

W.D. Li
S.K. Ong
Andrew Y.C. Nee
Chris McMahon
Editors

Collaborative Product Design and Manufacturing Methodologies and Applications



Springer

F406.3

C697 W.D. Li, S.K. Ong, Andrew Y.C. Nee and
Chris McMahon (Eds.)

Collaborative Product Design and Manufacturing Methodologies and Applications



Springer



E2008000071

W.D. Li, PhD, Senior Lecturer
Chris McMahon, Professor
Department of Mechanical Engineering
University of Bath
Bath BA2 7AY, UK

S.K. Ong, PhD, Associate Professor
Andrew Y.C. Nee, PhD, DEng, Professor
Department of Mechanical Engineering
National University of Singapore
9 Engineering Drive 1, 117576 Singapore

British Library Cataloguing in Publication Data
Collaborative product design and manufacturing
methodologies and : applications. - (Springer series in
advanced manufacturing)
1. New products - Management 2. Teams in the workplace
I. Li, W. D.
658.5'75

ISBN-13: 9781846288012

Library of Congress Control Number: 2007923195

Springer Series in Advanced Manufacturing ISSN 1860-5168
ISBN 978-1-84628-801-2 e-ISBN 978-1-84628-802-9

Printed on acid-free paper

© Springer-Verlag London Limited 2007

ABAQUS®, CATIA®, Matrix10™ and SMARTEAM® are trademarks and registered trademarks of Dassault Systèmes, Suresnes, France, <http://www.3ds.com/>

Access™, ActiveX® and Visual Basic® are trademarks or registered trademarks of Microsoft Corporation, One Microsoft Way, Redmond, WA 98052-6399, USA, <http://www.microsoft.com/>

ACIS® is a registered trademark of Spatial Corp., 10955 Westmoor Drive, Suite 425, Westminster, Colorado 80021, USA, <http://www.spatial.com/>

MSC.Acumen™ and MSC.Nastran™ are trademarks of MSC Software Corporation, 2 MacArthur Place, Santa Ana, CA 92707, USA, <http://www.mssoftware.com/>

Alibre Design is a trademark of Alibre Inc., 1701 N. Greenville Avenue, Suite 702, Richardson, TX 75081, USA, <http://www.alibre.com/>

ANSYS®, and ANSYS Workbench™ are registered trademarks or trademarks of ANSYS, Inc., Southpointe, 275 Technology Drive, Canonsburg, PA 15317, USA, <http://www.ansys.com/>

AutoCAD® and Autodesk Steamline® are registered trademarks of Autodesk, Inc., 111 McInnis Parkway, San Rafael, CA 94903, USA, <http://www.autodesk.com/>

CORBA® is a registered trademark of The Object Management Group (OMG), 140 Kendrick Street, Building A, Suite 300, Needham, MA 02494, USA, <http://www.omg.org/>

DIVISION™ MockUp, Pro/E®, Pro/INTRALINK®, Windchill®, and Windchill ProjectLink™ are trademarks or registered trademarks of Parametric Technology Corporation (PTC), 140 Kendrick Street, Needham, MA 02494, USA, <http://www.ptc.com/>

eDrawings® is a registered trademark of SolidWorks Corporation, 300 Baker Avenue, Concord, MA 01742, USA, <http://www.solidworks.com/>

FIPER™ and iSIGHT™ are trademarks of Engineous Software Inc., 2000 CentreGreen Way, Suite 100, Cary, NC 27513, USA, <http://www.engineous.com/>

HyperWorks® and Process Manager™ are trademarks or registered trademarks of Altair Engineering, Inc., 1820 E Big Beaver, Troy, MI 48083-2031, USA, <http://www.altair.com/>

IX Design™ is a trademark of ImpactXoft Corp., 22 A Great Oaks Boulevard, San Jose, CA 95119, USA, <http://www.impactxoft.com/>

Java™, Java 3D™, EJB™, Enterprise JavaBeans™, and Sun ONE™ are trademarks of Sun Microsystems, Inc., 4150 Network Circle, Santa Clara, CA 95054, USA, <http://www.sun.com/>

