TEACHING CONSTRUCTION IN THE VIRTUAL UNIVERSITY: THE WINDS PROJECT

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ABSTRACT: The paper introduces the Web based INtelligent Design Support (WINDS) European Project to support education in design, i.e. the A/E/C Virtual University. The Project is divided into two actions. First, the research technology action is going to implement a learning environment integrating an intelligent design tutoring system, a computer instruction management system and a set of co-operative supporting tools. Second, the development action is going to build a large knowledge base supporting Architecture, Civil Engineering and Construction Design Courses and to experiment a comprehensive A/E/C Virtual University.

The main missions of the Project are advanced methodologies in design education, multidisciplinary design education, knowledge level integration, teamwork and collaboration in design education, innovative representation and access to design education, architecture and construction practice, and education brokerage.

At the heart of the WINDS Project there are a number of pedagogical methodologies developed over the 20th century. The basic issues can be pointed out through keywords like: "learning by doing", "incidental learning", "learning by reflection", "case-based teaching", "learning by exploring" and "goal based scenario". The core idea is that people learn better when directly involved in the topic, being motivated to seek out new knowledge and experience in order to solve a problem.

The missions of the WINDS project state many challenging requirements in both knowledge and system architecture. The project both develops and integrates information technology in an innovative and functionally sound Computer Aided Instruction system for A/E/C Design, which advances in standard learning technology architecture, representation, integration and distribution of knowledge.

KEYWORDS: design tutoring system, computer-aided instruction, A/E/C design education, case-based teaching, goal based scenario, knowledge integration, STEP, IFC

1. INTRODUCTION

Present education paradigms in architectural education still largely rely on a two-century-old tradition, deriving from the French Academies. Several patterns from the Academies' tradition still persist in the present studios: design exercise as simulation, educator role, graphic formulation and continuous teacher-student interaction (Cuff, 1991) (Schon, 1985 and 1987) (Argyris and Schon, 1996) (Oxman, 1999).

In undergraduate and graduate curricula the intersection between design and technology is often prevented by a clear-cut division between course subjects, an excessive rigidity of curricula, and a pervasive difficulty in defining effective multidisciplinary courses or studios.

In University departments, especially the technical ones, most successful courses tend to be those where there is a strong and deeply rooted research activity. This trend towards specialization causes the spreading of expertise over the territory as a direct consequence.

The contribution of best practice from architectural firms and construction industries is loosely accomplished.

Restoring quality to multidisciplinary design teaching therefore needs the reorganization of the didactic structure in view of rationalization and content integration.

On the other hand great things are expected from the capability of information technology to contribute innovating design education. As we look around Universities, we can see most professors still lecturing using the chalkboard. A few use videotape and fewer are using the computers in the classrooms or studios. Overhead and slide projectors are probably most used educational technologies. Therefore it is not realistic to expect computers *alone* to innovate design education, because social systems, such as Universities and Schools, are difficult to innovate. On the other hand, the Internet -by which we mean the entire digital information infrastructure- is the living demonstration of the impact the technology has on social structure, insofar the Net meets to the business, productive, communicative, entertainment, …, requirements of present society.

2. THE WINDS PROJECT

WINDS is a project funded by the European Community in the 5th Framework, Information Society Technologies programme, Flexible University key action. WINDS is divided into two actions:

- The research technology action is implementing a learning environment integrating an *intelligent design tutoring system*, a *computer instruction management system* and a set of *co-operative supporting tools*.
- The development action is building a large knowledge base supporting Architecture, Civil Engineering and Construction Design Courses and to experiment a comprehensive A/E/C Virtual University.

During 2000-2003 the WINDS project is spanning a total effort of about 150 man-years from 28 partners of 10 European countries.

In the third year of the project, more than 400 students all over Europe will attend the Virtual University, which, at present, offers 20 courses relating to 3 Departments: Architectural Design, Environmental and Building Technology, Construction Management.

3. WINDS MISSIONS

In our agenda the main missions that design education in the A/E/C Virtual University has to challenge are:

Advanced Methodologies in Design Education. WINDS drives a breakdown with conventional models in design education, i.e. studio, classroom or distance education. WINDS implements a problem oriented knowledge transfer methodology following Roger Schank's *Goal Based Scenario* (GBS) pedagogical methodology. GBS encourages the learning of both skills and cases, and fosters creative problem solving.

