

Mario Hirz · Wilhelm Dietrich
Anton Gfrerrer · Johann Lang

Integrated Computer-Aided Design in Automotive Development

Development Processes, Geometric
Fundamentals, Methods of CAD,
Knowledge-Based Engineering
Data Management

 Springer

Mario Hirz · Wilhelm Dietrich
Anton Gfrerrer · Johann Lang

Integrated Computer-Aided Design in Automotive Development

Development Processes, Geometric
Fundamentals, Methods of CAD,
Knowledge-Based Engineering
Data Management

 Springer

Integrated Computer-Aided Design in Automotive Development

Mario Hirz · Wilhelm Dietrich
Anton Gfrerrer · Johann Lang

Integrated Computer-Aided Design in Automotive Development

Development Processes, Geometric
Fundamentals, Methods of CAD,
Knowledge-Based Engineering Data
Management

 Springer

Mario Hirz
Institute of Automotive Engineering
Graz University of Technology
Graz
Austria

Anton Gfrerrer
Johann Lang
Institute of Geometry
Graz University of Technology
Graz
Austria

Wilhelm Dietrich
MAGNA STEYR Engineering
AG & Co KG
Graz
Austria

ISBN 978-3-642-11939-2 ISBN 978-3-642-11940-8 (eBook)
DOI 10.1007/978-3-642-11940-8
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2012954064

© Springer-Verlag Berlin Heidelberg 2013

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

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

Introduction

Automotive development requires flexible and powerful tools. In the current, highly competitive market, the need to continually reduce development time and costs is driving the ongoing creation of strategies that can provide intelligent and functional links between the many parties involved in vehicle development, including project engineers, ergonomic specialists, safety and crash departments, designers, and many more. While a combination of virtual design and simulation methods with physical development and testing procedures represents the current state-of-the-art, the trend is moving towards integrated virtual development processes. Such processes focus on the product itself while also taking into account a wide variety of potential production and supplier interrelationships, as well as lifetime-relevant factors pertaining to customer use, support, service, and disposal.

In automotive development, computer-aided design (CAD) is used to perform the geometrical product definition, which provides the basis for three-dimensional virtual product models. The models are built by combining main assemblies, sub-assemblies, and individual components, which brings the virtual models close to the configurations of physical products. In this process, design tasks are carried out using parametric-associative techniques, which require the implementation of design-process-related guidelines and project-specific default procedural steps. The realization of parametric-associative model structures and interlinked geometry elements in turn improves the geometry representation by adding elements related to design check features, information relevant to digital mock-ups, or calculations and logical functionalities. The separation of geometry elements and geometry-defining parameters enables the integration of complex computation procedures, the creation of interfaces with design-external processes, and the direct embedding of macro-based automated routines into the design software. In this way, formerly separated working fields (e.g. calculation and simulation) are integrated into or connected to CAD models.

To enhance engineering capabilities in modern product development, intelligent solutions for the collection, storage, and distribution of product and process-oriented data and knowledge must be implemented. Powerful management concepts are necessary to manage the complex information flow, processes, and

documents during the development or modification of products. Engineering data management (EDM), which organizes the data flow throughout the development processes and prevents data redundancy, represents an important component in the generation of complex product structures in the context of multi-firm and global collaborations.

The book offers a comprehensive overview of integrated CAD, with a focus on development processes in the automotive industry. This focus does not limit the application of the methods, strategies, and tools described here to a specific industry, but rather provides well-defined boundary conditions within which the topic can be effectively discussed. Nevertheless, the basic findings of this book can certainly be transferred to other industries in the area of mechanical or mechatronics product development.

One primary aim of the book is to introduce and discuss the entire process chain of product design, including the basic methods of geometry creation, the application of CAD, the integration of design and engineering, and finally the management of information related to both product and process. This comprehensive overview of the methods and tools of virtual product development will provide the reader valuable insight into the complex web of interactions and connections that characterize product development.

The following paragraphs provide brief summaries of the nine chapters included here:

Chapter 1, *Automotive Development Processes*, includes a retrospect of achievements in the automotive industry and highlights the very different factors that have influenced the development of cars over the past 120 years. The wide range of requirements for current and future cars is then elaborated, in order to clarify the current challenges facing automotive development. In addition, the stages in automobile development are explained through a detailed analysis of the different project phases, including a discussion on the integration of virtual product creation throughout the entire development chain.

