Didactic Tools for Learning Structural Design of Buildings based on Autonomous Apprenticeship

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Abstract — *For improving the quality and efficiency of their teaching activities, in 1993 the team of professors in charge of the subject Estructuras I at the Faculty of Architecture of Valencia have incorporated a set of innovative experiences on their teaching methods. As a result, some didactic and evaluation tools have been developed. All of them are based on e-learning principles and oriented to the autonomous apprenticeship. Some experiences like those associated with the projects entitled: "The study of Structural Design and the computer classroom as Virtual Laboratory" and "Didactic Resources Classroom oriented to the apprenticeship of Structural Design on Building Science" have been developed during the last seven years. The Didactic Resources Classroom contains a Virtual Laboratory on Structural Mechanics, a pool of Tests with automatic checking and a collection of Interactive Didactic Units. All of them are implemented into the computer classroom. There is also a set of real reduced models of structural systems and joints. Finally, a great number of computer based models of structural joints have been implemented. At this moment all those teaching tools are being applied to the students training and evaluation. In the near future an interactive book and an on-line course on Structural Mechanics applied to Building Science will be implemented into the local area network of our University. Probably the course will be offered trough Internet be means of the Open University department.*

Index Terms — *didactic resources, e-learning, structural analysis, virtual laboratory.*

SUMMARY

In order to improve the quality and efficiency of their teaching activities, in 1993 the faculty in charge of the Structures I course at the School of Architecture of Valencia incorporated a set of innovative experiences into their teaching methods. As a result, several didactic and evaluation tools were developed. All of these are based on e-learning principles and oriented towards autonomous learning. The goals were to create a favourable atmosphere for the active participation of the student in the learning process, promote student autonomy and to give the student the resources (material and human) for personally experiencing and evaluating the theories developed in the course.

Some experiences such as those associated with projects entitled: *The study of Structural Design and the Computer Classroom as a Virtual Laboratory* and *Didactic Resources Classroom Oriented Towards the Learning of Structural Design in Building Science* have been developed during the last seven years. The Didactic Resources Classroom contains the Virtual Laboratory on Structural Mechanics, a pool of tests with automatic checking and a collection of Interactive Didactic Units. All of these have been implemented into the computer classroom. There is also a set of real reduced models of structural systems and joints. Finally, a great number of computer based models of structural joints have been implemented.

Currently, a comprehensive student assessment system has been implemented into the course under the framework of the AME2 and AME3 programmes of *Proyecto EUROPA*. The experience accumulated and available resources in the Didactic Resource Classroom is being used for this experience. The Interactive Learning Book and online Structural Mechanics of Building course are being planned for the AMA7 programme of Proyecto EUROPA. The Upvnet intranet of the Polytechnic University is being offered for this. In the future the HAUPA system of the Open Polytechnic University through the Internet may be offered.

HISTORY

In 1992 the author presented the idea of using the Information Classroom as a Virtual Laboratory for the *International Conference ECAADE 92 , Education in Computer Aided Architectural Design in Europe* held in Barcelona. (Ref. 2).

Subsequently, during the 1993-94 academic year, under the Educational Innovation Plan of the Polytechnic University of Valencia, he prepared Teaching Innovation Project #130 entitled *Learning Structural Design in the Computer Classroom*. The object of this project was to adapt computing material (equipment and programmes) to the *Structures I* course at the

School of Architecture of Valencia in order to put the Virtual Laboratory into operation for the study of the structural mechanics which are most commonly used in building.

Over seven courses, the authors have been developing and refining an environment (Ref. 3) of Computer Aided Structural Design. This environment consists of a programme, named EFCiD, that analyses, calculates, and measures structures and foundations, and a group of other minor computer applications. The former was programmed in Visual Basic and Visual Lisp while the rest of the applications were created using Excel spreadsheets. As in a real laboratory setting, a group of structural models were developed in order to put these tools to use. These structural models could be "tested" by the students in the Virtual Laboratory of the computer classroom or on their own personal computers.

