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AN OVERVIEW OF THE NUMERICAL MODELING AND COMPUTER PROGRAMMING DISCIPLINES OF AN UNDERGRADUATE CIVIL ENGINEERING COURSE AND THE INSANE PROJECT EXPERIENCE

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Abstract. The world witnesses the progressive advancement of computing, whether it is in the raising power of data processing and storage, in the enhancement of modeling tools or in the improvement of the capacity to exchange information and knowledge. Today science seems to be dependent on informatics, and because of its nature, the Engineering (or the Exact Sciences, in a more general way) shares this connection even more. A need for understanding some real phenomena and the relentless search for rules that explain the behavior of physical systems drive the modern engineer to develop proper computational mechanisms that could handle the analysis of complex (mathematical) problems. Therefore, the appropriate training of engineering students regarding programming and numerical methods skills should be considered if a society wants to fully use its technological resources. In that sense, this work shares a brief overview of the numerical modeling and computer programming disciplines of the undergraduate civil engineering course of the Federal University of Minas Gerais, Brazil, towards a basic diagnosis and a critical appraisal of the curriculum. Trying to fill some gaps in the academic formation process, the INSANE (INteractive Structural ANalysis Environment) project was created; an interactive environment of structural analysis conceived to be used as a didactic resource in undergraduate and graduate courses of engineering, as well as a platform of high-level scientific research on numerical methods. Throughout the years, INSANE has contributed to the training of many students, either enabling programming proficiency or in-depth learning of finite element method formulations.

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1 INTRODUCTION

The progressive advancement of computer technology is undeniable and it seems to be fairly plausible to state that the future engineer will be quite dependent on computational tools, even more than today's professional. In this regard, one could underline not only the engineer's urge of incorporating operational knowledge (how to use new technology), a labor market demand, but also the necessity of learning their corresponding theoretical basis.

Moreover, the evolution of technology puts an inherent pressure on the academical science, in a way that older theories, which could not be extensively tested in the past (because of evident technological limitations), naturally re-appear and bring new colors to the higher education environment. Therefore, the researcher needs to be well prepared to contribute to this scientific development.

In that sense, the academy, as an active piece on the complex puzzle of the educational system, should incorporate into its practices the evolutionary components of the growing technological infrastructure. To do so, a critical eye towards the engineering curriculum is necessary, in order to build a diagnosis (even if it is preliminary) of how the instructional process is being handled.

With that in mind, this article shares a brief overview of the numerical modeling and computer programming disciplines of the undergraduate[1] civil engineering course (CE) of the Federal University of Minas Gerais (UFMG, in Portuguese), Brazil, towards a basic diagnosis and a critical appraisal of the curriculum. The text begins with a brief background of the brazilian higher education (Section 2). Next, in Section 3, an outline of the civil engineering curriculum is presented, along with the UFMG reality and the computer science disciplines of the undergraduate engineering courses of the aforementioned institution. In Section 4, the INSANE project is outlined. Finally, in Section 5, some final remarks are registered.

2 OUTLINING THE HIGHER EDUCATION IN BRAZIL

The education in Brazil is managed by a complex system with an intricate hierarchy. Here attention is placed on the Executive, because it is the State arm more directly related to administrative affairs. More specifically, the federal sphere (and its higher education segment) will be outlined. Besides, the Directive Law of the National Education – LDB, in Portuguese (Brasil. Ministério da Educação, 1996) – will be shortly referenced.

The higher education in Brazil is divided in four types of paths: the sequential courses (which are short duration courses, around two years, after high school formation); the undergraduate courses (bachelor and license degree programs, up to five years, open for students with high school degree); the graduate courses (*lato sensu* specialization, like MBA, or *stricto sensu* programs, such as master and doctoral studies, open for students having undergraduate/graduate degrees); and extension courses (e.g., language classes, open for candidates who meet the requirements of the institution). This courses can be offered by the so-called universities, university centres and faculties, that can be public or private institutions. The public ones offer completely free graduate and *stricto sensu* post-graduate studies (Brasil. Ministério da Educação, 1996, 2006).

