Online Ψ Calculator

Insulation ▼   Bearing layer ▼   Plaster exterior ▼   Plaster interior ▼

TITLE STORY // CIVIL ENGINEERING

PRACTICAL APPLICATION OF CAE-BASED RDO IN CIVIL ENGINEERING

At HALFEN, CAE-based virtual product development enables the automated determination of relevant parameters for various product combinations and mounting conditions.

Introduction HALFEN

HALFEN was founded in 1929 and is one of the leading international companies in the fields of anchoring, framing and reinforcement technology in civil engineering. With about 1100 employees and more than 60 branches, HALFEN offers worldwide intelligent technical solutions and customized engineering consulting. The company's portfolio comprises approximately 20,000 products, yielding an enormous variety of available technical solutions. Accordingly, there is a high demand for variation analyses to determine relevant parameters. Using CAE-based RDO at HALFEN ensures that these complex correlations are understood and taken into account in product development. Since 2010, a close cooperation between HALFEN and Dynardo GmbH has been developed in order to efficiently implement CAE-based RDO for the development of various product lines.

Approaches to the development of construction products

In civil engineering, similar to other industries, the global competitive pressure is also demanding more cost-efficient production of particularly reliable and ecologically more compatible products. In the past, construction products were often developed based on experiments or practical observations. The success of such a product development was usually not very controllable and often trusted to chance. The normally large amount of required tests caused relatively high development costs and time, leading to decreased efficiency.

Today, the combination of modern numerical simulation and CAE-supported optimization methods enables a very efficient virtual product development, as it is already well established in other industries, such as in the automotive sector. By using powerful simulation software, developers can literally "look" into their products and, thus, can directly visualize the effects of changed conditions. The analysis of different variations of input parameters can be conducted by simulation at a fraction of the comparable experimental effort. The automated coupling of simulation tools with methods of sensitivity analysis, mathematical optimization and robustness evaluation enables a targeted, best possible optimization of aimed product properties. Here, also experimentally obtained results can be included, e.g., for verifying or calibrating simulation models.

A special characteristic of many building materials is their non-linear and often brittle properties. With the help of modern simulation methods, e.g., the Finite Element Method (FEM), nowadays, simulations of nonlinear brittle material characteristics and the associated crack evolution can be conducted very realistically. For the non-linear simulation of building materials using FEM, elasto-plastic material models have proven to be very capable over the past few years. Dynardo has been developing the material model library multiPlas for the FE program system ANSYS. It is especially suitable for brittle materials, e.g., concrete, porous concrete, steel-fiber concrete, reinforced concrete, masonry, sand-lime brick or brick. In addition to mechanical characteristics, also thermal and hygric effects can be included in multiphysical simulations. Thus, new and more comprehensive possibilities for the simulation of the component behavior are opening up including all product stages from production up to the mounting.

In the following passages, practical examples will show the application of simulation-based optimization methods and sensitivity analyses in the development of construction products. For this purpose, Dynardo has been developing the optimization platform optiSLang for sensitivity analyses, robustness evaluation, single and multi-target optimization as well as stochastic analysis.

CAE-based RDO in virtual product development

The process of a simulation-based optimization is unitized in the following steps:

1. The generation of a suitable parametric simulation model and process

The simulation model can be composed of several partial models, just as the simulation process can include several different analyses (e.g., thermal, hydraulic or mechanical analysis – see Fig. 1). The entire simulation process, including the simulation model, is set in such a way that it can be run in batch mode. The input values (i.e., geometry parameters, material characteristics, influencing conditions) are defined as v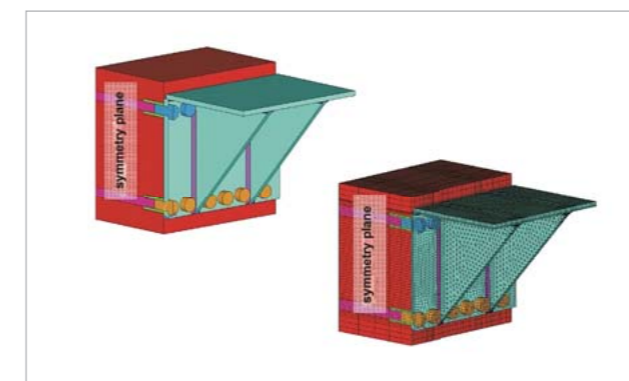ariables. Finally, the result values and plots required for product development are automatically generated after each simulation.

