Complete Table of Contents

List of Figures **IX**

List of Tables **XI**

List of Abbreviations **XIII**

List of Symbols **XVII**

1 Exposé **1**
1.1 Motivation . . . 1
1.2 Problem Statement . . . 3
1.3 Research Objectives and Questions . . . 5
1.4 Scientific Method Placement . . . 8
1.5 Thesis Structure . . . 10

2 Viewpoint-based FISA: Terminology **13**
2.1 Viewpoints: Foundation for Efficient FISA Engineering . . . 13
2.1.1 Viewpoint Definitions . . . 13
2.1.2 Viewpoint-based Methods . . . 14
2.1.3 Viewpoint Terminology . . . 15
2.1.4 Viewpoints for Bridging the Abstraction Levels . . . 17
2.2 Model Transformations, Resulting Impact Analysis and Recommendations . . . 18
2.2.1 Definition: Model Transformation . . . 18
2.2.2 Definition: Impact Analysis . . . 20
2.3 Terms and History of Information Systems and Enterprise Architectures . . . 22
2.3.1 Definition: Information System vs. Enterprise Architectures . . . 22
2.3.2 Brief Historical Emerging and Development of ISA . . . 24
2.4 Deriving the Term: Flexible Information System Architectures . . . 27
2.4.1 Flexibility Analysis Approaches . . . 27
2.4.2 Flexibility Term Delimitation . . . 29
2.4.3 Defining FISA . . . 33
2.4.4 Classification of Flexible Information System Architectures . . . 34
2.5 Chapter Summary: FISA Terminology . . . 39

3 FISA for Business-IT Alignment and Enterprise Governance **41**
3.1 Viewpoint-based FISA for Business and IT Alignment . . . 41
3.1.1 Viewpoints for FISA Construction . . . 42
3.1.2 Enterprise Alignment by Knowledge Engineering . . . 43
3.1.3 Viewpoint-based ISA Design . . . 44
3.1.4 Viewpoint Definition Analysis . . . 45
3.2 Enterprise Architecture Management, Governance, Growth . . . 46
3.2.1 ISA Complexity . . . 47
3.2.2 Data Provenance and Evolution Implications . . . 49
3.2.3 Management Life-cycles . . . 51
3.2.3.1 Business Process Management . . . 51
3.2.3.2 FISA Management . . . 53

3.2.4 ISA Governance . . . 55
3.2.5 Sustainable ISA Growth . . . 58
3.3 Viewpoint-based FISA Engineering Approaches and Methods . . . 60
3.3.1 Software Engineering for FISA . . . 60
3.3.2 Aspects of Reverse Engineering . . . 62
3.3.3 Impact Analysis by Recommendations . . . 64
3.3.4 MDD and MDA Approaches for FISA . . . 66
3.3.4.1 General Viewpoint-based FISA Engineering Method Analysis . . . 68
3.3.4.2 Dedicated Viewpoint-based FISA Engineering Method Analysis 70
3.4 Chapter Summary: FISA in Software Engineering and Management . . . 71

4 Viewpoint-based FISA: Viewpoints, Methods, Model Transformations 73
4.1 Viewpoint Definitions and Methods in FISA . . . 73
4.1.1 FISA Viewpoints Definitions . . . 74
4.1.1.1 Ainsworth et al. . . . 74
4.1.1.2 Dijkman et al. . . . 74
4.1.1.3 Finkelstein et al. . . . 74
4.1.1.4 ISO/IEC 42010 . . . 75
4.1.1.5 Kruchten's 4+1 View Model, Rozanski et al. . . . 75
4.1.1.6 Lankhorst and IEEE 1471 Standard . . . 76
4.1.1.7 Nuseibeh et al. . . . 77
4.1.1.8 PRAXEME . . . 78
4.1.1.9 RM-ODP . . . 78
4.1.1.10 RUP . . . 79
4.1.1.11 Steen et al. . . . 80
4.1.1.12 TOGAF . . . 81
4.1.1.13 Zachman Framework . . . 81
4.1.1.14 Comparison: Viewpoint Terms and Definitions . . . 82
4.1.2 FISA Viewpoint Engineering Methods . . . 83
4.1.2.1 FISA Software Systems Engineering Methods . . . 84
4.1.2.1.1 ANSI/IEEE Std. 1471-2000 . . . 84
4.1.2.1.2 ISO/IEC 42010 . . . 85
4.1.2.1.3 Kruchten's "4+1" Architectural View Model . . . 85
4.1.2.1.4 RM-ODP . . . 86
4.1.2.2 FISA Technical Systems Engineering Methods . . . 87
4.1.2.2.1 OMG SysML . . . 87
4.1.2.2.2 PRAXEME Framework . . . 88
4.1.2.2.3 RUP Approach . . . 89
4.1.2.3 FISA Enterprise Systems Engineering Methods . . . 91
4.1.2.3.1 Boiten Approach . . . 91
4.1.2.3.2 MODAF/DoDAF . . . 92
4.1.2.3.3 TOGAF . . . 93
4.1.2.3.4 Zachman Framework . . . 94
4.1.2.4 FISA MDA Research Project Methods . . . 96
4.1.2.4.1 MDA and SHAPE Research Project . . . 96
4.1.2.4.2 MDA and VIDE Research Project . . . 98
4.1.2.5 Comparison: Viewpoint-based Methods . . . 98
4.2 Model Transformation Approaches and Resulting Impact Analysis . . . 100
4.2.1 Model Transformation Classification . . . 102

