



VALIDATION OF QUALITY REQUIREMENTS THROUGH REQUIREMENTS-BASED TESTING WITH SEMI-FORMALISED MODEL

NOR AIZA BINTI MOKETAR

DOCTOR OF PHILOSOPHY

2018



Faculty of Information and Communication Technology

**VALIDATION OF QUALITY REQUIREMENTS THROUGH
REQUIREMENTS-BASED TESTING WITH SEMI-FORMALISED
MODEL**

Nor Aiza binti Moketar

Doctor of Philosophy

2018

**VALIDATION OF QUALITY REQUIREMENTS THROUGH REQUIREMENTS-
BASED TESTING WITH SEMI-FORMALISED MODEL**

NOR AIZA BINTI MOKETAR

**A thesis submitted
in fulfillment of the requirements for the degree of Doctor of Philosophy**

Faculty of Information and Communication Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitled “Validation of Quality Requirements through Requirements-Based Testing with Semi-formalised Model” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Nor Aiza Binti Moketar

Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of Doctor of Philosophy.

Signature :

Supervisor Name : Assoc. Prof. Dr. Massila Binti Kamalrudin

Date :

DEDICATION

I dedicate this thesis to

My husband Muhamad Hafiz, my children Nur Hani Sufia and Umar Hariz, my beloved parent, my parent-in-law, my brothers, and sisters.

ABSTRACT

The usage of software system and applications has increased massively to fulfill various kind of purpose for organization, business and individual. In this case, high quality software system and application are required to ensure it provides the intended functionalities. To achieve quality software system and application, a good quality of requirements needs to be defined and validated. However, it is difficult to accomplish due to the flexibility of natural language requirements that can be confusing and easily misinterpreted. This can lead to requirements-related problems such as incorrectness, incompleteness and inconsistency. These errors in requirements will produce defective software that can lead to undesirable and non-acceptance by stakeholders. Therefore, it is crucial for the software requirements to fulfill basic quality attributes such as correctness, completeness, and consistency (3Cs). Motivated from these problems, the main objective of this study is to develop an automated approach to validate the quality of requirements through Requirements-Based Testing methodology with semi-formalized model. This study proposes a new automated approach to assist the requirements engineer and client-stakeholders to validate the quality of requirements. For this, we generate abstract tests by integrating Requirements-based Testing (RBT) methodology and rapid prototyping with semi-formalized models: Essential Use Cases (EUCs) and Essential User Interface (EUI). Next, we have developed pattern libraries to support the automatic extraction of abstract tests from the EUC model. They are test requirements pattern library and testcase pattern library. Here, an automated tool support called TestMEReq is also developed to realize the approach. The test-authoring template to assist requirements engineer to write accurate tests is also developed. Then, a real-time collaborative approach is also integrated with the tool to encourage users' involvement in the validation process as well as to support better communication and collaboration among stakeholders. Finally, a comprehensive evaluation of the approach, comprising experiments of correctness test and usability test were conducted. In summary, the findings of the evaluations show that our approach can contribute to the body of knowledge of requirements engineering especially in enhancing the quality of requirements at the earliest stage. It is found that the approach is able to enhance the correctness level of the elicited requirements compared to the manual approach and produce correct generation of test. The results of the usability tests show that the approach is useful and helpful in validating the quality of requirements at the early stage of software development and able to ease the requirements validation process.