[1]The nomenclature of the superior education cycles in Brazil slightly differs from the anglo definition. In Portuguese, the first cycle is called *graduação*, translated as undergradute or graduate, depending on the course type. The second and third cycles, *mestrado* and *doutorado*, respectively, receive the name graduate, or less frequently, post-graduate studies. Here the therms undergraduate and graduate will be employed for graduation and post-graduation cycles.

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In the Brazilian Administrative Law, two types of Federal Administration co-exist: the first one, the Direct Administration, encompasses a group of public bodies, which integrates the Federal Union, that performs activities of the Presidency and Ministries. The second one, the Indirect Administration, is composed by different legal entities, which can be public or private law legal entities, that serve and help the State to manage assets and community interests, have their own equity and legal autonomy, but are bounded to a specific Ministry (Meirelles and Filho, 2016).

The organizational structure of the educational administrative affairs is build upon the Ministry of Education (MEC, in Portuguese), a direct administration public body responsible for the national educational policy. In parallel, there is the National Council of Education (CNE, in Portuguese) helping the MEC with normative activities. Apart from some other executive offices and institutes, there is the Higher Education Secretariat (SESU, in Portuguese), the office responsible for planning, coordinating and supervising the process of formulation and implementation of the National Higher Education Policy. Within the indirect administration, the National Institute of Studies and Investigations Anísio Teixeira (INEP, in Portuguese) provides the government with essential data for the development of state policies; more precisely, it its responsible for evaluating the quality of the higher education sector by means of a variety of indexes. Finally, one would mention the Coordinating Body of Graduate Personnel Development (CAPES, in Portuguese), a special entity working as a driving force towards the maintenance and expansion of graduate studies in Brazil. With the same intent, it is noteworthy the National Council for Scientific and Technological Development (CNPq, in Portuguese), a non-profit public foundation, tied to the Ministry of Science, Technology, Innovation and Communication (MCTIC, in Portuguese), which grants financial aid for research purposes. More information is available in www.portal.mec.gov.br/.

3 AN OVERVIEW OF THE CIVIL ENGINEERING CURRICULUM IN BRAZIL

In Brazil, the engineering curriculum has a fundamental core, which should be shared by all the engineering specialties. The total amount of hours of an engineering course cannot be less than 3600 hours. Thirty percent of this workload might be distributed among general theoretical subjects. Fifteen percent of the work hours should be conveniently selected by the institution within some subjects devoted to training/vocational matters The remaining hours have to be dedicated to specific topics related to the particular engineering modality, in order to improve the previous group of disciplines, as well as to develop other abilities (Brasil. Conselho Nacional de Educação, 2002, 2007).

Regarding the civil engineering, the specific curriculum in Brazil tends to be more generalist, i.e., the student will take classes of a variety of topics, corresponding to the following five big topics, primarily: Construction and Civil Construction Materials; Structural Systems and Structural Theory; Geotechnics; Hydraulics, Applied Hydrology and Basic Sanitation; and Transport and Logistics. With few exceptions within the federal institutions, the student has no flexibility to entirely focus on a specific field.

Usually a civil engineering first cycle course – undergraduate – takes five years to be completed. The second cycle – master – demands two years. And the third cycle – doctorate – goes up to four years. *Lato sensu* courses have a variety of durations, but, generally, require one year. So, one could states that the complete formal training of a researcher in the civil engineering field in Brazil demands ten years, on average.

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3.1 The UFMG Reality

The UFMG civil engineering course (CE-UFMG) follows the generalist path. The training begins with a two years period of basic mathematics, physics, chemistry and informatics learning (fewer different introductory subjects may also be present, such as topography). After this, professional and specific topics are taught. The main core of the aforementioned track is handled by virtually only five departments, namely Departament of Construction Materials (DMC, in Portuguese), Department of Sanitary Engineering (DESA, in Portuguese), Department of Structural Engineering (DEES, in Portuguese), Department of Water Resources Engineering (DEHR, in Portuguese) and Department of Transport Engineering and Geotechnics (DETG, in Portuguese). More precisely, time is dedicated to learn Construction (materials, construction technology etc.), Structural Mechanics (applied mechanics, structural analysis, mechanics of materials etc.), Hydraulics and Hydrology, Sanitation (water distribution, water treatment, wastewater treatment etc.), Geotechnics (soil mechanics, foundations etc.) and Transport Engineering (road design, traffic studies etc.)

