Towards an Integrated Grid- and Cloud-based Structural Analysis Platform

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ABSTRACT

The Building Information Modeling (BIM) approach has revolutionized the way buildings are getting designed and constructed. The BIM design method combined with web services, grid and cloud computing power opens the door for construction engineers to improve the building design through enabling them to run advanced structural analyses for design alternatives quickly with low cost. However, the high hard- and software cost for complex computations like parametric studies are usually reserved for big companies or research facilities. This paper introduces an ongoing research with the project SE-Lab (http:/www.selba.eu) to develop a web-based Structural Engineering platform which allows small and medium enterprises (SMEs) to bundle their already available computing resources for complex simulations. Furthermore it provides data management functions, supports the creation of model variations and offers a collaboration layer to experts of different disciplines.

INTRODUCTION

More slender structures, new architectural design paradigms, retrofitting of historical buildings, life-cycle extension of civil engineering structures and an increased demand for safety in our society require broader application of advanced non-linear mechanical modelling and probabilistic safety concepts for structural design. Both demand advanced information management and the automation of the bulk of simulations for design variations and probabilistic evaluation and hence much more computing power. The partial safety factor approach, that is commonly used today, cannot be applied in combination with structural non-linear analysis and has to be replaced by the full probabilistic approach (Alonso et al., 2012). In addition, for non-linear structural analysis the linear superposition principle is not valid, which means that for multitudes of load combinations separate non-linear analyses must be carried out (Caballer et al., 2013: 2-3). With currently available tools this exceeds the labor resources and the computer power of SMEs (Alonso et al., 2012:1; Caballer et al., 2013:1). Therefore new methods, preferable integrated on Building Information Modeling, are needed.

Civil engineering companies usually own lots of powerful desktop computers whose capacity isn't entirely used by the employees working at them and hence waste money (Wertel, 2013). The capacity of the single machines isn't sufficient for the computations mentioned above, but bundled together they can provide enough computing power to solve complex tasks. With an appropriate software solution, which combines the single machines to a private grid and helps managing the huge bulk of data, civil engineering SMEs have new simulation possibilities without additional investments in hardware or external services. This paper gives a brief overview of a grid-based Structural Analysis web platform which represents such a solution.

First we give an overview of the platform architecture and outline a basic workflow. Section 3 will focus on the management of the engineering model and computed data as well as the generation of model instances for parametric studies. The integration of grid-/cloud- computing power into the platform is covered by section 4. Finally section 5 draws conclusions about the presented approach and addresses future work.

THE STRUCTURAL ANALYSIS WEB PLATFORM

The software system described in this paper is a service-oriented architecture (SOA) and web-based information management platform which provides integrated interfaces with computational kernels for non-linear and probabilistic structural analyses as a web service and thus enables the porting of computation into a grid/cloud environment. Consequently a huge amount of computation tasks can be carried out simultaneously and hence time-saving and cost-efficient. The platform is developed as an extension component of the Integrated Virtual Engineering Laboratory *(IVEL)* platform (Baumgärtel, Katranuschkov and Scherer, 2011).

Figure 1 schematically shows the architecture of the system. Integrated solver kernels provide algorithms for parallel execution of different tasks. Web-based graphical user interfaces provide basic interaction functions for users such as up-/download of models or start and control of simulation instances. Furthermore the platform is going to offer collaboration possibilities for interdisciplinary project teams of architects, construction engineers, numerical engineers and others through provision of a shared data server and a communication layer. A basic design-analysis workflow could consist of the following steps: (1) the structural engineer prepares the numerical model for the FE analysis using ATENA pre-processing software or other supported FEM-solvers and uploads the FEA input file to the platform; (2) desired parameter variations are specified in a XML-based variation model (see section 3.1); (3) on a web GUI the structural engineer specifies further relevant information for the structural analysis and chooses from a set of predefined computation infrastructures (grid, single server, …); (4) the Model Generator creates variants from the numerical model according to the information given in the variation model and passes them to the Computational Service; (6) computation jobs are created and distributed to the available computers in the grid where the solver executes them; (7) computed results are passed to the Data Manager and persisted on the data server to be accessed through the web GUI.

