DEVELOPING A WEB-BASED RESEARCH ADMINISTRATION AND MANAGEMENT SYSTEM: CASE STUDY OF A SOUTH AFRICAN HIGHER EDUCATION INSTITUTION

By

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Declaration

I, Misheck Nyirenda, hereby declare that this dissertation is my own work and has not been previously submitted in any form to any other university or institution of higher learning by other persons or myself. I further declare that all the sources of information used in this dissertation have been acknowledged and a list of references is provided.

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Dedication

I dedicate this dissertation to my beloved wife Mjesa who has given me and our children the unconditional love and friendship. I also dedicate this dissertation to my children Shalom and Ezekiel who are so precious to us. Without their enduring support and encouragement, the writing of this dissertation would not be a success.

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I would like to express my sincere gratitude to the Association of Commonwealth Universities (ACU) for the financial support to allow me to study for my Master's degree. Surely without the Commonwealth scholarship it would have been very difficult for me to embark on my Masters study.

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Above all, I thank the Almighty God who makes everything possible for me. His incredible work in lives of many people for my sake. Surely God's grace wins every time.

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LIST OF ABBREVIATIONS

AAU	Association of African Universities
ACU	Association of Commonwealth Universities
ASM	Abstract State Machines
CERIF	Common European Research Information Format
CESSDA	Consortium of European Social Science Data Archives
CRIS	Current Research Information System
CSS	Cascading Style Sheets
DHET	Department of Higher Education and Technology
DSR	Design Science Research
DSRM	Design Science Research Methodology
DST	Department of Science and Technology
DUT	Durban University of Technology
EPSRC	Engineering and Physical Sciences Research Council
FEDS	Framework for Evaluation in Design Science
HEIs	Higher Education Institutions
HR	Human Resources
HTML	Hypertext Markup Language
HTTPS	Hyper Text Transfer Protocol Secure
IDRC	International Development Research Centre
IS	Information Systems
IT	Information Technology
ITSS	University's Information Technology Support Services
NEH	National Endowment for the Humanities
NIH	National Institutes of Health
NRF	National Research Foundation
NSF	National Science Foundation
OCL	Object Constraint language
OECD	Organisation for Economic Co-operation and Development
ORCID	Open Researcher and Contributor ID
PC	Personal Computer
PHP	Hypertext Preprocessor
RAMS	Research Administration and Management System
RDM	Research Data Management
RIMS	Research Information Management System
SUS	System Usability Scale
UI	User Interface
UK	United Kingdom
UML	Unified Modelling Language
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United States of America
VDM	Vienna Development Method

Artefact

The artefact resulting from this work is currently being considered for patent by the Durban University of Technology. For the purposes of evaluation, the artefact was hosted on a web server and can be accessed at https://www.dutresearch.co.za. All the data that may be currently present in the system was entered primarily for purposes of testing and evaluation. For demo purposes the following login details can be used:

Username: rose

Password: 2017_rose123456%

ABSTRACT

Research has become one of the major activities of higher education institutions (HEIs) worldwide. Increasingly important is research information that emanates from the published research as it has now become one of the major sources of funding especially within the South African higher education landscape. However, many HEIs are facing numerous problems managing research information to sustain and attract more funding. The lack of resources to build or acquire appropriate systems for managing research information has been identified as one of the major challenges in HEIs. However, recent studies show that advancements have been made in some countries to address the challenge. For instance, in South Africa, a proprietary research information management system (RIMS) has been implemented in some HEIs. Nevertheless, some HEIs still face problems regarding the use of RIMS. Studies further show that most proprietary systems do not adequately satisfy requirements as desired by the HEIs. This is mostly because proprietary systems are developed without fully understanding the user requirements of individual HEIs. Moreover, most proprietary systems are developed following ad hoc approaches which neglect the requirements specification stage in the development life cycle. Requirements specification is important as it brings developers and users to a common understanding about the requirements of the system before development. The initial lack of consensus about system requirements results in systems that have technical barriers which make users shun from using them. For instance, such systems do not adapt very well to devices with small screens such as mobile phones, and do not have attractive interfaces to make users want to use them. Proprietary systems are also costly to acquire and maintain. Moreover, HEIs may not be able to immediately implement the new desired features in the system because proprietary systems usually do not allow them access to the source code. This study develops a web-based research administration and management system (RAMS) as a proposed solution to the problems of using a proprietary system to manage research information at a South African higher education institution. The study emphasises the use of formal methods for requirements specification to build an optimal system. Consequently, the Zermelo-Fraenkel Z specification language was used to specify the requirements of the proposed system which was developed in close collaboration with the intended users who also assessed its usability. The system evaluation responses were made on a 5-point Likert scale ranging from Strongly Disagree to Strongly Agree. The overall results of the evaluation show that RAMS is usable and suitable for managing research information, nonetheless improvements are recommended.

CHAPTER 1: INTRODUCTION

It is almost next to impossible to think how life would be without any sort of development in the way we live. Most developments and I will venture to say all developments, in one way or the other, are a result of research. There is a plethora of advancements that we have come to see manifest in different aspects of our lives which were not present in the past thousand years. In fact, in the past, some of these advancements were only seen as a figment of imagination while other people thought they were impossible to realize. Thanks to research, we now have come to acknowledge that what is seen as impossible is possible. Napoleon Hill realized the same when he stated that "whatever the mind can conceive and believe, it can achieve" (Hill 2011).

In the 18th century, when Alexander Graham Bell invented a telephone (Karamian 2012), no one thought that one-day people would depend on this innovation to conduct their daily business transactions and to use it to stay connected with their family, friends and relatives. In those early days, telephones were merely used for exchanging information through voice transmission (Karamian 2012). The advent of the telephone technology has undergone a number of improvements which have radically transformed the lives of people and many businesses today. These improvements have been strongly depended on continued research in the telephone technology. Due to the continuity of research in this field, today we have special forms of telephones called smartphones that have a variety of innovative features which are used for various purposes such as entertainment, gaming, social networking, education and research (Sarwar and Soomro 2013). These advances, therefore, go to show that research is an integral part of many aspects that constitute our lives, in particular the research that is conducted in HEIs.