JSDAI™ is a trademark of LKSoftWare GmbH, Steinweg 1, 36093 Kuenzell, Germany, <http://www.lksoft.com/>

ModelCenter® is a registered trademark of Phoenix Integration, Inc., 1715 Pratt Drive, Suite 2000, Blacksburg, VA 24060, USA, <http://www.phoenix-int.com/>

Parasolid™ and Teamcenter® are trademarks or registered trademarks of UGS Corp., 5800 Granite Parkway, Suite 600, Plano, TX 75024, USA, <http://www.ugs.com/>

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms of licences issued by the Copyright Licensing Agency. Enquiries concerning reproduction outside those terms should be sent to the publishers.

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

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability for any errors or omissions that may be made.

9 8 7 6 5 4 3 2 1

Springer Science+Business Media
springer.com

Springer Series in Advanced Manufacturing

Series Editor

Professor D. T. Pham
Intelligent Systems Laboratory
WDA Centre of Enterprise in Manufacturing Engineering
University of Wales Cardiff
PO Box 688
Newport Road
Cardiff
CF2 3ET
UK

Other titles in this series

Assembly Line Design

B. Rekiek and A. Delchambre

Advances in Design

H.A. ElMaraghy and W.H. ElMaraghy (Eds.)

*Effective Resource Management in Manufacturing Systems:
Optimization Algorithms in Production Planning*

M. Caramia and P. Dell'Olmo

Condition Monitoring and Control for Intelligent Manufacturing

L. Wang and R.X. Gao (Eds.)

Optimal Production Planning for PCB Assembly

W. Ho and P. Ji

Trends in Supply Chain Design and Management: Technologies and Methodologies

Hosang Jung, F. Frank Chen and Bongju Jeong (Eds.)

Process Planning and Scheduling for Distributed Manufacturing

Lihui Wang and Weiming Shen (Eds.)

Preface

During the past few decades, there have been major innovation and paradigm shifts in product development methodologies and strategies. The current R&D trend is towards the development of collaborative design and manufacturing systems. The research theme is in line with the growing demand for global cooperative design and outsourcing in product development to gain better competitive advantage. Using the collaborative systems, designers and manufacturers can participate in global design chains and collaborate with partners locally and overseas to pursue competitive advantages. Furthermore, collaborative systems allow designers to work closely with suppliers, manufacturing partners and customers across enterprises' firewalls to obtain valuable inputs for their design and manufacturing activities.

From the early 1990s, some major R&D works have been reported, including the CyberCut system by the University of California at Berkeley; the FIPER (Federated Intelligent Product EnviRonment) system (FIPER Project, www.fiperproject.com/fiperindex.htm) funded by NIST; the Web-DPR system by the Georgia Institute of Technology), *etc.* Commercial systems include SolidWorks eDrawing™, Autodesk Streamline™, Impactsoft IX Design™, Onespace™, SmarTeam™, PTC ProjectLink™ and Windchill™, UGS TeamCentre™, *etc.* However, the developed strategies, methodologies and solutions still fall short of the expectation of the practical needs. They have not been generally accepted due to the weaknesses and limitations in collaboration management, interactive capabilities, security of data, real-time and ease of collaboration, *etc.* Different culture, educational background, or design habit of people also make it difficult to organize optimal collaborative design and outsourcing activities. To address the issues and make collaborative engineering more realistic and applicable, more efforts are being made.

The aim of this book is to update the relevant and recent research and development in this field. In this book, thirteen original and innovative chapters have been included to address the major challenges of developing collaborative design and manufacturing systems and techniques, with scientific and rigorous foundations as well as application values. The covered topics include: collaborative methodologies and strategies between humans, and between systems and humans

to facilitate collaborative design and manufacture; cooperation across domains for multi-disciplinary design and manufacture; distributed system and service architectures for collaborative design and manufacture; interoperability of collaborative systems; new feature- and assembly-based methodologies for facilitating collaborative design and manufacture; workflow and conflict resolution/management in collaborative design and manufacture; design process and design change management in collaborative development, *etc.*

This book can be used as reference for mechanical/manufacturing/computer engineering graduate students and researchers in the fields of concurrent engineering and collaborative engineering for the efficient utilization, deployment and development of collaborative product design and manufacturing.