2. The conduction of a sensitivity analysis

The aim of a sensitivity analysis is to investigate the sensitivity of individual output parameters, which are important for product development in regard to the variation of input parameters. For this purpose, different designs are generated and simulated by varying the input parameters within predefined parameter limits. For a meaningful statistical evaluation, it is necessary to scan the entire design space within the upper and lower limits of all parameters as accurately as possible. For accomplishing this task, optiSLang provides powerful sampling techniques (i.e., Latin Hypercube Sampling).

In order to identify the correlations between input parameters and result variables, metamodels representing the best possible prognosis quality are generated and applied with the help of optiSLang. With sufficient accuracy, these metamodels are then capable of determining in real-time the values of the result variables according to the respective input parameters. If there is an adequate prognosis quality of the metamodels, they can be used instead of solver runs. As a result of a sensitivity analysis, it is possible to identify the relevant input parameters for the optimization (i.e., those parameters which substantially influence the result variables). Subsequently, unimportant input parameters are filtered out and the parameter space required for optimization can be reduced. Further important knowledge can be gained from the variability space of the result values and from the possible indication of competing optimization targets.

3. The conduction of an optimization

In this step, target functions and constraints (or restrictions that cannot be violated by optimization) must be defined. optiSLang offers different strategies for the optimization, i.e., gradient methods, response surface methods, particle swarm methods, as well as evolutionary and genetic methods. The suitability of the individual optimization methods depends, i.e., on the number and the type of variables, as well as on the characteristics of the target variables. In addition to the direct simulation results, e.g., stresses, deformations, loadings, heat transfer, even cost or production-relevant parameters can be particularly considered.

