Topology Optimization For Additive Manufacturing

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MARSHALL BRIA

Topology Optimization Springer Nature
Design for Additive Manufacturing is a complete guide to design tools for the manufacturing requirements of AM and how they can enable the optimization of process and product parameters for the reduction of manufacturing costs and effort. This timely synopsis of state-of-the-art design tools for AM brings the reader right up-to-date on the latest methods from both academia and industry. Tools for both metallic and polymeric AM technologies are presented and critically reviewed, along with their manufacturing attributes. Commercial applications of AM are also explained with case studies from a range of industries, thus demonstrating best-practice in AM design. Covers all the commonly used tools for designing for additive manufacturing, as well as descriptions of important emerging technologies Provides systematic methods for optimizing AM process selection for specific production requirement Addresses design tools for both metallic and polymeric AM technologies Includes commercially relevant case studies that showcase best-practice in AM design, including the biomedical, aerospace, defense and automotive sectors

Topology Design Methods for Structural Optimization Springer Science & Business Media
In Topology Optimization the goal is to find the ideal material distribution in a domain subject to external forces. The structure is optimal if it has the highest possible stiffness. A volume constraint ensures filigree structures, which are regulated via a Ginzburg-Landau term. During 3D Printing overhangs lead to instabilities, which have only been tackled unsatisfactorily. The novel idea is to incorporate an Additive Manufacturing Constraint into the phase field method. A rigorous analysis proves the existence of a solution and leads to first order necessary optimality conditions. With an Allen-Cahn interface propagation the optimization problem is solved iteratively. At a low computational cost the Additive Manufacturing Constraint brings about support structures, which can be fine tuned according to engineering demands. Stability during 3D Printing is assured, which solves a common Additive Manufacturing problem.

Topology Optimization with Additive Manufacturing Constraints Elsevier
This book has grown out of lectures and courses given at Linköping University, Sweden, over a period of 15 years. It gives an introductory treatment of problems and methods of structural optimization. The three basic classes of geometrical - timization problems of mechanical structures, i. e. , size, shape and topology op- mization, are treated. The focus is on concrete numerical solution methods for d- crete and (?nite element) discretized linear elastic structures. The style is explicit and practical: mathematical proofs are provided when arguments can be kept e- mentary but are otherwise only cited, while implementation details are frequently provided. Moreover, since the text has an emphasis on geometrical design problems, where the design is represented by continuously varying—frequently very many— variables, so-called ?rst order methods are central to the treatment. These methods are based on sensitivity analysis, i. e. , on establishing ?rst order derivatives for - jectives and constraints. The classical ?rst order methods that we emphasize are CONLIN and MMA, which are based on explicit, convex and separable appro- mations. It should be remarked that the classical and frequently used so-called op- mality criteria method is also of this kind. It may also be noted in this context that zero order methods such as response surface methods, surrogate models, neural n- works, genetic algorithms, etc. , essentially apply to different types of problems than the ones treated here and should be presented elsewhere.
Springer
Topology Optimization in Engineering Structure Design explores the recent advances and applications of topology optimization in engineering structures design, with a particular focus on aircraft and aerospace structural systems. To meet the increasingly complex engineering challenges provided by rapid developments in these industries, structural optimization techniques have developed in conjunction with them over the past two decades. The latest methods and theories to improve mechanical performances and save structural weight under static, dynamic and thermal loads are summarized and explained in detail here, in addition to potential applications of topology optimization techniques such as shape preserving design, smart structure design and additive manufacturing. These new design strategies are illustrated by a host of worked examples, which are inspired by real engineering situations, some of which have been applied to practical structure design with significant effects. Written from a forward-looking applied engineering perspective, the authors not only summarize the latest developments in this field of structure design but also provide both theoretical knowledge and a practical guideline. This book should appeal to graduate students, researchers and engineers, in detailing how to use topology optimization methods to improve product design. Combines practical applications and topology optimization methodologies Provides problems inspired by real engineering difficulties Designed to help researchers in universities acquire more engineering requirements

An Introduction to Structural Optimization John Wiley & Sons
This book gathers papers presented at the International Joint Conference on Mechanics, Design Engineering and Advanced Manufacturing (JCM 2016), held on 14-16 September, 2016, in Catania, Italy. It reports on cutting-edge topics in product design and manufacturing, such as industrial methods for integrated product and process design; innovative design; and computer-aided design. Further topics covered include virtual simulation and reverse engineering; additive manufacturing; product manufacturing; engineering methods in medicine and education; representation techniques; and nautical, aeronautics and aerospace design and modeling. The book is divided into eight main sections, reflecting the focus and primary themes of the conference. The contributions presented here will not only provide researchers, engineers and experts in a range of industrial engineering subfields with extensive information to support their daily work; they are also intended to stimulate new research directions, advanced applications of the methods discussed, and future interdisciplinary collaborations.