ABSTRAK

Penggunaan perisian sistem dan aplikasi telah meningkat secara besar-besaran untuk memenuhi pelbagai keperluan organisasi, perniagaan dan individu. Maka, perisian sistem dan aplikasi yang berkualiti tinggi amat diperlukan untuk memastikan ia menyediakan fungsi yang dikehendaki. Bagi mencapai perisian sistem dan aplikasi yang berkualiti, keperluan perisian yang berkualiti tinggi perlu dikenalpasti dan divalidasikan. Walau bagaimanapun, ia sukar untuk dicapai disebabkan oleh fleksibiliti keperluan bahasa semulajadi yang mengelirukan dan mudah disalah tafsir. Ini akan menyebabkan masalah berkaitan-keperluan seperti kesilapan, ketidaksempurnaan, dan tidak konsisten. Kesilapan di dalam keperluan ini akan menghasilkan perisian yang rosak dimana ianya tidak diinginkan and diterima oleh pemegang kepentingan. Oleh itu, ia amat penting untuk keperluan perisian memenuhi atribut berkualiti seperti ketepatan, lengkap dan konsisten (3Cs). Motivasi kepada masalah ini, objektif penyelidikan ini adalah untuk membina satu pendekatan automatic untuk menvalidasikan kualiti keperluan melalui Ujian berasaskan Keperluan (RBT) bersama model separa formal. Penyelidikan ini mencadangkan satu pendekatan automatik baharu untuk membantu Jurutera Keperluan dan pelanggan-pemegang kepentingan untuk menvalidasikan kualiti keperluan perisian. Untuk ini, kami menjana ujian abstrak dengan mengintegrasikan metodologi Ujian berasaskan Keperluan (RBT) dan prototaip pantas bersama model separa formal: Kes Berguna Penting (EUC) dan Antara-muka Penting (EUI). Kami kemudiannya telah membangunkan pangkalan data untuk menyokong pengektakan ujian abstrak daripada EUC model secara automatik. Pangkalan data tersebut terdiri daripada ujian keperluan dan kes ujian. Disini, satu alatan sokongan automatik dipanggil TestMEReq juga dibangunkan untuk merealisasikan pendekatan tersebut. Templat pengarang-ujian untuk membantu Jurutera Keperluan menulis ujian yang tepat juga dibangunkan. Kemudian, satu pendekatan kolaborasi masa-sebenar juga diintegrasikan bersama alatan tersebut untuk menggalakkan penglibatan pengguna dalam proses validasi serta menyokong komunikasi dan kolaborasi yang lebih baik diantara pemegang kepentingan. Akhir sekali, penilaian menyeluruh pendekatan terdiri daripada eksperimen ujian ketepatan dan kebolegunaan telah dijalankan. Kesimpulannya, dapatan daripada penilaian menunjukkan pendekatan kami mampu menyumbang kepada badan pengetahuan kejuruteraan keperluan terutamanya dalam meningkatkan kualiti keperluan perisian di peringkat awal. Ianya dikenalpasti bahawa pendekatan ini boleh meningkatkan ketepatan keperluan yang dicungkil berbanding manual dan menghasilkan ketepatan ujian penjana. Kemudiannya, keputusan ujian kebolegunaan menunjukkan pendekatan ini berguna dan membantu dalam menvalidasikan kualiti keperluan perisian pada peringkat awal pembangunan aplikasi dan memudahkan proses validasi keperluan perisian.

ACKNOWLEDGEMENTS

All praise and thanks belong to Allah the Most Gracious, the Most Merciful for choosing me to experience this wonderful journey. I was blessed with good health, strength, and ability to complete this study.

I would like to thank all who contributed in the completion of this thesis. My sincere thanks go to my supervisors, Associate Professor Dr. Massila Kamalrudin and Professor Dr. Mokhtar Mohd Yusoff for the patience guidance, encouragement and advices toward the completion of this thesis. I am extremely lucky to have committed supervisors who willing to spare their precious time to help me with my study; for many fruitful discussions and constructive suggestion for improvement.

In addition, I would like to thank everyone from my research group for their continuous assistance and support. A very special thanks to Associate Professor Dr. Safiah Sidek for valuable proofreading and numerous advice on the organisation of this thesis.

My deepest thanks go to my family who always be with me through thick and thin, especially to my husband and my children for their incomparable patience, support and understanding.

Thanks for all your encouragement.