Chapter 2, *Overview of Virtual Product Development*, first provides a summary of the various stages in the life cycle of mechanical products. The main terms, definitions, and methods of computer-aided product development are then introduced. This includes the historical development of CAD, simulation, and data management. In addition, some selected, representative development workflows in automotive engineering are presented and discussed, and the chapter then closes with a brief introduction to the concepts of collaborative product development.

Chapter 3, *Geometric Fundamentals*, introduces the reader to the mathematical and geometrical concepts which form the basis of a CAD system. It starts from scratch and leads the reader through the fields of curves, surfaces, freeform techniques, interpolation, approximation, and a range of other geometrical topics. In effect, this section might also be considered a manual for standard CAD concepts. However, rather than simply listing the methods and algorithms, this chapter actually explains the ideas behind these elements. A proper understanding of these ideas and properties can help engineers perform their jobs more effectively.

Chapter 4, *Modeling Techniques in CAD*, includes a detailed introduction of design methods within the CAD environment. Structures and strategies of wire-frame, surface, and solid modeling are presented and discussed in terms of their application in collaborative product development processes. Beyond the application of primary CAD functionalities, this chapter uses specific examples from the automotive industry to present a variety of methods for the efficient creation of mechanical components and assemblies.

Chapter 5, *Knowledge-Based Design*, covers the use of template models, integrated calculation and simulation procedures, and automated routines to support product design. Knowledge-based design enables the collection, storage, and reuse of expert knowledge, as well as the subsequent integration of know-how into development processes. Using examples from component and assembly development, the chapter elaborates on the potential of enhanced parametric-associative design and knowledge-based engineering used in combination with simultaneously linked calculation procedures.

Chapter 6, *Engineering Data Management (EDM)*, describes the fundamental principles of this approach, which involves the interdepartmental and interdisciplinary integration of data and workflows in automotive product development. Both complete EDM use cases and the basic functional modules of CAD and computer-aided engineering (CAE) are described in the context of process-oriented product life cycle management approaches. Finally, the chapter also presents the system-oriented view by describing EDM system architecture with integrated computer-aided applications and data management systems.

Chapter 7, *Knowledge Management in Product Development*, describes product knowledge as a basis for investigation, as well as the development of such knowledge across the product life cycle. The chapter introduces and discusses the fundamentals of knowledge, knowledge management, and knowledge transfer, as well as the principle related basic models and approaches. Thus, the chapter offers a summary of current scientific findings in the area of knowledge management that serves as background for further analysis.

Chapter 8, *Knowledge-Based Engineering Data Management*, describes an approach for using process-oriented knowledge management to identify and organize knowledge-intensive activities in relation to data management activities. Modern design processes involve a variety of tasks (e.g. geometry creation, simulation) and product-specific characteristics (e.g. functional layout, materials, process-relevant data (e.g. for production), product structure, configuration), all of which can be managed with knowledge-based methods. Comprehensive knowledge exchange in product development requires effective data management strategies, which can be applied within knowledge-based EDM.

Chapter 9, *Advanced Applications of CAD/EDM in the Automotive Industry*, offers a selection of concrete use cases in automotive development. One use case includes an application of knowledge-based EDM, which highlights the importance of the interaction of knowledge processes and data management throughout virtual product development. This use case also describes the integrated application of CAD, simulation, and management throughout the daily operations of

development processes. Another use case describes the integration of CAD data management in automotive engineering, which is an essential topic in the area of EDM. Finally, a use case describing an approach of a parametric-associative concept model for initial vehicle development highlights the various working fields involved in automotive concept phases and introduces a model for geometrical and functional integration.