Figure 1 shows a summary of the compulsory CE-UFMG curriculum in terms of number of disciplines. The basic cycle and the professional cycle are indicated. Each of the discipline groups are pointed out in a self-explanatory abbreviated way. The *Others* group comprises Management, Law and Humanities courses, among others.

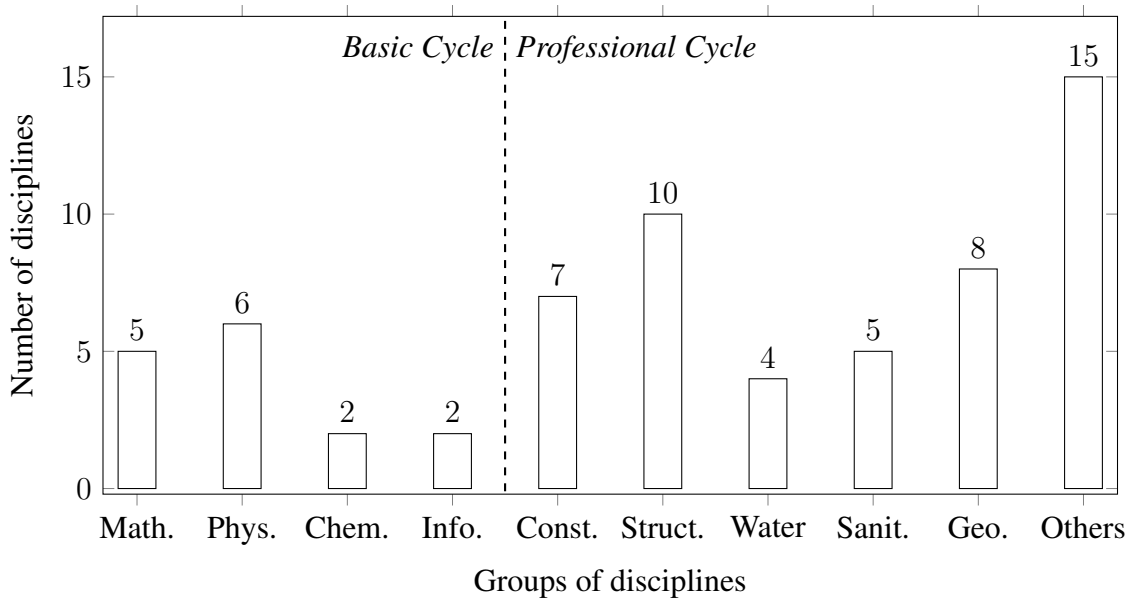

Figure 1: Overview of the UFMG civil engineering curriculum.

3.1.1 Programming and Numerical Methods within the CE-UFMG

Here, the programming and numerical modeling disciplines of the mandatory CE-UFMG curriculum will be registered and compared to the same path of other engineering courses of the institution, such as Electrical Engineering (EE), Systems Engineering (SE), Automation Engineering (AE), Mechanical Engineering (ME), Metallurgical Engineering (MEE), Mining Engineering (MIE), Industrial Engineering (IE), Chemical Engineering (CHE), Environmental Engineering (ENE), Forest Engineering (FE), Agricultural and Environmental Engineering (AEE).

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As it can be seen in Fig 1, the standard CE-UFMG curriculum have only two courses directly related to computer science, namely *Programação de Computadores* (Computer Programming): software development methods, high-level programming language, basic commands, data structures, modularization; and *Cálculo Numérico* (Numerical Calculus): finite differences, interpolation, numerical integration, solution of algebraic and transcendent equations, linear systems, numerical treatment of ordinary differential equations. These courses are offered in the first and third semesters, respectively.

