

Lectures

Virtual Product Development – CAE-based Simulation, Optimization and Robustness Evaluation of Construction Components Made of Brittle Materials

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1 Approaches to the development of construction products

As in other industries, the international competition also forces in civil engineering a permanent development towards cost-effective production of reliable and sustainable products. In the past, construction products were mostly developed based on experiments or practical experiences. The process and result of such product development was usually not very controlled and often unreliable. The generally large amount of required experiments was time-consuming and caused high development costs as well as low efficiency.

Today, the combination of modern numerical simulation and CAE-based optimization methods allows a very efficient virtual product development, as already proved for example in the automotive industry. By using powerful simulation software, developers are practically capable to x-ray the product and visualize the effects of modifications instantly. The analysis of different input parameter variations by simulation is conducted in just a fraction of a comparable experimental effort. The automated coupling of simulation tools with methods of sensitivity analysis, mathematical optimization and robustness evaluation allows a targeted and best possible optimization of desired product properties. Also experimental information can be included at any time, for example to verify or calibrate the simulation model.

A distinctive feature of many materials is their non-linear and often brittle behavior. Modern simulation methods, such as the Finite Element (FE) method, are capable to simulate realistically non-linear and brittle material behavior as well as the associated cracking evolution. In recent years, for non-linear simulation of construction materials using the Finite-Element Method, mainly elasto-plastic material models have proved very useful. Dynardo developed the material library multiPlas for the FE program system ANSYS to simulate especially brittle materials such as concrete, porous concrete, steel fiber reinforced concrete, reinforced concrete, sand-lime brick, masonry and brick. In addition to mechanical effects, also thermal and hydraulic effects can be considered in multi-physics simulations. From production up to the state of installation, simulating the behavior of construction components evolves extensive optimizing opportunities.

Using selected examples, this paper presents how simulation-based optimization methods and sensitivity analyses are applied in the development of construction products. For this purpose, Dynardo developed the optimization platform optiSLang for sensitivity analyses, single and multi-objective optimizations and robustness evaluations based on stochastic analytical methods.

2 CAE-based optimization within virtual product development

The process of simulation-based optimization consists of several steps:

- i) The generation of an parametric simulation model and process:

Here, the simulation model can also be composed of multiple sub-models or the simulation process is conducted using several different analyses, e.g. thermal, hydraulic, mechanical analysis. The entire simulation process, including the simulation model, is generated automatically after each simulation regarding the variation of input parameters, e.g. geometry parameters, material properties, loads, as well as the generation of result data and plots necessary for product development (see figure 1).