During the development of this book, we have received invaluable input and support from the chapter authors. We are also grateful to the editors of Springer-Verlag for their patience and professionalism during the editing process.

<i>W.D. Li</i>	<i>(Cranfield University)</i>
<i>S.K. Ong</i>	<i>(National University of Singapore)</i>
<i>A.Y.C. Nee</i>	<i>(National University of Singapore)</i>
<i>C.A. McMahon</i>	<i>(Bath University)</i>

January 2007

Contents

1 An Adaptable Service-based Framework for Distributed Product Realization

*Jitesh H. Panchal, Hae-Jin Choi, Janet K. Allen, David Rosen
and Farrokh Mistree*..... 1

1.1	Introduction	2
1.1.1	Need for an Adaptable Framework	3
1.1.2	An Open Engineering Systems Approach	3
1.2	Requirements and Features of an Adaptable Framework	4
1.3	Review of Capabilities Provided by Existing Frameworks	8
1.3.1	Web-based Systems	8
1.3.2	Agent-based Systems	10
1.3.2.1	Distributed Object-based Modeling and Evaluation (DOME)	13
1.3.2.2	NetBuilder	13
1.3.3.3	Web-DPR	14
1.3.3.4	Federated Intelligent Product EnviRonment (FIPER)	14
1.4	Motivating Example: Design of Linear Cellular Alloys (LCAs).....	15
1.5	X-DPR (eXtensible Distributed Product Realization) Environment	17
1.5.1	Overview of X-DPR.....	17
1.5.2	Elements of the Framework	18
1.5.2.1	Data Repository	20
1.5.2.2	Process Diagram Tool	21
1.5.2.3	Dynamic UI Generation	23
1.5.2.4	Interface Mapping Tool	24
1.5.2.5	Messaging and Agent Description in X-DPR.....	26
1.5.2.6	Publishing a Service	26
1.5.2.7	Asset Search Service	26
1.5.3	Using the X-DPR framework for LCAs design.....	27
1.5.4	X-DPR as an Adaptable Framework	28
1.6	Conclusions	30

1.7	Acknowledgments	32
1.8	References	32
2	A Web-based Intelligent Collaborative System for Engineering Design	
	<i>Xiaoqing (Frank) Liu, Samir Raorane and Ming C. Leu</i>	37
2.1	Introduction	37
2.2	Related Work.....	38
2.2.1	Current State-of-the-art on Computer-aided Collaborative Engineering Design Systems	38
2.2.2	Current State-of-the-art on Argumentation-based Conflict Resolution	39
2.3	A Web-based Intelligent Collaborative Engineering Design Environment and Its Application Scenarios.....	40
2.4	Argumentation-based Conflict Resolution in the Collaborative Engineering Design Environment	40
2.4.1	Structured Argumentation Through Dialog Graph	42
2.4.2	Argument Reduction Through Fuzzy Inference.....	43
2.4.2.1	Linguistic Variable Through Fuzzy Membership Functions.....	45
2.4.2.2	Fuzzy Inference Rules	46
2.4.2.3	Fuzzy System and Defuzzification	47
2.4.3	Structured Argumentation Through Dialog Graph	49
2.5	Design and Implementation	49
2.6	An Application Example.....	50
2.7	Conclusions.....	56
2.8	Acknowledgements.....	56
2.9	References	57
3	A Shared VE for Collaborative Product Development in Manufacturing Enterprises	
	<i>G. Chryssolouris, M. Pappas, V. Karabatsou, D. Mavrikios and K. Alexopoulos</i>	59
3.1	Introduction	59
3.2	Background	60
3.3	Building the Shared VE.....	61
3.4	Virtual Environment Functionality	63
3.4.1	Virtual Prototyping Function	63
3.4.2	Behavioral Simulation Function	63
3.4.3	Assembly Support Function.....	64
3.4.4	Collision Detection Function	65
3.5	Pilot Application	65
3.6	Conclusions and Future Research	67
3.7	Acknowledgements.....	68
3.8	References	68