Using Topology Optimization to Improve Design for Additive Manufacture Linköping University Electronic Press
Topology optimization tools are useful for distributing material in

a geometric domain to match targets for mass, displacement, structural stiffness, and other characteristics as closely as possible. Topology optimization tools are especially applicable to additive manufacturing applications, which provide nearly unlimited freedom for customizing the internal and external architecture of a part. Existing topology optimization tools, however, do not take full advantage of the capabilities of additive manufacturing. Prominent tools use micro- or meso-scale voids or artificial materials to parameterize the topology optimization problem, but they use filters, penalization functions, and other schemes to force convergence to regions of fully dense (solid) material and fully void (open) space in the final structure as a means of accommodating conventional manufacturing processes. Since additive manufacturing processes are capable of fabricating intermediate densities (e.g., via porous mesostructures), significant performance advantages could be achieved by preserving and exploiting those features during the topology optimization process. Towards this goal, a topology optimization tool has been created by combining homogenization with parametric smoothing functions. Rectangular mesoscale voids are used to represent material topology. Homogenization is used to analyze its properties. B-spline based parametric smoothing functions are used to control the size of the voids throughout the design domain, thereby smoothing the topology and reducing the number of required design variables relative to homogenization-based approaches. Resulting designs are fabricated with selective laser sintering technology, and their geometric and elastic properties are evaluated experimentally.
Evolutionary Topology Optimization of Continuum Structures Springer Science & Business Media
The study of optimal shape design can be arrived at by asking the following question: "What is the best shape for a physical system?" This book is an applications-oriented study of such physical systems; in particular, those which can be described by an elliptic partial differential equation and where the shape is found by the minimum of a single criterion function. There are many problems of this type in high-technology industries. In fact, most numerical simulations of physical systems are solved not to gain better understanding of the phenomena but to obtain better control and design. Problems of this type are described in Chapter 2. Traditionally, optimal shape design has been treated as a branch of the calculus of variations and more specifically of optimal control. This subject interfaces with no less than four fields: optimization, optimal control, partial differential equations (PDEs), and their numerical solutions-this is the most difficult aspect of the subject. Each of these fields is reviewed briefly: PDEs (Chapter 1), optimization (Chapter 4), optimal control (Chapter 5), and numerical methods (Chapters 1 and 4).
2021 7th International Conference on Optimization and Applications (ICOA) Springer
This book covers in detail the various aspects of joining materials to form parts. A conceptual overview of rapid prototyping and layered manufacturing is given, beginning with the fundamentals so that readers can get up to speed quickly. Unusual and emerging applications such as micro-scale manufacturing, medical applications, aerospace, and rapid manufacturing are also discussed. This book provides a comprehensive overview of rapid prototyping technologies as well as support technologies such as software systems, vacuum casting, investment casting, plating, infiltration and other systems. This book also: Reflects recent developments and trends and adheres to the ASTM, SI, and other standards Includes chapters on automotive technology, aerospace technology and low-cost AM technologies Provides a broad range of technical questions to ensure comprehensive understanding of the concepts covered
Proceedings of the International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing (JCM 2016), 14-16 September, 2016, Catania, Italy Elsevier
Additive manufacturing (AM) is opening a new creative landscape for designers. Freedom of form and material creates opportunities for customization, increased functionality, and higher complexity in manufactured objects. Characterizing and understanding the unique manufacturing constraints of AM is a key to enabling the designer to leverage the full potential of AM to produce highly complex geometries. In this work, “minimum feature size”, defined as the smallest scale at which a feature of a particular shape in a particular orientation can be manufactured, is examined in detail. A parameterization for shape and orientation of small features is developed, and an adaptive, iterative experimental procedure is created to accurately estimate the minimum feature size for a particular feature type in the parameter space. A design of experiments process is used to systematically explore the minimum feature size over the space of parameterized shapes and orientations. This process is applied to three different AM platforms, and in each case minimum feature size spans an order of magnitude over the set of considered features. The data collected are used to create a parametric design rule for each process, a function which provides a detailed map of the minimum feature size achievable over the parameter space. The parametric design rule is applied to typical design problems, used to assess existing 3D models for manufacture, and applied to design optimization frameworks. The parametric design rules produced are found to more tightly follow the actual capabilities of the AM processes, increasing the envelope for complexity compared with existing design guidelines consisting of one or two constant minimum feature sizes and improving accuracy in predicting the minimum feature sizes for new geometries by as much as 50%. Application is made to three design problems, realizing significant improvements in each case. The experimental study of minimum feature size is complemented by an adaptation of topology optimization to incorporate the parametric design rules into an automated design process. A new variant of the Moving Morphable Components (MMC) approach is created, improving convergence through a “bootstrapping” approach and integrating the feature-dependent design rules to ensure manufacturability of the result. Experimentally-verified manufacturable outputs are achieved while sacrificing less than 5% of the objective function value for several test problems. By bringing together experimental assessment of minimum feature size and design optimization through the creation of parametric design rules, a novel, reproducible, and practical process for ensuring manufacturability of optimized designs is created.
A Multidisciplinary Optimization approach Springer Nature
Topology optimization is an exciting and powerful method for generating insightful, high-performance designs. The objectives of this text are to introduce the readers to topology optimization terminology, illustrate various sensitivity analysis techniques, and, most importantly, provide numerous examples and case-studies to illustrate the merits of topology optimization. The primary audience include senior undergraduate students, first year graduate students and practicing engineers. No prior background in topology optimization is assumed. However, a

