TEXTILE REINFORCED CONCRETE PART I:
PROCESS MODEL
FOR COLLABORATIVE RESEARCH AND DEVELOPMENT

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Abstract

This paper describes concepts used in the development of a technical information system (TIS) for supporting collaborative material research. The system has been set up to support the development of textile-reinforced concrete (TRC) by applying the modern theoretical concepts of software and database engineering to integrate the available open source tools in an effective way. The system works as a database powered internet server with a transparent definition of the product and process model.

Keywords: object-oriented methods, software engineering, product modeling, model calibration

1. Introduction

The goal of the collaborative research center (SFB 532) “Textile reinforced concrete (TRC): the basis for the development of a new material technology” installed in 1998 at the Aachen University is a complex assessment of mechanical, chemical, economical and productional aspects in an interdisciplinary environment. The research project involves 10 institutes performing parallel research in 17 projects. The coordination of such a research process requires effective software support for information sharing in form of data exchange, data analysis and data archival. Furthermore, the processes of experiment planning and design, modification of material compositions and design parameters and development of new material models in such an environment call for systematic coordination applying the concepts of operational research [1][2]. Flexible organization of the data coming from several sources is a crucial premise for a transparent accumulation of knowledge and, thus, for a successful research in a long run.

The technical information system (TRC-TIS) developed in the SFB 532 has been implemented as a database-powered web server with an object-oriented data model. It serves as an intranet server with access domains devoted to the involved research groups. At the same time, it allows the presentation of selected results just by granting a data object an access from the public area of the server via internet. The architecture of the technical information system is described in detail in [3][4].

2. System design

The data classes defining the database scheme are organized in separate product- and process models. The product model captures the organizational and structural relations between the material components, experiment samples and simulation models. The process model introduces basic scenarios involved in the investigation of the aspects of the material behavior.

2.1. Product model

The top level structuring of the product model is shown in the Figure 1. The diagram gives an overview of the relations between the meta classes i.e. classes which describe other classes from a higher point of view.

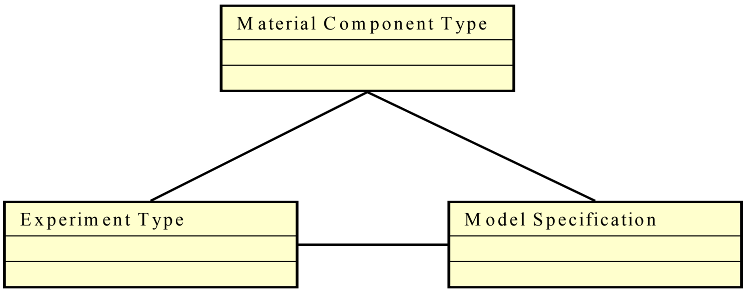


Figure 1: Class categories of product model

The building elements of the material are the material components (e.g. textiles, filaments and concrete mixtures) and their parameters. The properties of material components are described by a set of parameters specified in instances of the meta-class *Material Component Type.*

Material components are combined and varied to construct experiment types that are used to compare their performance. The general definition of an experimental setup is concentrated in the class *Experiment Type*. This class defines the possible input and output parameters of an experiment and the possible composition of material components. This class serves as a template for designing experiment sequences to explore a particular response with respect to selected input parameters or different choices of material components.

Further, the idealizations of an experiment with the input parameters specified in the instances of the meta-class *Model Specification* are applied in form of theoretical and/or numerical models with the goal to quantify the material parameters. Models use parameters to quantify properties of the material components. If the parameter is known it can be applied to an idealization. Otherwise the attributes of a material component must be extended by the new parameter.

The product model describes the available basic data structure. Obviously, the data structure evolves in the course of the research process. In order to capture this evolution a process model must be designed that defines the dependencies and interactions between particular classes introduced into the product model.

2.2. Process model

The data definition and data accumulation is carried out in the framework of three major processes: design of experiments, model development and model calibration. If these processes are formalized, the evolution of the data structures may be automated. Indeed, in the TRC-TIS the data structures representing the material components and experiments are defined as a side effect during the elaboration of a particular research task formalized in the process model.

The top level decomposition of the research process is shown in the Figure 2. The fundamental research tasks are formalized in form of process classes for data analysis to evaluate correlation between material parameters, calibration of material models, sensitivity analysis and validation of numerical models. Each of these classes may be specialized with respect to the particular application context, i.e. with respect to the particular combination of material component types and experiment types. The instantiated process classes can manage the data flow involved in the particular process.