Multidisciplinary Design Education. Design requires creative synthesis and open-end problem definition at the intersection of several disciplines. WINDS experiments a valuable integration of multidisciplinary design knowledge and expertise to produce a high level standard of education.

Knowledge Level Integration. Present education paradigms need an overhaul to accommodate students in thousands of locations and then multiply the effort to produce and present courses. One important innovation of the WINDS approach is the integration of a widespread design expertise, at present 20 courses, so that it can be effectively used to produce a high level standard of multidisciplinary education. To this aim WINDS gathers area knowledge, design skills and expertise under the umbrellas of common knowledge representation structures and unambiguous semantics. We define this approach as knowledge level integration, in contrast with data level integration. In other words WINDS produces the shift in design education from Data Base technology to Artificial Intelligence.

Teamwork and Collaboration for Design Education. Today's Internet is the enabling medium for the collaboration of educators spread in different countries. WINDS knowledge level integration provides the information infrastructure for effective collaboration in writing the shared design knowledge expertise.

Teamwork and Collaboration in Design Education. "In architecture, as in other professions today, the debate continues over the issues of specialization and generalist training." (Cuff, 1991). WINDS approach is to challenge students in design, where they are requested to creative synthesizing at the intersection of several disciplines. While in the traditional studio punctual interaction with experts from several knowledge domains proves difficult; the Internet can support asynchronous access and interaction with the widespread design knowledge base as well as synchronous interaction with experts from different disciplines. WINDS supports design revision fostering the collaboration between teacher and student (remote tutoring) and co-operation among students (peer tutoring).

Innovative Representation, Delivery and Access to Design Education. WINDS delivers individual education customisation by allowing the learner access through the Internet to a wide range of on-line courses and structured learning objects by means of personally tailored learning strategies. WINDS promotes the *3W* paradigm: learn *W*hat you need, *W*here you want, *W*hen you require.

Architecture and Construction Practice. Architecture firms and construction industries are a repository of "best practices" and knowledge that the WINDS profits from. WINDS system benefits the ISO10303 and IFC standards to acquire knowledge of the construction process directly in digital format. On the other hand, WINDS reengineers the knowledge in up-to-date courses, educational services, which A/E/C firms and industries can use to provide just-in-time rather than in-advance training.

Education Brokerage. Life-long learning is going to be a major requirement increasingly specialized and decentralized workplace of 21st century. Furthermore firms and companies are actively looking for just in time rather in advance learning. Education brokers are defined the collaborative alliances among academic institutions, training companies, in-house training department, multimedia editors and telecommunication companies. Digital communications allows the setting of these alliances, which match the needs of the learner with courses and expertise provided by educational suppliers, without sacrificing the quality and effectiveness of learning. Education Brokerage promises to significantly reduce the cost structure of present education paradigms, which require multiplying efforts and costs to create and delivery courses.

4. THE PEDAGOGIC APPROACH

At the heart of the Virtual University there is a pedagogy being developed over the 20th century. The basic issues can be pointed out through keywords: "learning by doing", "incidental learning", "learning by reflection", "case-based teaching", "learning by exploring" and "goal based scenario".

The core idea of "learning by doing" is that people learn better when directly involved in the topic, motivated to seek out new knowledge and experience because they need them in order to solve a problem. WINDS assumes Design as the privileged learning environment: *learning design by doing designs*. Therefore WINDS curricula and courses are arranged according to design skills. Each WINDS course has a cover story that is a real world design task, providing an authentic context in which to situate the knowledge the student access; and confronting students with specific challenges that require them to analyse the information they access, and put it to use. WINDS cover stories can be understood as Schank's goal based scenarios (Schank, 1992). Here the focus is on motivation, which is the most valuable tool for learning, and learning is a goal driven activity, where the goals are chosen to fit the interests and requirements of the learner.

More specific strategies have been adopted on a finer grain, considering the student's knowledge building process, which starts from experience and go through abstraction. The centre here is on the learner and her/his needs while going through structured learning material. Adopted strategies can be summarised as follows.

Learning by Exploring. When students get involved into design, they naturally generate questions, issues, and new topics. And they are ready to learn from those questions. An important method of teaching is to let them explore whatever follows up questions and issues they have generated. WINDS provide students with support for free associative exploration of concepts, issues and solution examples, providing a measure for the relevance of conceptual associations and giving insights for building explanations.

Learning by Reflection. Sometimes a student does not need to be told something, but rather reflect to what he is doing. This process let the student rationalize his design process and criticize it for better solutions. WINDS provides student with a tool called Design Pad aimed at fostering design process elicitation and reflection.

