Preface

In this monograph we address a new paradigm in the field of simulation-based engineering sciences (SBES) to face the challenges posed by current ICT technologies.

In materials, processes, and structural design many scenarios must be considered and carefully analyzed, and this task is expensive from a computational point of view. Moreover, the design parametric space is too large to consider its exhaustive exploration. In general, only coarse samplings of the parametric spaces are performed, complemented with the use of design security coefficients for including the unknown information and also the inevitable uncertainty. Thus, in practice, designers consider very well-tested materials, manufacturing processes, and loading scenarios in order to guarantee a smooth design process (fine and expensive simulations are restricted to the analysis of few critical designs) and in consequence the resulting designs remain suboptimal.

Nowadays, industry is using materials and manufacturing processes that are, for most of them, 30-years old. New designs, and more precisely, a new design framework is urgently needed, allowing us to explore regions of the design space never until now explored, making possible breakthroughs in both the design (in its largest sense) and the product technologies. Moreover, this new framework should allow us to address uncertainty quantification and its propagation throughout the whole design chain (including processes and experimental tests). It should also allow addressing efficiently high-fidelity models developed in the last quarter of the century but until now inefficiently considered because of their complexity for current decision-making strategies.

Real-time analysis of complex systems is compulsory for making possible real-time decision-making that needs the evaluation of many possible scenarios under the real-time constraint. Decision making is at the heart of material, processes, and structural optimization and also of the incipient simulation-based control. Moreover, for democratizing accessibility to efficient design technologies, decision-making tools should run in light computing devices.

These apparently contradictory requirements, the real-time evaluation of system responses based on high-fidelity models and involved in decision-making tools and the suitability of running these applications and tools in light computational devices, could be possible if we generate offline a sort of a computational vademecum containing the solution of the model under consideration for all possible design scenarios and then use it online for decision-making purposes.

We developed in recent years a novel technique, called Proper Generalized Decomposition (PGD). It is based on the assumption of a separated form of the unknown field and it has demonstrated its capabilities in dealing with high-dimensional problems overcoming the strong limitations of classical approaches. Many challenging problems can be efficiently cast into a multidimensional framework. For instance, parameters in a model (loads, initial conditions, boundary conditions, material parameters, geometrical parameters, etc.) can be set as additional extra-coordinates of the model. In a PGD framework, the resulting model is solved once for life, in order to obtain a general solution that includes all the solutions for every possible value of the parameters, that is, a sort of computational vademecum. Under this rationale, optimization of complex problems, uncertainty quantification, simulation-based control, and real-time simulation are now at hand in highly complex scenarios and on deployed platforms.

Consider a material, process, or structural model, or one coupling these three items. This model has an associated output (displacement field, stress field, temperature field, electric or magnetic fields, etc.) of engineering interest. However, this output depends on several parameters that were fixed before solving it (e.g., position and magnitude of the applied loads, boundary conditions, initial conditions, material parameters—young modulus, thermal conductivity, etc.—or geometrical parameters associated with the system under consideration). Thus, for each possible scenario or tentative design we must solve the model, a very costly task in practice that makes unaffordable a design (in its largest sense) based on a high-fidelity modeling on the whole parametric space domain.

For a given family of problems, imagine now, that we consider all the model parameters as coordinates (as the space and time are in standard models). Now, by solving offline and only once the resulting multidimensional model, we have access to the output (the fields of engineering interest) for any value of the design parameters (e.g. position and magnitude of the loads, boundary or initial conditions, material or geometry). By considering this multiparametric solution, a sort of modern "vademecum," design (in its largest sense) becomes extremely efficient because designers can explore in real-time and on light computing platforms, the whole parametric design space related to the high-fidelity model solution. We can visualize this multiparametric solution as a sort of virtual chart, a design facility that makes possible fast and extremely accurate optimization, inverse analysis, control, and uncertainty propagation that only requires particularizing the multiparametric solution as many times as required.

PGD also allows alleviating the solution of complex 3D models defined in degenerated domains (plate and shell-like domains), the solution of transient models in a non-incremental way, and the solution of models defined in a multi-dimensional domain, those in general making use of a number of conformation coordinates as encountered in the fine modeling of the mechanics of materials, most of them revisited in this monograph.

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