To fully realise the potential benefits of research, it is important to manage the information that emanates from it. The information produced as a result of research usually serves many purposes such as referencing, development, innovations, and further research. The effective management of research information has recently become one of the major ventures of most HEIs worldwide. As a result of this, we have seen a paradigm shift in terms of managing research information in HEIs, moving from paper-based to computer-based management. This shift has been motivated by the high volume of research information produced in HEIs which has posed numerous challenges in terms of processing and analysing (Biddick 2012). The literature reveals that there are a number of HEIs, especially in Europe and America, that have shifted towards computer-based research information management

systems (Green *et al.*, 2010; Borden *et al.*, 2013). However, this is not the case with most HEIs in Africa. Nevertheless, the South African government has attempted to bridge this gap through a proprietary system called Research Information Management System (RIMS) which was launched on 26th February 2008 (RIMS 2011). RIMS was implemented with an aim of providing a common system platform for publicly funded South African HEIs to support their research administration processes. However, there are serious issues regarding its usability. Hence this study was instituted to uncover these issues and find a solution to address some of the issues identified in the implementation of RIMS across South African higher education system.

1.1. Problem statement

The monitoring and management of research in HEIs generally is a complex and extensive set of processes that, taken together, encompass comprehensive work for HEIs (Board *et al.*, 2013). It is further reported that in the early days of government funding, the process of research management was largely paper-based, with research administrators steering research projects through to completion. However, over time, the scope of funding possibilities, the amount of money and resources involved in the research, and the requirements attached to administering the research grew so large such that paper-based management is no longer viable nor sustainable. Therefore, research administrators are continually looking for better ways to properly manage research information in HEIs and computer-based systems have been preferred and have become one of the fundamental components in effective management of research information in recent years.

According to Biddick (2012), the higher volume of research data emanating from research as more and more researchers engage in research, coupled with funder requirements to publicize the outputs of publicly funded research, is one of the serious challenges that most HEIs face in managing research information. In addition, most HEIs particularly in developing countries do not have appropriate systems for managing research information. Moreover, most HEIs in developing countries do not have proper research data management plans, hence, research information management is carried out haphazardly (Tsang 2014; Biddick 2012). The high volume of research information together with lack of appropriate management tools in HEIs makes the processing and analysing of research information intrinsically difficult, monotonous, and complex. These challenges have impelled HEIs globally to call for technological ways to effectively and efficiently manage and disseminate their research

information. For instance, in South Africa, a proprietary research information management system (RIMS) has been implemented in some HEIs to support their research administration processes (RIMS 2011). This system is at the heart of this research because it presents a number of issues that can be considered as limiting factors to the users who want to exploit the full potential of RIMS. Some of the major issues that are associated with RIMS implementation include inflexibility to support the changing requirements of HEIs and high maintenance costs (Kazmeyer 2017; Pankaja and Mukund 2013). Since RIMS is a proprietary system it is difficult for this system to immediately house any desired changes in the requirements because of the restrictions in accessing source code. A study by Brown *et al.* (2015) affirms that the major concern for many HEIs regarding their research information management systems is mainly inflexibility. According to Pankaja and Mukund (2013), the high maintenance cost that is identified in RIMS is common with many proprietary systems. Another issue of RIMS is inadequacy in terms of features that are desirable specifically by each HEI in South Africa. Moreover, RIMS is complex to use as it comprises interfaces that are not appealing and require the user to perform many steps to achieve a simple task.

The combination of the various issues of RIMS and the ever-growing new pressures on research administrators in HEIs in South Africa to properly manage research to effectively report outputs to the Department of Higher Education and Technology (DHET) and other internal and external stakeholders begs for departure to another evolutionary level. The goal therefore, is to get to a new level of research information management that is not costly and affords research administrators in South African HEIs the flexibility to ease of access to data for reporting and analytics to ensure compliance, operating efficiency and timely decision making. To attain this goal, we need to design and develop an optimal web-based system that could be used for managing research information within HEIs in South Africa.

This study aimed at developing a web-based research administration and management system (RAMS) that could be used for managing research information in South African HEIs. The Durban University of Technology (DUT) was selected as a case study because of the availability of information pertaining to the management of research information. DUT was also one of the institutions that had joined the RIMS Consortium and had first-hand experience of the challenges in using the proprietary system. It is worth mentioning that the system proposed in this study is aimed at addressing some of the technical barriers such as ease of use, access, completeness, quality and competing architectures which are present in RIMS. These barriers have been well enunciated by Jeffery (2012). He further explains that most research

information management systems usually have interfaces that only work well with a keyboard and screen, and the vast majority are not compatible with mobile devices with their small screens and use of gestures for interaction.

1.2. Research question

It is apparent that the nature of the various problems of RIMS can be resolved through the design and implementation of a system in close collaboration with the intended users. Therefore, to achieve this, the following research question is rigorously pursued in this study.

- How can we model and implement an optimal web-based system for effectively and efficiently managing research information in higher education institutions in South Africa?

1.3. Aim and objectives

In line with the research question articulated above, the main aim of this study is to develop a web-based research administration and management system that could be used for managing research information in South African higher education institutions. To succeed in the pursuit of the aforesaid aim, the following objectives were established:

1. To elicit the requirements of an optimal web-based research administration and management system for HEIs;

2. To model the requirements of an optimal web-based research administration and management system as a formal specification;

3. To design and implement the specification of an optimal web-based research administration and management system; and

4. To evaluate the developed web-based research administration and management system.

1.4. Research method

This study is accomplished by employing the design science research methodology (DSRM) (Peffers *et al.*, 2007). The DSRM is preferred because of its flexible and iterative nature which enables the design and evaluation of an artefact to produce a viable solution to the research problem identified. In addition, the Design Science Research (DSR) guidelines proposed by Hevner *et al.* (2004) are employed in conjunction with DSRM to provide a robust framework of this study.