Case-Based Teaching. This paradigm relies upon two ideas: experts are repositories of cases and good teachers are good storytellers. Because isolated facts are difficult for students to integrate into their memories, useful knowledge is typically best presented in the form of design cases.

These pedagogical ideas are not new, but their implementation is. These theories have been generally tried in research laboratories only or in industrial systems on a small scale where, they showed to be very effective. Moreover they have not been implemented in the design domain before.

5. THE LEARNER-CENTERED VIRTUAL UNIVERSITY

How the A/E/C Virtual University fares and implements the previous considered pedagogical issues?

5.1 WINDS Knowledge Model

WINDS demonstrates that it is possible and valuable to integrate widespread design expertise so that it can be effectively used to produce a high level standard of education. To this aim WINDS gathers area knowledge, design skills and expertise under the umbrellas of common knowledge representation structures. A considerable research effort has been undertaken to develop a knowledge representation framework able to represent design expertise in domains ranging from well structured engineering (e.g. structural engineering, HVAC, etc.) to ill-defined scenarios emerging during architectural design conception (De Grassi et al., 1999).

Cases are one of the most valuable means for the representation of design expertise. Cases are noteworthy stories, which describe solutions, integrate technical details, contain relevant design failures, etc. (Figure 1). Cases are collections of *learning objects* (e.g. product models, HTML pages, pictures, videos etc.) that are indexed highlighting their relevant features. The set of indexes produced are gathered together and represents the conceptual framework. Indexes and documents are further qualified according to the *issue-concept-form* paradigm and arranged into networks, which are called *strategies*. A strategy is the representation of a fragment of expertise. It relates design issues to ideas, examples and solutions or failures, so that it captures design relevancies. A sequential arrangement of learning objects is also provided in order to support standard teaching techniques.

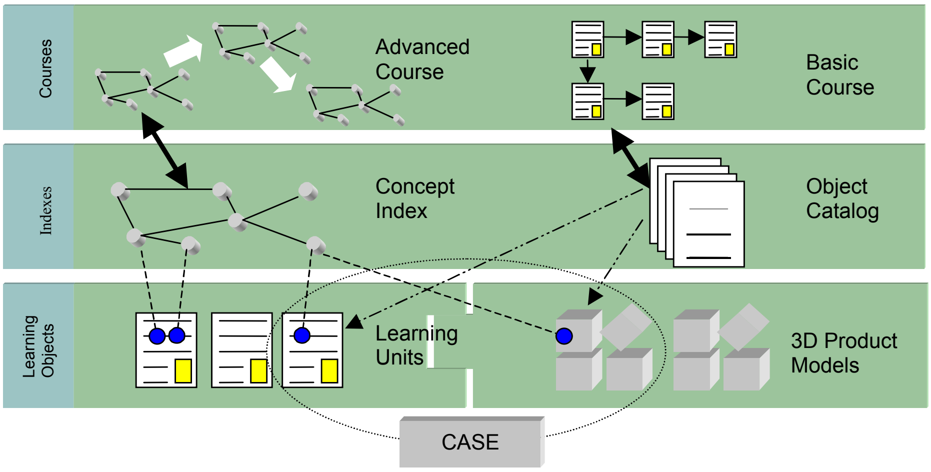

Figure 1. Knowledge Representation.

5.2 WINDS Expert Model

The second step of WINDS knowledge representation framework is the expert model. The WINDS expert model has been built according to the well-known *issue-concept-form* (ICF) paradigm (Oxman, 1999) that has been adapted to support intelligent tutoring. ICF provides a cognitively plausible framework for representing design flow; it is particularly suitable to capture the conceptual phases of design ideation and conception. A fragment of typical ICF flow is shown in Figure 2. The four topics on the far left represent design issues (i.e. design a roof, remember trees, etc.). Issues are refined into concepts categories, which in turn recall forms. Forms are usually richly indexed, so that they provide relevant concept associations (i.e. structure). An expert ICF flow has been identified it can be encoded one to one into a WINDS strategy, thus becoming the knowledge source for tutoring.