4. The conduction of a robustness evaluation

After the optimization procedure, the robustness of the optimal design should be verified. For this purpose, a stochastic analysis is conducted for the optimized product, taking into account the natural scattering (distribution) of the important input parameters. As a result of the robustness evaluation, the statistical measures (mean values, standard deviations and variational coefficients) of the result variables or product properties can be verified. If there is a small scatter of important product properties, the design can be considered robust.
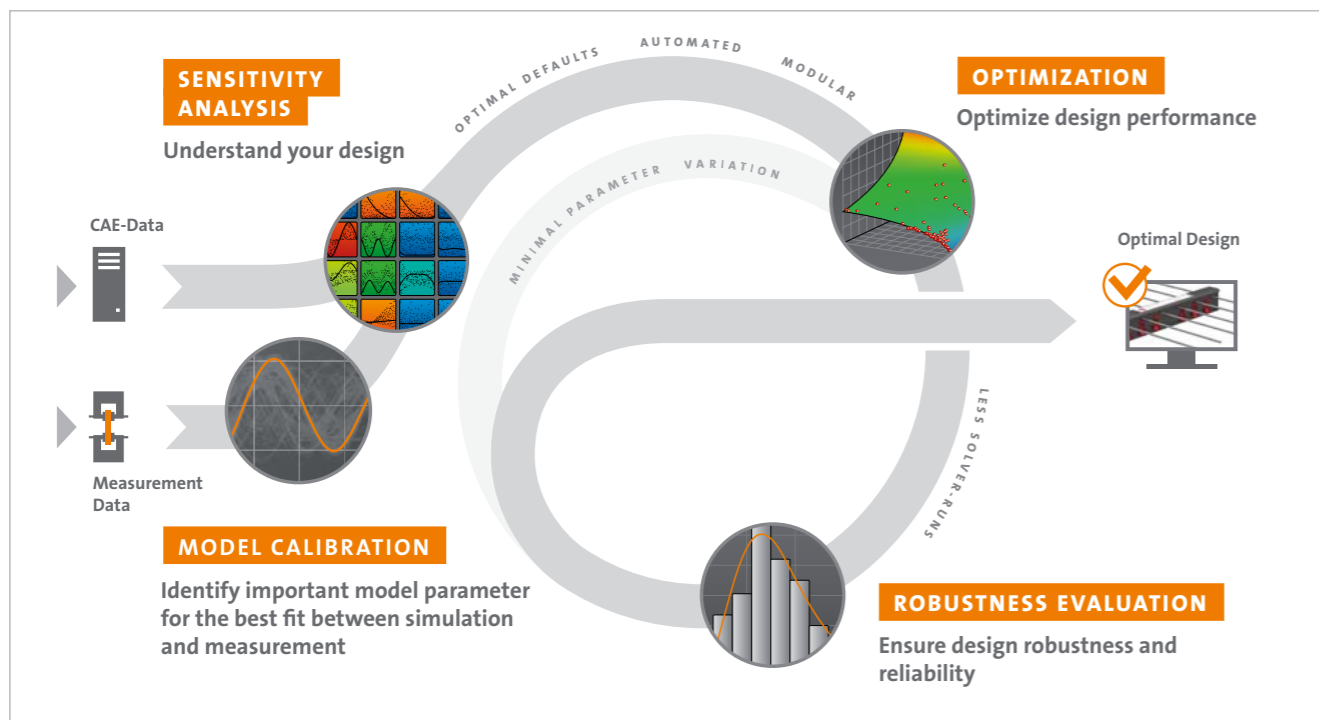

Fig. 1: FEM simulation of a steel anchoring

Fig. 2: Schematic chart of Robust Design Optimization based on multiple designs, measurement or observation points using optiSLang

Example of practical RDO application at HALFEN

With the HALFEN HIT ISO-element, the company offers a versatile and innovative product line for thermally insulated balcony connection. In practice, they are used, e.g., to prevent mold growth and to ensure increased structural physical requirements. The elements consist of load-bearing and heat-insulating parts for the thermal separation of reinforced concrete components (Fig. 3). The ETA-13/0546 approval and the corresponding CE-marking as well as the ICC-ES approval (ES-3799) means the elements are certified and can be used in over 30 countries in Europe and USA. The patented modular system considerably reduces transportation and storage costs by up to 65 % as well as the CO_2 emission and increases the flexibility and planning reliability in the precast concrete industry. The HALFEN Insulated Connection already comes with a fire resistance of REI 120 as standard. This avoids incorrect planning or wrong assembly in respect of the fire protection requirements.

For the thermal insulation certificate according to the Energy Saving Regulation (EnEV), simulations of thermal bridges have to be conducted. In order to determine these bridges regarding balcony connections, ψ-values are required for modeling the construction. The HALFEN HIT ISO-elements are very flexible and can be applied for various installations, e.g., for different wall constructions as a thermal insulation composite system, a monolithic wall, a multi-leaf wall or in a sandwich construction. In addition, a variation of floor and balcony mountings, required load capacities or window connections can be considered to select the right heat transfer coefficients (ψ-values) for further calculations. Altogether, more than 100 million individual variations would be basi-

Fig. 3: HALFEN HIT ISO-element HIT-HP/SP MVX for the thermally insulated connection of balconies and projecting cladding parts

cally possible. In the past, production engineers and architects had to commission thermal calculations based on the particular case or had to use catalog values for standardized cases. On behalf of HALFEN, Dynardo generated parametric FE models and metamodels in ANSYS optiSLang for the simulation of the HIT ISO-elements. Subsequently, the ψ-values can be calculated in real time depending on the input parameters. Thus, HALFEN can provide end users with the appropriate characteristic values via an MOP service on their website. In the following, the methodology of this service will be presented by explaining the individual five project steps.