working knowledge of finite element analysis (FEA) is helpful. Pareto, a topology optimization software developed at the University of Wisconsin-Madison, is used throughout the text to illustrate the main concepts. However, the reader could potentially use other topology optimization software capable of handling the class of problems posed in this text.

Progress Toward Topology Optimization (TO) for Additive Manufacturing (AM) and Fatigue Springer

Multiscale Structural Topology Optimization discusses the development of a multiscale design framework for topology optimization of multiscale nonlinear structures. With the intention to alleviate the heavy computational burden of the design framework, the authors present a POD-based adaptive surrogate model for the RVE solutions at the microscopic scale and make a step further towards the design of multiscale elastoviscoplastic structures. Various optimization methods for structural size, shape, and topology designs have been developed and widely employed in engineering applications. Topology optimization has been recognized as one of the most effective tools for least weight and performance design, especially in aeronautics and aerospace engineering. This book focuses on the simultaneous design of both macroscopic structure and microscopic materials. In this model, the material microstructures are optimized in response to the macroscopic solution, which results in the nonlinearity of the equilibrium problem of the interface of the two scales. The authors include a reduce database model from a set of numerical experiments in the space of effective strain. Presents the first attempts towards topology optimization design of nonlinear highly heterogeneous structures Helps with simultaneous design of the topologies of both macroscopic structure and microscopic materials Helps with development of computer codes for the designs of nonlinear structures and of materials with extreme constitutive properties Focuses on the simultaneous design of both macroscopic structure and microscopic materials Includes a reduce database model from a set of numerical experiments in the space of effective strain

Topology Optimization of Parts for Additive Manufacturing Via Directed Energy Deposition Createspace Independent Publishing Platform

Abstract: Additive manufacturing (AM) has had unprecedented growth as a manufacturing tool in many sectors. In recent years, more companies from various industries have used AM methods not only for creating prototypes but also for product mass production. AM can bring many advantages to the design optimization of complex-shaped parts. It can be used to develop products that would normally be fabricated with various conventional manufacturing methods such as casting, machining, etc., which would typically require more time, effort and cost. In combination with Topology Optimization (TO), AM can also be used to minimize the amount of material to create lightweight parts, which can be beneficial for many industrial products, especially in the aerospace application.

Design for Additive Manufacturing Elsevier

ICTAEM_1 treated all aspects of theoretical, applied and experimental mechanics including biomechanics, composite materials, computational mechanics, constitutive modeling of materials, dynamics, elasticity, experimental mechanics, fracture, mechanical properties of materials, micromechanics, nanomechanics, plasticity, stress analysis, structures, wave propagation. During the conference special symposia covering major areas of research activity organized by members of the Scientific Advisory Board took place. ICTAEM_1 brought together the most outstanding world leaders and gave attendees the opportunity to get acquainted with the latest developments in the area of mechanics. ICTAEM_1 is a forum of university, industry and government interaction and serves in the exchange of ideas in an area of utmost scientific and technological importance.