Figure 2 depicts the computer science disciplines of all the engineering courses of UFMG in comparison with the CE course. Every discipline which explicitly makes reference to programming languages, computational algorithms, implementation techniques, software engineering, numerical methods or numerical solution of equations, among other topics, were considered. Anyhow, as the present analysis have qualitative drive, some specific discipline might be forgotten. Also, simple CAD (Computer Aided Design) courses (to learn how to draw using a specific commercial software) were not computed. Although the numbers do not highly differ, some of the engineering modalities (EE, SE, AE, IE) have more advanced informatics courses, which are taken by Computer Science and Computational Mathematics students as well, such as: *Algoritmos e Estrutura de Dados I* (Algorithms and Data Structures I) *Algoritmos e Estrutura de Dados II* (Algorithms and Data Structures II) and *Análise Numérica* (Numerical Analysis) In general, the amount of hours of each discipline can vary from 30 to 60 hours (2 to 4 UFMG academic credits). The interested reader could refer to www.ufmg.br for more information.

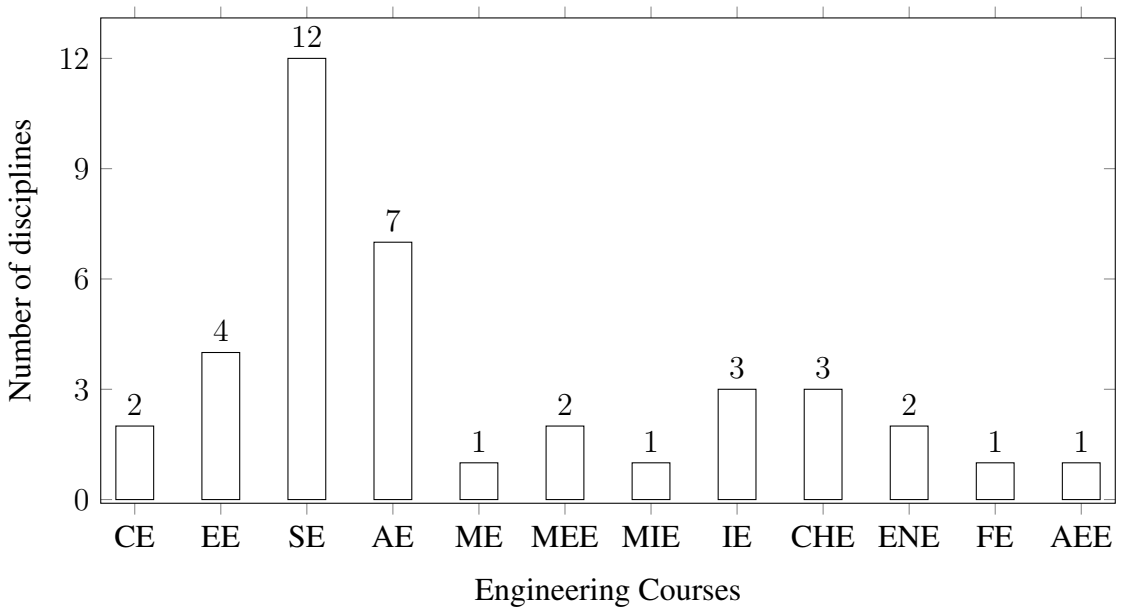

Figure 2: Programming and numerical methods courses.

4 THE INSANE PROJECT

4.1 Short Description

Trying to fill some gaps in the academic formation process, the INSANE project was created: a structural analysis software conceived to be used as a didactic resource in undergraduate and graduate courses. Over the years, following its own progressive expansion, it also became a robust platform for research on numerical engineering methods. Since the beginning, the

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software development seeks some fundamental premises: ease of use, open source, use of Java language and total separation between numerical core and graphical interface (Fonseca and Pitangueira, 2004).

The project's name is a acronym of Interactive Structural Analysis Environment, and at first, faced some resistance of the academic community. The name, as well as the logo (Fig. 3a), have direct relation to the Cervantes' Quijote.

In 2007, granted by FAPEMIG (a support agency), the Free Software Laboratory (INSANE LAB) was created in the Department of Structural Engineering (DEES) of UFMG. Today the team has the support of six UFMG professors, one external full professor, a computer scientist consultant, sixteen doctorate students (some of them also teaching in different institutions), eight master students and five undergraduate students. Besides that, the project had important contributions from other people in the past, and has already published doctorate and master thesis, journal and conference papers.