1.5. Important definitions and concepts

This section presents some of the definitions and key concepts as used in the study. Before presenting some of the definitions, it is worth pointing out that although some authors make a point of distinguishing between data and information, the distinction is avoided in this study. It is perceived that by strongly focusing on the distinction between the two concepts, the study will lose its value. Therefore, the two terms, namely, research data management and research information management, are used interchangeably in this research. The literature reveals that there are some authors who have used either of the two terms as encompassing activities of data and information management in the research process. The definition of research data management provided by Dora and Kumar (2015) encompasses the activities of data management as well as information management.

1.5.1. Research

There are many different definitions of the term "research" which appear in academic literature. Goddard and Melville (2004), defines research as "the systematic method consisting of enunciating the problem, formulation of a hypo dissertation, collecting the facts or data, analysing the facts and reaching certain conclusions either in the form of solutions towards the concerned problem or in certain generalisation for some theoretical formulation". According to Mackenzie and Knipe (2006) research is "a systematic investigation or inquiry whereby data are collected, analysed and interpreted in some way in an effort to understand, describe, predict or control an educational or psychological phenomenon or to empower individuals in such contexts". Norton (2014) defines research as original work conducted to produce new knowledge. Bodla (2014) gives a simple and concise definition of research as the process of finding solutions to a problem after a thorough study and analysis of the situational factors. All these definitions are precise and to some extent similar. In this study the definition provided by Bodla (2014) is adopted because it appropriately aligns itself with the current study.

1.5.2. Research information

Jeffery *et al.* (2014), define research information as any information that describes the research output as well as the context in which research is being conducted. According to the Association of Commonwealth Universities (ACU 2015), in a paper titled "Managing research-related information in African universities" research information is the term used to describe

the administrative information surrounding the research outputs of an institution. The authors state that research information comprises publications, projects, grants and professional activities.

1.5.3. Research information management

According to Cox and Pinfield (2014), "research data management or research information management concerns the organisation of data, from its entry into the research cycle through to the dissemination and archiving of valuable results. It aims to ensure reliable verification of results and permits new and innovative research built on existing information". Dora and Kumar (2015) describes research data management as a service consisting of different activities and processes that include creation, storage, security, preservation, retrieval, sharing and re-use of data including technical capabilities, ethical consideration, legal issues and governance framework. Dempsey (2014), defines research information management as the integrated management of information about the research life-cycle, and entities which are party to it. These definitions are accepted in the study. However, the definition by Dempsey (2014) is clearly appealing to the aim of the work of this study. This study mainly focuses on the management of research outputs which for example include publications such as journals, books, proceedings and chapters in books.

1.6. Significance of the study

This study is significant to higher education institutions in South Africa as it presents a solution that addresses their numerous problems in the aspect of research information management. It is anticipated that the resulting artefact from this research will assist research managers in HEIs to effectively and efficiently manage research information. Moreover, the prototyped system will assist research managers to easily and quickly gain a comprehensive overview of research in their respective HEI and to timely compile reports of research outputs for submission to DHET for subsidies. The study is also significant to system developers as it demonstrates and promotes the use of formal methods to specify unambiguous, consistent and verifiable requirements of an optimal research information management system.

1.7. Scope of study

The scope of this study is limited to a case study of a specific institution in HEIs of developing countries in Africa. However, the proposed system can be extended to HEIs who are facing similar challenges. This is possible because the proposed system is characterized with high

flexibility which accommodates adaptation to suit diverse needs of HEIs. It is anticipated that the proposed system will greatly assist research managers and researchers in HEIs to overcome some of the challenges they face in managing research information.

1.8. Study contributions

The key contribution of this study is the full-fledged web-based research administration and management system (RAMS) that has been produced, along with the documentation of its design and development process which is covered in this dissertation. The resulting software artefact could be utilized in HEIs within South Africa to manage research information and to produce various types of reports as may be required. Moreover, the study contributes by demonstrating how formal methods, specifically the Zermelo-Fraenkel Z language, can be applied to specify the requirements of research information management. Using formal methods for specifying system requirements is extremely crucial for achieving optimal systems.

1.9. Study outline

This dissertation is comprised of five chapters. Chapter one covers the introduction, the research problem statement, research question, aim and objectives of the research and research method. This chapter also highlights definitions of key concepts related to the study, followed by the scope of study, study contributions, and the outline of the dissertation. Chapter two provides a comprehensive review of literature related to the study. Specifically, it covers the following sections: A global perspective of research management, impacts of research information management on society, importance of research in higher education institutions (HEIs), management of research information in HEIs, challenges of research information management in HEIs, existing research information management systems, and formal methods for information systems specification. The Chapter concludes with a summary of all the sections.

Chapter three presents the methodology adopted for the execution of this study. This chapter covers the research approaches in information systems, design science research, and design science research methodology. The Chapter concludes with a recap of the all sections included in it. Chapter four of this dissertation provides the implementation and evaluation results of the proposed research administration and management system. The Chapter presents the implementation of the proposed research administration and management system,

functional description of the proposed system, evaluation of the system and results, and finally a summary of the whole chapter is presented. Lastly, chapter five presents the conclusion of the dissertation by providing the summary of the whole dissertation and the suggestions for possible future work arising from this study. Chapter five also presents the limitations of the study and recommendations.

CHAPTER 2: LITERATURE REVIEW

This Chapter provides a comprehensive review of literature related to the study. In particular, it focuses on a global perspective of research management, impacts of research information management on society, importance of research in higher education institutions (HEIs), benefits of managing research information in HEIs, challenges of research information management in HEIs, existing research information management systems, and formal methods for information systems requirements specification. The Chapter concludes with a recap of all the sections.

