REFRESHING “GRAPH OF INTERNAL FORCES”

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Abstract

This paper presents a refreshing of the educational tool “GRaph of Internal FOceS” (GRIFOS). The main aim of this software is to enhance the learning methods used to teach the distribution of internal forces in building structures. This tool allows students to practise drawing schemes of Flexure Moments, Shear Strength and Axial force of structures. Thus, it is able to automatically check the structural schemes of the mechanical behaviour laws of typical building structures, helping the self-study.

The group of innovative education $E^4$ (Exploración de Enseñanzas en Estructuras de Edificación) promotes the use of the Information and Communication Technologies (ICT). One of the initiatives of $E^4$ group consists of continuous modernization of GRIFOS from the early versions of this question type, in which the numerical values were checked using variables data for each student, to the latest version significantly more advanced and complex, which is able to automatically check the schemes of the internal forces of building structures.

The improvements that are currently taking place in GRIFOS are presented in this work. The main enhancement made is to incorporate the possibility to copy and paste the schemes from a frame to another frame of the same structure. This is an option that is present in computer-aided design (CAD) programs, and it is an excellent option to imitate them because the architecture students are acquainted to that choice. An example of other improvement is the incorporation of the option of modifying an already drawn scheme. This option, combined with the previous one, will allow to speed up the drawing process of schemes in complex structures composed by several frames. Other enhancements that could be developed are focused on the improvement of the visual characteristics.

The improvements made in GRIFOS are based on the results of satisfaction surveys, in which students and teachers from the Technical University of Madrid have participated, and the main objective is to obtain a powerful educational tool than can be useful to other Universities and Technical Schools.

Keywords: ICT, e-learning, educational tool, building structures.

1 INTRODUCTION

This paper presents a refreshing of the educational tool “GRaph of Internal FOceS” (GRIFOS). The main aim of this software is to enhance the learning methods used to teach the distribution of internal forces in building structures. This tool allows students to practise drawing schemes of Flexure Moments, Shear Strength and Axial force of structures. Thus, it is able to automatically check the structural schemes of the mechanical behaviour laws of typical building structures, helping the self-study.

2 GRIFOS

The group of innovative education $E^4$ (Exploración de Enseñanzas en Estructuras de Edificación) [1] promotes the use of the Information and Communication Technologies (ICT). One of the initiatives of $E^4$ group consists of continuous modernization of GRIFOS from the early versions of this question type, in which the numerical values were checked using variables data for each student, to the latest version significantly more advanced and complex, which is able to automatically check the schemes of the internal forces of building structures.

Figure 1 shows an example of exercise in which GRIFOS has been used in the subject “Structures 2” at the School of Architecture of the Technical University of Madrid (UPM). From a real structure, a simplification model is presented and the schemes of axial forces, shear strength and bending moments are requested.
Dibuje el esquema del mecanismo de colapso para las acciones indicadas en la figura \( f_x = \gamma_f \cdot 15,00 \), indicando las posiciones de las rotulaciones plásticas y el sentido de rotación de las mismas.

Dibuje el gráfico de momentos de colapso (M, en kNm) y los correspondientes de cortantes (V, en kN) y axiles (N, en kN).

Valores mínimos de la fuerza horizontal \( f_x \) para el cual el mecanismo de colapso es el lateral

Valores mínimos de la fuerza horizontal \( f_x \) para el cual el mecanismo de colapso es el combinado

Valor de \( M_p \) para \( f_x = \gamma_f \cdot 15,00 \)

Armadura en el centro de la viga, \( A_s \) en cm².

**Figure 1: An example of structures exercise.**

### 2.1 Design of “GRaph of Internal FOrces”

**GRIFOS** has been designed as a new question type of Moodle and it has been incorporated into the bank of questions inside the questionnaires, because the suitability on structures teaching had been proved. There are an open access Moodle [2] in which both students and professors can use **GRIFOS**. This Moodle is provided by UPM and the access is using the user “estructuras” and the password “estruc”. Currently, a wide range of examples of linear and non-linear building structures are available. Students can use them to self-study and professors to teaching building structures.