TABLE OF CONTENTS

| | PAGE |
|---|-------------|
| DECLARATION | |
| APPROVAL | |
| DEDICATION | |
| ABSTRACT | i |
| ABSTRAK | ii |
| ACKNOWLEDGEMENTS | iii |
| TABLE OF CONTENTS | iv |
| LIST OF TABLES | vii |
| LIST OF FIGURES | ix |
| LIST OF APPENDICES | xii |
| LIST OF ABBREVIATIONS | xiii |
| LIST OF PUBLICATIONS | xiv |
| | |
| CHAPTER | |
| 1. INTRODUCTION | 1 |
| 1.1 Introduction | 1 |
| 1.2 Research Background | 1 |
| 1.3 Problem Statement | 3 |
| 1.4 Research Questions | 5 |
| 1.5 Research Objectives | 6 |
| 1.6 Research Contributions | 7 |
| 1.7 Thesis Organization | 8 |
| 1.8 Summary | 10 |
| | |
| 2. LITERATURE REVIEW | 12 |
| 2.1 Introduction | 12 |
| 2.2 Software Requirements and Quality Attributes | 12 |
| 2.2.1 Quality Criteria of Requirements | 15 |
| 2.2.2 Analysis on Quality Criteria of Requirements | 16 |
| 2.3 Requirements Validation | 19 |
| 2.3.1 Requirements Validation Techniques | 22 |
| 2.3.1.1 Requirements Review | 22 |
| 2.3.1.2 Requirements Prototyping | 23 |
| 2.3.1.3 Requirements Testing | 24 |
| 2.3.1.4 Viewpoint-Oriented Requirements Validation | 25 |
| 2.3.1.5 Summary of Requirements Validation Techniques | 27 |
| 2.3.2 Related Work on Requirements Validation | 28 |
| 2.4 Preliminary Studies | 35 |
| 2.4.1 User Study of Generating Abstract Tests for Requirements Validation | 36 |
| 2.4.2 Interview | 39 |
| 2.4.3 Discussion and Summary of Preliminary Studies | 41 |
| 2.5 Research Gap Analysis | 43 |
| 2.5.1 Essential Use Case (EUCs) and Essential User Interface (EUI) Models | 46 |

| | | |
|-----------|--|------------|
| 2.5.2 | Requirements-based Testing | 48 |
| 2.5.3 | Template-based Approach | 50 |
| 2.6 | Summary | 51 |
| 3. | RESEARCH METHODOLOGY | 52 |
| 3.1 | Introduction | 52 |
| 3.2 | Research Design | 53 |
| 3.3 | Phase 1: The Analysis | 53 |
| 3.3.1 | Literature Review | 54 |
| 3.3.2 | Preliminary Study | 58 |
| 3.3.2.1 | User Study | 58 |
| 3.3.2.2 | Interview | 61 |
| 3.4 | Phase 2: The Design and Development | 63 |
| 3.5 | Phase 3: Testing and Evaluation | 65 |
| 3.5.1 | Correctness Test | 65 |
| 3.5.1.1 | Comparison between Manual and Automated Approach | 65 |
| 3.5.1.2 | Correctness Ratio | 66 |
| 3.5.2 | Usability Test | 66 |
| 3.5.2.1 | Usability Test I: Survey Questionnaire | 67 |
| 3.5.2.2 | Usability Test II: Interview | 82 |
| 3.6 | Summary | 82 |
| 4. | AUTOMATED REQUIREMENTS VALIDATION APPROACH | 83 |
| 4.1 | Introduction | 83 |
| 4.2 | Automated Approach for Requirements Validation | 83 |
| 4.2.1 | Extraction of Abstract Tests for Requirements Validation | 85 |
| 4.2.1.1 | Development of Test Requirements and Test Cases Pattern Libraries | 88 |
| 4.2.2 | Template-based Tests Authoring to Write Quality Abstract Test | 96 |
| 4.2.3 | Real-Time Collaborative Requirements Validation for Effective Communication and Collaboration | 97 |
| 4.3 | Requirements Dependency and Quality Checking | 97 |
| 4.4 | Tool Support | 102 |
| 4.5 | Usage Example | 103 |
| 4.6 | Tool Architecture | 106 |
| 4.7 | Summary | 110 |
| 5. | RESULT AND DISCUSSION | 112 |
| 5.1 | Introduction | 112 |
| 5.2 | Correctness Test | 112 |
| 5.2.1 | Correctness Test I: Comparison Study between Manual Task and TestMEReq Tool | 113 |
| 5.2.2 | Correctness Test II: Correctness Ratio | 113 |
| 5.3 | Usability Test | 115 |
| 5.3.1 | Usability Test I: Survey Questionnaire | 115 |
| 5.3.2 | Usability Test II: Interview | 145 |
| 5.4 | Threat to Validity | 146 |
| 5.5 | Summary | 148 |

| | | |
|-----------|---|------------|
| 6. | CONCLUSION AND FUTURE WORK | 150 |
| 6.1 | Introduction | 150 |
| 6.2 | Summary of Research Objectives | 150 |
| 6.2.1 | Summary of Research Objective 1 | 150 |
| 6.2.2 | Summary of Research Objective 2 | 151 |
| 6.2.3 | Summary of Research Objective 3 | 152 |
| 6.3 | Limitations | 152 |
| 6.4 | Conclusion and Recommendation for Future work | 153 |
| | REFERENCES | 155 |
| | APPENDICES | 173 |