4.2 Didactic Strategies

There are two main pillars in the INSANE project: teaching and research. The first one concerns the integration of the software to formal courses (whether it is a pre-existing subject or a self-created one) and the development of new extra-curriculum abilities, most of them related to programming and computational modeling. The research activity is very broad; besides standard and generalized FEM (Alves et al., 2013), the INSANE has formulations of Meshless Methods (Pinheiro et al., 2017) and Boundary Elements (Peixoto et al., 2016), as well as constitutive models (Gori et al., 2017), graphical tools and solver algorithms. In the following, some characteristics of the project which help in filling some of the aforementioned gaps will be outlined.

4.2.1 Teaching

Currently, INSANE is formally used as a support resource of the disciplines *Análise Estrutural I* (Structural Analysis I), *Análise Estrutural II* (Structural Analysis II), *Introdução ao Método de Elementos Finitos* (Introduction to the Finite Element Method), of the Civil Engineering Undergraduate course; *Análise Estrutural* (Structural Analysis) and *Método de Elementos Finitos* (Finite Element Method), of the Mechanical Engineering Undergraduate Course; *Método de Elementos Finitos* (Finite Element Method), *Computação Aplicada à Engenharia* (Computing Applied to Engineering) and *Análise Fisicamente Não linear via Método de Elementos Finitos* (Physically Nonlinear Analysis by the Finite Element Method), of the graduate courses in Structural Engineering. These last two courses were idealized and are handled by researchers of INSANE. In these subjects we teach object oriented programming, a high-level programming language (Java), UML design, data structures, constitutive modeling, elasticity theory, linear system solver algorithms, numerical integration techniques, finite element method formulations and material nonlinear analysis, among other topics.

The didactic approach of the INSANE team is project-based, i.e., besides formal tests and exercises which are a standard requirement of the Department, we have many "hands-on" projects in which the students develop totally functional finite element programs, nonlinear solvers etc. from scratch.

The first version of INSANE, the one that is used by undergraduate student, is depicted in Fig. 3b. This picture shows the main screen of the program, where the diagram of bending moments of a continuous beam model is displayed.

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4.2.2 Advanced Research

The researches are carried out by full professors, doctorate students, master students and undergraduate students. Over the years, the project has developed scientific studies in different matters such as Structural Elements, Finite Element Method, Generalized Finite Element Method, Meshless Methods, Boundary Element Method, Computational Solids Mechanics, Computational Mechanics of Concrete, Linear and Nonlinear Fracture Mechanics, Hydraulic Fracturing, Material Nonlinear Analysis, Geometrical Nonlinear Analysis, Dynamic Analysis, Multiscale Analysis, Constitutive models, Generalized Continuous, Computer Graphics, Parallel Processing, among others. These researches directly help the members in their career evolution.

INSANE uses object oriented programming, Java language, a vast set of design patterns, version control, computer graphics and numerical solvers libraries. The lab has its own server and several workstations, all with the Linux operating system. Figure 3c shows the main screen of the current INSANE version, and depicts the Mesh module. The pre-processing resources follow a standard FEM-based software, in which restraints, loads, material, section and mesh can be conveniently chosen. Figures 3d, 3e and 3f show examples of application of the software. The interested reader can refer to www.insane.dees.ufmg.br for more information.

4.2.3 Scientific Initiation

INSANE offers opportunities to undergraduate students to start their research career in computational mechanics. Periodically, INSANE arranges some public calls by which a certain number of candidates are chosen to be a part of INSANE. This process could be formally structured, when it is possible to count on federal or state funding to implement a type of scholarship (by means of the previously referred agencies); or voluntary, when the student is integrated to the team without a wage. In this process, the freshman student can start to learn more specific topics in the beginning of the engineering course.

4.2.4 Constructive Environment

The project environment is constructive, i.e., we try to develop a productive knowledge space in different instances. At the microlevel (within the project itself), orientation meetings are a important tool. The students have periodic discussion sessions with the teachers, in which doubts and complex themes can be considered. Group meetings are also used to level the skills of the project members assigned to a specific research. The team work is always encouraged and it is usual that doctorate students take part in the guidance of master and undergraduate students. At the macrolevel, the teachers enrolled to the project have a different perspective of teaching. Even tough some default practices need to be implemented (such as exams, tests, assignments), the professors try to establish a more comfortable relationship with the students, boosting the learning by improving the curiosity and showing the fundamentals of each taught subject.

