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International Centre for Mechanical Sciences

Courses and Lectures Vol. 561

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Gernot Beer · Stéphane Bordas
Editors

Isogeometric Methods for Numerical Simulation

Springer

Editors

Gernot Beer
Technical Univ. of Graz, Graz, Austria

Stéphane Bordas
Cardiff University, Cardiff, Great Britain

ISSN 0254-1971
ISBN 978-3-7091-1842-9 ISBN 978-3-7091-1843-6 (eBook)
DOI 10.1007/ 978-3-7091-1843-6
Springer Wien Heidelberg New York Dordrecht London

All contributions have been typeset by the authors
Printed in Italy

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

PREFACE

The initial idea of isogeometric methods is due to Tom Hughes, who proposed a tighter connection between computer aided design (CAD) and simulation. Practically, most simulations are performed based on some sort of model of the geometry constructed within a CAD framework. Subsequently, this CAD geometry is "meshed" so that the problem can be solved using the finite element method (FEM) or the Boundary Element Method (BEM). Based on the solution of the problem, engineers monitor quantities of interest, e.g. the maximum stress or displacement in a structure to decide upon the suitability of the chosen geometry for the intended use of the object. If this initial geometry must be modified, the corresponding mesh must usually be at least partly discarded, and a new mesh constructed, for the new geometry. This process must be repeated as many times as is required to converge to an allowable solution.

It thus appears that the practice of using the CAD data to generate a series of meshes for simulations is cumbersome, time consuming and prone to errors. Anyone that has performed serious simulation work is aware of the effort required to produce a mesh of suitable quality and of the pitfalls associated with mesh generation. Although many excellent mesh generators are available, to generate meshes from CAD data, there is always the possibility that for awkward geometries, elements with bad aspect ratios are encountered and the mesh has to be repaired to yield acceptable results. Also, in addition to the (discretization) error introduced by approximating the unknown solution, one has to control the (geometrical) error introduced when approximating the geometry by the mesh. For some applications in shell theory, electromagnetics for example and many others, an accurate description of the geometry is paramount. Any method able to reduce both discretization and geometrical errors is expected to be welcomed by practitioners. It was the very goal of this course on Isogeometric Analysis, addressed to newcomers to the field, to simplify the transition from the standard "CAD-Analysis" pipeline to the "Isogeometric" paradigm where meshing is either completely suppressed (in Isogeometric Boundary Element Methods) or greatly simplified (in Isogeometric Finite Element, Collocation and Meshless Methods).

Although the initial intention of combining CAD and simulation was no doubt to avoid mesh generation by using the CAD data directly for the simulation, it became soon clear that there was an added value to this approach. The functions used by CAD programs to describe the geometry (NURBS) also happened to have significant advantages in approximating the unknown fields. Early work reported in the first book on the topic[1] *indicated that with these functions much better results could be obtained with a smaller number of degrees of freedom. This appealing property is partly due to NURBS' improved continuity properties and are amenable to efficient hpk-refinement strategies.*

The aim of the course "Isogeometric Methods for numerical simulation" was to give an in depth overview of the fundamentals behind this technology and to present some of its most recent applications to a range of problems from fluid to fracture mechanics simulations. This book contains some of the lecture material presented at the course.

The book starts with an introduction by B. Jüttler to B-splines and NURBS. The next chapter by V.P. Nguyen and S. Bordas deals with the implementation of isogeometric methods in structural mechanics using Finite Element and eXtended Finite Element Methods, which can be used to model cracks and delamination in composite structures. This chapter also refers to alternative methods to isogeometric analysis, in particular when the field and the geometrical approximations are to be kept independent. The next chapter covers the implementation of isogeometric techniques into the BEM. It can be seen that the BEM is an ideal companion to CAD because both use a surface representation. Here G. Beer and B. Marussig present the basic idea of a geometry independent approximation of field variables for the first time. The next chapter by A. Reali and T.J.R. Hughes provides a concise introduction to isogeometric collocation methods and proposes a brief review of some of the most important results obtained so far in that context. In the last chapter some new concepts for the description of complex surfaces are presented. D. Thomas and M. Scott explain how such surfaces can be described and simulated with few control points using T-spline technology. The course also covered fluid-structure interaction, through most inspiring lectures by Y. Bazilevs who was, unfortunately, unable to contribute to this book.

[1] J.A. Cottrell, T.J.R. Huges and Y. Bazilevs *Isogeometric Analysis*, J. Wiley 2009

The course was very well attended and we would like to thank all participants, in particular those coming from industry, for their interest and for the many fruitful discussions which ensued. Thanks are also due to the lecturers for taking time within busy schedules to prepare and present excellent lectures. We hope that the course and this book will inspire many to work in this exciting and continuously expanding area.

Last but not least, we would like to thank the people at Springer for their assistance and patience.

Gernot Beer and Stéphane Bordas

CONTENTS