4.2.2 Methods of Impact Analysis . . . 105
4.2.3 Models for Model Transformations . . . 108
4.2.3.1 Acceleo . . . 109
4.2.3.2 ATL . . . 109
4.2.3.3 AToM^3 . . . 110
4.2.3.4 ETL . . . 110
4.2.3.5 JET . . . 111
4.2.3.6 JTL . . . 111
4.2.3.7 Kermeta . . . 112
4.2.3.8 QVT . . . 113
4.2.3.9 Xpand . . . 113
4.2.3.10 Xtend . . . 114
4.2.3.11 Models for Model Transformations Comparison . . . 114
4.3 Chapter Summary: Viewpoints in FISA . . . 115

5 Requirements Elicitation for FISA Engineering Approach 117
5.1 State of the Technique for FISA Engineering . . . 117
5.1.1 FISA Processes in Evolution . . . 118
5.1.2 Open Source and Research Viewpoint Supporting Prototypes . . . 119
5.1.2.1 ArchiMeDes . . . 119
5.1.2.1.1 Viewpoint Tool Functionalities . . . 119
5.1.2.1.2 Dynamic View Handling and Exchange . . . 120
5.1.2.2 CIMFlex . . . 120
5.1.2.2.1 Viewpoint Tool Functionalities . . . 120
5.1.2.2.2 Dynamic View Handling and Exchange . . . 121
5.1.2.3 DSML4MAS . . . 121
5.1.2.3.1 Viewpoint Tool Functionalities . . . 121
5.1.2.3.2 Dynamic View Handling and Exchange . . . 122
5.1.2.4 Eclipse EMF/GMP/CDO . . . 122
5.1.2.4.1 Viewpoint Tool Functionalities . . . 123
5.1.2.4.2 Dynamic View Handling and Exchange . . . 123
5.1.3 Proprietary Viewpoint Supporting Solutions . . . 123
5.1.3.1 IBM: Rational Rhapsody/DOORS/RIF . . . 123
5.1.3.1.1 Viewpoint Tool Functionalities . . . 124
5.1.3.1.2 Dynamic View Handling and Exchange . . . 124
5.1.3.2 ikv++: m2c . . . 125
5.1.3.2.1 Viewpoint Tool Functionalities . . . 125
5.1.3.2.2 Dynamic View Handling and Exchange . . . 126
5.1.3.3 Obeo: Obeo Designer . . . 126
5.1.3.3.1 Viewpoint Tool Functionalities . . . 126
5.1.3.3.2 Dynamic View Handling and Exchange . . . 126
5.1.3.4 Softeam: Modelio . . . 127
5.1.3.4.1 Viewpoint Tool Functionalities . . . 127
5.1.3.4.2 Dynamic View Handling and Exchange . . . 127
5.2 Requirements for Flexible Viewpoint-based System Specification . . . 127
5.2.1 FISA Viewpoint Concept . . . 128
5.2.1.1 Architectural Viewpoints . . . 129
5.2.1.2 Architecture Consistency Assurance . . . 130
5.2.1.3 Architecture Life-cycle Support . . . 130

