MAKING EASIER THE TEACHING - LEARNING PROCESS OF OPENSEES AND ITS USE IN PRACTICE AND RESEARCH

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Abstract. This article shows the links between teaching, research and practice by means of a calculation engine called OpenSees. OpenSees is a well-known framework to perform linear or non-linear analysis, developed at University of California, Berkeley. Its use is widespread all over the world and allows users to simulate efficiently the response of structural and geotechnical systems subjected to earthquakes and other hazards. Initially, OpenSees was difficult to learn because of the lack of user-friendly and guided environment (script input) and, for this reason, it was little used in practice and in research, despite it is a powerful tool. Cype S.A. integrated OpenSees as calculation engine in its new suite for analyzing and designing structures: StruBIM. This suite integrated OpenSees in a user-friendly interface, interactive view of the model, guided calculation process and post-processor of results after performing the analysis. The results of this integration are that it is much easier to teach and learn how to use OpenSees, its scope of application, its functionality and the resolution of educational practical cases with it. Bearing in mind the current requirements of the European society, a practical approach using a powerful and widespread tool valid for practical and research work is needed for learners' studies. Besides, another result, which is related to the previous one, is that OpenSees is currently an attractive tool for civil engineers and architects to use in practice and to solve complex actual cases. Analogously, Cype is currently working on extending StruBIM to make use of all functionality of OpenSees to be used in research world. Therefore, the teaching - research - practice cycle is closed again, this time with a teaching-learning process so much easier to achieve and a practice and research part able to use the functionality and the high performance of OpenSees. This is fruit of the detecting that the former teaching - research - practice cycle had serious deficiencies.

1 INTRODUCTION

Software has become very important for engineering practice. The size of the engineering problems is enough to be almost indispensable the use of engineering software. For this reason, it is a key aspect that students become familiar with the philosophy behind the computer tools. It is necessary to remember that Spain took part, together with other member states, in the elaboration of the European educative reform regarding university that completely changed the organisation of the teaching plans, the curriculum and the teaching-learning approach. After

embracing all the required changes in the structure of the educative system, that were stated by the Bologna's plan [1], students' title is a European one which is valid to work in all the state members since it is obtained in a country that is part of the European Higher Education Area. This possibility has brought about more chances for the learners but also a huge responsibility for the countries in the achievement of qualified engineers.

The students' training needs to be eclectic in order to deal with the different skills that are valuable to become a good engineer. A more real-life direction and a pragmatist approach of teaching-learning process is important as the Council of Europe [2] stated in its educative recommendations. Bearing in mind all this information, university studies should provide learners with an actual practice and a real insight about their future jobs such as the use of engineering software.

In this context, OpenSees [3] is a powerful engineering software tool developed at University of California, Berkeley. It let users simulate efficiently the response of structural and geotechnical systems subjected to earthquakes and other hazards in a linear or non-linear way. Besides it is free to use in teaching and research purposes. However it is very hard for students to learn to use OpenSees because of the lack of user interface (script input) and guided environment. CYPE Company is trying to avoid this problem by integrating OpenSees as calculation engine in its new program to analyze structures: StruBIM Analysis [4].

StruBIM Analysis [4] forms part of StruBIM suite, which is a group of structural programs, each one related to one stage of structural design integrated in a BIM workflow. StruBIM Design is responsible of designing and checking columns, beams, slabs and walls. It imports the analytical model results from StruBIM Analysis [4] or from a file with a specific format. Besides, it is able to manage a local analytical model of each floor to design tendons, slabs and beams. It uses OpenSees as calculation engine. Analogously to StruBIM Design, Cype has created StruBIM Foundations to design foundation elements.

As a consequence of integrating OpenSees as a calculation engine of StruBIM Analysis [4], it is much easier to teach and learn how to use OpenSees, its scope of application, its functionality and the resolution of educational practical cases with it. Besides, OpenSees is integrated in a BIM workflow since StruBIM is integrated too. This fact causes that students can learn OpenSees taking advantage of BIM philosophy, which makes easier the student focuses just in learning OpenSees and not in the modeling phase.

