administered by the learning management subsystem);
- the "awareness outcomes", i.e. a description of the users' capabilities to interact, and of the gain that such capabilities will produce in the project work;
- a set of metrics to evaluate the above mentioned outcomes;
- a set of metrics to evaluate the gain, for the project work, derived by the system's effects on the users (as they are supposed to have gained knowledge and

45 Limongelli C. et al (2011b). The Use of eLearning methodologies and technologies for generating personalized tours in cultural heritage environments, International Journal of Tourism Anthropology, 1:3

46 www.freightwise.info

47 Limongelli C. et al (2010). An Ontology-driven OLAP System to help teachers in the analysis of web learning object repositories, Information Systems Management, 27:3, pp 198–206

48 Limongelli C et al (2011a). ibid

49 Sterbini A. & **Temperini M.** (2009). Collaborative projects and self evaluation within a social reputation-based exercise-sharing system, Proceedings IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology, 2nd International Workshop on Social and Personal Computing for Web-Supported Learning Communities, Milan, Italy, pp 243-246

50 Sterbini A. & **Temperini M.** (2011). SOCIALX: reputation based support to social collaborative learning through exercise sharing and project teamwork, Journal of Information Systems and Social Change, 1:2, pp 64–79

51 De Marsico M. et al (2011). The Definition of a Tunneling Strategy between Adaptive Learning and Reputation-based Group Activities. In: Proceedings 11th IEEE International Conference on Advanced Learning Technologies, ICALT 2011, Athens, Georgia, USA awareness of the other colleagues' realms, after their learning activities); examples of these metrics may be:

+ the saving in time for a given actor "a", during a project work, in having information given to others, about her realm "A" (our expectation is: the larger the team, the larger the saving);
+ the flexibility of each user's learning activities, in time, space, and pace, and the saving in time;
+ the weight of the additional time needed by "a", in order to create and/or select the learning material needed by a user in another realm, form the *A kb*;
+ the possibility to deliver learning material of better quality, since it has been produced by a variety of users of the disciplinary realm;
+ the amount of interactions that can be stored for future reuse (creating automatically FAQ-like repositories, for transmitting part of the knowledge developed within a project to other projects).

eLearning cannot be considered a substitute of other tools conceived for Collaborative Working Environments, but its adoption can contribute to reduce the burden of knowledge management in large design teams, due to: an offline service-oriented peer-to-peer communication pattern, an adaptivity to various user needs, a modularity in integrating knowledge bases, reusability of the available information resources.

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