**2.1.1 Platform for GRIFOS**

In order to promote the self-study of the laws of internal forces, a platform in which students could draw these schemes must be selected.

The broad development of the Learning Content Management System (LCMS) promoted its application in structures teaching and the election of Moodle became promoted by the Technical University of Madrid (UPM). However, **GRIFOS** could have been built up in other LCMS.

Current sources easily allow to incorporate draw tools into the interface of Moodle and develop a configuration in order to obtain a friendly desktop environment similar to CAD. Thus, Moodle is a tool, open source software, which is well known and flexible enough to support patches.

Likewise, it is easily possible to emulate the commercial programs of drawing and it is an excellent option due to ETSAM students are acquainted. Figure 2 shows the interface of **GRIFOS** for students.

### 2.2 Brief User Guide for students

**GRIFOS** allows drawing the structural schemes using a similar interface to CAD ones, which Architecture and Civil Engineering students tend to use day by day.

Figure 2 shows the interface of **GRIFOS**. It can be observed that the mode of drawing remembers, or at least visually, to the drawing programs as Auto-Cad, Revit, etc.
Basic tools as zoom, move, adjust, etc. have been defined according to commercial programs well known by the students. Users can move between the different elements of the structural model and easily draw the scheme of the internal forces on each of them.

2.2.1 Structural schemes

The law of internal forces can be defined by straight lines or second order lines and it is possible to be continuous or not continuous between the points in which the law changes. Geometrically, a straight line is determined by two points and the second order line is defined by three points. Every point which defines the geometric lines depends on his coordinates, independently of the order in which the points are defined drawing the second order line.

Therefore, GRIFOS allows to draw and to check schemes of bending moments derived from any different load combination: local or continuous load. In this way it is possible to model most typical loads in building structures.

2.2.2 Lacks of GRIFOS

At this moment, it is not possible to work with other load types in GRIFOS because it is not necessary for the aim of the structure subjects at the ETSAM. Nevertheless, it could be possible to incorporate them in the future, i.e. continuum linear loads.

Obviously, it could be possible to evaluate laws of shear strength derived from bending moments.

2.2.3 Drawing structural schemes in GRIFOS

Figure 3 shows an example of GRIFOS question used at the School of Architecture of the UPM. On the left of figure 3 the exercise is shown, where the structure model is geometrically defined and the loads and boundary conditions are described. On the right of figure 3 the vision of GRIFOS for ungraduated is shown. This view is a screenshot of a GRIFOS question and it correspond to the aspect under students role in Moodle.

In figure 2 and on the right of figure 3 it can be observed that the “active” frame of the structure is in yellow color. In both cases, it correspond to the left column, and is this column in which the draw can be made. On the right of figure 3 it can be observed that the “zoom” options of the question are in visible mode.
Figure 3. Left: Example of class question. Right: Screenshot of GRIFOS of the same question.

Figure 4 shows the answer of the student. In this image, the values of the beginning and the end of the active frame have been introduced.

The “tooltip” (blue rectangle above centered) shows the coordinates, according to local axis of the last clicked point (10, -132). GRIFOS allows to define the values that describe the geometrical scheme both numerically (manually introducing the numbers) and graphically (clicking on the graph, as can be observed in figure 4).

The main objective of GRIFOS is to promote the self-study in university studies, as can be seen in the website of the group of the educational innovation [3]. That is why the question is predetermined to automatic show if the introduced answer is correct or not. When a correct question is answered the scheme become colored in green, as figure 5 shows, and the active frame is blocked in order to prevent students overwrite a false value over the correct one.

Figure 4 shows the process of drawing the scheme of bending moments in the central beam. The numbers of the “tooltip” show that the third geometrical point of the second order line has been defined in the middle of the beam (it can be observed that the cursor on the abscissa 10) and the main guidelines of the second order line are drawn in grey.