Even if ICF is a valuable tool to capture almost completely the conceptual design expertise, it is not so comprehensive in the representation of the expertise in well structured domains like for example in structural engineering. In that case expertise is mostly related in the control of well-defined (sometimes standard) design scenarios (e.g. bracing techniques, load paths, etc. for structural engineering), so that it mostly concerns figuring out and managing system behaviours from a design choice. In this case conceptually based simulation tools are the most valuable means to represent expertise and support tutoring. WINDS simulation tool is based on Bayesian Networks (BN). BN are used to represent the causal network underlying noteworthy cases in engineering design and to simulate their behaviour according to a number of boundary conditions. In the WINDS knowledge architecture BN are considered as basic learning objects and, therefore, they can be indexed so that they can be embedded inside a design flow, like any other reference or example.

5.3 WINDS Intelligent Tutoring

The value added by knowledge level integration is that, once the epistemological schemes have been defined, it is possible to produce a number of general purpose tutoring actions that can be used to teach in a content-independent way. In fact WINDS shifts from Data Base technology to Artificial Intelligence for design education.

WINDS Intelligent Design Tutoring (ITS) basically is a differential model. It consists of a number of strategies that are intended to coach the student according to predefined expert scenarios. Strategies are defined so that they control a number of cognitive and pedagogical aspects like the minimization of the changes between visual and conceptual reasoning, information overload, learning path control etc. One of the main features of the WINDS ITS

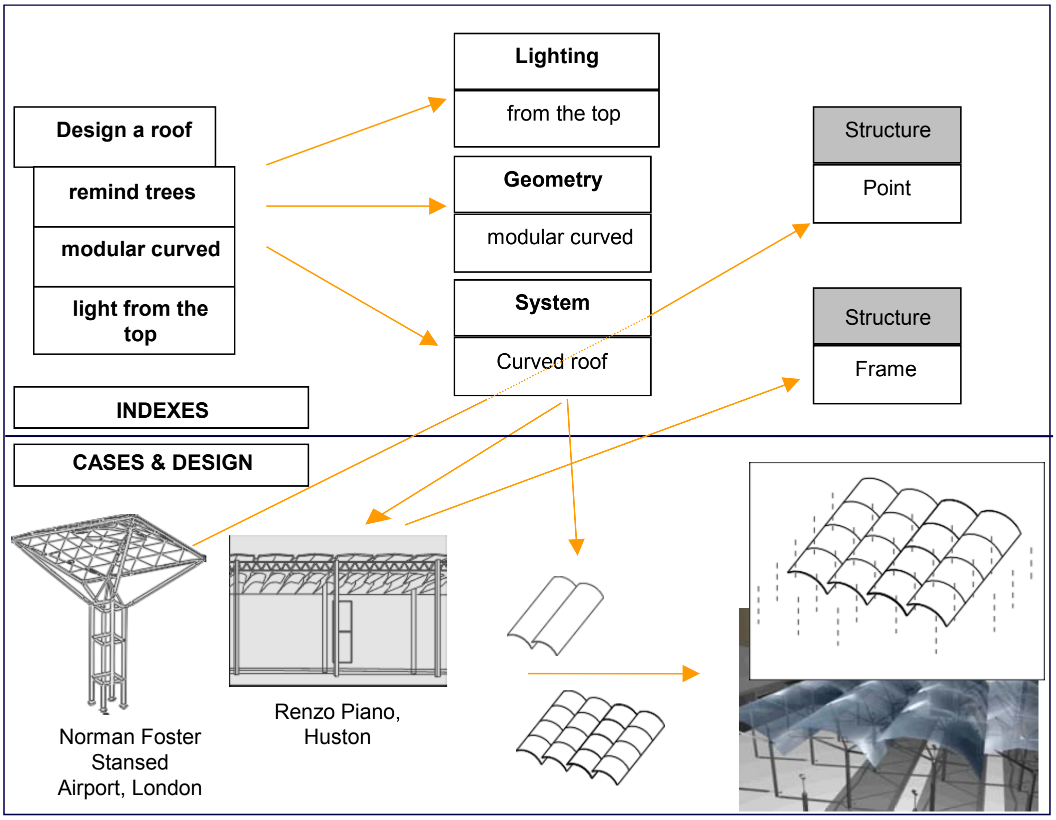

Figure 2. Example of a design flow with concepts (indexes) and cases.

is that it avoids explicitly representing any comprehensive student model, and provides a reactive behaviour established on the basis of local evaluations. Moreover a considerable effort in WINDS design has been devoted to provide an interface to maximize the information bandwidth between the student and the system during design. To this aim WINDS provides students with a smart design rationale capture tool (*Design Pad*), which they can use to develop and document their design at a conceptual level. On this tool, students enter the concepts they are considering and connect them to the documents and CAD models they are producing. *Design Pad* not only documents the project evolution for teacher and students, but is also the main interaction area with the ITS. This assistant monitors the progress tracing and analysing the student design representation on the tool and suggests new concepts based on associative, didactic and ontological relations among concepts. Design Pad assists students in annotating the conceptual evolution of their design exercise, and in inserting textual comments and graphical models of their work.