Contents

| | | |
|----------|---|----|
| 1 | Automotive Development Processes | 1 |
| 1.1 | Manifold Requirements in the Past and in the Future | 3 |
| 1.2 | The Process of Automotive Development | 11 |
| 1.2.1 | Project Periods | 13 |
| 1.2.2 | Phases of Automotive Development | 14 |
| 1.3 | Application of CAD in Automotive Development | 21 |
| | References | 23 |
| 2 | Overview of Virtual Product Development | 25 |
| 2.1 | Development of Mechanical Products | 25 |
| 2.2 | Virtual Product Development | 29 |
| 2.2.1 | Product Models | 32 |
| 2.2.2 | CAD-CAE Workflows in Automotive Engineering | 34 |
| 2.2.3 | Management of Product Data | 43 |
| 2.2.4 | CAD-CAE Data Exchange | 45 |
| 2.2.5 | Concepts of Collaborative Product Development | 47 |
| | References | 49 |
| 3 | Geometric Fundamentals | 51 |
| 3.1 | The 3-Space, Transformations and Motions | 52 |
| 3.1.1 | Planar Reflections | 55 |
| 3.1.2 | Translations and Rotations | 55 |
| 3.1.3 | Orientation | 57 |
| 3.1.4 | Helical Displacements | 59 |
| 3.1.5 | Euclidean Motions | 60 |
| 3.1.6 | Some Fundamentals of Line Geometry | 62 |
| 3.2 | Polynomials | 65 |

| | | |
|--------|---|-----|
| 3.3 | Curves | 70 |
| 3.3.1 | Parametric Representation of a Curve. | 70 |
| 3.3.2 | Planar Curves | 72 |
| 3.3.3 | Derivatives and Tangents | 73 |
| 3.3.4 | Arc Length Parameter. | 76 |
| 3.3.5 | Curvature and Torsion | 77 |
| 3.3.6 | Osculating Circle and Osculating Plane | 78 |
| 3.3.7 | The Frenet Frame | 79 |
| 3.3.8 | Planar Algebraic Curves | 81 |
| 3.3.9 | Rational Curves | 82 |
| 3.3.10 | Second Order Curves | 83 |
| 3.4 | Freeform Curves | 85 |
| 3.4.1 | Bézier Curves | 86 |
| 3.4.2 | B-Spline Curves. | 99 |
| 3.4.3 | Rational Freeform Curves, NURBS | 109 |
| 3.5 | Univariate Interpolation | 116 |
| 3.5.1 | Lagrange Interpolation | 119 |
| 3.5.2 | Interpolation by Cubic Segments | 122 |
| 3.5.3 | Parameterization | 134 |
| 3.6 | Univariate Approximation | 136 |
| 3.6.1 | Improving the Quality of Approximation | 140 |
| 3.6.2 | Approximation with Cubic B-Splines | 143 |
| 3.7 | Surfaces | 144 |
| 3.7.1 | Parametric Representation of a Surface. | 144 |
| 3.7.2 | Surface Curves | 146 |
| 3.7.3 | Derivatives and Tangent Planes | 147 |
| 3.7.4 | Curvature Theory of Surfaces | 152 |
| 3.7.5 | Surfaces Represented by Equations | 157 |
| 3.7.6 | Algebraic Surfaces | 158 |
| 3.7.7 | Rational Surfaces | 159 |
| 3.7.8 | Quadrics | 160 |
| 3.7.9 | Ruled Surfaces. | 165 |
| 3.7.10 | Developable Surfaces | 167 |
| 3.7.11 | Surfaces of Revolution | 170 |
| 3.7.12 | Helical Surfaces. | 173 |
| 3.7.13 | Moving a Curve or a Surface in Itself | 174 |
| 3.7.14 | Intersection of Surfaces | 176 |
| 3.8 | Tensor Product Surfaces | 180 |
| 3.8.1 | Bézier Surfaces | 182 |
| 3.8.2 | B-Spline Surfaces | 192 |
| 3.8.3 | Rational Tensor Product Surfaces, NURBS Surfaces | 198 |