The conceptual model of the TIS has been formalized by using the UML. Its focus is on capturing the relations and dependencies at the level of the meta-data in order to allow for a simple reflection of the requirements induced by the mentioned research tasks. The data structure evolution and establishment of the data flow on the example of a model calibration are presented below.

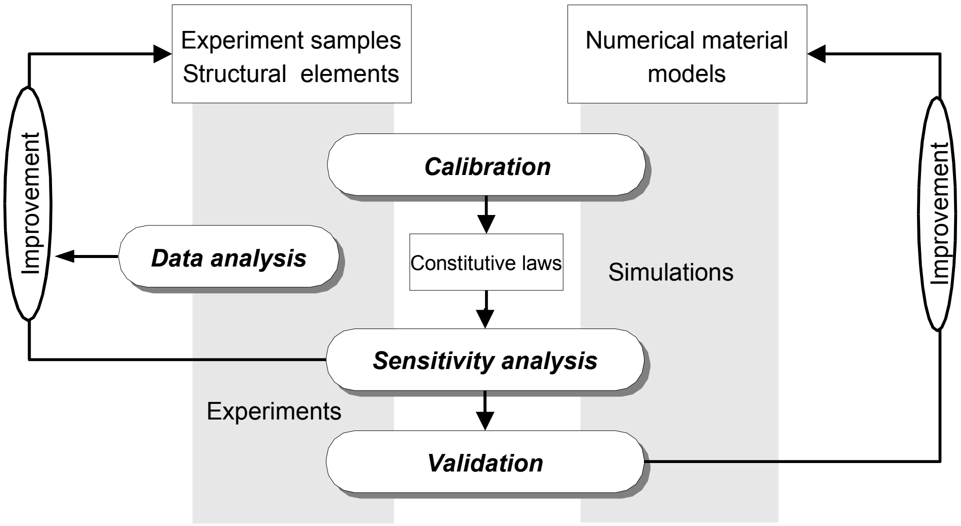


Figure 2: Top-level research scenario with the base process classes

2.2.1 Calibration use case

The quantitative characteristics of material components like material parameters, constitutive laws and statistical characteristics of the material structure are quantified by using idealizations. The material parameters are identified either in a closed form, e.g. Young modulus, or in an iterative form by fitting the response of the idealized model to the experimental response. Thus, the product model reflects the association between an experiment sample or group of samples with the same material composition in an idealization object to identify material parameters. In terms of UML a calibration is a use case that includes a set of sub use cases (Figure 3).