1. Generation of parametric FE simulation models for the HALFEN HIT-MVX ISO-elements

In order to simulate the variations, parametric FE models were generated in ANSYS optiSLang representing the different installation conditions (e.g, with or without a window or balcony door, above and below the respective connection).

These parameters include:
- Two different joint widths
- Two to twelve different compression shear bearings and two to eighteen tension bars (depending on load carrying capacity)
- Four different types of wall mounting
- Up to eight geometry and material parameters for wall mounting (Fig. 4 top left)
- Up to three concrete coverings
- Up to nine geometry and material parameters for floor slab mounting (Fig. 4 top right)

The FE models also take into account the various outside and inside conditions of temperature. For each design, five structural-physical response variables are calculated: ψ-value, U-value, $\Theta_{si,min}$-value, an equivalent thermal conductivity value, and the f_{Rsi}-value.

2. Validation of the simulation model

Fig. 5 exemplarily shows the calculated temperature profiles for two different conditions with or without windows. These temperature gradations as well as derived and calculated response variables were compared with real measured values. The outcome indicated a high correspondence and accuracy of the calculation results in regard to the measured values.

3. Sensitivity analyses regarding the relevant parameter spaces for various product lines using the sampling strategies of optiSLang

A total of 48 different installation conditions with approx. 20 parameters were calculated using an automated workflow. Up to 700 designs were generated and calculated for each installation condition using the advanced Latin Hypercube sampling available in optiSLang. The FE calculations were processed in parallel with ANSYS Parametric Pack licenses on the Dynardo cluster. Thus, up to 64 designs could be parallely calculated. The calculation time for one design was approx. 10 minutes (using 4 CPUs). The max and min limits of the parameter variation ranges were considered according to the possible installation conditions.

4. Generation and verification of metamodels

Metamodels with prognosis quality of 99 percent Coefficient of Prognosis (CoP) value were created for all response variables of the examined mounting conditions. The latest optiSLang MOP technology of Kriging or Moving Least Square approximations (Fig. 6/7, see next page) was applied to achieve an high and accurate prognosis quality (CoP-values).
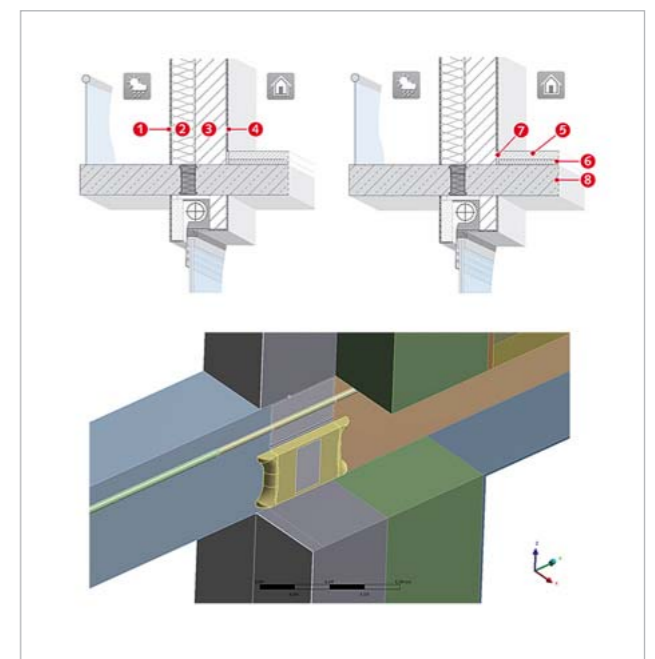