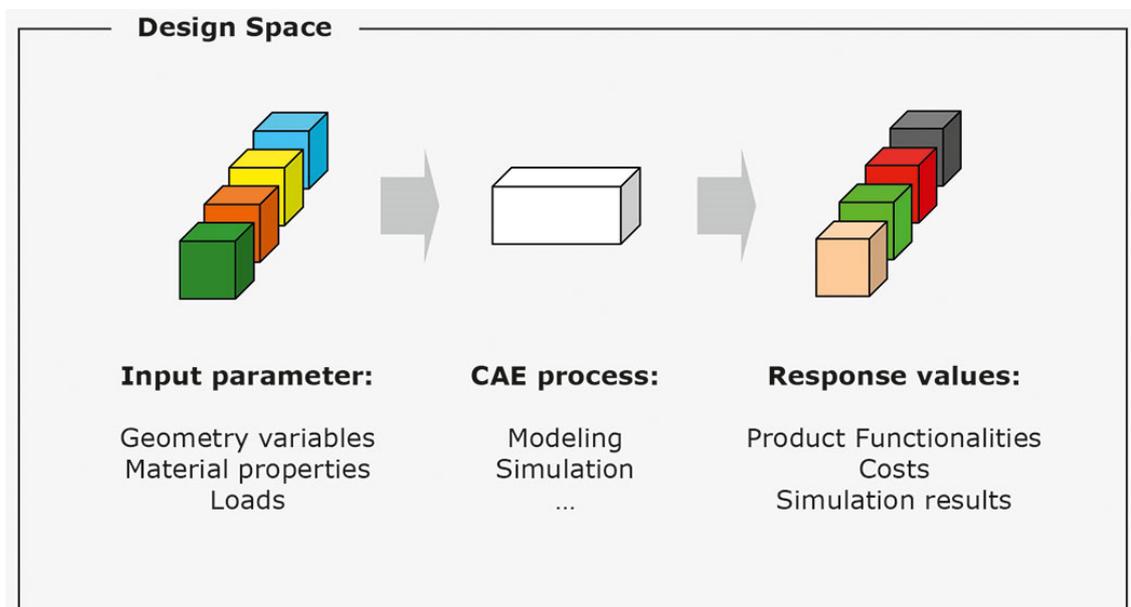


Figure 1 Parametric modeling and calculation

ii) The sensitivity analysis

The objective of a sensitivity analysis is to identify the sensitivity of those result values important for product development in regard to the variation of input parameters. For this purpose, various designs are created and calculated by varying the input parameters within predefined constraints. For a significant statistical analysis, it is necessary to cover the entire design space properly within upper and lower boundaries of all parameters. This can be conducted with optiSLang's [1] effective sampling methods, such as the Latin Hypercube Sampling.

A sensitivity analysis enables the identification of input parameters that are relevant for the optimization, e.g. those affecting the output variables significantly. Insignificant input parameters will be sorted out and the focused space of optimization parameter will be reduced. Other crucial information can be obtained from the variation spaces of the result variables as well as from competing multi-objective optimizations.

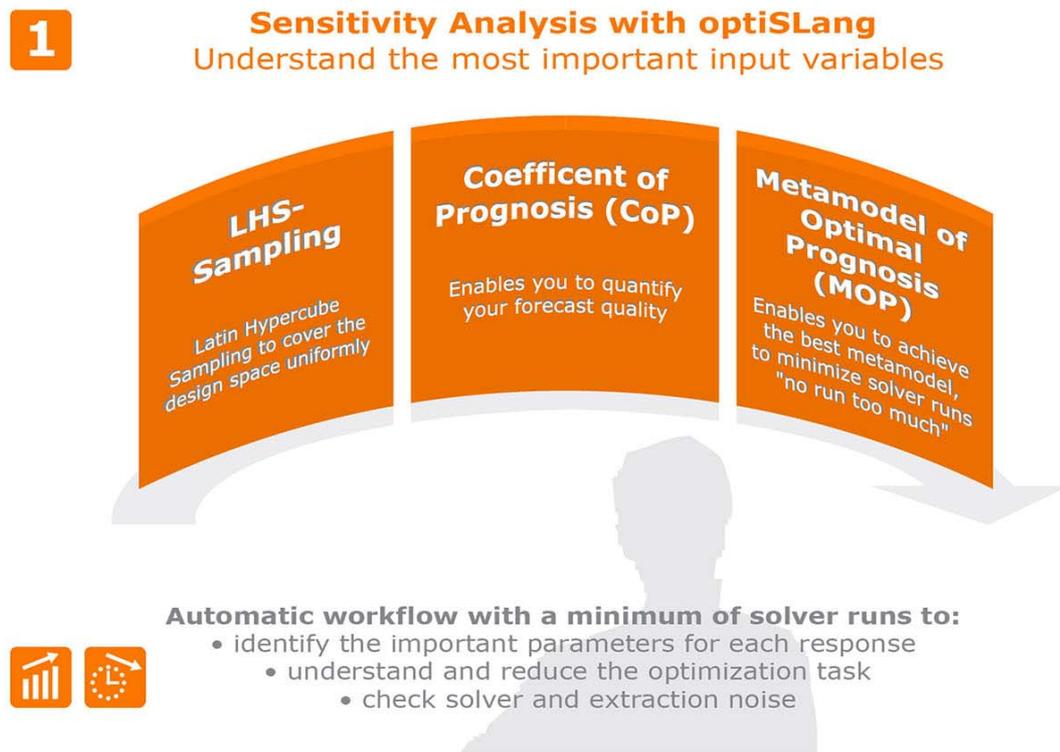


Figure 2 Sensitivity Analysis

iii) The optimization:

In this step, objective functions and constraints or restrictions which may not be violated by an optimization can be defined. For the optimization procedure, there are different strategies available in optiSLang [1], e.g. gradient method, response surface method, particle swarm methods as well as evolutionary and genetic processes. The suitability of each optimization method depends, among others, on the number and type of variables as well as on the characteristics of the objective values. The latter consider not only result values derived directly from calculations such as stresses, deformations, loads or heat transfer, but also include particular cost or production-related values.

iv) The robustness evaluation:

After an optimization, the robustness of the optimal design is evaluated. For this, an optimized product is simulated under natural circumstances of scattering (distributions) important input parameters using stochastic analysis. Thus, a robustness evaluation assesses statistical measures of result values or product properties, e.g. mean values, standard deviations and coefficients of variation. A design is considered robust if it shows just little scatter regarding the important performance values.