Innovational Teaching Project #10066 entitled *Didactic Resource Classroom for Learning Structural Building Design*, approached the development of interactive learning material in such a way that the students could carry out their educational activities independently. They could make self-assessments of their learning progress in the course content. At the same time, the Virtual Laboratory was created with more computer resources such as virtual models of structural joints, as well as non-computer resources such as conceptual models of basic phenomena of structural mechanics and scale models of certain conventional structures.

Accordingly, the Computer Classroom has become the Didactic Resource Classroom (Ref. 5) in which the students have the following available to them:

- A Virtual Laboratory, implemented in the Computer Classroom which allows the student to experience the behaviour of different types of structures by using computer models and programmes based on fundamental didactic objectives.
- A collection of virtual, conceptual and scale models which serve to illustrate theoretical concepts of the subject and to show some of the most common structural systems. This material allows the student to overcome the existing distance between the theory and practice of these concepts.
- A series of *self-assessment tests* and a series of *interactive didactic units* which cover practically all of the course content.

ACTIVITIES CARRIED OUT IN THE DIDACTIC RESOURCE CLASSROOM

Virtual laboratory

The following is the work procedure presented to the student in the Virtual Laboratory:

- A problem is presented and the student reflects on the behaviour of the proposed structure and the order of magnitude of the results that may be obtained.
- The student must manually solve the proposed problem using conventional methods. In order to do this the student will break down the problem into parts and will solve them step by step.
- Once the first part of the problem is solved, the student will create a virtual model of the structure with the aid of a computer. Given that the programmes have a mainly didactic objective, it is easy to compare the results obtained manually with those from the programme for each part.
- If the manual and computer results agree, the student continues with the problem. If they do not agree, then there will be a debate regarding which method produced the error and where it is to be found (it goes without saying that the results given by the computer will not be allowed to be considered correct *a priori*).
- This process is repeated until the analysis has ended and the same results are obtained with both methods.

This methodology bases its effectiveness on three main tenets:

- The students are intrinsically interested in learning and solving the problems presented by the professor, or by the students themselves.
- The students will learn from their mistakes and will try to find the errors in their reasoning and calculations.
- The students are emulating a professional practice which, in the majority of cases, is based on the study of an extensive casuistry made up of a great number of similar cases.

All of this endows the student with criteria and knowledge regarding the order of magnitude of the problem; this favours problem solving for oneself and, all in all, goes beyond pure memorisation of formulas and calculation processes.

The following programmes have been implemented into the Computer Classroom with the object of solving the problems posed by the professor:

- Environments for the analysis, calculation and measurement of structures: EFCiD and METAL.
- Programmes for calculating normal stresses using rules for elastics: SigmaCad and ATN.

- A considerable number of Excel spreadsheets for: finding parameters which characterise the geometry of masses of a section, calculating and tracking the distribution of loads on beams and frames, measuring the bars in reinforced concrete, finding the deformation in flexion bars and checking the elastic stability of compressed bars.

The professor will have previously given a practical demonstration in class on the use of these tools. In order to facilitate the use of these tools off campus, a way is now being sought of make them available for the students' personal computers.

SCALE MODELS, VIRTUAL MODELS AND CONCEPTUAL MODELS

Scale models allow the student to easily visualise the structural elements which make up the structure, its hierarchical dependency, the dimensional relationships of its elements, the behaviour of its joints and lines and the modulations of the system (Fig. 1).

The professor finds it easier to explain these concepts as the three-dimensional and realistic nature of the model visually clarifies questions which are very difficult to explain verbally, or even using conventional graphic material (e.g. ground plans, elevations, sections, and the like).

Likewise, the use of conceptual models in lecture classes not only allows explanation by using a more visual method which makes it easy to assimilate some concepts, but also has made them dynamic and has brought the professor closer to the student.