Development of a Process for Determining Minimum Feature Size in Additive Manufacturing with Applications to Topology Optimization Springer Science & Business Media

In recent decades, the development of computer-controlled manufacturing by adding materiallayer by layer, called Additive Manufacturing (AM), has developed at a rapid pace. The technologyadds possibilities to the manufacturing of geometries that are not possible, or at leastnot economically feasible, to manufacture by more conventional manufacturing methods. AMcomes with the idea that complexity is free, meaning that complex geometries are as expensiveto manufacture as simple geometries. This is partly true, but there remain several design rulesthat needs to be considered before manufacturing. The research field Design for Additive Manufacturing(DfAM) consists of research that aims to take advantage of the possibilities of AMwhile considering the limitations of the technique. Computer Aided technologies (CAx) is the name of the usage of methods and software thataim to support a digital product development process. CAx includes software and methodsfor design, the evaluation of designs, manufacturing support, and other things. The commongoal with all CAx disciplines is to achieve better products at a lower cost and with a shorterdevelopment time. The work presented in this thesis bridges DfAM with CAx with the aim of achieving designautomation for AM. The work reviews the current DfAM process and proposes a new integratedDfAM process that considers the functionality and manufacturing of components. Selectedparts of the proposed process are implemented in a case study in order to evaluate theproposed process. In addition, a tool that supports part of the design process is developed. The proposed design process implements Multidisciplinary Design Optimization (MDO) witha parametric CAD model that is evaluated from functional and manufacturing perspectives. Inthe implementation, a structural component is designed using the MDO framework, which includesComputer Aided Engineering (CAE) models for structural evaluation, the calculation ofweight, and how much support material that needs to be added during manufacturing. Thecomponent is optimized for the reduction of weight and minimization of support material,while the stress levels in the component are constrained. The developed tool uses methodsfor high level Parametric CAD modelling to simplify the creation of parametric CAD modelsbased on Topology Optimization (TO) results. The work concludes that the implementation of CAx technologies in the DfAM process enablesa more automated design process with less manual design iterations than traditional DfAM processes.It also discusses and presents directions for further research to achieve a fully automateddesign process for Additive Manufacturing.

Boundary Control in Multiphysics Topology Optimization for Advanced Manufacturing Springer

The topology optimization method solves the basic enginee- ring problem of distributing a limited amount of material in a design space. The first edition of this book has become the standard text on optimal design which is concerned with the optimization of structural topology, shape and material. This edition, has been substantially revised and updated to reflect progress made in modelling and computational procedures. It also encompasses a comprehensive and unified description of the state-of-the-art of the so-called material distribution method, based on the use of mathematical programming and finite elements. Applications treated include not only structures but also materials and MEMS.

Advances on Mechanics, Design Engineering and Manufacturing II Topology Optimization with Additive Manufacturing ConstraintsTopology Optimization for Additive Manufacturing Involving High-Cycle Fatigue

This book contains the papers presented at the International Joint Conference on Mechanics, Design Engineering and Advanced Manufacturing (JCM 2018), held on 20-22 June 2018 in Cartagena, Spain. It reports on cutting-edge topics in product design and manufacturing, such as industrial methods for integrated product and process design; innovative design; and computer-aided design. Further topics covered include virtual simulation and reverse engineering; additive manufacturing; product manufacturing; engineering methods in medicine and education; representation techniques; and nautical, aeronautics and aerospace design and modeling. The book is divided into six main sections, reflecting the focus and primary themes of the conference. The contributions presented here will not only provide researchers, engineers and experts in a range of industrial engineering subfields with extensive information to support their daily work; they are also intended to stimulate new research directions, advanced applications of the methods discussed, and future interdisciplinary collaborations.

A Hands-on Introduction to Topology Optimization Walter de Gruyter GmbH & Co KG

Additive manufacturing (AM) is a relatively new technology that is making its way into different industries at a fast pace. In order to take full advantage of flexibility and freedom that this technology provides, a proper and comprehensive approach towards Design for Additive Manufacturing (DfAM) is necessary. Topology optimization is one of the tools that is commonly used to design or redesign a component to be printed by AM technologies. Utilizing topology optimization, the best design for a component subjected to various loading conditions can be obtained. The implementation of topology optimization becomes more challenging when the part is subjected to different loading cases, especially at high thermal loads. In this thesis, a new method is proposed to perform coupled thermo-mechanical topology optimization, and then a workflow is presented to implement this method in DfAM. In the suggested guideline, the effect of different filters, as well as initial setup conditions, are considered for topology optimization. In addition, some common software tools for topology optimization are also discussed. Among the existing software systems, HyperWorks is selected to be utilized in this study due to its distinguished capabilities which offer favorable controllability over the process. Then, the proposed method and workflow for DfAM are applied in HyperWorks to redesign a gas turbine rotor seal, which is subjected to high temperature, high pressure, and centrifugal loads. Also, In order to validate the workflow and the methodology, an experimental setup is designed to test the performance of a topology optimized cantilever under thermo-mechanical loadings. The experimental results validated simulations and proved that the part designed based on thermo-mechanical optimization has a better performance overall for thermal and mechanical loads.