4 A ‘Plug-and-Play’ Computing Environment for an Extended Enterprise

F. Mervyn, A. Senthil Kumar and A. Y. C. Nee..... 71

4.1	Introduction	71
4.2	Related Research	72
4.3	Application Development Framework	75
4.3.1	Geometric Modeling Middleware Services	77
4.3.1.1	Modeling Functions.....	77
4.3.1.2	Geometric Data XML File	79
4.3.1.3	Application Relationship Manager (ARM)	80
4.3.2	Process Data Exchange Middleware Services	83
4.3.3	Reusable Application Classes.....	84
4.4	Illustrative Case Study.....	84
4.5	Conclusions	89
4.6	References	90

5 Cooperative Design in Building Construction

Yuhua Luo..... 93

5.1	Introduction	93
5.2	System Architecture and Components.....	95
5.2.1	The Cooperative 3D Editor.....	96
5.2.2	The Cooperative Support Platform	98
5.2.3	The Integrated Design Project Database	98
5.3	Considerations and Implementation for Collaborative Design.....	99
5.3.1	Interoperative and Multi-disciplinary	99
5.3.2	The On-line Cooperative Working	101
5.3.3	Design Error Detection During Integration	102
5.4	System Evaluation.....	103
5.5	Conclusions	106
5.6	Acknowledgements	107
5.7	References	107

6 A Fine-grain and Feature-oriented Product Database for Collaborative Engineering

Y.-S. Ma, S.-H. Tang and G. Chen..... 109

6.1	Introduction	109
6.2	Generic Feature Model.....	112
6.2.1	Feature Shape Representation.....	113
6.2.2	Constraint Definition	113
6.2.3	Other Feature Properties	114
6.2.4	Member Functions	115
6.2.5	Application-specific Feature Model	116
6.3	Mapping Mechanisms	116

6.3.1	Mapping from Extended EXPRESS Model to ACIS Workform Format.....	117
6.3.1.1	Geometry Mapping	117
6.3.1.2	Generic Feature Definition Under ACIS Framework...	118
6.3.2	Database Representation Schema	119
6.4	The Integration of Solid Modeler and Database	119
6.4.1	Feature Model Re-evaluation and Constraint Solving.....	120
6.4.2	Save Algorithm.....	121
6.4.3	Restore Algorithm	122
6.5	Feature Model Re-evaluation	122
6.5.1	Problems of Historical-dependent System	122
6.5.2	Dynamically Maintaining Feature Precedence Order	124
6.5.3	History-independent Feature Model Re-evaluation.....	125
6.5.3.1	Adding a New Feature Instance	125
6.5.3.2	Deleting a Feature Instance	126
6.5.3.3	Modifying a Feature Instance.....	130
6.5.3.4	B-rep Evaluation	130
6.6	A Case Study	130
6.7	Conclusions	133
6.8	Acknowledgements	134
6.9	References	134
7	A Web-based Framework for Distributed and Collaborative Manufacturing	
	<i>M. Mahesh, S. K. Ong and A. Y. C. Nee</i>	137
7.1	Introduction	137
7.2	Distributed and Collaborative Manufacturing	139
7.3	Proposed Framework and Implementation.....	140
7.4	A Case Study	142
7.5	Conclusions	148
7.6	References	148
8	Wise-ShopFloor: A Portal toward Collaborative Manufacturing	
	<i>Lihui Wang</i>	151
8.1	Introduction	151
8.2	Enabling Technologies	152
8.3	Wise-ShopFloor Framework	153
8.4	Adaptive Process Planning and Scheduling	155
8.4.1	Architecture Design.....	155
8.4.2	Machining Process Sequencing	156
8.4.3	Function Block Design And Utilization.....	158
8.4.4	Shop Floor Integration.....	163
8.5	Web-based Real-time Monitoring and Control	164
8.5.1	System Configuration	164
8.5.2	Sensor Data Collection for Real-Time Monitoring.....	165