2.1. A global perspective of managing research information

There is clear indication in numerous studies in the literature that governments and other private institutions across the globe have a keen interest in research information and its management. Their interest has called for special attention in terms of management of research information effectively and efficiently. Flores *et al.* (2015) affirms that organizations, institutions, and governments are increasingly recognizing the importance of research data management. In fact, management of research information has become a concern for many research organizations, funding agencies, HEIs, and government entities (Quix and Jarke 2014).

Good practice in research information management plays a critical role in the lives of many people as it provides easy access to vital information that different actors can use to improve their day to day lives. It is widely acknowledged that "research information causes wealth creation and improves quality of life" (Asserson and Jeffery 2010). Asserson and Jeffery (2010) provide an analysis of how different actors in society such as researchers, research managers, innovators, funders, educators, students, policy makers and the media can benefit from good practices in research information management. The HEIs are one special entity that are acting impressively toward achieving effective and efficient management of research information, through their comprehensive research data management policies, strategies, and infrastructures (Kahn *et al.*, 2014).

Thanos (2011) highlights that, in the past years, there has been growth in research, which has resulted in a large amounts of research information. Consequently, this has increased the demand to collect, integrate, and analyse research information for various reasons (Quix and Jarke 2014). Even though managing research information is problematic, due to diverse goals of different stakeholders; Dora and Kumar (2015) point out that the management of

research information has recently emerged as a strategic priority for HEIs worldwide. Many HEIs across the globe are introducing research information management services to preserve and manage research information for future reuse and transparency as far as research is concerned. Pinfield *et al.* (2014) state that HEIs and governments, especially in developed countries, have initiated the building of their infrastructures for managing research information. Thanos (2011) indicates that "to take advantage and make use of these vast amounts of research data, e-infrastructures are required".

According to the Group of Eight (2013), governments worldwide understand that research can help drive innovation which often results in economic growth, national development and improved human welfare. However, research in HEIs worldwide is continually evolving owing to a number of factors such as the shifting budgetary climate, the growing internationalisation of higher education, advances in computing and telecommunications, and the increased demand pressed by governments on public HEIs to be more effective in managing research information (Delaney 1997). Furthermore, the demands of other research funders placed on HEIs have also contributed to this evolution. Winn (2013) affirms that in developed countries such as the UK, research funders, researchers, information professionals and government ministers stress that it is in the public interest to ensure that data which forms the basis of research findings should be made available for re-use and verification.

Kahn *et al.* (2014) affirms that in UK, funders are insisting on some level of research data management and data sharing from researchers they fund and the institutions that employ them. As a direct response to funder requirements, many HEIs, specifically in UK, are reviewing their current research data management practices and research environments to identify the additional support that is needed to ensure that compliance can be realised (Kahn *et al.*, 2014). They further state that in South Africa, the National Research Foundation (NRF) also recognises that the management of research data is an important aspect of research. Thus, HEIs in South Africa are mandated to conform to the policies stipulated for research outputs emanating from government funded research (Republic of South Africa 2015).

2.2. Impacts of managing research information on society

Good practice in research information management plays a critical role in the lives of people in society as it provides easy access to vital information that different actors can use to improve their day to day lives, as it is widely acknowledged that "research information contributes to wealth creation and improves quality of life" (Asserson and Jeffery 2010). Research

information is very crucial because it is a source of new knowledge, intellectual property and technology for creating new companies and introducing new products at the marketplace (Ghvedashvili *et al*., 2015).

Asserson and Jeffery (2010) provide an accurate analysis of how different actors in society such as researchers, research managers, innovators, funders, educators, students, policy makers and the media can benefit from good practice in research information management. For instance, researchers need access to research information that has been efficiently managed as it may help them to find potential collaborators with whom they can work with on their new research idea (Asserson and Jeffery 2010). Furthermore, efficient management of research information is also important for research managers in HEIs as it allows them timely and convenient access to it such that they can "check completeness of recorded outputs from researchers within their institutions" (Asserson and Jeffery 2010; Scholze and Maier 2012). This allows research managers to compare research outputs from their own institutions with other institutions (Asserson and Jeffery 2010). In addition, it helps research managers to make appropriate decisions regarding how to stay a step ahead of other institutions especially in these times where funding opportunities are highly competitive and are largely dependent on demonstrable research excellence and impact (Guy 2015).

Good research information management also helps funders to have access to it and "to ensure that defined outputs from the funded research proposal are delivered, to compare outputs with those from other funders, and to find appropriate referees" (Asserson and Jeffery 2010). Good research information management is also important to innovators because it helps them to timely access new and relevant "ideas which are exploitable for wealth creation and improvement in the quality of life" (Asserson and Jeffery 2010). Effective and efficient management of research information can be a rich source of teaching and learning materials for educators and students respectively (Asserson and Jeffery 2010). The media can benefit from good research information management by obtaining information that can be reorganised as stories which popularises research or raises social, ethical, political or economic issues regarding the research for public interest (Asserson and Jeffery 2010).

2.3. Importance of research in higher education institutions

Research in HEIs worldwide is of utmost significance. According to the literature, we are living in the knowledge economy where knowledge is recognised as the driver of productivity and economic growth which has led to a new focus on the role of information, technology and

learning in economic performance (Department of Science and Technology 2007; Godin 2006). In a knowledge economy, research, particularly research in HEIs, plays a vital role in advancing the economic status of society. Bernardo (2013), states that knowledge production through research has been identified as an integral contributor in a country's economic competitiveness. Therefore, universities clearly have a central role in the generation of knowledge and innovation; they are major stakeholders in national innovation strategies (Wolski and Richardson 2011; Department of Science and Technology 2007).