3D Printing, Rapid Prototyping, and Direct Digital Manufacturing Springer Science & Business Media

Topology Design Methods for Structural Optimization provides engineers with a basic set of design tools for the development of 2D and 3D structures subjected to single and multi-load cases and experiencing linear elastic conditions. Written by an expert team who has collaborated over the past decade to develop the methods presented, the book discusses essential theories with clear guidelines on how to use them. Case studies and worked industry examples are included throughout to illustrate practical applications of topology design tools to achieve innovative structural solutions. The text is intended for professionals who are interested in using the tools provided, but does not require in-depth theoretical knowledge. It is ideal for researchers who want to expand the methods presented to new applications, and includes a companion website with related tools to assist in further study. Provides design tools and methods for innovative structural design, focusing on the essential theory Includes case studies and real-life examples to illustrate practical application, challenges, and solutions Features accompanying software on a companion website to allow users to get up and running fast with the methods introduced Includes input from an expert team who has collaborated over the past decade to develop the methods presented

TOPOLOGY OPTIMIZATION ALGORITHMS FOR ADDITIVE MANUFACTURING. Butterworth-Heinemann

Additive manufacturing (AM) offers new design freedom to create topologies with complex surfaces and internal structures that could not be produced by traditional manufacturing processes. Due to this design flexibility, parts designed for AM have the potential to withstand the same structural loads as traditionally manufactured parts at lower masses. In an attempt to reduce the mass of structural parts to a minimum, optimization techniques such as topology optimization can be employed to achieve geometries that may be unintuitive to designers. While in many cases AM is the only means to realize such an optimized design, the constraints of the particular AM process may require a design to be modified before it can be produced. This thesis examines the current state of topology optimization technology and investigates how topology optimization software fits into the workflow of design for AM. This is achieved by exploring the problem of minimizing the mass of a mounting plate for an aerospace vehicle. Optimization is performed with varying boundary conditions and materials to observe their effect on resulting topologies and design performance. The results are then manually interpreted to conform to AM constraints. A 60% weight savings was achieved over the current mounting plate design, but the optimization software did not take AM constraints into account. Manual design modifications were required to ensure that the design was one continuous part and that a suitable prototype of the optimized design could be produced. In the context of this problem, the benefits and limitations of incorporating topology optimization into design for AM are presented. It was found that manual design workflow for AM requires the designer to iterate design around performance, while incorporating topology optimization into the workflow requires the designer to iterate design around manufacturability.

Theory, Methods, and Applications Linköping University Electronic Press

Additive Manufacturing (AM) is gaining popularity in aerospace and automotive industries. This is a versatile manufacturing process, where highly complex structures are fabricated and together with topology optimization, a powerful design tool, it shares the property of providing a very large freedom in geometrical form. The main focus of this work is to introduce new developments of Topology Optimization (TO) for metal AM. The thesis consists of two parts. The first part introduces background and theory, where TO and adjoint sensitivity analysis are described. Furthermore, methodology used to identify surface layer and high-cycle fatigue are introduced. In the second part, three papers are appended, where the first paper presents the treatment of surface layer effects, while the second and third papers provide high-cycle fatigue constraint formulations. In Paper I, a TO method is introduced to account for surface layer effects, where different material properties are assigned to bulk and surface regions. In metal AM, the fabricated components in as-built surface conditions significantly affect mechanical properties, particularly fatigue properties. Furthermore, the components are generally in-homogeneous and have different microstructures in bulk regions compared to surface regions. We implement two density filters to account for surface effects, where the width of the surface layer is controlled by the second filter radius. 2-D and 3-D numerical examples are treated, where the structural stiffness is maximized for a limited mass. For Papers II and III, a high-cycle fatigue constraint is implemented in TO. A continuous-time approach is used to predict fatigue-damage. The model uses a moving endurance surface and the development of damage occurs only if the stress state lies outside the endurance surface. The model is applicable not only for isotropic materials (Paper II) but also for transversely isotropic material properties (Paper III). It is capable of handling arbitrary load histories, including non-proportional loads. The anisotropic model is applicable for additive manufacturing processes, where transverse isotropic properties are manifested not only in constitutive elastic response but also in fatigue properties. Two optimization problems are solved: In the first problem the structural mass is minimized subject to a fatigue constraint while the second problem deals with stiffness maximization subjected to a fatigue constraint and mass constraint. Several numerical examples are tested with arbitrary load histories.