

**"LEARNING STRUCTURAL DESIGN.
COMPUTERS AND VIRTUAL LABORATORIES"**

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ABSTRACT

This paper shows how the spreading use of computers can improve the quality of education, specially in the field of Architecture. An Innovative Teaching Project oriented to the discipline Structural Design of Buildings has been implemented at the School of Architecture of Valencia. The main objective of this project is the transformation of the computer room into a virtual laboratory for simulating the behaviour of structural typologies using mathematical models of them. An environment, specially oriented to Structural Design, has been integrated in a Computer Aided Design platform to teach how design the Structure of Buildings.

INTRODUCTION

In Spain, it is the responsibility of the architects to specify in their building projects not only the kind of structural system to be used but also the detailed description of every element and connection. As a consequence, they need a deep knowledge about subjects like: Strength of Materials, Structural Analysis and Code specifications and appropriate Detailing for each material.

At the School of Architecture of Valencia the students can learn those contents along their career in five annual subjects. The number of concepts involved, their complexity and the great amount of practice necessary to use properly the different solving methods require from the students a very high dedication.

With the aim of improve the teaching methods, an Innovative Teaching Project has been introduced during the last three years at the Dep. of M.M.C. y Teoría de Estructuras. The objective of this experience was the introduction of new teaching methods and didactic resources based on the last computer technology. The incorporation of Computer Aided Structural Design environments to the teaching of this discipline at the schools of Architecture and the development of the concept of **virtual laboratory** was the main object of the experience shown in this paper.

BACKGROUND

One of the first applications of computers in Architecture and Civil Engineering was the structural analysis. Some programs like STRESS, NASTRAN, STRUDL, and others, have been used during the last four decades as calculation tools not only in the technical offices but also in the academic context. However, it was necessary to implement those programs on big and expensive computers making difficult their use on ordinary projects.

The introduction of Personal Computers and Workstations into the computer market during the last decade made possible the development of a new generation of structural analysis programs. These new software and hardware were rapidly incorporated to the technical offices and computers became of general use. However, these programs built a model of the structure using alphanumeric data bases. For this reason they were tools reserved just for expert users. The programs had a very limited level of interactivity and there was not any integration with other programs.

Recently, the new platforms of computer aided design have introduced a new approach for the structural design applications. This new trends try to integrate such programs into the CAD systems in such a way that they share the data bases (alphanumerical and graphic) which represent the computer model of the building. This possibility improves substantially the representation of the structure and its behaviour. Their character highly interactive make possible their transformation into efficient teaching environments.

TEACHING STRUCTURAL DESIGN. OUR SCENARIO

The teaching of this discipline takes into account the analysis of the determining factors and restraints established by the building to provide a physical support for the spaces and activities established in the functional programme proposed. For this training it is necessary to know the basic behaviour of the different structural systems as well as the parameters governing them. This knowledge has been transmitted with different approaches and teaching effectiveness. Among other methods we must mention how useful the practices carried out at the experimental laboratories have proved to be and the experience acquired by projecting the structural system of paradigmatic buildings. Nevertheless, both the high material cost of laboratory experiences and the time devoted to the study of the building's structure by conventional methods, have substantially limited its effectiveness as teaching experiences.

Fortunately, in contrast to some others aspects of the building, the design of the structural system can be divided into several basic modules. Most of them can be implemented as computer programs. The others, like in every design activity, cannot be expressed by means of mathematical equations and require a considerable amount of experience and rules of thumb.

Currently teaching program

The students in the third year of Architecture study for the first time Structural Design. The contents of this subject are:

1. Structural typologies. Behaviour and appropriateness.
2. Statically determinated structures. Reactions and Member Forces.
3. Stress diagrams and detailed design of elements.
4. Strains an displacements.
5. Buckling and instability.
6. Statically indeterminated structures.

For years, the teaching resorts of this contents have been the theoretical and practical sessions, laboratory practices and applied projects.

The theoretical sessions are attended by nearly 60 students and usually the contents are shown on the blackboard or by means of slides and overhead projectors. A general explanation of the basic principles and hypothesis is done and those more relevant are outlined.