The conceptual model in Figure 2 helps to explain the bracing systems normally used in buildings with rigid joint frames. Setting up rigid boards which simulate siding and partitioning allow the student the see the increase in the rigidity of the structure from horizontal forces (normally due to wind or tremors). The triangulation of the panels defined for the frames can be either single or double (cross bracing). In the former case, rigidity only occurs in one direction since when the forces act in the opposite direction, the bracing (cables) become compressed and lose their stability. Double triangulation resolves this problem as there is always an active cable (brace). It also shows the need to brace different vertical planes and the overall torsion phenomena of the building resulting from asymmetrical storeys.

Using video images of these real models showing structural details and behaviour of the structure is very useful for illustrating Interactive Didactic Units.

The virtual models created using Computer Aided Design allow the student to make virtual construction details of the joints between different structural elements. These details allow the student to identify the building solutions for the different type of joints used in the calculation.

The student can manipulate these computer models because they are made up of three-dimensional models which are coupled and organised in a way which allows the following:

- Identification of the elements which make up the section.
- Selective presentation of all or some of the elements which make up the joint.
- Preparation of section or plane projections which allow the student to see how the structure is assembled.
- Dynamic visualisation of the joint, whether complete or not, with quality detailed real time images.

The Computer Aided Design software used for creating these virtual models is AutoCAD 2000. In addition to those mentioned above, this type of didactic material has the following advantages:

- The cost of preparation and maintenance is much lower than for conventional models and is infinitely lower in comparison to real joints at full scale.
- With these it is both possible and easy to do the following: break down the elements, visualise the models from many different perspectives and in the different stages of executing the joint, create animated sequences and give the students copies so that they can be studied elsewhere.

Currently, more than 50 types of models of joints between metals have been created including pillar support bases, beam and pillar joints, corner joints and truss joints. Some examples are shown below

SELF-ASSESSMENT TEST AND INTERACTIVE DIDACTIC UNITS

The self-assessment tests allow the student to be actively involved in the learning process and to control his or her progress. On the other hand, when presenting the material to the student, the professor may explain the basic concepts of the material more clearly with a dynamic aid which allows the student to learn them at a deeper level throughout the course.

The preparation of the series of self-assessment tests requires three processes to be carried out: objectification of the of the material (Ref. 7), implementation of the questions (Ref. 1) and verification of the discrimination index (Ref. 4) of each question.

Objectification of the material and preparation of questions and answers

This part of the experience is at a more advanced stage. At this stage the student has already objectified a group of more than 200 questions and their corresponding answers. As the days go on, the educational activity allows new questions to be added thus expanding and making better the available questions.

This is a complex task as meaningful and well-posed questions must be asked. For each of these several possible answers have to be designed which do not seem to be obviously correct or incorrect. Additionally, each answer should be accompanied by corresponding comments and justification in order to offer feedback to the student which allows him or her to experience a growing education and strengthen their criteria.

Computer implementation of the questions and their evaluation

After trying out the objective tests in several settings, we chose to implement the available material by using the ToolBook II Instructor v. 8 programme. This programme is specially devised for preparing multimedia didactic material and several adjustments had to be made due to the requirements of the project. See Figure 5.

Verification of the index and discrimination of the questions

All of the students who regularly attend class took the previously prepared self-assessment test. This allowed us to compare the index of discrimination for the test questions. In order to achieve this, we compared the results of the tests taken throughout the course for each student with the Test on this same material. The result was evaluated by taking into account the overall work carried out by the student during the entire course.

Also compared were the all of the answers given by the students to all of the questions of the tests.

Finally, the information was cross-referenced with these two objectives:

a) to remove the questions that were irrelevant for evaluating the knowledge of the students (this dealt with non-credit sample questions which the majority of students answered correctly).

b) to remove the questions to which a strong majority of students (including those who passed the course) responded incorrectly. This means that the material either had not been well-explained or that the question was badly phrased.