That rich representation of students' design is stored in the students' workspaces and can be shared with teachers. In this way teachers receive a comprehensive representation of the students' design and can revise the design consistently even without a direct (face-to-face) student interaction. Design Pad challenges the problems raised by distance and asynchronous interactions between students and teachers.

5.4 WINDS Courses

At the end of the second year WINDS will have produced 20 courses in the A/E/C domain, which entail about 200 learning units and thousands of learning objects. The writing of such a large knowledge base is aimed to develop a "critical mass" of contents largely exceeding the capabilities of a single professor or student. In that way professors and students can effectively benefit from the knowledge base during the course preparation through the setting

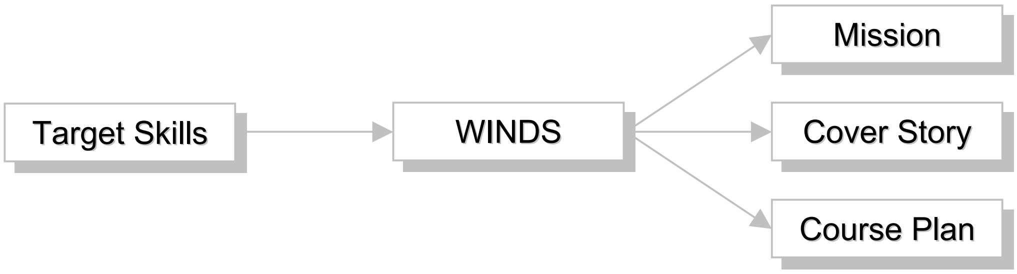

Figure 3. Structure of the WINDS course.

of references and the reuse of knowledge in course units and design cases created by the others participants.

The WINDS course structure is designed to support both natural learning pedagogical requirements and dynamic curricula management. In order to implement a Goal Based Scenario, courses are always constructed around skills (Figure 3). Target skills are simply the set of skills the course designer wishes to convey using the course as a vehicle. They are the pedagogical goal of the overall course.

The *Mission* of a WINDS course states the kind of goal students are trying to accomplish. For instance, in a studio - design course the kind of design the student is going to pursue (Figure 3).

The *Cover Story* establishes the scenario of the WINDS course. It defines the subject, the context and the requirement under which the student pursues the mission. In effect the cover story is a real-world design assignment, which very naturally maps into a Goal Based Scenario. The *Course Plan* contains the actual course structure.

Learning Units are the building blocks of the WINDS courses. They are sets of self-contained educational material aimed at the acquisition of a well-defined set of skills. Learning Units are designed to pursue well-defined pedagogical goals (i.e. acquisition of skills on design, diagnosis, discovery, control, pure knowledge transfer, etc.) (Figure 4).

Learning Units are activated when their set of preconditions is satisfied. Learning Units arrange self-contained learning material, which only has indirect reference to the Cover Story problem. Learning units are controlled according to two pedagogical strategies (Figure 5). They can be either expository or exploratory. Expository learning units are traditionally conceived as a quite fixed path among different learning objects (Figure 5a). Exploratory learning units are built of a set of strategies and support free exploration of the conceptual space they define (Figure 5b).

6. COMPUTER INSTRUCTION MANAGEMENT

At the heart of the WINDS instruction management are functions at the state of the art of

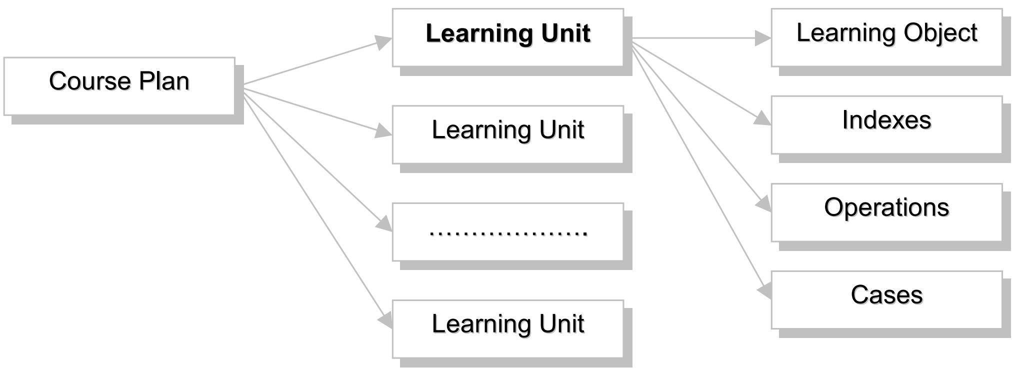

Figure 4. Structure of the Learning Unit.