8.5.3	Data Packet Format.....	167
8.5.4	Java 3D Enabled Visualization	167
8.5.5	Web-based Remote CNC Control.....	169
8.6	A Case Study	169
8.7	Conclusions	172
8.8	Acronyms	173
8.9	References	174

9 Real Time Distributed Shop Floor Scheduling: An Agent-Based Service-Oriented Framework

Chun Wang, Kewei Li, Hamada Ghenniwa, Weiming Shen

and Ying Wang..... 175

9.1	Introduction	175
9.2	Scheduling Problems in Multiple Workcell Shop Floor.....	176
9.2.1	Workcell Scheduling Problem	177
9.2.2	Dynamic Scheduling Problem	179
9.2.3	Distributed Scheduling Problem	180
9.3	Scheduling Algorithms for Multiple Workcell Shop Floor	181
9.3.1	Workcell Scheduling Algorithm	182
9.3.2	Dynamic Scheduling Algorithm	183
9.3.3	Distributed Scheduling Algorithm.....	185
9.4	Agent-Based Service-Oriented System Integration	187
9.4.1	System Overview.....	188
9.4.2	Dynamic Scheduling Algorithm	189
9.4.3	Scheduler Agent Design	190
9.4.4	Coordination between Scheduler Agent and Real Time Controller Agent	191
9.4.5	Coordination between Scheduling Services.....	192
9.4.6	System Implementation	194
9.5	A Case Study	194
9.6	Conclusions	195
9.7	References	197

10 Leveraging Design Process Related Intellectual Capital – A Key to Enhancing Enterprise Agility

Jitesh H. Panchal, Marco Gero Fernández, Christiaan J. J. Paredis,

Janet K. Allen and Farrokh Mistree 201

10.1	Design Processes – An Enterprise’s Fundamental Intellectual Capital.....	202
10.2	Examples of Design Process Scenarios	204
10.2.1	Description of LCAs design problem	205
10.2.2	LCAs design process strategies	206
10.2.2.1	Strategy 1: Sequential Design – Thermal First.....	206
10.2.2.2	Strategy 2: Sequential Design – Structural First.....	207
10.2.2.3	Strategy 3: Set-based Design.....	207

- 10.2.2.4 Strategy 4: Use of Surrogate Models..... 207
 - 10.2.2.5 Strategy 5: Parallel Iterative Design..... 208
 - 10.3 Requirements and Critical Issues for Leveraging Design Process
Related Intellectual Capital..... 209
 - 10.3.1 Support for Design Information Transformations..... 209
 - 10.3.2 Support for Design Decision-making 210
 - 10.3.3 Modeling and Representation of Design Processes 210
 - 10.3.4 Analyzing Design Processes 211
 - 10.3.5 Synthesizing Design Processes 211
 - 10.4 Research Issues and Strategies for Designing Design Processes 212
 - 10.4.1 Modeling Design Processes 214
 - 10.4.1.1 Research Issue 214
 - 10.4.1.2 Previous Work..... 214
 - 10.4.1.3 Research Questions 214
 - 10.4.1.4 Strategy: a Decision-centric Approach..... 214
 - 10.4.2 Computational Representations for Design Processes 216
 - 10.4.2.1 Research Issue 216
 - 10.4.1.2 Previous Work..... 216
 - 10.4.1.3 Research Questions 217
 - 10.4.1.4 Strategy: Separating Declarative Information from
Procedural Information 217
 - 10.4.3 Storage of Design Information..... 218
 - 10.4.3.1 Research Issue 218
 - 10.4.3.2 Previous Work..... 218
 - 10.4.3.3 Research Questions 219
 - 10.4.3.4 Strategy: Process Templates..... 219
 - 10.4.4 Developing metrics for assessing design processes 220
 - 10.4.4.1 Research Issue 220
 - 10.4.4.2 Previous Work..... 221
 - 10.4.3.3 Research Questions 221
 - 10.4.3.4 Strategy: Process Templates..... 221
 - 10.4.5 Configuring Design Processes 222
 - 10.4.5.1 Research Issue 222
 - 10.4.5.2 Previous Work..... 222
 - 10.4.5.3 Research Questions 222
 - 10.4.5.4 Strategy: Process Families..... 223
 - 10.4.6 Configuring Design Processes 223
 - 10.4.6.1 Research Issue 223
 - 10.4.6.2 Previous Work..... 224
 - 10.4.6.3 Research Questions 224
 - 10.4.6.4 Strategy: Identifying Process Decisions 224
 - 10.4.7 Integrating Design Processes with Other Processes in PLM 225
 - 10.4.7.1 Research Issue 225
 - 10.4.7.2 Previous Work..... 225
 - 10.4.7.3 Research Questions 226
 - 10.4.7.4 Strategy: a Decision-centric Approach..... 226
 - 10.5 Conclusions..... 227