4.2.5 Cultural and Intellectual Space

More than a engineering community, the INSANE project tries to be a cultural and intellectual space. The project inherits some of the visions and behaviors of its founders and instigate the members to pursue different subjects, such as arts, literature, politics, music, among others.

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It is an important aspect for some of the members that the academy forms people, citizens, more than just engineers, and a space to debate different nuances of science and culture is very important and helps to enhance the ability of the student to be imaginative and inventive.

4.2.6 Learning and Self-Development Promotion

From inside the project domains, the adopted learning processes rely on supervised and self-taught procedures. The almost constant availability of the teachers is a point of stimulus and increase of interest in the study subjects and this mentoring style helps the self-learning of the students. The attendance at conferences, seminars and courses is frequently encouraged, as well as publications are demanded. Also, the laboratory has a library with many technical and literature books available to the members.

5 CONCLUSIONS

An overall depiction of the civil engineering curriculum of a brazilian federal university and a brief comparison of some computer science subjects of different engineering courses were presented. It could be noticed that the CE course has just two mandatory disciplines related to programming and numerical calculus. Although the curriculum meets the legal requirements (previously indicated), it is quite small the number of compulsory hours dedicated to these affairs. Despite the homogeneity of the observed index among the different engineering courses, some of them have considerably more workload in the area, not just from a quantitative point of view (bigger number of disciplines), but also from a qualitative spectrum (some of the disciplines are more advanced than the ones taken by CE students). In this regard, it is worth mentioning that newer engineering courses have more well established computer science topics (either the number of spent hours or the scope quality) and the most traditional engineering courses of the institution (CE and ME, for example), have some of the smaller indexes. For instance, the SE course is the newer one and have a variety of computational subjects. Even tough this course has a prominently focus on the development of computational systems, its curriculum covers many types of meaningful topics, which are relevant to other engineering modalities, e.g., Computational Electromagnetism and Computational Thermodynamics, that are not covered by the respective compulsory curricula.

As previously stated, nowadays the importance of computational methods raises very fast and the labor market (to say the least) demands from the engineer some expertise in this regard. In that sense, it seems fairly questionable the absence of at least one mandatory finite element method course in every engineering track, even more within the courses that have the professional prerogative of designing structures, of modeling fluid or thermal phenomena, among others. The CE curriculum, built upon a big number of structural mechanics disciplines, should obey this logic, but maybe the generalist composition hides that coherence.

In this context, the INSANE project experience was summarized. Trying to enhance the capabilities of the UFMG engineering students (mostly of CE and ME), the INSANE was developed. Over the years, the project has tried to contribute to the learning and formation processes of a number of students. It attempts not only teaching people how to use a finite element method system (and related numerical methods), but also how it works, i.e., what are the computations performed underneath the screen and how to implement them. Besides that, related topics are also embedded in the training process, in a way that different computer science subjects are learnt.

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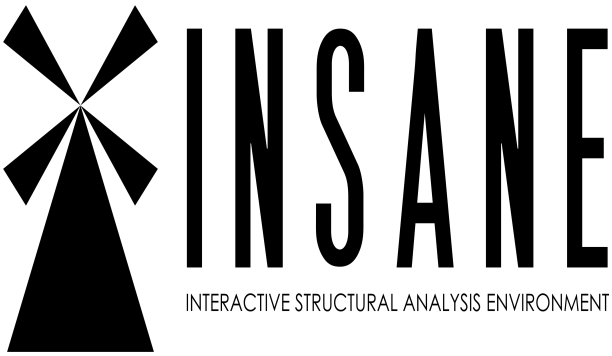
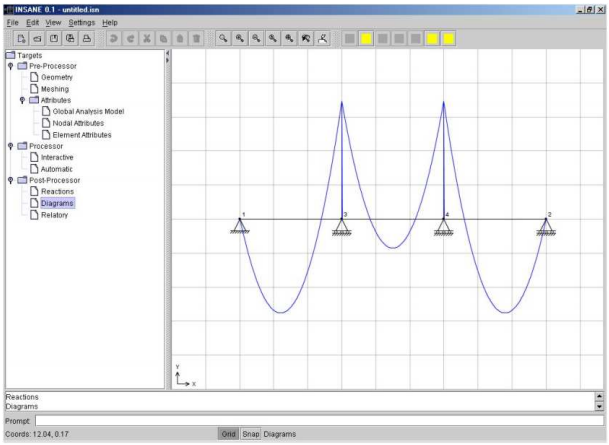
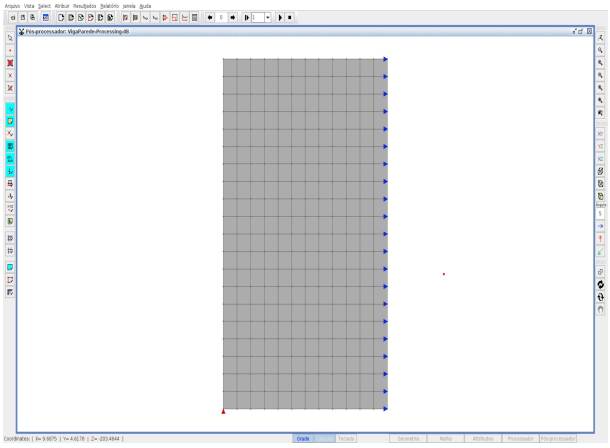