existing Computer-Aided Instruction systems. There are, however, some important aspects that distinguish the WINDS approach from the most widespread systems and from other systems used at present (ARIADNE) (Brusilovsky et al., 1997) (Goldberg et al., 1996) (WBT Systems, 1998) (TopClass) (Harasim et al., 1997) (Lotus, 1999) (CourseInfo, 1997) (ToolBook) (Docent Software, 1997) (IBTauthor) (Interactive Factory, 1997) (CHALK) (liveText Publishing, 1997) (madDuck Technologies, 1997) (CourseNet) (WebCT).

6.1 Collaboration Spaces

WINDS presents students with a co-operative environment for project development, which is integrated with the traditional design supports. In the Virtual University knowledge acquisition and studio work are two complementary and closely linked activities. The students of the Virtual University have access to a networked design-tutoring environment, which provides educational resources typical of Campuses: administrative offices, courses, teachers, reviews, cooperation with other students and libraries. The system opens its educational services through the Internet by means of shared instruments, web-browsers and the most widely used CAD systems. It promotes co-operation both among students (peer tutoring) and between students and teachers (remote tutoring). The system can also autonomously assist students during design courses - studios by means of intelligent tutoring techniques. Collaboration spaces implement the collaborative environment to provide the students the access to the basic functionality of the Virtual University. Students can access administrative services, obtain personal workspaces where they safely store their documents and assignments, access Departments, where they can enrol on courses, interact with teachers workspaces to obtain work revision and so on. Collaboration spaces allow students to co-operate by means of shared resources and asynchronous communication tools. A special workspace containing the university library is provided too. The university library allows the students to freely browse the university educational material.

Student assessment. In courseware systems management tools are usually provided including quizzes and questionnaires that help students and/or teachers monitor a student's progress. In design such multiple-choice tests are inadequate. Instead students are given tasks that are carried out individually or in co-operation within small design projects. Typically, the results of a design project are presented in a set of documents and CAD models. In this case the student's assessment is much more complex. WINDS supports design revision fostering the collaboration between teacher and student.

Course structure. The modular structure of didactic material and dependence networks among university course modules allow the dynamic definition of special curricula according to students' profiles and training needs. A WINDS personalized learning profile can be built

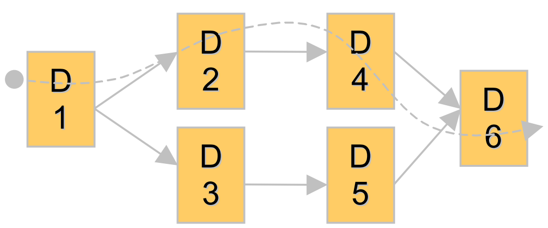

Figure 5a. Student's Expository path in arrangement of documents.

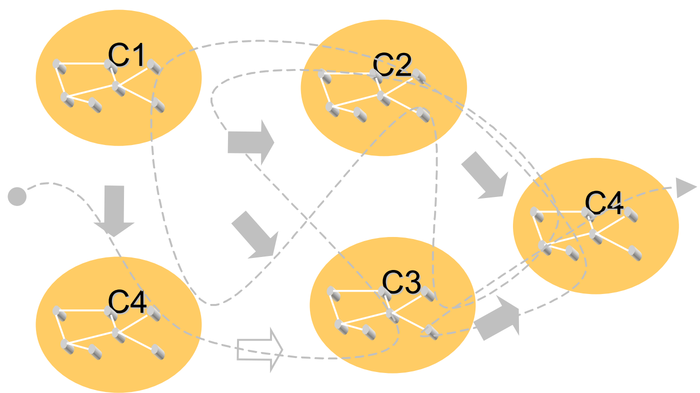

Figure 5b. Student's Exploratory path in arrangement of documents.

on demand arranging learning units (Figure 6). Although this is not an absolute innovation in the field of training assistance, especially in the sector of industrial training, it is a remarkable example of re-engineering of university education.