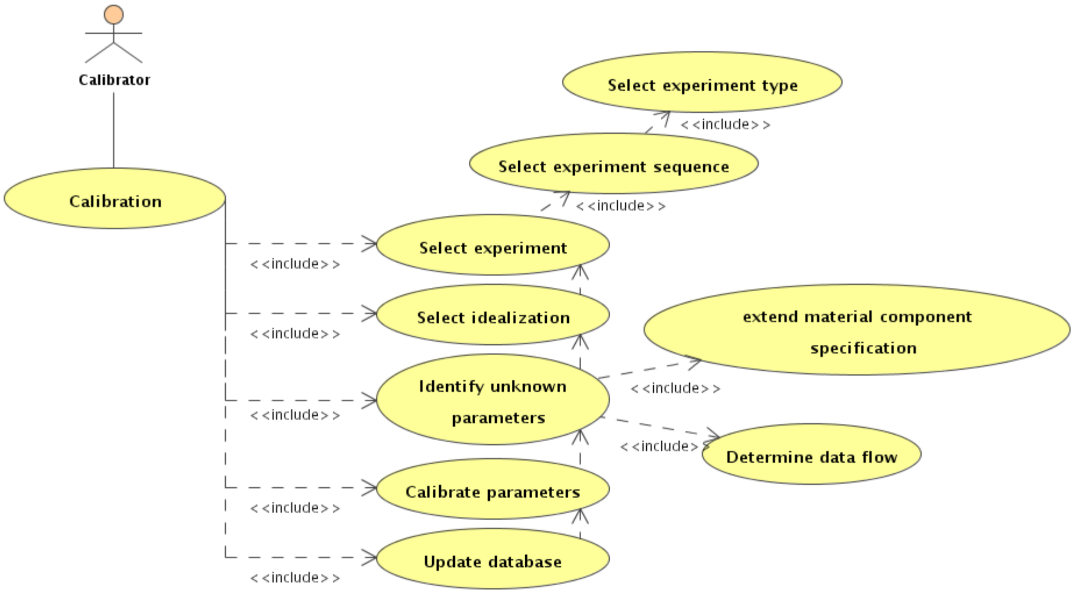


Figure 3: UML use case diagram for calibration

The first step in a calibration is to select an experiment by choosing type, sequence and finally a particular experiment treatment which has usually been performed in several replications. Choosing an experiment type restricts the set of applicable idealizations. In the calibration process, the material parameters involved in the idealization can be classified in view of the calibration procedure into known and unknown. The former ones can be retrieved from the database while the later are target to the calibration process. Identifying these parameters includes the extension of the involved material components (i.e. extension of the data structure) and setting up the data flow.

Once that all the information is collected for calibrating the parameters the data flow within the product model can be established. Then a genetic optimization algorithm controls the iteration. The derived parameter values are made persistent according to the previously determined data flow and thus stored with the material components.

Figure 4 shows the relation of the main objects in the calibration of the bond law of a filament embedded in a concrete matrix. The experiment has been conducted with a filament taken from a yarn (ITA-CAB-ARG) and a concrete mixture (TZ-2-2) and the force-displacement curve has been determined. A simple idealization is chosen which uses a bond element that can be described by 5 parameters. Thus the data structure is automatically extended by an interaction class for interaction of filaments and concrete mixtures and the data flow is prepared to fill in the parameter values after the calibration is done.

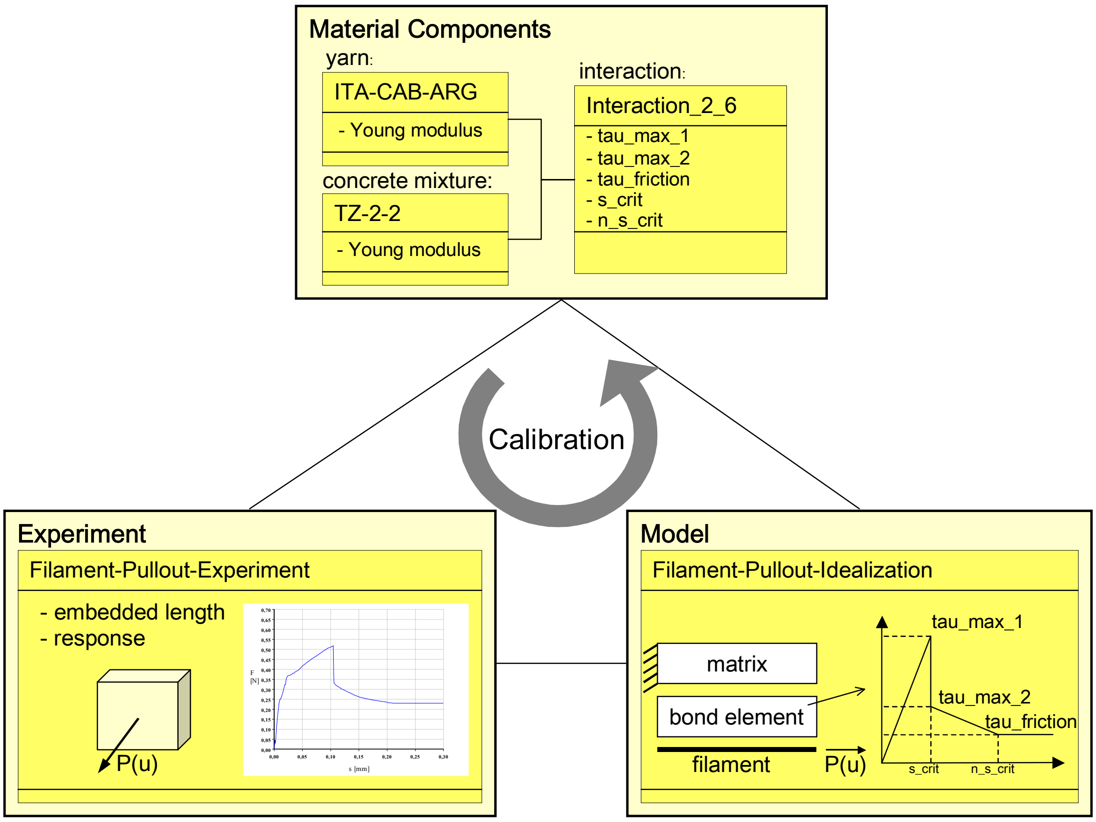


Figure 4: Data flow in calibration process

The calibration process after about 400 iterations can been seen in Figure 5. A tree structure on the left allows navigation through the objects. On the right two diagrams can be seen: The upper one shows the response values of the experiment (red, solid) and the current simulation (blue, dotted). The second plot traces the lack-of-fit values for every iteration. The genetic algorithm allowed us an automatic determination of the 5 material parameters describing the bond law in about 500 simulations.