The potential contribution and the evolving nature of research that is conducted in HEIs to society have been well documented in the literature. Research plays a pivotal role in the systematic development of new knowledge and is central to the effectiveness of all HEIs (Njuguna and Itegi 2014). Therefore, the research function of HEIs remains a prime source of knowledge and innovation at national, regional and international levels (Kearney 2009). In an article titled "Importance of research to the University", that appears on the California State University website, it is stated that research in HEIs "discovers, elucidates and evaluates new knowledge, ideas, and the technologies essential in driving the future of society and humanity" (CSU 2016). It is further elaborated that "regionally, nationally and internationally, research activities and services of HEIs have critical economic, societal and environmental impacts". Indeed, given the current global experiences in the transference from an industrial economy to one that is driven by information and technology or a knowledge based economy, research that is carried out in HEIs, increasingly plays a vital role in the advancement of the country's economic growth and therefore raises the country's competitiveness internationally. As indicated in a paper by IDRC and AAU (ND), "the hallmark of any HEI is to undertake research that can contribute to expand the frontiers of knowledge and generate innovations that can accelerate the socioeconomic development of nations".

Research in HEIs is critical for expanding the university knowledge base, driving improvements in teaching, and in advancing social and economic gains (Green *et al.*, 2010). Additionally, research emanating from HEIs, is geared towards improving the standard of living in societies through enhancing, and generating new knowledge (IDRC and AAU ND). It is further elaborated that through innovative research, HEIs can enlighten their communities, empowering them with knowledge born of discovery. Dora and Kumar (2015), states that research emanating from HEIs is an important indicator of national development and reflects the potential of a nation to harness its human resources to solving the problems of mankind. They affirm that global problems of health, education, poverty, etc. can be better understood

and addressed effectively through research. They further point out that scholarly research broadens the horizon of policy thinking in addressing many critical issues that governments face.

According to the Group of Eight (2013), one of the essential roles of HEIs is performing research that creates new understanding, new technologies and the potential for action; and by providing a store of knowledge and capabilities that society as a whole has been able to draw upon. It is further stated that through research, HEIs have significantly contributed through the many transformations we witness today in society such as electronic communication which has become pervasive and has made it possible for us to know whatever happens almost anywhere in the world as soon as it happens. Furthermore, a significant proportion of our better health, wealth and general wellbeing (whether environmental, cultural, social or spiritual) was made possible by the research performed by HEIs. Moreover, through research, HEIs have helped society to understand the various changes, such as environmental changes that we experience today. This is largely because researchers in HEIs have taken their time to identify the trends, examined them, considered their implications now and in the future.

In a technical paper by UNESCO (2010), it is stated that the research and development work carried out in HEIs is one of the drivers of quality in higher education. Research Universities Futures Consortium (2012), affirms that research that is carried out in HEIs drives improvements in teaching and learning which then results in social and individual gains. Njuguna and Itegi (2014), state that "one of the core missions of HEIs is to advance, create and disseminate knowledge through research and provide service to the community, constant supply of qualified young researchers to assist societies in cultural, social and economic development. They further postulate that through research, HEIs contribute to innovation for mobilization of resources. Altbach *et al.* (2009), state that "research has been and continues to be an extremely important contribution of the university to the larger society".

Atkinson and Stewart (2011) posit that the U.S. economic growth is actualised through the impact of research emanating from HEIs. They further state that "companies spun out of research universities have a far greater success rate than other companies. They support this argument by providing examples of companies such as Google, Medtronic, iRobot and Facebook. These companies are making a huge impact on society as far as information and communication technology is concerned. Ghvedashvili *et al.* (2011), mention that well-developed research institutions like HEIs, are a strong basis for economic growth and sustainability because they are sources of new knowledge, intellectual property and technology

for creating new companies and introducing new products at the marketplace. According to Guy (2015), universities and stakeholders are interested in how research supports academic progression and the positive influence it has on society and the economy.

The effect of research is widely known as 'research impact' and tends to be more highly regarded when demonstrable and supported by evidence. Furthermore, demonstrable research impact is very important to HEIs, as it is routinely used to place them in international league tables and often used to support decision-making by funders in future funding rounds (Guy 2015). A study by the Research Universities Futures Consortium (2012), informs us that research is key to a university's reputation and increasingly the basis of its academic and financial success. This is especially true in the knowledge based economy where there is stiff competition for funding in HEIs as funding is tied to excellence in research as evidenced in the research outputs policy (Republic of South Africa 2015) in South Africa. This is also the case in other countries across the globe where the government has recognised research as the driver for economic growth.

Research in HEIs also serves to expand the knowledge pool, where most private sectors often draw ideas that give birth to life-changing products and services (Gachie and Govender 2015). Creso (2013) also realises the significance of research in HEIs and its impact on the private sector. HEIs provide the private sector with the opportunity to access specialized expertise, the latest knowledge in relevant disciplines, and potential future employees (students). He further explicates that the private sector also "benefit from the outputs of HEIs, in the form of additional knowledge that feeds into their own innovative processes, improved products and processes, and from technical solutions for their problems". Therefore, the stated arguments and many others lucidly point out how significant research in HEIs is and, that its importance in HEIs cannot be overstated. Indeed, as Norton (2014) states, "research is a key activity of universities" and "without research, universities could not use the 'university' title".

The importance of research in HEIs has been recognised by governments and funders in many countries worldwide and therefore they invest in research in HEIs through funding in anticipation of economic growth and research impact or solutions to real life problems. For instance, the South African government, through Department of Higher Education and Training (DHET) distributes a limited pool of funding to universities based on the measurement of research outputs (Schulze, 2008; Republic of South Africa 2015). The research funding from government comes as an incentive to HEIs to extensively engage in research because the more quality research is produced, the more funding HEIs get. Consequently, there is a stiff

competition for these funds. In turn a lot of research is being conducted in most HEIs resulting in research information which when applied appropriately leads to the economic development of society. Accordingly, there is an increasing demand for HEIs to be proactive and become more accountable to government, external and internal stakeholders in terms of reporting research outputs to sustain and access more funding. This therefore calls for efficient management of research information in HEIs where a substantial amount of research is conducted. This need has led to the evolution of computer-based research information management systems. The evolution is evident in HEIs in many countries, especially in the developed countries, where the government supports research through funding.