7. WINDS IT SOLUTIONS

The missions of the WINDS project state many challenging requirements both in knowledge and system architecture. Many of the solutions adopted in these fields are innovative; others are evolution of existing technologies. This paper focuses on the integration of this set of state-of-the-art technologies in an advanced and functionally sound Computer Aided Instruction system for A/E/C Design. In particular the paper deals with the following aspects:

7.1 Standard Learning Technology Architecture

The WINDS system relies on the in progress ISO/IEC JTC 1/SC 36 and the IEEE P1484.1 Learning Technology Standard Architecture (Figure 7). According to these standards the system consists of two data stores, the Knowledge Library and the Record Database, and four processes: System Coach, Delivery, Evaluation and the Learner.
WINDS implements the Knowledge Library in a three-tier architecture:

1. Learning Objects:
   - Learning Units are collections of text and multimedia data.
   - Models are represented in either IFC or STEP formats.
   - Cases are sets of Learning Units and Models. Cases are noteworthy stories, which describes solutions, integrate technical detail, contain relevant design failures etc.

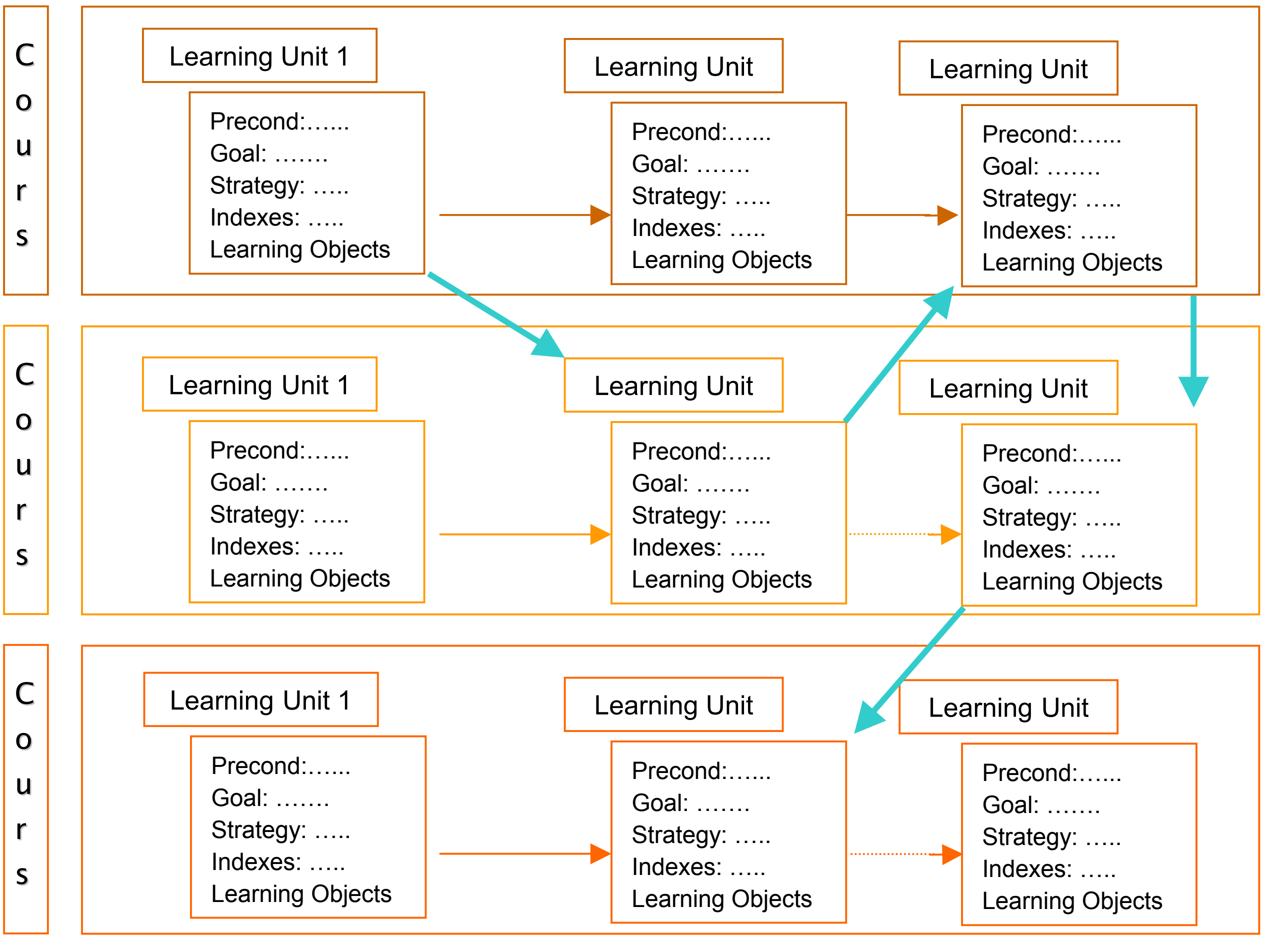

Figure 6. Personalized learning profile.