LIST OF TABLES

| TABLE | TITLE | PAGE |
|--------------|--|-------------|
| 2.1 | Common Quality Criteria Validated in Related Studies | 17 |
| 2.2 | Frequency Table With Heat Map Representation | 18 |
| 2.3 | Comparison of Requirements Validation Techniques | 27 |
| 2.4 | The synthesis Results on Requirements Validation | 29 |
| 2.5 | The Distribution of Common Requirements Validation Techniques | 32 |
| 2.6 | The Requirements Sample (left-hand side) and EUC Model (right-hand side) | 37 |
| 2.7 | Correctness Measurement | 38 |
| 2.8 | The Correctness Results From the Participants | 38 |
| 2.9 | Background Information of the Experts | 39 |
| 2.10 | Requirements Validation Techniques Used by the Experts | 40 |
| 2.11 | Medium of Communication Used to Validate Requirements | 41 |
| 2.12 | Relation between the Problems and Research Contribution | 46 |
| 3.1 | Quality Assessment Checklist | 57 |
| 3.2 | Requirements Sample and Associated EUC Model | 60 |
| 3.3 | Background Information of the Respondents | 62 |
| 3.4 | Summary of Usability Tests | 67 |
| 3.5 | The Demography Details of the Survey Participants | 69 |
| 3.6 | CD Dimension and Meaning by Blackwell | 71 |
| 3.7 | CD Notations Used and Question Evaluating Them | 72 |

| | | |
|-----|---|-----|
| 4.1 | The Detail Description of the EUI Pattern Category | 90 |
| 4.2 | The EUI Pattern and Test Case Category of the EUC Model | 91 |
| 4.3 | Decision Table for Login Function | 94 |
| 4.4 | Final Test Case Derives from Decision Table | 95 |
| 4.5 | The Main Component of Our Test Case Pattern Library | 95 |
| 4.6 | The Dependency Relationship Between EUC Model, Test Requirements and Test Cases | 98 |
| 5.1 | Results from Comparison of Manual and Automated Approach | 113 |
| 5.2 | CD Study Result – Generate Abstract Tests | 118 |
| 5.3 | Frequency Table for the Result of Open-ended Question | 121 |
| 5.4 | CD Study Result – Template-based Test Authoring | 125 |
| 5.5 | CD Study Result – Real-Time Collaborative Approach | 131 |
| 5.6 | Coding Scheme for Communication Pattern | 136 |
| 5.7 | Statements Extracted from the Discussion | 137 |

LIST OF FIGURES

| FIGURE | TITLE | PAGE |
|---------------|---|-------------|
| 1.1 | Waterfall Model | 2 |
| 1.2 | The Structure of the Thesis | 8 |
| 2.1 | Requirements Engineering Process | 20 |
| 2.2 | The Concept of Viewpoint-oriented Requirements Validation (Kotonya and Sommerville, 1998) | 26 |
| 2.3 | Type of Contribution by the Related Studies in Requirements Validation | 31 |
| 2.4 | Modes of Approaches in Requirements Validation | 31 |
| 2.5 | Heat Map Representation: Categorisation of Type of Contribution, Mode of Approach, Requirements Type and Requirements Validation Techniques | |
| | Heat Map Representation: Classification of the Model Used as a Semi-formal | 34 |
| 2.6 | Requirements Validation Approach | |
| | Findings from Preliminary Studies | 35 |
| 2.7 | Theoretical Framework of Our Research | 42 |
| 2.8 | Example Natural Language Requirement (Left Hand Side) and Example of | 45 |
| 2.9 | EUC | |
| | Example of EUI Prototype Iterates from EUC Model | 47 |
| 2.10 | The 12 Step Process of RBT Methodology (Skoković et al., 2010) | 48 |
| 2.11 | Research Design | 49 |
| 3.1 | The Systematic Literature Review Protocol | 53 |
| 3.2 | The Flowchart of the Procedure for Usability Test | 55 |