10.6 Acknowledgments.....	228
10.7 References	228

11 Manufacturing Information Organization in Product Lifecycle Management

<i>R. I. M. Young, A. G. Gunendran and A. F. Cutting-Decelle</i>	235
--	-----

11.1 Introduction	235
11.2 Information and Knowledge Infrastructures for Manufacture	236
11.3 Context Awareness: Its Significance for Information Organization.....	239
11.3.1 Product Context	239
11.3.2 Life Cycle Context.....	241
11.3.3 Context Relationships	242
11.4 Exploiting Manufacturing Standards.....	246
11.4.1 STEP for Manufacturing.....	246
11.4.2 Mandate – Resource, Time And Flow Models	247
11.4.3 Process Specification Language	248
11.5 Exploiting Product and Process Knowledge in Future	249
11.6 Conclusions	251
11.7 References	252

12 Semantic Interoperability to Support Collaborative Product Development

<i>Q. Z. Yang and Y. Zhang.....</i>	255
-------------------------------------	-----

12.1 Introduction	255
12.2 Semantic Interoperability Concepts and Technologies.....	257
12.2.1 Data-driven Interoperability Standard	258
12.2.2 Ontologies.....	258
12.2.3 Product Models	260
12.3 Product Semantics Capturing and STEP Extension Modeling	263
12.3.1 Representing Semantics in Supplementary Information Models.....	263
12.3.2 Embedding Supplementary Information in CAD Models.....	264
12.3.3 Modeling STEP Extensions	265
12.3.4 Capturing Semantics in STEP-compliant Product Models	266
12.4 Taxonomy and Ontology	267
12.4.1 Vocabulary Taxonomy	267
12.4.2 OWL Ontology	268
12.5 Semantics-driven Schema Mapping	270
12.6 Software Prototype Development.....	272
12.6.1 Software System Architecture	272
12.6.2 Client Toolkits	273
12.6.3 Collaboration Server Components and Services.....	276
12.7 Collaboration Scenarios.....	278
12.7.1 Support of Collaborative Design Process	278
12.7.2 Design Objects Modeling and Semantics Capturing	279

12.7.3 Semantics Sharing with Heterogeneous Systems	281
12.8 Conclusions	283
12.9 Acknowledgements	284
12.10 Acronyms	284
12.11 References	284
13 A Proposal of Distributed Virtual Factory for Collaborative Production Management	
<i>Toshiya Kaihara, Susumu Fujii and Kentaro Sashio</i>	287
13.1 Introduction	287
13.2 Distributed Virtual Factory	288
13.2.1 Concept	288
13.2.2 Structure	289
13.2.3 Time Bucket Mechanism	289
13.3 Cost Analysis	291
13.3.1 Cost Analysis In Manufacturing Systems	291
13.3.2 Activity Based Costing (ABC)	291
13.3.3 DVF and ABC	292
13.3.4 Manufacturing Model	292
13.3.5 Formulations for Cost	292
13.4 Experimental Results	297
13.4.1 Simulation Model	297
13.4.2 Total Factory Management in DVF	297
13.4.3 Cost Analysys	300
13.5 Conclusions	301
13.6 References	303
Index	305

