CONTENTS

1 Introduction **2**

1.1 Overview of the Chapter 2

1.2 Motivation 3

1.3 Problem Statement 7

1.4 Contribution 8

1.5 Research Methodology 10

1.6 Thesis Context 11

1.7 Outline 12

2 Background **16**

2.1 Overview of the Chapter 16

2.2 Autonomic Computing 17

2.2.1 Definition 17

2.2.2 Properties of Autonomic Computing 18

2.2.3 The MAPE-K Autonomic Loop 20

2.3 Model Driven Development 26

2.3.1 Definition 27

2.3.2 Model Driven Software Development Initiatives 27

2.3.3 Domain Specific Languages 29

2.4 Software Product Lines 31

2.4.1 Definition 31

2.4.2 Software Product Line Processes 32

2.4.3 Dynamic Software Product Lines 34

2.5 Conclusions 35

3 State of the Art **38**

3.1 Overview of the Chapter 38

3.2 Classification Criteria 39

3.2.1 Adoption Level of Autonomic Computing 39

3.2.2 Relevance of the Autonomic Computing 40

3.2.3 Reinforcement of the Autonomic Knowledge 41

3.2.4 Maturity of the Software Engineering Approach 41

3.3 Analysis of Approaches for System Family Reconfiguration 44

3.3.1 Gomaa and Hussein Approach 45

3.3.2 Lee and Kang Approach 47

3.3.3 Hallsteinsen et al. (MADAM) Approach 50

3.3.4 White et al. Approach 52

3.3.5 Trinidad et al. Approach 55

3.3.6 Mori et al. Approach 57

3.3.7 Hallsteinsen et al. (MUSIC) Approach 59

3.3.8 Parra et al. Approach 62

3.3.9 Istoan et al. Approach 64

3.4 Discussion 66

3.4.1 Architectural Patterns 68

3.5 Conclusions 71

4 Overview of the Approach **74**

4.1 Overview of the Chapter 74

4.2 Introduction 75

4.3 Main Building Blocks 78

4.4 Application 80

4.5 Implementation 85

4.6 Validation 86

4.7 Conclusions 88

5 Autonomic Computing through the Use of Variability Models **90**

5.1 Overview of the Chapter 90

5.2 Variability Modelling 91
5.2.1 Variability and Software Product Lines 91
5.2.2 Model Driven Software Product Lines 93
5.3 Specifying Reconfigurations through Feature Models 100
5.3.1 Evaluation of the Autonomic Behaviour through Feature Models. 103
5.4 Model-Based Validation of Reconfigurations 104
5.5 Applying the approach to other Variability Language: Autonomic Behaviour through Common Variability Language 106
5.6 Conclusions 110

6 Achieving Autonomic Computing through Models at run-time 112
6.1 Overview of the Chapter 112
6.2 Renconfigurable System Architectures 113
6.2.1 The OSGi Framework: A Realization of the Renconfigurable System Architecture 116
6.3 Reconfiguring the System Architecture through Feature Models 119
6.4 MoRE: Model-based Reconfiguration Engine 123
6.4.1 MoRE Model Operations 124
6.4.2 MoRE Reconfiguration Actions 131
6.5 Scalability Evaluation of Model-management Technologies at Run-time 138
6.6 Conclusions 141

7 Strategies for Variability Transformation at run-time 144
7.1 Overview of the Chapter 144
7.2 From Design Variability to run-time Variability: Challenges 145
7.3 Managing Variability at Run-time 148
7.3.1 Feature-based Approach 148
7.3.2 Fragment-based Approach 150
7.3.3 Assessment between Feature-based and Fragment-based 152
7.4 Strategies for Variability Transformation 154
7.4.1 Common Operations of the Strategies 154

7.4.2 Regenerative Strategy . . . 157
7.4.3 Incremental - Copy Strategy . . . 159
7.4.4 Incremental - Move Strategy . . . 160
7.4.5 Implementation of the Strategies . . . 161
7.5 Validating the Strategies Implementation . . . 162
7.5.1 Tool Support for Testing Strategies . . . 164
7.6 Extra-Functional Properties of Strategies . . . 166
7.7 Applying the Strategies to Smart Homes . . . 168
7.8 Conclusions . . . 169