The calibration process has been implemented in Python as an extension of the ORFEUS finite element simulation toolkit [5][6]. The steps described above are realized in a wizard-tool that allows us to assemble a calibration instance in several steps. The database classes are made available in Python by automatic script-generation.

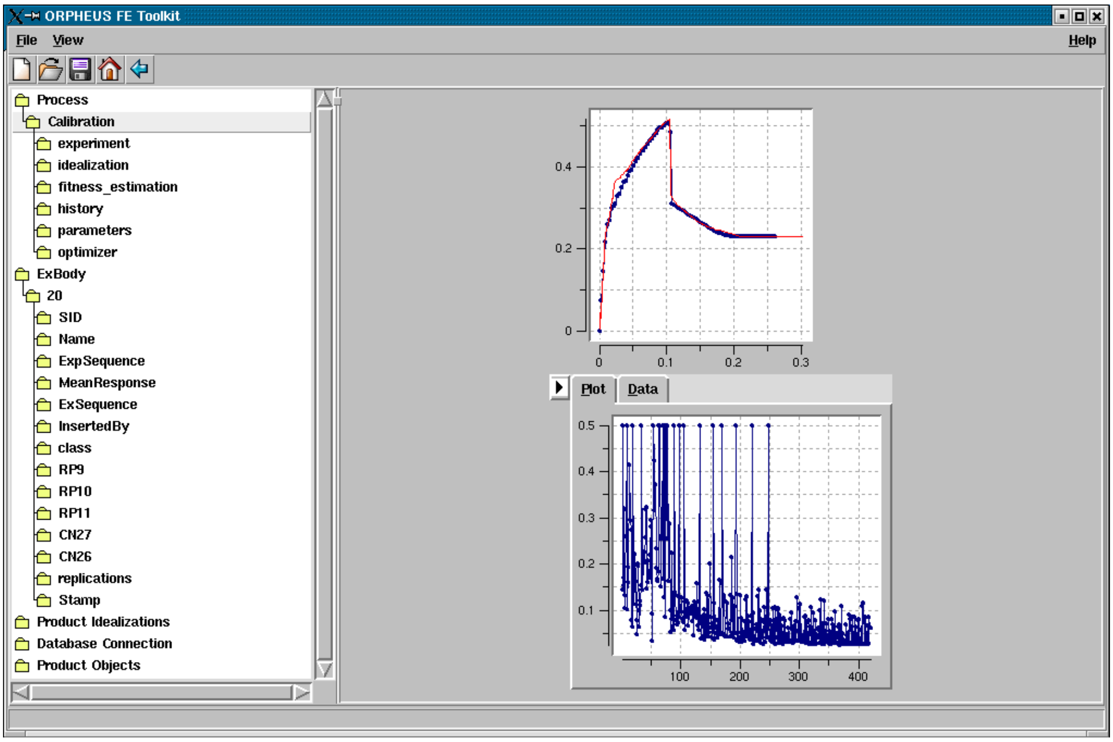
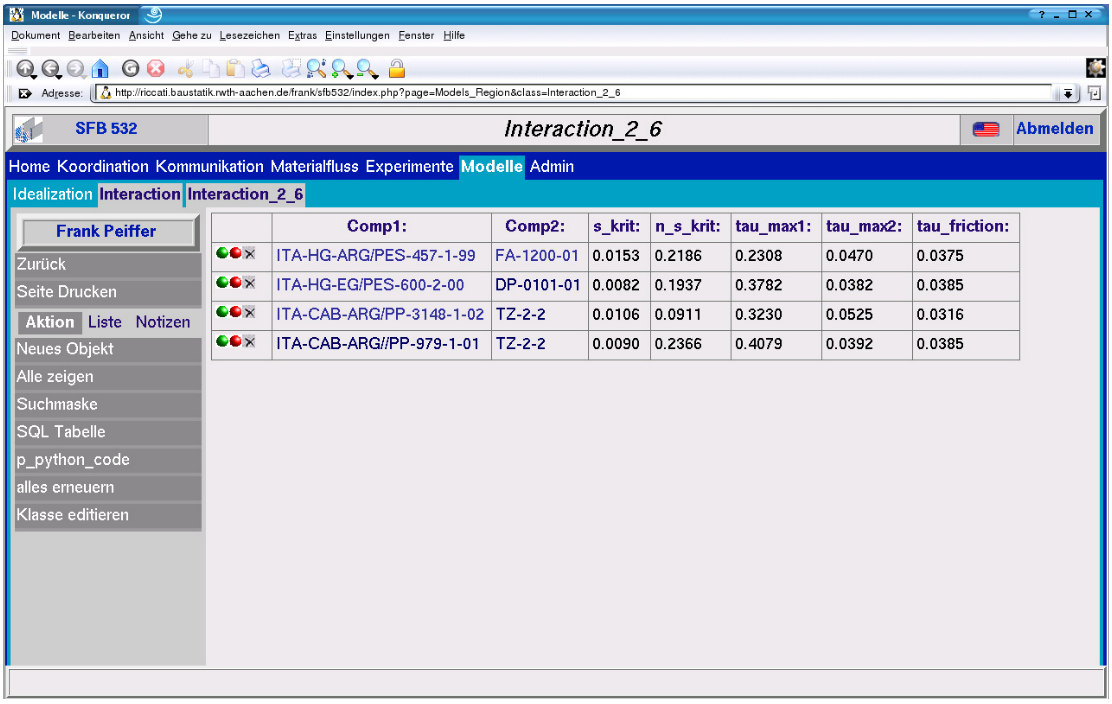