Fig. 4: Parametric wall construction (top left), parametric floor slab mounting (top right), parametric FE model (bottom)
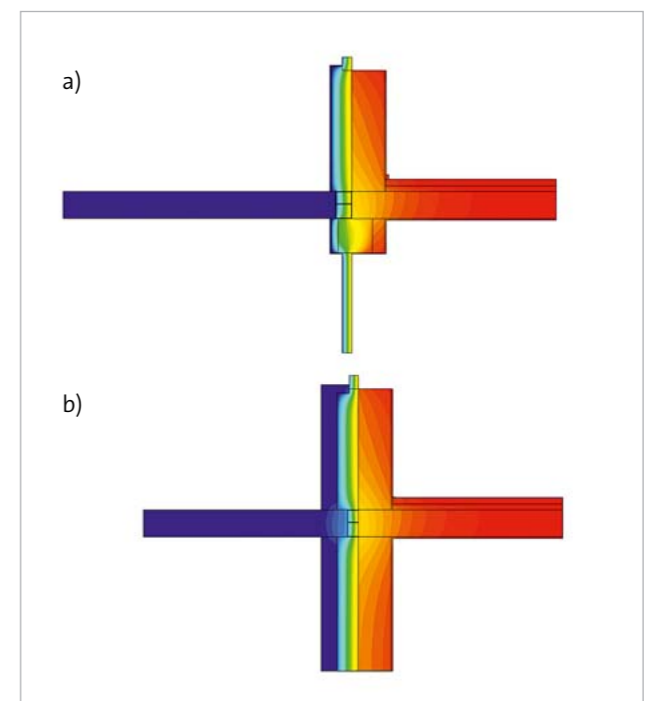

Fig. 5: Temperature distribution from thermal analysis for different conditions, ETICS facade with windows on top and bottom (a), sandwich construction with window on top (b)

5. Implementation of a metamodel-based service as a real-time solver solution at the HALFEN website

For the integration of the metamodels into a web application, Dynardo developed a MOP service providing the metamodels as stand-alone and real-time solver solution. The HALFEN Ψ-Calculator allows end users an efficient and professional calculation of structural-physical properties regarding their particular construction to find the corresponding thermal values.
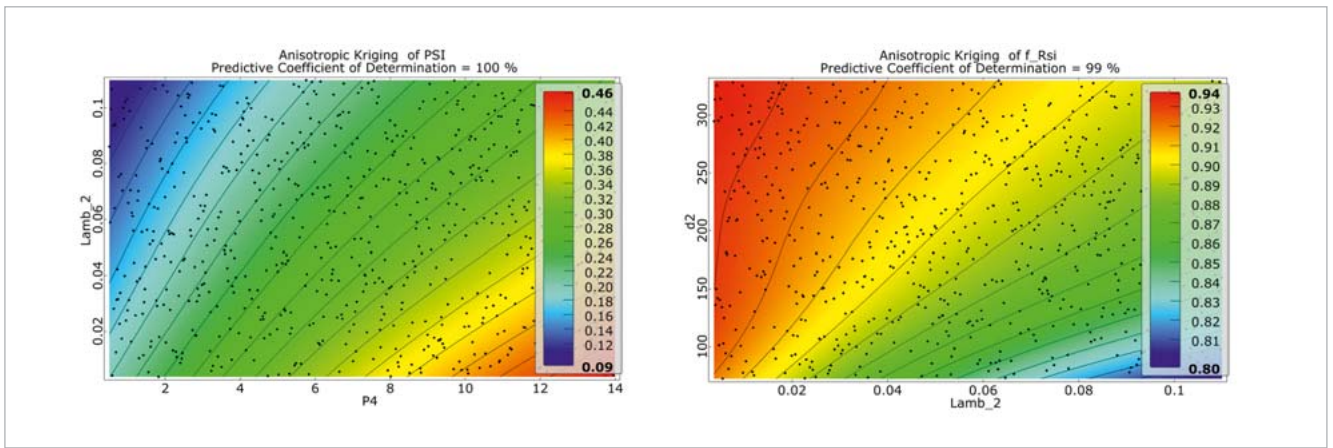
Fig. 6: Metamodels for different response variables (left: Ψ-value, right: f$_{R,Si}$-value)