The modular and service-oriented design of the platform also allows the dynamic adding and removal of functionality through plugins such as post processing modules, e.g. a toolbox for the generation of different model views such as introduced in Windisch, Scherer & Katranuschkov (2012), or, like Saitta, Raphael & Smith (2005) propose, tools for the filtering of candidates which fulfill some specific criteria from the bulk of results to increase the reliability of a system identification task.

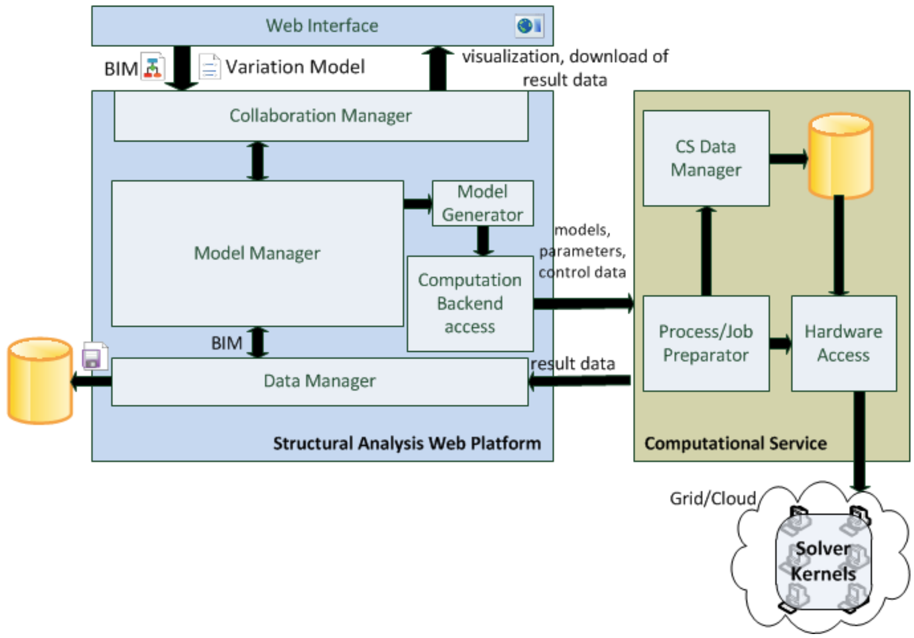

Figure 1. Top-level architecture of the Structural Analysis web platform

MODEL GENERATION AND DATA INTEGRATION

This section covers the creation of simulation model variations and the management of the input- as well as the potential huge amount of result data for collaboration purposes.

Model Generation. Parametric studies like system identification for the determination of an optimal parameter set for a building model require a huge number of model instances because of the non-deterministic variation possibilities for design/material parameters or a huge number of different supposable load cases. Already the manual creation of so many models is very time consuming and from the economical point of view impractical.

Therefore our approach offers support for model generation techniques. The basic idea is to define the parameter variations in a generic variation model which can be combined with an engineering model in order to provide the basis for the generation of concrete model instances for structural analyses. The advantage of this approach is that there is no need to change the original model. Figure 2 shows the general scheme of a variation model. The approach assumes that every variation point in the engineering model is uniquely addressable by an identifier which is used to assign it to variation elements in the variation model. The engineer now has the possibility to define exact values for an element in a comma separated list. The second possibility is to define an algorithm which generates the parameter values. Specific values not covered by the algorithm can be included explicitly or, the other way round, excluded for some reason if covered by the algorithm.