An Adaptable Service-based Framework for Distributed Product Realization

Jitesh H. Panchal, Hae-Jin Choi, Janet K. Allen, David Rosen and Farrokh Mistree

*Systems Realization Laboratory
G.W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology, USA*

In this chapter, we propose a service-based engineering framework to support distributed product realization. Adaptability is the key strength of this framework, which arises from an appropriate balance between the ease of use of the framework and the flexibility for reconfiguration. *Standardization of the interfaces* between services permits communication between diverse software agents and relieves users from having to handle routine operations, resulting in the ease of use of the framework. *Flexibility of the framework's configuration* allows users to rapidly reconfigure the framework to changing design processes, and reduces the burden of customization. The capabilities for this adaptable distributed product realization framework are developed based on the Open Engineering Systems paradigm. Various existing distributed frameworks are evaluated against the requirements and missing features are identified. Our efforts towards the development of such a framework – the eXtensible Distributed Product Realization (X-DPR) environment are discussed. X-DPR is flexible and applicable to general industrial product realization processes. It is used to integrate distributed, collaborative product realization activities over the Internet. We trace the development of the framework based on design requirements. Features of X-DPR are implemented to satisfy the requirements. X-DPR is compared to existing engineering frameworks based on the required features. The key words and phrases used in this chapter are defined below.

Agent – Software component that can be invoked remotely to perform tasks in a product realization process.

Client – A software component that requests services from remote agents.

Framework – A computational backbone that facilitates deployment and utilization of agents.

Open Engineering Systems – Systems of industrial products, services, and/or processes that are readily adaptable to changes in their environment which enable

producers to remain competitive in a global marketplace through continuous improvement and indefinite growth of an existing technological base.

Service – An activity that an agent can perform based upon a client's request.

1.1 Introduction

1.1.1 Need for an Adaptable Framework

Competition, globalization, a decreasing half-life of information, and greater product complexity necessitate the effective utilization of distributed resources and the management of the derived information. A distributed product realization process consists of a philosophy, a systematic approach and implementation methods to organizing product development activities. This process must be able to incorporate information from all parts of the product lifecycle. It is intended to support collaborative, concurrent decision making by geographically dispersed engineers who have different goals, knowledge, experiences, tools and resources. Software frameworks that facilitate globally distributed design and manufacturing activities are becoming more and more important, and many universities and industries have developed specific frameworks to complete specific tasks. However, in these frameworks, there is often a trade-off between agility, flexibility and implementation/customization effort.

If an engineering framework is implemented as *middleware*, it may be flexible enough to be useful for various product realization processes, but requires a significant effort to particularize it for a specific process. Middleware tools free users from having to write their own routines to handle reliable data transfer between applications or from having to worry about complexities when multiple systems are integrated. However, users still must write codes to integrate application functionalities. Examples of middleware toolkits include OMG's CORBA (Common Object Request Broker Architecture) [1] and Microsoft's DCOM (Distributed Component Object Model) [2]. On the other hand, if an engineering framework is developed as *end-user software*, the user must only put forth minimal effort but, in general, these frameworks are inflexible and cannot be modified easily when new situations arise, such as, when the company's design processes change. In other words, middleware tools provide standardization of communication protocols and leave a lot of integration work to the users whereas engineering frameworks (end-user software) provide easier integration capabilities but are not flexible. Hence, *choosing between the flexibility and ease-of-use of engineering frameworks is one of the primary challenges.*

Using a simple example, we demonstrate why an adaptable engineering framework is necessary. Imagine an engineering designer developing a simulation program and wanting to deploy it to a network so that it is available remotely for other engineers. To do this, a designer needs to do the following:

1. Implement a message and data construct to convey specifications (input and output) and data to and from the simulation program,