| | | |
|------|--|-----|
| 3.3 | The Flowchart of the Task List for Part 1 of the Evaluation | 75 |
| 3.4 | The Flowchart of the Task List for Part 2 of the Evaluation | 77 |
| 3.5 | The Flowchart of the Task List for Part 3 of the Evaluation | 78 |
| 3.6 | The 12 Step Process of RBT Methodology (Skoković et al., 2010) | 80 |
| 4.1 | The Overview of Our Automated Approach for Requirements Validation | 86 |
| 4.2 | The Development Flow of Abstract Tests Pattern Libraries | 86 |
| 4.3 | The Phrase Structure Tree for Our Test Requirements Pattern Library | 89 |
| 4.4 | The Dependency Relationship between EUC Model, Test Requirements, Test | 93 |
| 4.5 | Cases and Test Scripts | |
| | Outline of our Requirements Quality Checking Process | 98 |
| 4.6 | Our Conceptual Model to Define the Consistency, Completeness and | 99 |
| 4.7 | Correctness of the Requirements Representation and Abstract Tests | |
| | User Interface of TestMEReq in Used | 101 |
| 4.8 | The Real-Time Collaborative Platform Embedded in TestMEReq | 104 |
| 4.9 | Test-Authoring Template of TestMEReq | 106 |
| 4.10 | The MVC Design Pattern | 106 |
| 4.11 | Basic Layout of Three-tier Architecture | 107 |
| 4.12 | The High-Level Architecture of TestMEReq | 107 |
| 4.13 | The Results of Tool Correctness | 108 |
| 5.1 | Usability Study Result – Generate Abstract Tests | 114 |
| 5.2 | Usability Study Result - Template-based Test Authoring | 118 |
| 5.3 | Usability Study Result – Real-Time Collaborative Support | 125 |
| 5.4 | Requirements Errors Found by Each Group | 131 |
| 5.5 | Communication Interaction Pattern of Each Group | 135 |
| 5.6 | Comparison Result of Usability Study | 137 |
| 5.7 | Comparison Results of CD Study for the Three Parts of the Evaluation | 139 |
| 5.8 | Comparison Results of Undecidability of Responses in CD Studies | 141 |

LIST OF APPENDICES

| APPENDIX | TITLE | PAGE |
|-----------------|-------------------------------------|-------------|
| A | Consent form (Survey Questionnaire) | 173 |
| B | Preliminary Study | 174 |
| C | Interview Protocol | 178 |
| D | Generate Abstract Tests | 180 |
| E | Template-based Test Authoring | 186 |
| F | Real-Time Collaborative Validation | 193 |
| G | Observational Checklist | 201 |
| H | Consent form (Interview) | 202 |
| I | Sample Requirements Scenario | 203 |

LIST OF ABBREVIATIONS

| | | |
|-----------|---|---|
| TestMEReq | - | Test Malay English Requirements |
| 3C | - | Correctness, Completeness and Consistency |
| RBT | - | Requirements-Based Testing |
| EUC | - | Essential Use Case |
| EUI | - | Essential User Interface |
| UTeM | - | Universiti Teknikal Malaysia Melaka |
| TR | - | Test Requirements |
| TC | - | Test Case |
| IT | - | Information Technology |
| CD | - | Cognitive Dimensions |
| GUI | - | Graphical User Interface |

LIST OF PUBLICATIONS

1. Moketar, N., Kamalrudin, M., Mohd Yusof, M., & Sidek, S., “A Review on Requirements Validation for Software Development”, *Journal of Theoretical and Applied Information Technology*, vol.96(11), pp. 3182-3193, 2018.
2. Moketar, N., Kamalrudin, M. “Extraction of Essential Requirements from Natural Language Requirements”, *Journal of Telecommunication, Electronic and Computer Engineering*, vol.10(2-2), pp. 35-38, 2018.
3. Moketar, N., Kamalrudin, M., Mohd Yusof, M., & Sidek, S., “A Study of Generating Abstract Test for Requirements Validation among Requirements Engineers”, *Journal of Theoretical and Applied Information Technology*, vol.95(7), pp. 1381–1388, 2016.
4. Moketar, N., Kamalrudin, M., Sidek, S., Robinson, M., & Grundy, J., “An Automated Collaborative Requirements Engineering Tool for Better Validation of Requirements”, 31st IEEE/ACM International Conference on Automated Software Engineering (ASE), pp. 864-869, 2016.
5. Moketar, N., Kamalrudin, M., Sidek, S., Robinson, M., & Grundy, J. (2016). “TestMEReq: Generating Abstract Tests for Requirements Validation”, 3rd International

Workshop on Software Engineering Research and Industrial Practice (SER&IP), pp. 39-45, 2016.