The required parameters are entered in five simple steps:
- Wall construction
- Wall mounting
- Floor slab mounting
- Window / door
- HALFEN HIT ISO-element

Regarding the wall construction, the user can choose between thermal insulation composite systems (ETICS), as well as monolithic, double-leaf or sandwich constructions.
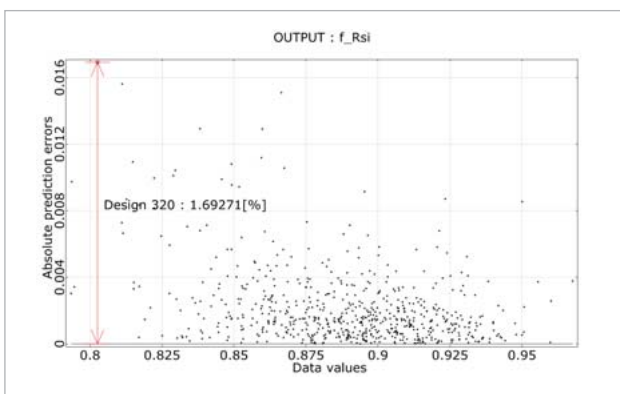

Fig. 7: New output of the maximum local deviation of a metamodel in optiSLang

All wall constructions consist of different layers, e.g., exterior plaster, insulation or bearing layer. The materials, their thermal conductivity and the dimensions of the individual layers can be defined in further steps. Standard materials with their properties will be suggested for a quick choice. The tool also offers menu items regarding required windows or doors above the balcony.

The results of the Ψ-value calculation can be processed to a PDF file containing all relevant parameters as a attachment to, e.g., planning or project documents. The PDF output can be completed with user's individual project data. The results can be saved and reused via link for editing or changing conditions at any time.
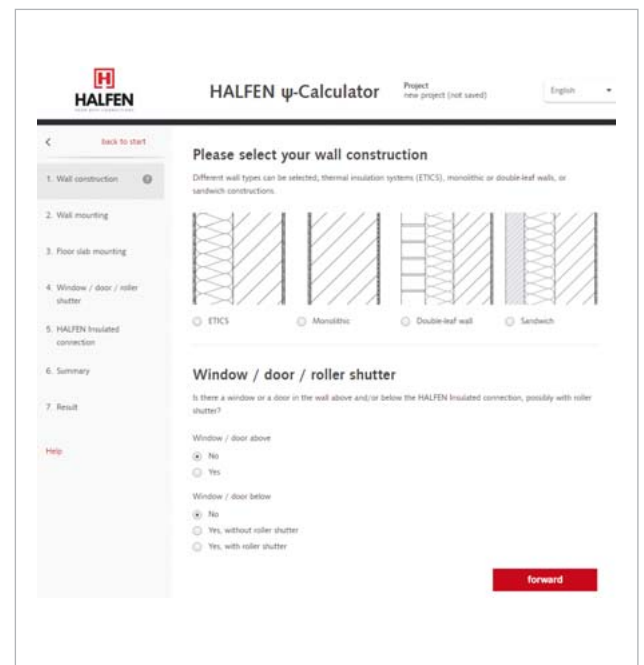
Link to the MOP-web service:

http://psi.halfen.com/de-de/start

Fig. 8: Screenshot of HALFEN Ψ-Calculator

Conclusion

As in many other industries, RDO has been also established in civil engineering. HALFEN has implemented a virtual product development and optimization, which is successfully applied in all production phases. The described MOP web service provides end users, e.g. engineers or architects, with an easy access to individual HALFEN products. It is thus directly supporting the sales and service activities of HALFEN.

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