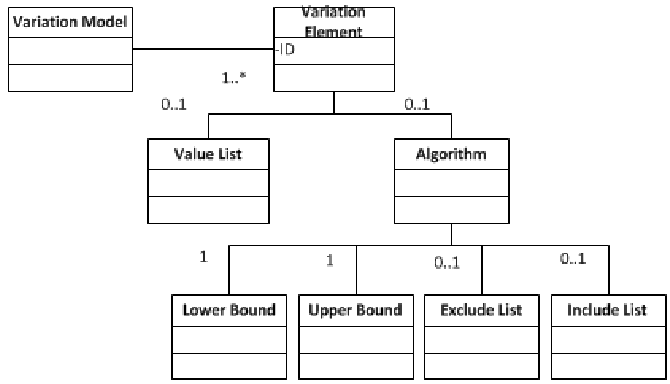

Figure 2. Schematic structure of a variation model

Internal the building models are managed as STEP files according to the ISO 10303-21 standard (International Organization for Standardization, 2002). Hence all building elements and parameter definitions own a STEP line id of the form *#xxx* (x={0,…,9}) which can be used to identify the element / parameter uniquely. One application in case of BIM design model would be the iteration over alternative load cases or standardized dimensions of a specific building element to determine an optimal design variant. Figure 3 shows an example extracted from an IFC compliant model and a possible variation model based on XML. The left STEP file model extract shows a solid element (e.g. a wall) and a material layer definition. As shown in the figure, the depth of the solid area, which is the only variable parameter in this line, is varied five times. The thickness of the material layer is increased in steps by 10 mm between the values 300 and 400 mm.

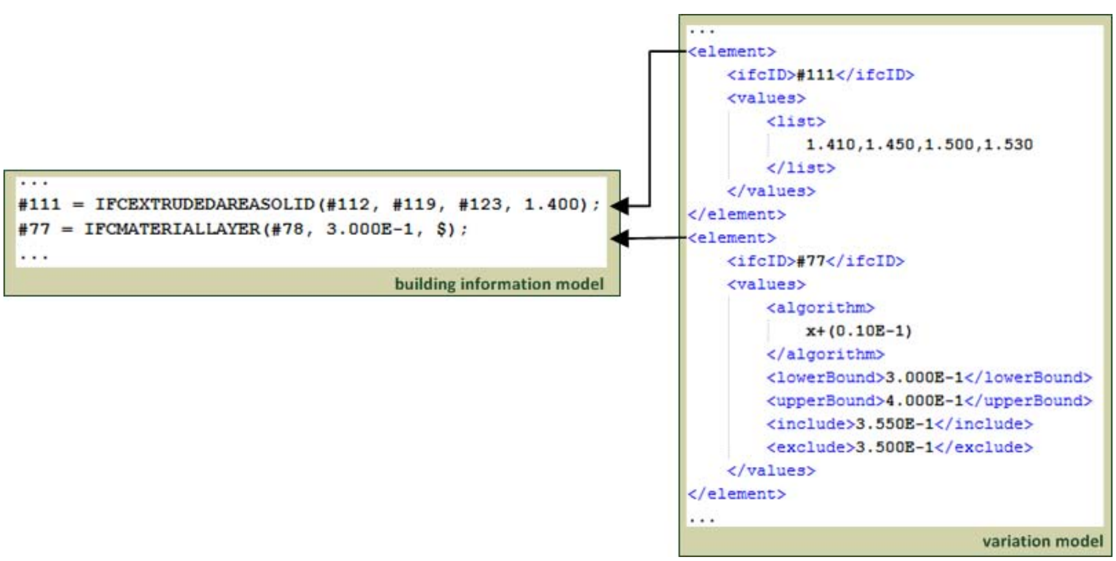

Figure 3. Definition of parameter variations in a variation model

The text-based IFC format facilitates the creation of new model instances for simple cases due to the fact that only parameter values have to be replaced. This is done by the Model Generator with simple file manipulation operations.

Data Integration. The generation and computation of a huge number of model and load variations require an efficient data management. Experiences from a previous project show that computed FE models for one analytic problem can easily reach a size up to 5 gigabytes (Hollmann, Faschingbauer & Scherer, 2012: 7). Consequently, there is a need for data reduction techniques to reduce the amount of data which has to be transferred over the network or persisted on the data server. The strategy of our approach allows the marking of relevant parameters in the initial engineering model before the model instance generation starts. In addition, the engineer can specify a set of key results, for example the displacement of selected nodes or the maximum load for pushover analysis. In a post processing step the system extracts the computed values for the marked parameters from the result model and transmits solely these values over the network. Hence the required bandwidth and disk space for the storing of result data can be reduced significantly.