2. Indexes refer to the process in which the identification of relevant topics in design cases and learning units takes place. Indexing process creates structures of Learning Objects for course management, profile planning procedures and reasoning processes.
3. Courses are taxonomies of either Learning Units or a design task and Course Units.

7.2 Knowledge Integration

Indexes are a medium among different kinds of knowledge: they implement networks for navigation and access to disparate documents: HTML, video, image, CAD and product model (STEP or IFC). Concept indexes link-learning topics to learning objects and group them into competencies (Figure 1) (Voss et al., 2000). Index relationships are the base of the WINDS reasoning processes, and provide the foundation for system coaching functions, which proactively suggest strategies, solutions, examples and avoids students' design deadlock.
Some courseware includes facilities for an automatic index, but this is an index of terms, rather than of concepts. As far as we know, managing the associations of concepts with the design media (e.g. drawings, CAD and product models) is a unique feature of the WINDS system.

7.3 Knowledge Distribution

To support the data stores and the process among the partners in 10 countries efficiently, WINDS implements an object-oriented client/server as COM objects. Behind the DCOM components there is the Dynamic Kernel, which dynamically embodies and maintains data stores and process. Components of the Knowledge Library can reside on several servers across the Internet. This provides for distributed transactions, e.g. a change in one Learning Object affects the Knowledge Library spread across several servers in different countries.
Learning objects implemented as COM objects can wrap ownership data, a digital "fingerprint" for copyright purposes. Clear and univocal definition of ownerships rights enables Universities, in collaboration with telecommunication and publisher companies, to act as "education brokers". Brokerage in education and training is an innovative paradigm to provide just-in-time and personally customized value added learning knowledge.

8. CONCLUSIONS

We consider the A/E/C Virtual University a laboratory where new paradigms for design education are experimented. In this laboratory information technology is a catalyst for innovation: it provides the medium to implement and experiment pedagogical paradigms.
The ultimate goal of the laboratory is to provide answers to the questions raised by our present rapidly evolving society. On the one hand, are increasing the requests of specialization and decentralization in education and training. On the other hand, this can

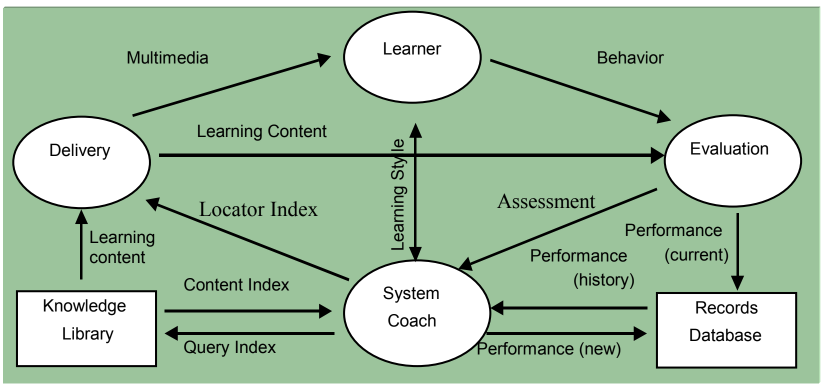

Figure 7. IEEE P1484.1 - Boxes are data store, ovals are processes.

produce an increased fragmentation of knowledge, avulse from any enabling “cultural” framework.
There are major challenges in deploying any new paradigm in reality of Architecture and Civil Engineering Schools. Economical viability is certainly one of these. While education is potentially one of the largest information industries in the world, at present it still lacks critical mass. Moreover the educational paradigms for the information age are not yet perfectly clear. To experiment new teaching models and curricula organization and to achieve critical mass, the European Community decided to allocate resources to the WINDS project to implement the information system and to create 20 on-line courses in the Virtual University as a result of the collaboration of 28 partners from 10 European countries.

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