2   TEACHING-LEARNING PROCESS OF OPENSEES: BEFORE AND AFTER

Before integrating OpenSees in a user-friendly and guided environment, OpenSees was used mainly in research. Both experienced researchers and PhD candidates must learn how to use OpenSees by resorting to the help on the Internet. This process was slow because the programming language that uses OpenSees to insert the data had to be learned. Consequently, neither engineering students nor engineering companies used OpenSees. This situation has changed since OpenSees was integrated in StruBIM because of two main reasons: (1) OpenSees is provided with a user-friendly and guided interface. Therefore, researchers, students and professional engineers can use OpenSees in their everyday life, (2) OpenSees is integrated within a BIM workflow which is displayed in Section 4.

A program like OpenSees, which was created to use it in the research world is now attractive to be used by anybody. First, research sector created and used OpenSees. Then, professional sector (CYPE S.A.) realized OpenSees could be widely used. Last, engineering students have an opportunity to learn a powerful tool within and user-friendly, didactic and motivating environment. Of course, engineering professionals and researcher can take advantage of OpenSees much easily. In turn, students and professionals can improve OpenSees because it is an open source software where user community can contribute with their code. Therefore, the three sectors (researchers, professionals and students) feed each other to make OpenSees better and more widespread.

3   EXTENSIONS PERFORMED TO OPENSEES TO ITS INTEGRATION IN STRUBIM

Several extensions have been carried out to integrate OpenSees inside StruBIM. Two new elements have been developed for Opensees: A one-dimensional elastic 2 node bar and a 6-node triangular shell element. Both support a wide kind of loads, local eccentricities, and stiffness multipliers. One-dimensional element calculates sectional forces and deflections at any inner points of the element without adding new nodes. Shell element supports thick sections and it works for non-linear analysis. Besides, we have implemented a new solver of system of called MUMPS (Multifrontal Massively Parallel Sparse Direct Solver) [5], which was developed in several European universities. It speeds up the calculation process. Other extensions were the capability of calculating several load cases in parallel and a new system of relating degrees of freedom. **Figure 1** shows how to run the analysis in StruBIM Analysis [4] selecting OpenSees as calculation engine. Currently, all non-linear performance of OpenSees is being implemented in StruBIM Analysis [4] to make use of it.

4   BENEFITS FOR STUDENTS OF USING OPENSEES INSIDE A BIM WORKFLOW

The integration of OpenSees in StruBIM not only means a user-friendly interface but also the integration in a BIM workflow. OpenSees, as all structural computer programs, models analytical elements such as one-dimensional elements, shells elements, the relation between degrees of freedom, etc. In order to perform the structural analysis, it is necessary to gather some initial information from the architectural model. This flow implies that the structural analysis tool is able to read the structural model (beams, columns, slabs…) and create the analytical model adding the information that cannot be described in the modeling tool (if it is necessary). This is carried out by StruBIM Analysis [4]. The procedure from creating the architectural model to having the drawings is illustrated in **Figure 2**.
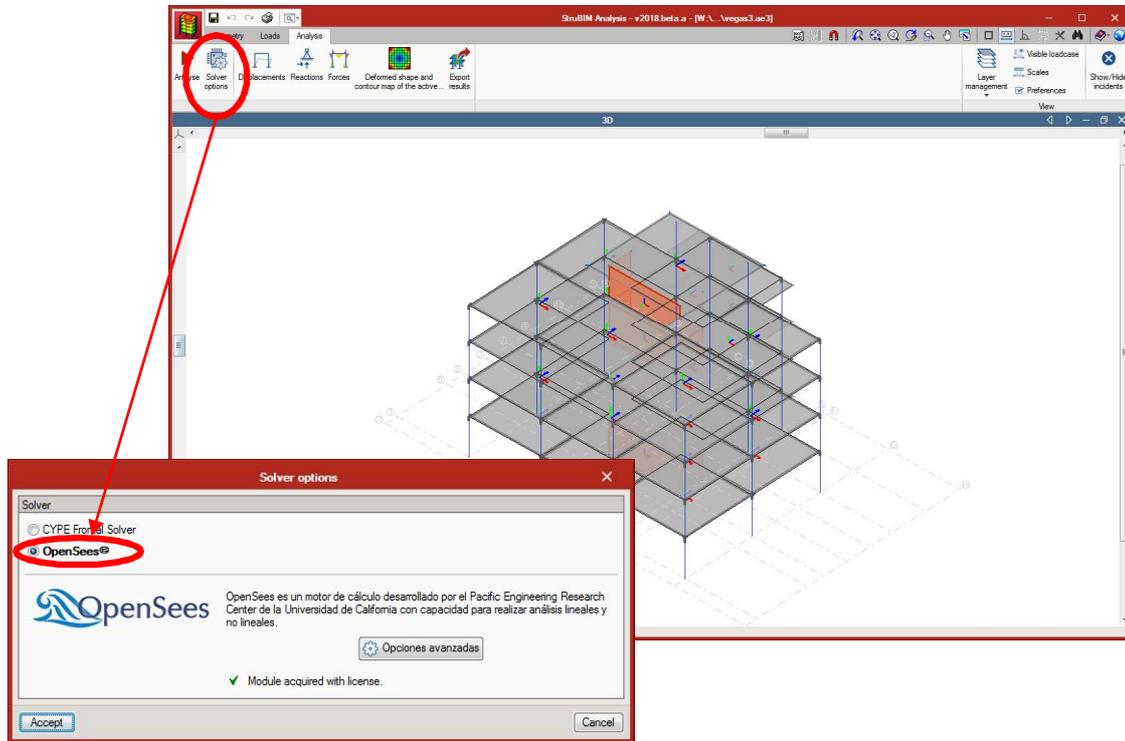
Figure 1: StruBIM analysis with OpenSees as calculation engine