GRID / CLOUD INTEGRATION

As mentioned in section 3 there is a need for parallelization of computations and advanced data management as well as provision of high performance computing power through grid or cloud access. Dependent on the engineer's task the architecture of the platform allows the dynamic selection of the computational infrastructure, e.g.:

- A HPC server owned by the engineering company for sequential computation of huge models
- A private grid consisting of the employee's local machines for parallel computation of a huge number of small-medium sized models (sensitivity and probabilistic analysis)
- Access to a public HPC cloud if the company's resources are not sufficient

To date the prototype supports grid- and single server-based structural analyses with the ATENA solver (Cervenka, 2013) and uses the UNICORE[1] middleware as access framework to the grid resources. A special component called *Job Preparator* (see figure 1) processes the task description, model instances and further input and generates computation jobs according to the chosen infrastructure. In case of grid-based computation it creates UNICORE jobs in form of batch files which are transferred to the different grid nodes where they trigger the solver. When finished, the results are sent back to the platform and stored in a shared data server. Figure 4 schematically shows the usage of the company's computing resources bundled in a private grid.

[1] http://www.unicore.eu/

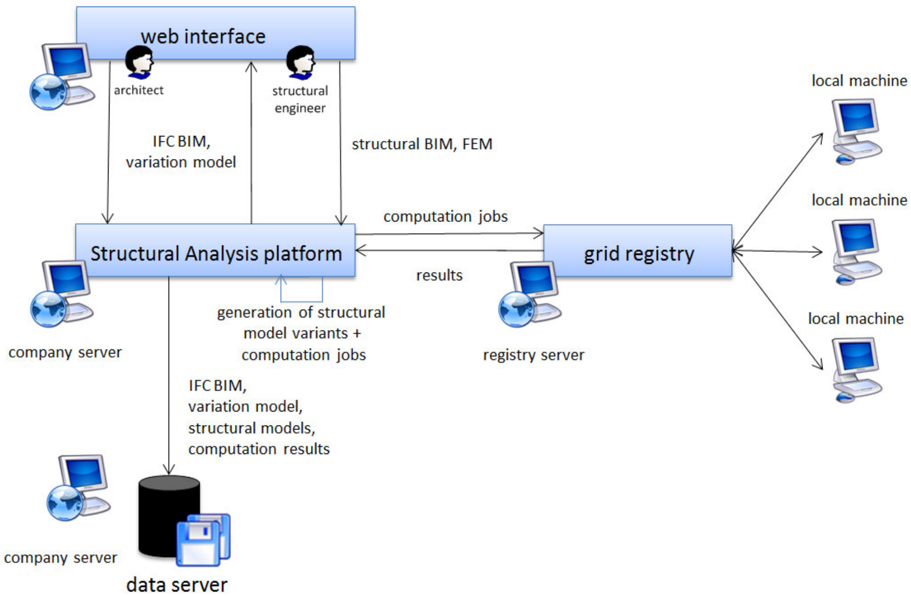

Figure 4. Grid-based computation infrastructure.

CONCLUSIONS AND FUTURE WORK

This paper has introduced a work in progress to integrate grid and cloud technologies within a web platform for structural analysis. The platform enables SMEs to run complex simulations in an acceptable amount of time on their already available IT infrastructure.

Furthermore the system provides support for the generation of model multitudes for parametric studies. Therefore the variation model approach allows the definition of parameter variations distinct from the original engineering model. An integrated model generator combines the initial engineering- and variation model and creates model instances.

The grid middleware distributes the jobs to the PC nodes registered in the grid and collects the computed results.

Finally a data management component handles the storing and retrieval of the uploaded/computed data and supports web-based collaboration.

For the future we plan the integration of further solvers into the platform to use the grid infrastructure for the execution of tasks besides structural analyses like energy simulations. The objective is to generalize the platform for any kind of engineering problems and to control the engineering computations from one common building model. Another key aspect will be the investigation of advanced data storage technologies to improve the data management. The objective there is to store all computed data and to do result analysis on demand and at any time also repeatedly applying data analysis, data mining, fuzzy and statistical methods. This means that methods are to be investigated which allow identification of sets of models through meta information and the subsequent tracing of the model results to extract desired parameters from the bulk of simulated data. The catalog of requirements is continuously updated through focus group interviews (FGIs) and discussions with industry partners.

The generation of model variants shall be extended to suspend needless parameter variations a priori and hence to reduce the amount of computations to be executed. More effective parametrization methods are under research and will be developed by means of thorough literature review.

Performance and usability of developed prototypes will be tested using test cases from real projects.

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