Figure 4. Draw of bending moments scheme in the central beam.
In figure 4 it can be observed that the central beam is active. In this case, a bending moment law has been defined. However, it can be observed that the values defined in two extreme and in central point are not correct, but the equation of the curve that define the law is appropriate: the drawn law does not become in green.

In figure 5 can be observed that the cantilever beam has been drawn. In spite of the numerical values are correct, GRIFOS identified the scheme as a correct one because a second order line was drawn.

2.3  Brief User Guide for professors

GRIFOS is an evolution of a standard question of Moodle. In this way, all its properties are extended from the original one.

The visual characteristic used by teachers to define this new question type is very similar to the any other question. In GRIFOS, new sections are incorporated in which the geometry, the topology and additional properties can be defined for each question, as is exposed below. The way to define the title of the question, the text, images, values of the answers, feedback, etc. is the same that the one used for every question of LCMS.

2.3.1  Definition of GRIFOS questions

The way to define the topology and geometry of the structural model is similar to the way of define of typical programs of building structures.

The correct answer is defined frame by frame, defining a mathematical function by piecewise. They are polynomials of first or second degree, depending on the case. Each equation is mathematically defined by two or three couple of points, in which the value of the internal force and the abscise coordinate must be defined.

GRIFOS is characterized by additional properties to allow the adaptation of different teacher scenarios or diverse teacher tendencies: the auto-correction criteria can be active or not. Examples or these auto-correction tools are the blocking of a correct scheme, or the immediate highlighting in green when a correct answer is introduced.
There are two very important options incorporated in GRIFOS. First one is the possibility of calibrating the tolerance of the numerical answer. Second one is to incorporate the option of changing the sign of the law of the internal forces of the structural models. First one is an extended property of the Moodle questions. Second one is very important because to impose a sign criteria would have restricted the use of GRIFOS to teachers who have the same criterion that the authors of this paper.

Figure 6 shows the pre-visualization mode of the same question represented in previous questions. In this mode, the geometry and the topology of the structural mode is displayed. In addition, the maximum and the minimum schemes of the law of the internal forces are represented. Any law that is drawn by students inside both limits will be automatically checked as a correct scheme. The draw tools are active in figure 6. In this mode, teachers can graphically define both upper and lower limits of correct schemes.

As it has previously mentioned, GRIFOS allows an automatic evaluation. In addition, it is possible to see every answer of a student (figure 7). Teacher can see at the same time the structural mode, the upper and lower limits of the scheme that determine the correct schemes and the answers of the students. To simplify the results, the correct answers of students are highlighted in green.

At the same time, the false results are represented in black, as can be observed in the bending moments of the upper beam of figure 6. It must be noted that in this example, if only numerical values would be checked the answer of the student would be corrected as a valid scheme because the flexure moment in extreme and middle points are correct. Obviously, in this pre-visualization view the draw tools are not active.
3 IMPROVEMENTS IN PROGRESS

The improvements that are currently taking place in GRIFOS are presented in this work. The main enhancement made is to incorporate the possibility to copy and paste the schemes from a frame to another frame of the same structure. This is an option that is present in computer-aided design (CAD) programs, and it is an excellent option to imitate them because the architecture students are acquainted to that choice.

An example of other improvement is the incorporation of the option of modifying an already drawn scheme. This option, combined with the previous one, will allow to speed up the drawing process of schemes in complex structures composed by several frames.

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4 MAIN ADVANTAGES OF GRIFOS

GRIFOS reinforces this self-study and extends it: the quantitative learning and the self-correcting are promoted in the study of the laws of internal forces.

The use of GRIFOS is fully effective in big student groups (i.e. 3 groups of 75 students as is currently working at the School of Architecture). In addition, it makes possible the utilization of complex questionnaires, with weight geometrical and graphical components according to building structures.

The use of GRIFOS is well confirmed in computers. At the moment, it is not fully established in tablets. This software tool has been developed at the ETSAM (Technical University of Madrid) and it is able to automatically check the schemes of the internal forces of building structures. Furthermore, it allows the quantitative and qualitative self-study of the laws of the mechanical behaviour or typical building structures.

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REFERENCES