Robust Design Optimization (RDO) with optiSLang

Optimal Product Performance / Minimal Development Time

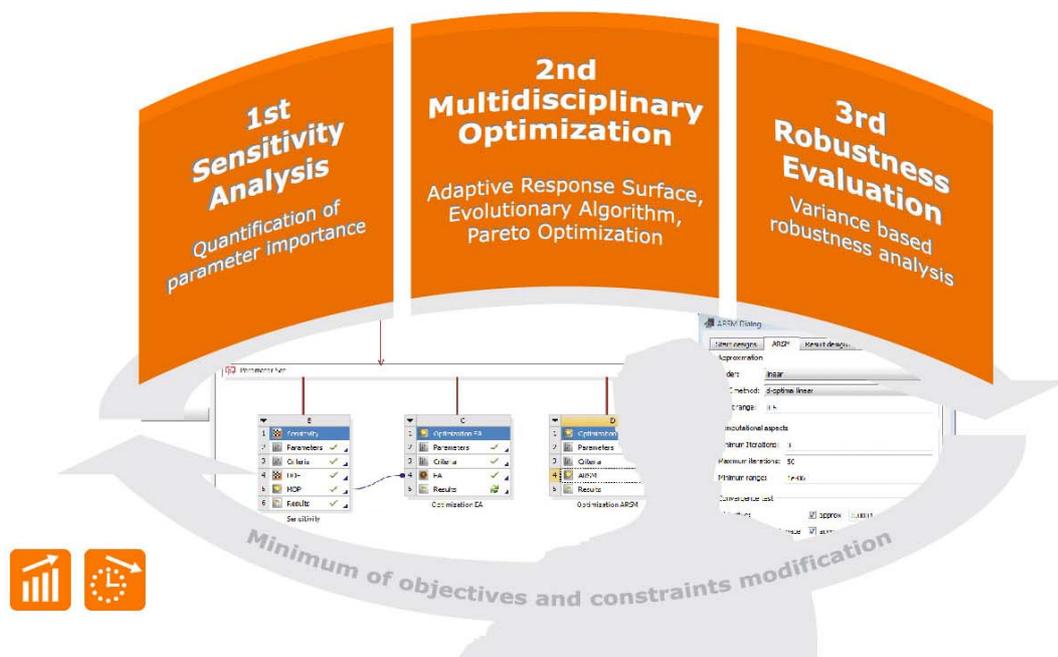


Figure 3 Robust Design Optimization (RDO)

4 Examples

4.1 Sensitivity analysis of operational loads at porous concrete wall panels

Task: Crack resistance evaluation of porous concrete wall panels

Solution: Non-linear load-history analysis regarding the following loads:

- Autoclaving and cooling process (thermal - mechanical)
- Dead load when installed on the facing
- Shrinking
- Temperature loads in summer / winter
- Wind loads

Sensitivity analysis including scatter of material values and variable geometry parameters

Result: Identification of the crucial parameters for optimization of the crack resistance

4.2 Fire resistance analysis of calcium silicate masonry walls

Task: Systematic analysis of relevant influences and phenomena regarding the fire resistance of calcium silicate masonry walls.

- Development of a realistic FE- simulation model for prognosis of
 - ** temperature field / temperature development
 - ** 3D-deformation field
 - ** fire resistance time
- of calcium silicate masonry walls

Solution: Generation of a parametric thermal-mechanical coupled simulation model of the fire resistance test, CAE-based sensitivity analysis and parameter identification

Results: Identification of relevant parameters, generation of a reliable model of prognosis for virtual testing, reduced number of hard ware experiments

4.3 Roller Compacted Concrete (RCC) Dam

Task: Increased crack resistance regarding hydration, development of a work schedule, identification of the optimal RCC-mixture

Solution: Parametric FE-Model of the dam, hydration-simulation

Results: Identification of the optimal jointing arrangement and work schedule, identification of the optimal RCC-mixture