In the practical sessions the more significant problems and their solving methods based on the exposed theory are enunciated. At this moment these sessions require almost the 70% of the available time.

Laboratory practices permit to observe the behavior of some full scale structural elements or reduced models. Although they are very useful didactic resources, their physical and economic limitations have reduced them to a minimum.

The applied projects are oriented to the analysis of the structural system of some paradigmatic buildings. In addition to this the student must fulfill the structural requirements of a building, preferably their building project.

A NEW APPROACH FOR THE TEACHING PROJECT

The Innovative Teaching Project is founded around the concept of **virtual laboratory**. This new arrangement of the computer room as a teaching platform integrate Computer Aided Design (CAD) systems and structural analysis programs to build an specific environment oriented to the Computer Aided Structural Design (CASD). It will permit to simulate that kind of practices usually performed at the structures laboratory.

The participants of this experimental groups were studying the third year of Architecture. For that, they had enough knowledge on the fields of Mathematics, Physics, Strength of Materials, Building Procedures and Detailing. They had also designed buildings of different complexity. However they did not have any experience with computers.

The incorporation of the CASD environment as a teaching tool made necessary to re-elaborate the different units of the course and its schedule, but our experience shows an improvement of the students efficiency.

In the new focus of the subject we emphasize those aspects related with the design and behaviour of the structural system rather than those concerned with its mathematical calculations.

This allows the students to reinforce the fundamental concepts and establish the design criterion to be applied on their future projects.

The teaching method intends to show the students how to elaborate the computer model of the building structure and provide them with a tool to make this activity clearer and faster. This virtual model became an object (something like a laboratory specimen) that can be used to experiment on it and learn about its behaviour. Successive calculations and refinements improve the initial solution. If the computer performs all the calculations it is possible to test some alternatives and choose the most suitable.

With the incorporation of the CASD environment the teaching has been oriented mostly to the practical aspects of the design. The theoretical sessions had the same contents and organization but the practical ones had changed in such a way that the students are more involved. The kind of exercises proposed are:

- 1 . Using the structural systems contained on a library,
the students are required to test their response and perform an intuitive approach to the problem proposed on each exercise. The object is to substitute the real laboratory by a virtual one based on the CASD environment. Each student has the control of his virtual laboratory. Figure 1. 1, 1.2 and 1.3 show some examples.
2. Research practices to find the best values of the parameters governing a given structural solution. In such a way the student can set some sort of design criterion. Fig. 2.1 and 2.2 show some examples. These exercises make easier the comprehension of fundamental aspects like the logical proportions of the structural systems and its elements.
3. Exercises where the CASD environments is used just like a calculator with advanced functions for solving problems in a traditional way. This approach keeps the didactic benefits, the compared analysis and discussion about the results of every step being possible. The high calculation speed, the lack of mathematical operations and the reliability of the results improve the comprehension process. A statically indetermined structure is solved in figure 3 using the method of the compatibility of displacements. The influences of the redundants are obtained using the CASD environment as if they were different support alternatives.

4. The students are required to define and calculate the structure of the building that they are designing that course. They test different structural solutions checking which one fits better. The accuracy of the results obtained with the CASD help permit to reach conclusion with a high degree of reliability.

making possible to focus the students attention on the tasks directly related with the conception of the structural solution and reaching efficiently the didactic objectives of the subject.

COMPUTER ROOM LIKE A VIRTUAL LABORATORY

At this moment the teaching activities take place into the computer room. The incorporation of the CASD environment transforms it into a virtual laboratory.

Hardware

Our computer room was equipped with 15 personal computers. Taking into account that each computer is potentially a virtual laboratory it can be noticed the didactic rentability of the classroom.

Software

The fundamental characteristics required from the structural analysis programs installed on the computers should be: high degree of interactivity (very friendly environments), graphic based presentations and high calculation speed.

For this reason the CASD program should include: a graphic interface for representing the structure, its dimensions, loads and connections; a module to perform the necessary calculations, and two libraries, one of them containing basic structural types and the other with structural shapes for the elements.

The graphic interface would display the structure dimensions, its elements and their proportions and connections, the supports, the member force variations on each element, the stress level for every cross section and the deformed configuration of the structure for each load case. This would make easier for the student the conception and analysis of the structure.