5.2.1.4 Architecture Validation and Verification . . . 131
5.2.1.5 Architecture Concrete Syntax and Extension . . . 131
5.2.2 FISA Viewpoint Tooling . . . 132
5.2.2.1 Viewpoint Definition and View Creation . . . 132
5.2.2.2 View Visualisation . . . 133
5.2.2.3 Viewpoint-specific Tool Adaptation . . . 133
5.2.2.4 View Exchange . . . 134
5.2.2.5 View Handling . . . 134
5.2.2.6 Dynamic View Definition and Usage . . . 134
5.2.2.7 Dynamic Views for Reviewing Tasks . . . 135
5.2.3 Viewpoint Requirements Overview . . . 135
5.3 Chapter Summary: Requirements for FISA . . . 136

6 Viewpoint-based FISA Engineering: Procedure and Reference Models 139
6.1 FISA Reference Procedure Model . . . 141
6.1.1 Stakeholder-centred Software Engineering Domain Delimitation . . . 141
6.1.2 Viewpoint-based Reference Construction Procedure Model . . . 143
6.1.2.1 Viewpoint Definition: Top-down and Bottom-up . . . 144
6.1.2.2 Conceiving FISA procedure model . . . 146
6.1.2.3 Phase Model and Classification . . . 149
6.2 FISA Definitions, Metamodel Assembly and Delimitation . . . 151
6.2.1 Viewpoint Terms Definition . . . 152
6.2.2 Viewpoint Metamodelling Approaches . . . 156
6.2.2.1 Centralised Viewpoint-based Metamodelling . . . 156
6.2.2.1.1 Purpose . . . 156
6.2.2.1.2 Metamodel Definition . . . 156
6.2.2.2 Federated Viewpoint-based Metamodelling . . . 158
6.2.2.2.1 Purpose . . . 158
6.2.2.2.2 Metamodel Definition . . . 158
6.2.2.3 Weighted Viewpont-based Metamodelling . . . 159
6.2.2.3.1 Purpose . . . 159
6.2.2.3.2 Metamodel Definition . . . 160
6.2.2.4 Generalised Viewpoint-based Metamodelling . . . 161
6.2.2.4.1 Purpose . . . 161
6.2.2.4.2 Metamodel Definition . . . 161
6.2.3 FISA Viewpoint Metamodel Instantiation . . . 163
6.3 FISA Viewpoint-based Engineering Method . . . 166
6.3.1 FISA Application Reference Models . . . 166
6.3.1.1 Centralised Viewpoint-based Engineering . . . 168
6.3.1.1.1 Reference Model . . . 168
6.3.1.1.2 Model Instance . . . 169
6.3.1.2 Federated Viewpoint-based Engineering . . . 170
6.3.1.2.1 Reference Model . . . 170
6.3.1.2.2 Model Instance . . . 172
6.3.1.3 Weighted Viewpoint-based Engineering . . . 173
6.3.1.3.1 Reference Model . . . 173
6.3.1.3.2 Model Instance . . . 175
6.3.1.4 Generalised Viewpoint-based Engineering . . . 176
6.3.1.4.1 Reference Model . . . 176

6.3.1.4.2 Model Instance . . . 179
6.3.2 FISA Viewpoint Set Extension . . . 181
6.3.2.1 Minimal Covering Viewpoint Set and Criteria of Negligibility . . 181
6.3.2.2 Enriching the Vertical Viewpoints Axe . . . 183
6.3.2.3 Enriching the Horizontal Viewpoint Axe . . . 187
6.3.3 FISA Life-cycle Support by Viewpoints . . . 188
6.3.3.1 FISA for ARIS vs. MDA vs. Zachman . . . 189
6.3.3.2 BPM and System Life-cycle Approaches . . . 190
6.3.3.2.1 Business Process Classification . . . 190
6.3.3.2.2 Supported Business Processes . . . 193
6.4 FISA Relations: Model Transformations and Viewpoint Assignments . . . 194
6.4.1 Model Transformations . . . 195
6.4.1.1 Model Transformation Procedure . . . 195
6.4.1.2 Horizontal Transformations . . . 197
6.4.1.2.1 Delimitation of source and target domains . . . 197
6.4.1.2.2 Pattern Mapping . . . 199
6.4.1.3 Vertical Transformations . . . 201
6.4.1.3.1 Experts Level to Technical Level Transformations . . . 201
6.4.1.3.2 Reverse Expert to Technical Level Transformations . . . 201
6.4.1.4 Model Transformation Validation and Verification . . . 203
6.4.2 Impact Analysis Assessment . . . 206
6.4.2.1 Structuring the Expert Knowledge . . . 206
6.4.2.2 Structured Model Refinement . . . 207
6.4.2.3 Abstraction Level Gap Overcoming . . . 209
6.4.3 Viewpoint Recommendation Engineering . . . 211
6.4.3.1 Overview . . . 211
6.4.3.2 Stakeholder-Centred Method . . . 212
6.4.3.3 Data-centred Method . . . 212
6.5 Chapter Summary: FISA Concept, Models and Method . . . 213