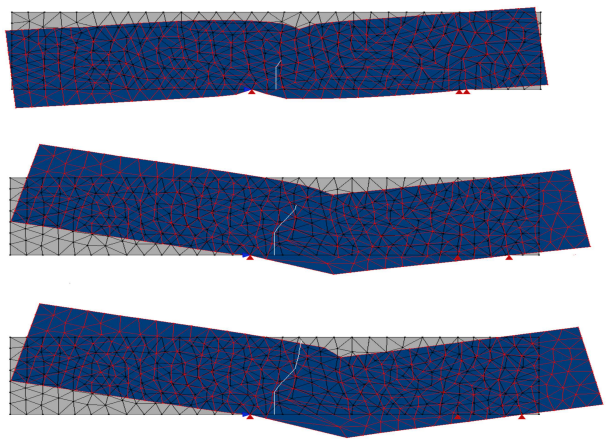
(a) INSANE's logo.



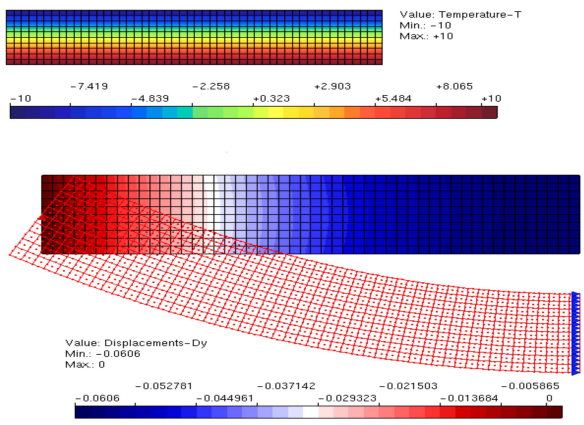
(b) Main screen of INSANE's first version (Fonseca and Pitangueira, 2004).



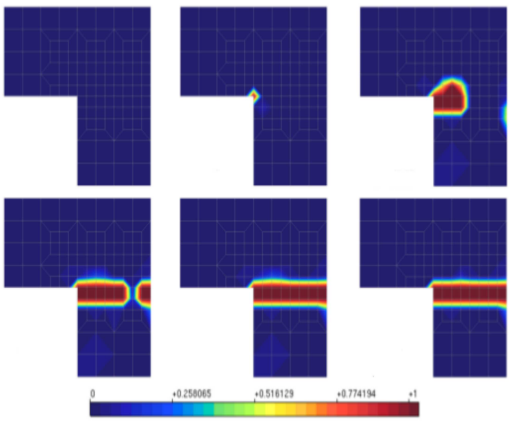
(c) Mesh screen of INSANE's current version.



(d) Crack propagation by the Generalized Finite Element Method (Silva, 2016).



(e) Thermomechanical analysis (Botelho et al., 2015).



(f) Microplane constitutive model (Wolenski, 2013).

Figure 3: The Interactive Structural Analysis Environment.

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