CURRENT OBJECTIVES AND FUTURE PLANS

In the 2001-2002 academic year and during the current academic year for the course *Structures I* of the ETSAV, a methodology based on the AME2 and AME3 programmes of *Proyecto EUROPA* has been used. Its object is to introduce new methods of education and the improvement of assessment systems. The objective of this experience is to promote the use of the Didactic Resource Classroom. This will allow the guided and unguided activities that the students carry out to make up part of the overall evaluation of their progress in the material which is reflected in the students' grade at the end of the course.

Currently the Interactive Learning Book is being prepared which will be the starting point for implementing an online course of Structural Building Mechanics using the UPVnet intranet of the Polytechnic University of Valencia, and can be offered by the Open Polytechnic University by Internet. The preparation of the course content, the material which makes it up, and the student evaluation procedure will be managed by using the HAUPA application which is mentioned in Ref. 6.

CONCLUSIONS

Both professors and students have shown that they believe the didactic resources developed during these years have been very useful in transmitting the course material with greater effectiveness.

Now that the mould has been cast from the results obtained from the self-assessment tests and the grades obtained during the course and final grades, the following conclusions can be drawn:

- after evaluating the results, the Test had a lower degree of difficulty than the partial tests and greater than the overall difficulty of the course.

- The percentage of passing grades for the partial examination on the material covered for each test as well as the final exam for the course is higher for the students who passed the Test. Therefore, the Test is a good indicator of the level of preparation of the students.
- the percentage of passing grades in the course for students who took the Test, whether they passed it or not, was much higher than that of students who showed no interest in taking it.

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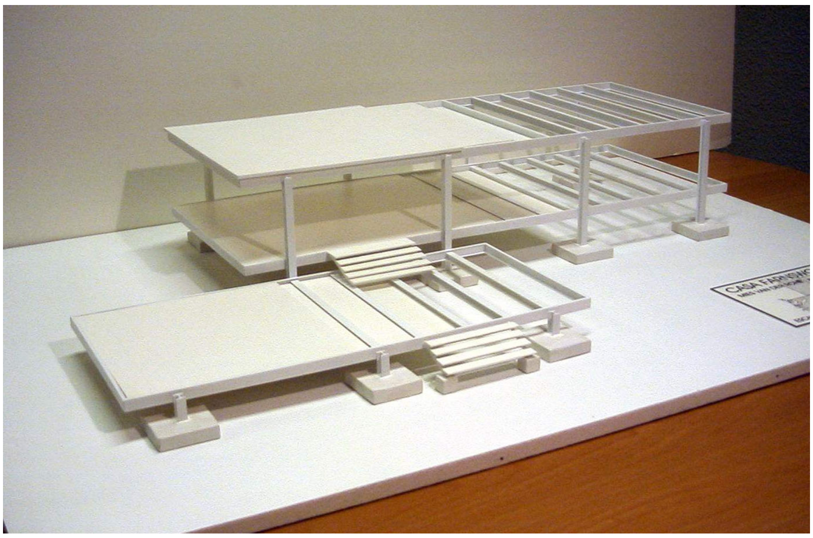
FIGURES AND TABLES

FIGURE. 1
STRUCTURE AND DETAIL OF THE FARNSWORTH HOUSE. ILLINOIS, 1950. ARCHITECT MIES VAN DER ROHE



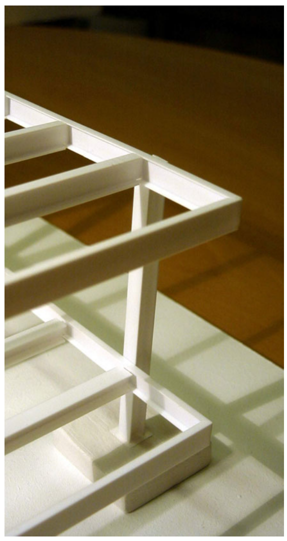


FIGURE. 2
BRACING SYSTEM OF A STRUCTURE OF RIGID JOINT FRAMES AND THEIR DETAIL USING TRIANGULATIONS WITH BRACES OR SCREENS.