The calculation module should include all the necessary algorithms for solving the system of equations that represents the mathematical model of the structural behaviour of two-dimensional bar systems. Routines to obtain reactions at the supports, displacements of joints, variations of member forces and the deformed geometry of the structure would be also necessary. The evaluation of the stress distribution on the elements cross section would be a very interesting tool for sizing and estimating costs.

The library of basic structural types would offer to the students a collection of simple models ready to be used. The detailed definition of elements and connections would permit to experiment with them like real structures into real laboratories.

Among the evaluated programs, CYPECAD was the most suitable for our purposes. This computer application was developed by the firm CYPE Ingenieros S.A. which offered educational copies to be installed at the department computer room.

Using the CASD-CYPECAD platform

The CASD-CYPECAD environment installed into the virtual laboratory is a simplified version to manage two-dimensional structural systems composed by linear elements made of steel or reinforced concrete. The bar cross-section must be constant. There was also some restrictions on the number of joints and members to improve the program performance.

The CASD-CYPECAD display has five areas to interface with the user. The figure 4 shows their relative size and position. Zone 1 is a status line. Zone 2 is the working area and behaves like a drawing interface. The complete structure can be observed on zone 3. This area is a map to specify which part of the structure the user wants to zoom in and display on zone 2. The different menus are on zone 4. Finally, there is a ruler and a calculator on zone 5 for introducing analogical and numerical data.

The first step is to establish the structure topology. This can be done easily just sketching it on the working area. This is a conceptual representation that has no dimensions at all. Figure 5 shows how to define the sketch. There are two possibilities: set up the nodes positions and join them with elements or just draw the bars directly and leave the system establish the joint positions. In such a way, the structure can be designed using basic typologies and the sketching procedure is similar to use our notepad.

When the structure configuration has been set up the connections between elements and the support conditions can be specified.

Figure 6 shows how to choose a kind of connection or support condition from the icon menu and apply it to different joints just pointing to them.

On the third step the length of each element is specified and the structure real proportions becomes evident. Figure 7 shows how the sketch is progressively transformed.

The type and cross-section size of every element is specified using the shapes library like in figure 8. However, it is advisable to group the bars. This makes easier the initial sizing and the final construction and erection of the building structure.

The last step on the definition procedure is the application of loads to joints and bars. Some icon menus let the user to choose the most appropriate ones. See figure 9. Loads are grouped into load cases and self-weight is evaluated from the length of elements and the data contained into the shape library.

This computer model of the structure can be evaluated and tested to check its strength, deformability and stability. The high calculation speed of this CASD platform makes possible to define and run rapidly different alternative solutions. Changes on support conditions, stiffness of elements, type of bar connections and elements addition or elimination are allowed.

The structural analysis results are displayed by means of graphics and tables. This is the easier way to find the weak points and to choose the most appropriate strategy to modify and solve the structure.

FUTURE DEVELOPEMENTS

One of the most important changes to be introduced into the CASD system is the possibility to deal with tri-dimensional structures composed of linear elements as well as the implementation of solid modeling platforms to manipulate surface elements like plates or shells. The library of basic structural types should be completed with these new systems.

At the same time it is necessary to work on the elaboration of advanced tutorials based on expert system techniques to keep track of the student progress and to suggest additional practices to improve the understanding of some concepts.

CONCLUSION

The virtual laboratory is based on computer models of the structural system that can be tested into the computer room to make them suitable for the purposes of a specific building. Using the hardware and software available at this moment it is easy and fast to perform this checking with a high degree of reliability. These analyses improve the structural behaviour comprehension without the students getting lost in collateral mathematical operations. In this way it is possible to improve the student's work and the efficiency of the teaching in terms of economy and time.

The results of this experience have been extremely satisfactory for both the teachers and students involved. The understanding of the subject has proved to be higher than that of conventional courses while students have needed less time to follow the course. Nevertheless, it seems necessary to reduce the number of students of each group to improve the teacher monitoring.

The didactic material usually employed must be revised and adjusted to the new trend. During the first year this represents an additional effort. As a consequence, it is highly recommended to share experiences and exchange the material elaborated on each School.

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