8 Evaluation of the Proposal 172
8.1 Overview of the Chapter . . . 172
8.2 Background on DSPL evaluation . . . 174
8.3 The Smart Hotel Case Study . . . 175
8.3.1 Reconfiguration Scenarios of the Smart Hotel . . . 176
8.4 Evaluation Logistics of the Case Study . . . 179
8.4.1 Participants and Training . . . 179
8.4.2 Challenges to involve Human participants in DSPL Evaluation 180
8.4.3 Experiment Operation . . . 184
8.4.4 Data Collection . . . 186
8.4.5 Keeping Track of the Reconfigurations . . . 186
8.5 Evaluation . . . 189
8.6 Discussion . . . 191
8.6.1 Introducing User Confirmations to Reconfigurations . . . 192
8.6.2 Improving Reconfiguration Feedback . . . 194
8.6.3 Introducing Rollback Capabilities to Reconfigurations . . . 195
8.7 Conclusions . . . 196

9 Conclusions and Future Work 198
9.1 Overview of the Chapter . . . 198
9.2 Contributions . . . 199
9.3 Research Visits . . . 202

9.4 Assessment and Future Work 203
9.4.1 Enabling End-user participation in the Design of Reconfigurable Systems 203
9.4.2 Enhancing Run-time Reconfigurations to Take into Account End-user Preferences 204
9.4.3 Providing Metrics to Quantify System Reconfiguration Capabilities 205
9.4.4 Guarantying Quality Properties on Run-time Reconfigurations 205
9.4.5 Addressing other Application Domains 206
9.5 Publications 207
9.6 Senior Theses Codirected 211
9.7 Seminars 212
9.8 Final Conclusion 213

Appendix **214**

A The Smart Hotel Case Study **214**

A.1 Overview of the Case Study 215
A.2 Scenarios of the Smart Hotel 217
A.3 Functionality of the Smart Hotel 220
A.4 Software Architecture of the Smart Hotel 221
A.5 Reconfigurations in the Smart Hotel 223
A.5.1 Check-in 224
A.5.2 Entering the room 229
A.5.3 Working 232
A.5.4 Watching a Movie 235
A.5.5 Sleeping 238
A.5.6 Leaving the room 241
A.5.7 House Keeping 244
A.5.8 Check-out 247
A.6 Summary 250

B Tool Support **254**

B.1 Support for Designing Autonomic Behaviour 254

B.1.1 Support for Reconfiguration Analysis 258

B.2 Support for Model-based Run-time Reconfigurations 259

Bibliography **264**

LIST OF FIGURES

1.1 Scope of Chapter 1 2
1.2 Research methodology followed in this thesis. 11
1.3 Roadmap of this Thesis. 12

2.1 Scope of Chapter 2 16
2.2 IBM's MAPE-K reference model for autonomic control loops 20

3.1 Scope of Chapter 3 38
3.2 Gomaa and Hussein Approach 46
3.3 Lee and Kang Approach 48
3.4 Hallsteinsen et al. Approach 51
3.5 White et al. Approach 53
3.6 Trinidad et al. Approach 56
3.7 Mori et al. Approach 58
3.8 Hallsteinsen et al. Approach 61
3.9 Parra et al. Approach 63
3.10 Istoan et al. Approach 65
3.11 Classification of the Approaches: Maturity - Autonomic Level 67
3.12 Connected DSPL Overview 69
3.13 Disconnected DSPL Overview 70
3.14 Classification of DSPL: Scope - Infrastructure 72

4.1 Scope of Chapter 4 74
4.2 Main Building Blocks of the Approach 78
4.3 Simplified overview of the Process to Apply the Approach 81
4.4 Overview of the Process to Apply the Approach 82

4.5 Overview of the Run-time Reconfiguration of the Approach 85

5.1 Scope of Chapter 5 90
5.2 SPL main concepts 92
5.3 SPL following the MDD Approach 94
5.4 Feature model of a smart home. 96
5.5 Main concepts of PervML Pervasive Systems 97
5.6 Two configurations of a Pervsive System. 98
5.7 Snapshot of a Feature Model. 99
5.8 OWL Ontology for Autonomic Homes. 101
5.9 Visualizing variability as an adaptation space. 104
5.10 Base-Variation-Resolution Approach. 107
5.11 Modelling Varibility with CVL. 108
5.12 Applying CVL for Autonomic Homes. 109
5.13 Feature Modelling and CVL. 110