FIGURE. 3
MOUNTING A RIGID JOINT BETWEENA BEAM AND A METAL PILLAR.

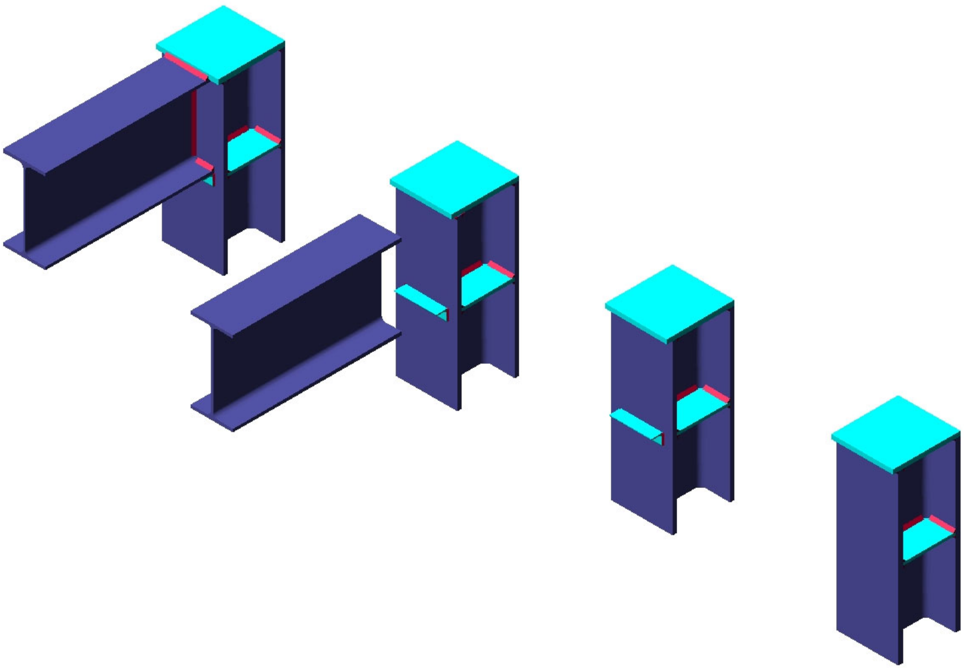


FIGURE. 4
SUPPORT OF REINFORCED CONCRETE.

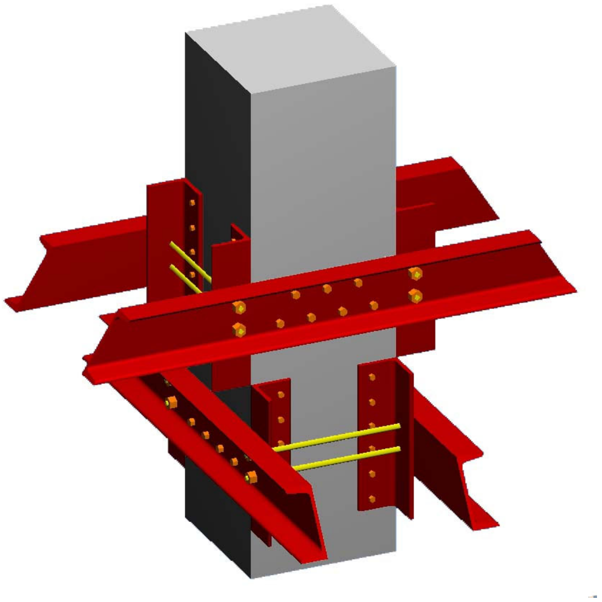


FIGURE. 5
AUTO EVALUATION TEST. QUESTIONNAIRE EXAMPLE