To effectively report research outcomes to funders, many HEIs are embracing computer-based systems as the best way to manage research information. Gaspar *et al.* (2013) alludes to the fact that information systems are built to enhance efficiency in general, in public or private sector, still they play an important role in the collection and dissemination of information in an organisation's environment. Therefore, information systems are always beneficial not only in the organisation or the public-sector environment but also in research (Gaspar *et al.*, 2013). Bian *et al.* (2014) assert that research administration and management is crucial to an organization's research infrastructure. It is therefore, not surprising to learn that many HEIs across the globe have come to recognise the value and importance of research information and have sort computerised means to properly manage research information. Yanosky (2009), writes that the National Science Foundation (NSF) in the USA recognised that "information technology had ushered in fundamentally new approaches to research and evolution" and noted that "digital data collections are at the heart of this change".

2.4. Benefits of managing research information in higher education institutions

The appropriate management of research information is extremely vital for HEIs; without excellent research information management, the potential benefits expected from the research, technology and development goals which most HEIs and countries at large have set would simply not be realised. Research information is regarded as an essential enabler in the knowledge based economy. As such many governments, national and international institutions consider efficient management of research information as vital. Curdt and Hoffmeister (2015), state that many national and international institutions such as NSF, OECD, UK Research Council have emphasized the importance of research data management in recent years. This

view is also evident in the promotion and establishment of research information management infrastructures in various HEIs worldwide.

There are many inherent benefits that can be realised from proper management of research information in HEIs. It is stated that good research data management practice can provide benefits for several key stakeholder groups, including, academic staff and researchers, students, professional services staff, and external collaborators and partners (Benefits of good RDM 2016). The proper management of research information in HEIs showcases research outputs to a global audience. Dora and Kumar (2015), assert that opening such research data sets for the public, enhances the visibility of the host institution and its researchers. Moreover, good research information management in HEIs attracts new collaborators and research partners nationally and internationally (Bruce, 2014). Kahn *et al*. (2014) affirm that collaboration between institutions, groups and individuals could help research more efficiently by reducing duplication of effort and avoiding data loss. In addition, proper management of research information ensures compliance with the research data expectations of most funding bodies. For instance, Halbert (2013), reports that most funding agencies in the United States such as the National Science Foundation (NSF), the National Institutes of Health (NIH), and the National Endowment for the Humanities (NEH), mandate data management plans as a requirement for research grant applications.

Hahnel (2015) also provides a list of funders who require research data management as a condition of grants. Green and Langley (2009) state that universities that are successful in securing research funding are required to fulfil a range of obligations. Research grants and contracts, are heavily audited, rigorously monitored and often tied to tightly-negotiated milestones and deliverables. All these necessitate the proper management of research information in HEIs. Bruce (2014) and Pink (2013) report that the EPSRC (the UK's Engineering and Physical Sciences Research Council) sent a clear message on compliance by stating that institutions that receive their funding for research must have developed a roadmap outlining support for researchers in implementing responsible and sustainable reuse of their data. Another benefit of good research information management in HEIs is that facilitates the sharing and re-use of research data for future research and therefore accelerates generation of more new knowledge. Dora and Kumar (2015) avows that long-term preservation of data provides for validation check of the data and this enhances the credibility and transparency of the research data used.

Bruce (2014) states that in addition to compliance requirements by funders, institutions want and need to demonstrate research excellence by making their studies and data discoverable, with the hope that it will drive new and exciting research efforts. She explicates that if an academic from one university has created useful datasets on a particular area, it would be much more efficient for other researchers working on that or similar areas to access these findings and build on the study rather than starting from scratch. This in turn reduces duplication and pushes research to the next level. Dora and Kumar (2015) concurs when they state that the preserved research data can be reused by the same researchers or maybe even others who may like to extend the use of such data for purposes unseen by the initial researcher. They further state that well managed research data can always be updated to enhance or extend the understanding of existing research on this data. Another benefit is that proper management of research information ensures visibility of research outputs from publicly funded research.

Dora and Kumar (2015) mentions yet another benefit that HEIs can derive through effective research information management as it becomes more economical to reuse the data, hence saving the time and resources for an institution and providing opportunities to invest elsewhere. It is also postulated that research data management enhances the discoverability of such data, thereby facilitating quality research. Van den Eynden *et al.* (2011), contends that well organised, documented, preserved and accessible and research data with controlled accuracy and validity at all times, result in high quality data, efficient research findings based on solid evidence and the saving of time and resources. Indeed, high quality research can only be realised if researchers in HEIs have access to an extensive range of relevant research information that has been produced and made public by other researchers nationally and internationally.

Appropriate management of research information brings great opportunities that exist to improve the pace and effectiveness of scholarly inquiry broadly if relevant data can be discovered, reused, recombined and repurposed in creative ways (Lynch 2014). Furthermore, good research data management practices allow reliable verification of results and pave a way for new and innovative research built on existing information (Van den Eynden *et al.,* 2011). Similarly, Mossink *et al.* (2013), state that good data management is essential for both productive research and optimal use of the new data infrastructures. The authors explain that effective management of research information is crucial for generating economic and scientific progress and for preserving this capital for future generations. In an article by CESSDA (Consortium of European Social Science Data Archives) (2015), it is stated that good research

information management practices are essential as they help to keep research information alive for generations thereby creating an impact long after the original research. Undeniably, as Bruce (2014) writes, managing research data is a crucial contributor to fulfilling research funder requirements, which will ultimately help achieve research excellence which in turn leads to economic growth. Indeed, good practice to research information management increases access to it and hence improves the sharing of new ideas thereby raising the prestige of research in HEIs, encouraging innovation and creating new growth opportunities. Therefore, HEIs are encouraged to embrace flexible and productive research information management (Ghvedashvili *et al.*, 2011) practices to realise the aforesaid and other benefits.