Figure 5: Calibration of bond material law

Figure 6 shows the calibrated parameter values for this particular combination material component in the HTML interface. In this form queries and further evaluation of the parameters can be conducted. The parameters of the bond are associated to the interaction constructed for the material components denoted as *Comp1* and *Comp2*, standing for the concrete and for the yarn.



	Comp1:	Comp2:	s_krit:	n_s_krit:	tau_max1:	tau_max2:	tau_friction:
●●✕	ITA-HG-ARG/PES-457-1-99	FA-1200-01	0.0153	0.2186	0.2308	0.0470	0.0375
●●✕	ITA-HG-EG/PES-600-2-00	DP-0101-01	0.0082	0.1937	0.3782	0.0382	0.0385
●●✕	ITA-CAB-ARG/PP-3148-1-02	TZ-2-2	0.0106	0.0911	0.3230	0.0525	0.0316
●●✕	ITA-CAB-ARG//PP-979-1-01	TZ-2-2	0.0090	0.2366	0.4079	0.0392	0.0385

Figure 6: Calibrated parameter values in the HTML interface

The material parameters determined using a particular idealization of the experiment are stored in the database together with the way how they have been determined. This feature is essential in the long run especially in the complex research project with a fluctuating staff running over several years.

2.2.2 Sensitivity analysis and parametric studies

The presented formalization of the calibration process can be performed for the remaining process including the sensitivity analysis with respect to the input parameters. There are two types of sensitivity analysis distinguished in the design of the system, the purely experimental method of “design and analysis of experiments” based on generalized regression model [7][8] and the sensitivity analysis supported by an idealization based on mechanical and physical theory.

In the former case, there is a number of software packages applying regression models to evaluate the significance and interactions of the varied input parameters. The definition of experimental classes in the TIS has been developed with regard to the methodology of design of experiments. This makes it possible to provide an interface between the database and external DOE tools like DesignExpert [9].

In case that robust material models are available, the sensitivity analysis may be supported by numerical analysis. An important issue in this case is the knowledge of the quality of the material model at hand which can only be obtained through the systematic validation [1][10]. The definition of the process templates for validation of models and sensitivity analysis is the subject of the further development.

3. Conclusions

The complex material research involves many aspects to be explored simultaneously at various levels of research. An effective information sharing and exchange can essentially increase the efficiency of research and enable more targeted progress of material development. The present article summarizes the applied concepts of software engineering that have been applied in the system design of the TIS for textile reinforced concrete. The major goals of the TIS is to support (1) the experimental design in a multi user environment, (2) the data mining and data analysis, (3) the calibration of newly developed material models, (4) the sensitivity analysis with respect to input parameters and (5) the validation of the developed material models.

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