The main benefits that users can take from the workflow of the **Figure 2** is that they will be able to use all the functionality of OpenSees just importing the structural model into StruBIM. The structural model which derives from the architectural model can be made with any modelling commercial tool available on the market. User will be able to perform a complex non-linear analysis of an actual structure with OpenSees with a minimum effort. This is unthinkable by coding the data input as OpenSees itself demands.

Another advantage of integrating OpenSees in a BIM workflow is that OpenSees could be part of an integrated teaching-learning strategy of university. Universities have based their organisation on both the current legal framework established by the Royal Decree 1393/2007 October 29th [6] which states the structure of the official university studies and the ECTS user guide (2015) [7] published by the Education Ministry. Both documents gather the new implementations in terms of high studies required by the European Union. The following sentences have been extracted from the Royal Decree 1393/2007 October 29th [6]: "the competence is understood as the capacity to transfer knowledge into practice", "prepare students for the practical and professional life". The following sentences have been extracted from the ECTS user guide (2015) [7]: "the curriculum should be designed to get necessary competences to be a professional", "students must be able to apply their knowledge to their job", "students must be able to transmit information and solutions to an specialized or non-specialized public", "students must be able to apply their knowledge in multidisciplinary contexts.".

Architectural model

Structural model

Feedback of architectural model

StruBIM Analysis generates the analytical model from the structural

Analytical model

Design, check, drawings and reports

The powerful calculation engine OpenSees confers StruBIM high processing performance