2.5. Challenges of managing research information in higher education institutions

There is a substantial amount of research that is carried out in most HEIs worldwide (Yanosky 2009). This research generates large amounts of research information. Yanosky (2009) reveals that there are problems which are connected to this information which is produced as a result of research such as ownership, preservation, and interpretation. Many HEIs and other research sectors are facing a serious challenge in preserving and managing voluminous research information (Winn 2013). Kahn *et al.* (2014) state that the sheer volume and distributed nature of data emanating from research has amplified the challenge of collecting, storing and reusing the research data. Yanosky (2009) states that there is a great need for institutional ability to support the long-term preservation of research data. Of course, this could be achieved in several ways, but research information management cannot be disregarded because it is at the heart of long-term preservation of research data.

Sripada (2002) elucidates that long-term research data storage, and associated data management, is the single most critical research computing need which is not being met by many HEIs, especially in developing countries. He further highlights the requirement to provide the "right information, at the right time, to the right people, in the right context, in the right format" that brings forth many information management challenges. According to Yanosky (2009), it is difficult for HEIs to provide tools that allow the right people to create, publish, find and preserve or winnow the right research content according to the needs of the institution. Njuguma and Itegi (2013) asserts that financial constraints, especially in African HEIs, negatively impact research including its mission, processes, participants' integrity, dissemination and preservation.

Most HEIs are challenged by the growth in volume of research information that they produce and required to manage (Williams and Hardy 2011). According to Biddick (2012) many HEIs in developing countries lack tools and management approaches to deal with the higher volume, complexity and dynamics of big data processing. It is further mentioned that without the right tools and architectures, HEIs will not be able to effectively use the information they have collected. Cox *et al.* (2014) reported that majority of HEIs do not have research data management infrastructures due to their lack of resources, in particular financial resources. The issue of research management approaches is also alluded to by Green and Langley (2009) and they refer to it as a lack of research strategy. The study of Green and Langley (2009) revealed that HEIs without a research strategy were not confident to have achieved their research goals. Jahnke and Asher (2012) highlights that that although digital technologies have brought new opportunities for researchers to create data sets that enable increasingly sophisticated analyses; the haphazard data management and preservation strategies endanger the benefits that this advancement might bring.

According to Bruce (2014) there is also a lack of a coordinated approach to research information management in HEIs. The literature reveals that in some HEIs there are small systems in different departments, which are concerned with managing research information in HEIs; however, these systems are operating in silos. The information about the research output and the context of research is held in numerous systems which are run by different organisational units (such as departments) using different formats and data models. This makes it impossible to combine, aggregate or integrate this rich information (Scholze and Maier 2012). Managing research information in a silo brings in risks and other challenges as HEIs cannot consolidate and standardize their research management processes, preventing HEIs from reducing costs of maintaining their information systems.

 Quix and Jarke (2014) highlighted that standardization, harmonisation and integration of research information are frequently mentioned challenges especially where computer-based (or electronic) systems have not been implemented. HEIs can reduce costs, time and effort needed for managing their research information by making a cross-institutional and departmental merger of different systems. The role of the libraries, researchers, senior leadership and information technology teams is emphasized as well as the need to work together to achieve a coordinated approach to gathering and maintaining the integrity of research data in HEIs. According to Njuguna and Itegi (2014), the challenges of research and its information management in most African HEIs are primarily caused by "failure of

governments to put in place policies that recognise the fundamental impacts that research activities could have on governance and efficient use of public resources". Curdt and Hoffmeister (2015) asserts that some of the challenges and problems to research data management in HEIs can be classified as technical, socio-cultural or ethical. They state that the insufficient communication between the involved researchers and the research managers in the design process of research information management systems is a major challenge that results in a lack of acceptance of the developed system by the researchers and a low motivation level to provide data.

The functions of university research offices in HEIs and the demands on staff working in research management have become more varied, growing to embrace a wide range of activities and responsibilities" Green *et al.* (2010). This implies that effective and efficient research management systems are essential in such environments for these individuals to effectively carry out their operations. Curdt and Hoffmeister (2015) suggests that the following be done by HEIs to solve the aforesaid problems:

1. The integration of the research data management system in the entire research process at an early stage.
2. Continuous communication between researchers and data managers within the designing and developing process of the research information system.
3. The establishment of user-friendly system interfaces.
4. The continuous provision of support and training to researchers.

2.6. Existing systems for managing research information

There are a number of initiatives that have taken place in many HEIs across the globe to address the challenges that are related to research information management. The need for proper management of research information has led to a revolution in recent years in line with the technological advancements concerning data collection, networking, storage and management. According to Jeffery *et al.* (2014), this fast-paced advancement has triggered a shift towards the paradigm of data-intensive science which has impressively changed the way research is being conducted and the way research information is managed worldwide. Increasingly important in various aspects of research activities are data infrastructures for the management of research information including research outputs (Hey and Trefethen 2005). Many HEIs in developed countries have devoted a remarkable effort in creating infrastructures or systems

that support management of research information. This section discusses some examples of various research management systems which have been realized in different HEIs world-wide.

2.6.1. Tbilisi state university research portal

A web-based research administration and information system called Tbilisi State University Research Portal (TSURP) was developed at Tbilisi State University to address the scarcity of systems that could easily provide information about research, researchers and research institutions in Georgia (Ghvedashvili *et al.*, 2011). This was perceived as an imperative need for HEIs in Georgia because the research emanating from Georgian universities was not available at the global level. The TSURP system enabled the visibility of researchers and their research projects in Georgian HEIs. The system provided new opportunities for national and international collaboration in HEIs and scientific community.