7 FISA in Context of Legacy Systems and Automotive Safety 215
7.1 Proof-of-concept Evaluation Approach of the Solution . . . 216
7.1.1 Evaluation Method . . . 216
7.1.2 Tooling Support . . . 217
7.1.3 Application Cases . . . 218
7.1.4 Evaluation Analyses and Requirements Review . . . 219
7.2 Architecture of the FISA Engineering Prototype . . . 219
7.2.1 Viewpoints-based Prototype . . . 220
7.2.2 Stakeholder Support in FISA Engineering . . . 222
7.2.2.1 CIMFlex: Model Transformations, Impact Analysis . . . 222
7.2.2.2 Viewpoint Recommendations . . . 223
7.3 FISA Engineering Industry Application Cases . . . 223
7.3.1 Steel Production and Legacy Systems . . . 224
7.3.1.1 Overview and Scope . . . 224
7.3.1.2 Scenario . . . 225
7.3.1.3 Vertical Viewpoint Extension . . . 226
7.3.1.4 Model Transformations and Impact Analysis . . . 228
7.3.2 Software Engineering for Automotive Safety Process Work Products . . . 230
7.3.2.1 Overview and Scope . . . 230

7.3.2.2 Scenario . . . 230
7.3.2.2.1 Conducting a Review . . . 231
7.3.2.2.2 Working on Review Comments . . . 231
7.3.2.2.3 Export of a Functional Safety View by OEM . . . 232
7.3.2.2.4 Feedback of Safety Information by Supplier to OEM . . . 232
7.3.2.2.5 Update of a Functional Safety View by OEM . . . 233
7.3.2.3 Horizontal Viewpoint Extension . . . 233
7.3.2.4 Context, Task and Sequence Assignment for Viewpoints . . . 234
7.4 Evaluation Results . . . 235
7.4.1 Requirements Fulfilment . . . 235
7.4.1.1 Viewpoint Concept Requirements . . . 235
7.4.1.2 Viewpoint Tooling . . . 236
7.4.1.3 Requirements Evaluation Overview . . . 236
7.4.2 Critical FISA Method Review for Evaluation . . . 239
7.4.2.1 Does FISA Technique Work? . . . 239
7.4.2.2 Aid for Steel Production and Automotive Safety . . . 239
7.4.2.3 ROI and Performance Measures . . . 240
7.4.2.4 SWOT Analysis and Implications . . . 241
7.5 Chapter Summary: FISA Application Cases and Evaluation . . . 243

8 Conclusions and Research Outlook 245
8.1 Summary of the Viewpoint-based Engineering Method for FISA . . . 246
8.2 Critical Acclaim of the Approach . . . 247
8.3 Future Research Areas for FISA . . . 249

Appendix XIX
A State-of-the-Technique Research Tool CIMFlex4FISA . . . XIX
B OMG Concepts and Standards for MDA . . . XX
B.1 MDA Concepts . . . XX
B.2 MDA Standards . . . XXI
C Model-to-Model Transformations . . . XXIII
C.1 Transformation Run-time Settings . . . XXIII
C.2 CIM-to-CIM Transformations . . . XXIV
C.3 CIM-to-PIM Transformations . . . XXVII
C.4 PIM-to-CIM Transformations . . . XXVIII
D Viewpoint Recommendation Engineering . . . XXX
D.1 Viewpoint Recommendation Implementation . . . XXX
D.2 Task Assignment . . . XXXIII
D.3 Sequence Recommendation . . . XXXV

References XXXIX