6.1 Scope of Chapter 6 112
6.2 Reconfiguration Pattern of a DSPL Architecture. 114
6.3 The Smart Home from an OSGi perspective. 118
6.4 Overview of the model-based reconfiguration process. 120
6.5 Architecture Increment and Decrement given a Resolution. 122
6.6 The model-based reconfiguration process overview. 123
6.7 Calculating A($A \triangle \bigtriangledown$) through the Model Operations. 130
6.8 Experimental results. 140

7.1 Scope of Chapter 7 144
7.2 Managing Varibility. 148
7.3 Overview of Feature-based superimposition. 149
7.4 Overview of the Variability Transformation. 151
7.5 Common operations for fragment substitution. 154
7.6 Regenerative Strategy. 158
7.7 Incremental-Copy Strategy. 159
7.8 Incremental-Move Strategy. 160

7.9 Possibility Space. 163
7.10 Testing Tool for Strategies. 165

8.1 Scope of Chapter 8 172
8.2 Reconfigurations among Scenarios. 178
8.3 Context Cards for triggering DSPL reconfigurations. 182
8.4 Visualizing reconfiguration effects by means of the Configuration Viewer. 183
8.5 Experimentation set-up. 185
8.6 Information of the Reconfigurations is Stored as Model-based Traces. 187
8.7 Snapshot of MoRE Traces tool. 188
8.8 Overall results from the Case Study. 190
8.9 Categories for confirmation of reconfigurations. 193

9.1 Scope of Chapter 9 198

A.1 Hotel's Smart Room 217
A.2 Reconfiguration through the Smart Hotel Scenarios 219
A.3 Feature Model of the Smart Hotel 221
A.4 PervML Model of the Smart Hotel 222
A.5 Mapping between features and PervML 223
A.6 Another mapping between features and PervML 224
A.7 Feature model of the Check-in Scenario 225
A.8 PervML model of the Check-in Scenario 226
A.9 Feature model of the Entering the room Scenario 230
A.10 PervML model of the Entering the Room Scenario 231
A.11 Feature model of the Working Scenario 233
A.12 PervML model of the Working Scenario 234
A.13 Feature model of the Working Scenario 236
A.14 PervML model of the Working Scenario 237
A.15 Feature model of the Working Scenario 239
A.16 PervML model of the Working Scenario 240
A.17 Feature model of the Leaving the Room 242
A.18 PervML model of the Leaving the room 243

A.19 Feature model of the Housekeeping Scenario 245
A.20 PervML model of the Housekeeping Scenario 246
A.21 Feature model of the Check-out Scenario 248
A.22 PervML model of the Check-out Scenario 249

B.1 Tool Support for Design Time. 255
B.2 Screenshots of the Tool Support for Design Time 256
B.3 Screenshot of the Resolution Editor 258
B.4 Screenshot of the Reconfiguration Analysis Tool 259
B.5 MoRE implemented as OSGi Bundles. 260
B.6 Package Diagram of MoRE Implementation 261
B.7 Class Diagram of MoRE Implementation 263

LIST OF TABLES

3.1 Template for Approach Classification. 44
3.2 Classification of Gomaa and Hussein Approach. 47
3.3 Classification of Lee and Kang Approach. 49
3.4 Classification of Hallsteinsen et al. Approach. 52
3.5 Classification of White et al. Approach. 54
3.6 Classification of Trinidad et al. Approach. 57
3.7 Classification of Mori et al. Approach. 59
3.8 Classification of Hallsteinsen et al. Approach. 62
3.9 Classification of Parra et al. Approach. 64
3.10 Classification of Istoan et al. Approach. 66

7.1 Extra-Functional Properties of the Strategies 166

8.1 Scale Definition of Reliability Metrics. 180

A.1 Reconfiguration Table: Check-in Scenario. 228
A.2 Reconfiguration Table: Entering the Room. 232
A.3 Reconfiguration Table: Working. 235
A.4 Reconfiguration Table: Watching a Movie. 238
A.5 Reconfiguration Table: Sleeping. 241
A.6 Reconfiguration Table: Leaving the Room. 244
A.7 Reconfiguration Table: Housekeeping. 247
A.8 Reconfiguration Table: Check-out. 250