6. Moketar, N., Kamalrudin, M., Sidek, S., Akmal, S., and Robinson, M., "A Template-based Test-Authoring Tool to Write Quality Tests for Requirements Validation", *Communication in Computer and Information Science* 671, pp. 113-120, 2016.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter presents an overview of this thesis. First, it describes the background of the research and introduces the motivation of the research. The next section presents the research questions as well as the objectives of the research, followed by the description of the contribution of the study in relation to the field of Requirements Engineering. Finally, the chapter concludes with the outline of the thesis structure.

1.2 Research Background

In-line with the massive growth of technology, the usage of software systems and applications has increased accordingly. The demand for the software has risen in the early 1960s and expanded greatly with the emerging of personal computers (PC) in the middle of 1970s. It has continued to grow in the recent years with the rapid evolution of mobile devices such as laptops, tablets, and smartphone. Software systems have been used for various kinds of purpose and have delivered many positive impacts to the way howan (a) organization, business and individual works and coordinates. They are designed and developed to automatically handle complex functionality in various domains of application to ease the manual tasks and processes as well as to increase the productivity. Accordingly, the demand for high quality of software system has also increased to ensure it provides the intended functionality as required by the users. High quality software system is extremely

important for the safety-critical domains such as healthcare, infrastructure, and transportation to avoid any risks such as failure or malfunction in the software that may result in serious injury or death, as well as lost or severe damage to equipment/property. However, developing an effective and high-quality software system is not an easy task. It involves a few critical phases and activities that require full commitment and collaboration from all client-stakeholders to ensure its success.

There were many Software Development Life Cycle (SDLC) models proposed such as waterfall, spiral, V-model, and agile model. Regardless of these various models and methodologies, a software development process generally involves five main phases, which include the requirements analysis, design, development, testing, and maintenance. Figure 1.1 shows the traditional SDLC model: the Waterfall model(Sommerville, 2001). Among these phases, the requirements analysis is claimed to be the most essential phase in a software development process since it gives critical impact to the quality of end product (Hsia et al., 1993)(Lamsweerde, 2000)(Vieira et al., 2012).

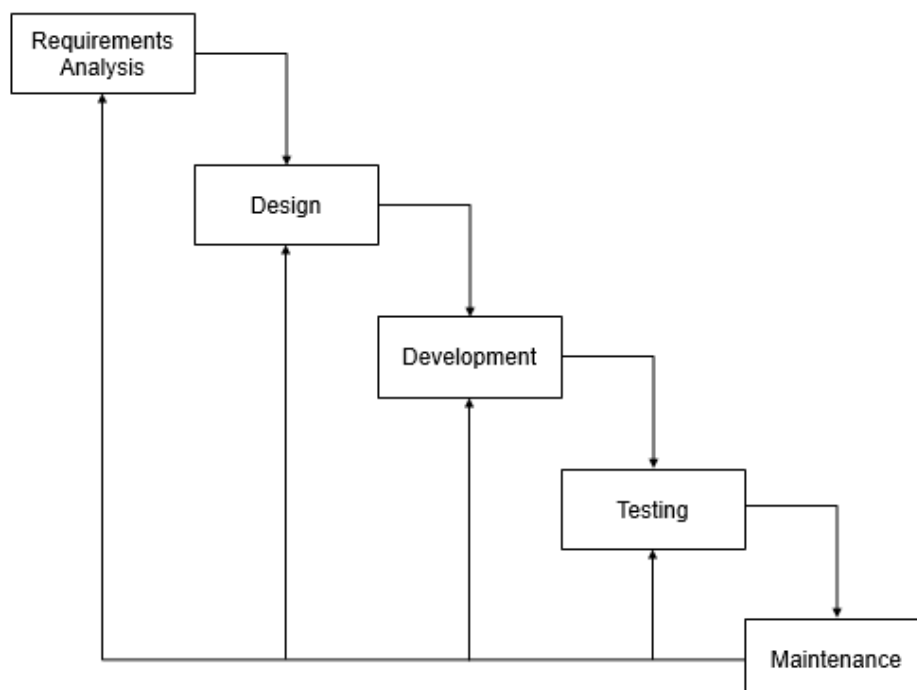


Figure 1.1: Waterfall Model