- 3.9 Bivariate Interpolation 204
 - 3.9.1 Coons Patches 204
 - 3.9.2 Interpolation of a Rectangular Point Set 206
 - 3.9.3 Bivariate Lagrange Interpolation 208
 - 3.9.4 Bivariate Hermite Interpolation 210
 - 3.9.5 Bivariate Cubic B-Spline Interpolation 214
- 3.10 Bivariate Approximation 216
 - 3.10.1 A Plane Fitting a Set of Scattered Points 216
 - 3.10.2 A Tensor Product Surface Fitting Scattered
Data Points 220
- 3.11 Triangular Bézier Patches 225
- 3.12 Tensor Product Volumes 232
- 3.13 Example: Side Window Kinematics 235
 - 3.13.1 The Appropriate Screw Motion to a Given Surface 236
 - 3.13.2 Constructing an Ideal Side Window Surface 237
- References 238

- 4 Modeling Techniques in CAD 241**
 - 4.1 Structures of 3D CAD Models 249
 - 4.1.1 Surface-Based Model Structure 250
 - 4.1.2 Solid-Based Model Structure 252
 - 4.1.3 The Role of CAD Models in Product Development 254
 - 4.2 Wireframe and Surface Design 256
 - 4.2.1 Reference Elements 256
 - 4.2.2 Wireframe Design 257
 - 4.2.3 Surface Design 260
 - 4.2.4 Operations in Wireframe and Surface Design 265
 - 4.2.5 Modeling in Wireframe and Surface Design 270
 - 4.2.6 Surface Analysis Functions 274
 - 4.3 Solid Design 276
 - 4.3.1 Modeling of Basis Solids 277
 - 4.3.2 Boolean Operations 279
 - 4.3.3 Editing and Detailing Functionalities 281
 - 4.3.4 Feature-Based Geometry Modeling 282
 - 4.4 Combination of Wireframe, Surface,
and Solid-Based Functions 285
 - 4.5 Assembly Design 289
 - 4.5.1 Organization of Product Structures 290
 - 4.5.2 Methods of Component Positioning 294
 - 4.5.3 Geometry-Based Interlinks in Assembly Design 301
 - 4.6 Derivation of 2D Drawings 305
 - References 308

- 5 Knowledge-Based Design 309**
 - 5.1 Parameterization as a Basis for Knowledge-Based Design. 312
 - 5.1.1 External Parameter Control 315
 - 5.1.2 Implementation of Non-CAD Data. 316
 - 5.2 Knowledge Integration Using Template Models. 317
 - 5.2.1 Template-Library-Based Design. 320
 - 5.2.2 Implementation of Mathematical and Logical Relations. 323
 - 5.2.3 Integrated Virtual Product Development Using Centralized Master Models 326
 - 5.3 Example: Integrated Design in Automotive Bumper System Development 328
 - References 330

- 6 Engineering Data Management. 331**
 - 6.1 The Concept of Engineering Data Management (EDM) 332
 - 6.1.1 The Y-CIM Model. 332
 - 6.1.2 PLM as a Foundation of EDM 334
 - 6.1.3 Definition of Engineering Data Management (EDM). 336
 - 6.2 EDM in Virtual Product Development 338
 - 6.2.1 Process Orientation in Product Development. 338
 - 6.2.2 EDM as Integrated Management Approach. 339
 - 6.2.3 The Product Development Process. 341
 - 6.2.4 EDM Support in Virtual Product Development 341
 - 6.2.5 EDM Process Integration 343
 - 6.3 EDM Database 344
 - 6.3.1 The Role of Development Data 344
 - 6.3.2 EDM Documents 346
 - 6.3.3 CAD Data in EDM 347
 - 6.3.4 Digital Mock-Up (DMU) 347
 - 6.3.5 The Virtual Product 348
 - 6.3.6 Data Security. 349
 - 6.4 Engineering Data Management System (EDMS) 350
 - 6.4.1 Product Data Management System (PDMS) 350
 - 6.4.2 Application-Related Functions of EDMS 354
 - 6.4.3 EDMS Architecture 356
 - 6.4.4 EDMS Interfaces 357
 - 6.5 Computer-Supported Engineering in the Context of EDM. 358
 - 6.5.1 How CAx Changes Product Development. 359
 - 6.5.2 CAD Integration 360
 - 6.5.3 CAD Implementation 361
 - 6.5.4 Virtual Computer-Generated 3D Product Design Models. 362