Calculation of analytical model
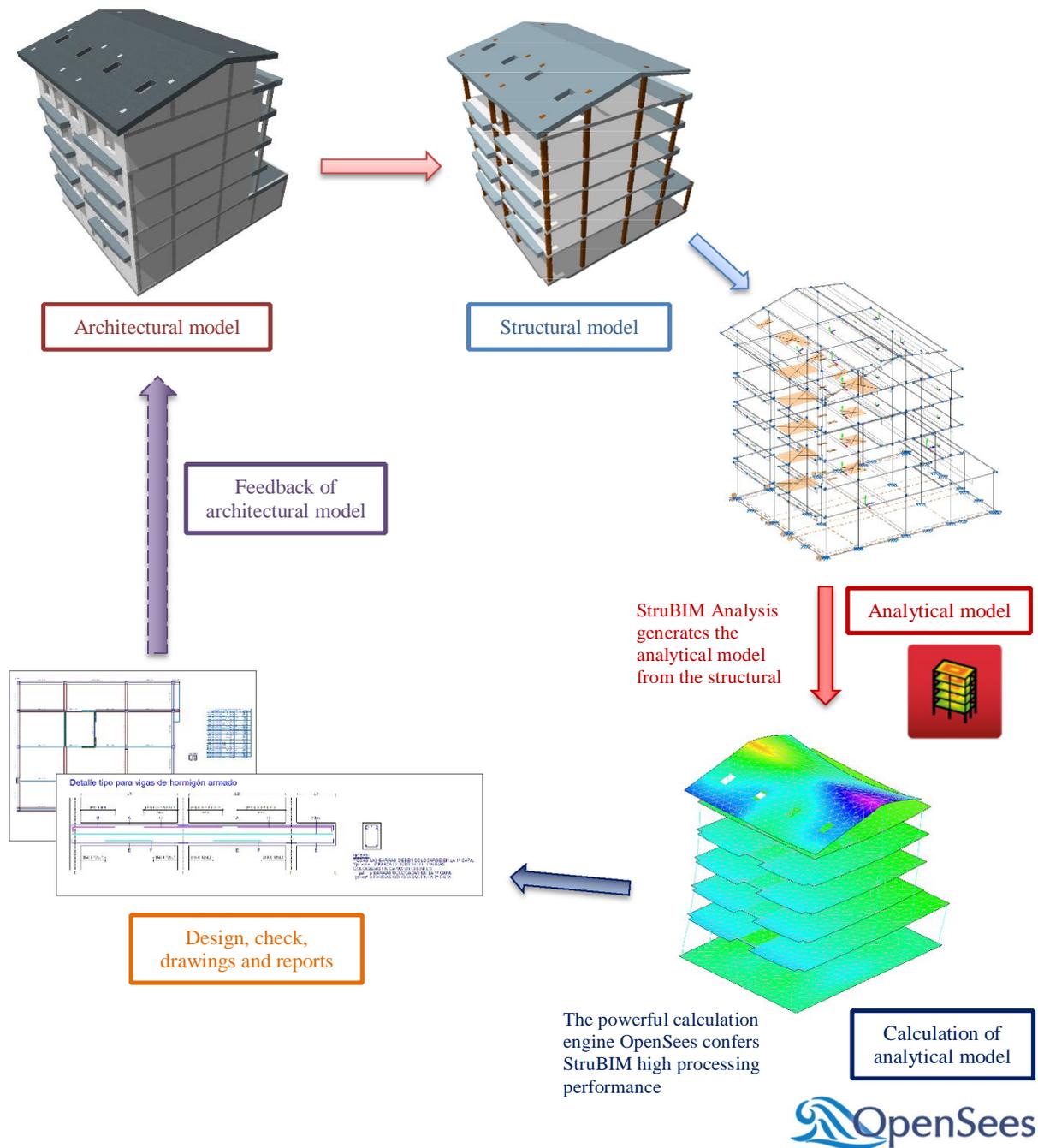
Figure 2: Structural analysis and design integrated in a BIM workflow

Therefore, curriculum of universities must teach students to be able to apply their knowledge on a multidisciplinary and professional context. To achieve it, a new approach based on BIM philosophy is being carried out in some masters. It consists of creating a professional actual project which will be developed in several subjects of the degree or of the master. For instance, a project of a building covers many knowledge areas such as modelling, structure, water supply, wastewater evacuation, illumination, heating, ventilating and air conditioning (HVAC), acoustics, telecommunications, etc. Each discipline would be treated in a subject with a specific software. In this way, each subject will contribute to the main global project. In order to integrate efficiently the results of every discipline, a BIM workflow is used. BIMserver.center [8] offers a bunch of programs integrated in an workflow to cover every discipline of a project. StruBIM is among these programs. For this reason, OpenSees could be used to cover the structural analysis discipline of the global project inside a multidisciplinary and multi-subject context.

6   CONCLUSIONS

- OpenSees has been equipped with a user-friendly and guided interface by integrating it as a calculation engine of StruBIM Analysis [4]. Consequently, the functionality of OpenSees is much easier to teach and learn.
- Before integrating OpenSees in a user-friendly and guided environment, OpenSees was used mainly in research with a great effort. Now, it is easy to use for students and professionals.
- Several extensions have been carried out to integrate OpenSees inside StruBIM. Two new complete finite elements, a new solver of system of equations (MUMPS) [5], the capability of calculating several load cases in parallel and a new system of relating degrees of freedom.
- A way with which universities could teach professional-oriented practical skills in a multidisciplinary context, as the Royal Decree 1393/2007 October 29th [6] and the "ECTS user guide" (2015) [7] states, is to create a professional global project which involves several subjects of the degree or of the master. Each subject would treat a discipline with a specific software. In order to integrate efficiently the results of every discipline of each subject, a BIM workflow is employed. In this context, OpenSees could be taught inside a professional and multidisciplinary project because it is integrated in StruBIM which is also integrated in a BIM workflow.

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