- 6.6 Integrated EDM Applications in Product Development. 364
 - 6.6.1 Functional Dimensioning and Optimization
in Early Design Phase 364
 - 6.6.2 Consistency of Simulation Data in Optimized
Design Processes 365
 - 6.6.3 Interdisciplinary Consistency of Simulation Data. 366
 - 6.6.4 Integration of Design and Simulation 367
 - 6.6.5 CAD/CAE Data Management 368
- References 369

- 7 Knowledge Management in Product Development. 371**
 - 7.1 Product Knowledge. 371
 - 7.1.1 Development of Product Knowledge 371
 - 7.1.2 Life Cycle of Product Knowledge 373
 - 7.1.3 Defining Product Knowledge. 373
 - 7.1.4 Product Knowledge Products. 374
 - 7.1.5 Product Knowledge Management. 374
 - 7.2 Fundamentals of Knowledge Management 375
 - 7.2.1 Knowledge and Knowledge Management 375
 - 7.2.2 Basic Elements of the Knowledge Base 376
 - 7.2.3 Knowledge Management in Industrial Management 379
 - 7.2.4 Basic Model of Knowledge Management 380
 - 7.2.5 System Orientation in Knowledge Management. 382
 - 7.3 Knowledge Transfer in Product Development 383
 - 7.3.1 Definition of Knowledge Transfer 383
 - 7.3.2 Transfer and Transformation Processes
in the Knowledge System 384
 - 7.3.3 Direct Versus Indirect Knowledge Transfer. 385
 - 7.3.4 Direct Knowledge Transfer 386
 - 7.3.5 Indirect Knowledge Transfer 386
 - 7.3.6 The Definition of Knowledge Logistics 388
 - 7.4 Process Orientation in Knowledge Management 389
 - 7.4.1 Knowledge-Oriented Process Management 390
 - 7.4.2 Process-Oriented Knowledge Management 390
 - 7.4.3 The Knowledge Process in Interaction
with the Added-Value Processes 391
- References 392

- 8 Knowledge-Based Engineering Data Management 393**
 - 8.1 Basic Models and Approaches
of Knowledge-Oriented EDM 394
 - 8.1.1 System-Oriented Reference Frame
of Knowledge-Oriented EDM 394

- 8.1.2 The Knowledge Process as Connection Between Business Process and Support Process of EDM 394
- 8.1.3 Integrated Approach to Added-Value Processes 395
- 8.1.4 Model for the Integration of Knowledge Processes and Data Management 396
- 8.1.5 From the Knowledge Transfer Model to the Knowledge-Oriented Engineering Data Management 398
- 8.1.6 Model for the Reconstruction of the Knowledge Base and Database 399
- 8.2 Requirements for the IT Support of Process-Oriented Knowledge Management in EDM 400
 - 8.2.1 Modeling Approach for the Technical Subsystem 401
 - 8.2.2 The Database of Knowledge-Oriented EDM 403
 - 8.2.3 EDM Workflow Support of Knowledge-Intensive Processes 403
 - 8.2.4 Management, Transfer and Steering of Knowledge-Oriented EDM 404
- 8.3 Knowledgeware in Product Development 404
 - 8.3.1 The Parametric-Associative Approach 405
 - 8.3.2 The Fundamentals of Parametric-Associative Design 406
 - 8.3.3 Knowledge Management and Product Configuration 407
- References 408

9 Advanced Applications of CAD/EDM

- in the Automotive Industry 409**
- 9.1 Applications for Knowledge-Based EDM 409
 - 9.1.1 Relevant Knowledge Operations in EDM 410
 - 9.1.2 Factors that Influence Knowledge Transfer Via Data Transfer at the Operational Level 410
 - 9.1.3 Data Management Barriers in Indirect Knowledge Transfer 412
 - 9.1.4 Reference Process for the Knowledge-Oriented Development of EDM Use Cases 413
- 9.2 Integrated CAD Data Management in Automotive Engineering 414
 - 9.2.1 Challenges Related to the Topic 415
 - 9.2.2 Concept of Integrated CAD Data Management 415
 - 9.2.3 CAD Scheduling 416
 - 9.2.4 A Concept of Geometry Reference 418
 - 9.2.5 CAD Data Quality, Progress and Maturity 419