Ghvedashvili *et al.* (2011) states that TSURP is composed of three major modules for managing research, namely; user profile-CV module, publications module and research projects module. The user profile-CV module provides basic personal information of a researcher and other related information such as field of interest, projects involvement, and article publications. The publications module enables the user to submit their new publications such as books or monographs, journals and conference proceeding to TSURP database. The Research Projects module enables the user to submit information about funded research projects to the TSURP system such as title, participants, funding organisation and resume of the project.

2.6.2. Scientific research information system

Gaspar *et al.* (2013) proposed the design of a scientific research information system (SRIS) after noticing that many systems for managing research information lack the technical point of view. They argue that most systems that exist can only manage research on the levels of papers, journals, conferences, researchers, research projects, project funding and expenses management. The design of SRIS primarily covered processes of the technical research including measurement planning, data collection, analyses, and secondarily the supporting environment which includes projects, finances, and publications. The SRIS was built based on the Common European Research Information Format (CERIF) which is suitable for a wide range of research environments in Europe. The system also comprises several extraordinary

functionalities such as qualitative parameter evaluation, measurement analysis, data mining, projects and publications, evidence and control and laboratory diary.

2.6.3. Scientific research management system

Zhang *et al.* (2009) developed a scientific research management system (SRMS) for managing scientific research in colleges which are within the region of China. The motive behind the development of SRMS was the increase in scientific research information in many colleges which brought about a challenge of research information management.

The SRMS has four categories of users, namely, scientific research administrators, department administrators, scientific research teachers and visitors. The system provides different functions to each user. Although the modules for the SRMS are not explicitly outlined, but it is recognized that the system has various modules which are responsible for handling different aspects of the system. There are modules, for instance, which are responsible for managing users; collecting, examining and querying scientific research information; and ranking of scientific research information.

2.6.4. Czech R&D&I Information System

Chudlarský and Dvořák (2012) report that, in Czech Republic, a national system called Czech R&D&I Information System was developed based on current research information system (CRIS) model for managing research information. This system was built with the intention to also increase accessibility to research information and therefore contribute to transparency in the research domain which leads to an enhanced level of trust, more open competition, strengthened equality of opportunities and information access equality. The Czech R&D&I Information system provides essential features such as research projects, institutional research plans, R&D result records, cleansed R&D results, research and development calls, and funding schemes.

2.6.5. Clinical research administration

Bian *et al.* (2014) report that a web-based platform was developed and implemented, called clinical research administration (CLARA), at the University of Arkansas for Medical Science (UAMS) in USA. This system was actualized after previous systems suffered from various technological and design deficiencies such as (1) scalability issues of back-end databases, (2) data inconsistency and quality issues, (3) slow system performance and bad user experience,

and (4) lack of support for data extraction and reporting. CLARA is described as a comprehensive web-based system that can streamline research administrative tasks such as submissions, reviews, and approval processes for both researchers and different review committees on a single integrated platform. This system assists researchers to meet regulatory requirements and provides tools for managing other clinical research activities including budgeting, contracting, and participant schedule planning.

Bian *et al.* (2014) mentions that CLARA has a number of key features and components: (1) a standards-compliant user authentication and role-based access control; (2) an integrated platform that supports collaboration and communications across regulatory and administrative bodies; (3) a flexible reporting unit that supports a wide variety of data extraction requirements; (4) a feature that handles auditing of various research publications; (5) an extensible interface engine for connecting to other clinical and research systems; (6) an extensible version and change control component; (7) a study calendar-like budgeting tool; and (8) a set of tools and metrics for benchmarking clinical research administration workflows.

2.6.6. SweCRIS

Johansson and Ottosson (2012) reports that in Sweden, a system called SweCRIS was developed to collect research information from different systems in various HEIs. The SweCRIS was actualized after several national initiatives faced serious challenges in collecting and presenting information on all current research in Sweden. According to Johansson and Ottosson (2012) one of the major difficulties was the use of manual systems to disseminate research information. This led to the development of SweCRIS which was hatched by the ten member universities in Sweden ScienceNet.

The goal of SweCRIS was to structure and present the research information in Sweden, in a coherent manner, increase the visibility of research activities, facilitate future collaborations, and enable strategic questions about the research funding to be answered. The SweCRIS was further developed as a national platform in cooperation with the HEIs in Sweden. This allowed all major public funding agencies to provide data to Sweden ScienceNet seamlessly, through SweCRIS.

2.6.7. Current Research Information System in Norway

Sidselrud and Lingjærde (2012) reports that in Norway a common national research information system called Current research information system in Norway (CRIStin) has been

used by 150 institutions since 2011. CRIStin was actualised through collaboration between the Ministry of Education and Research and the Ministry of Health by a restructuring process of a system called FRIDA that was previously used for research documentation in the four oldest universities in Norway (Sidselrud and Lingjærde 2012; Karlstrøm and Wenaas 2014). CRIStin is used to manage scientific publications from all publicly financed research institutions in Norway and hence fosters the open access initiative to Norwegian research publications (Karlstrøm and Wenaas 2014; Wenaas *et al*., 2012).

According to Sidselrud and Lingjærde (2012) and Karlstrøm and Wenaas (2014), the major benefit of CRIStin is that it showcases the university research outputs to the public and hence increases the opportunity for society to draw upon it for innovations. A publication record in CRIStin is entered once by the individual institution and the institution retains control over changes on the record until the record is submitted for annual reporting by the institution at which point the institution cannot make any changes to the record. The CRIStin is a single point of entry for all research publications in Norway and therefore is the main reporting tool for research-based funding, and simplifying administrative routines for researchers (Wenaas *et al*., 2012). CRIStin contains data about institutions and data about researchers and their institutional affiliations (Sidselrud and Lingjærde 2012).

2.7. Ideal systems for managing research information in HEIs in developing countries

To improve the management of research information in HEIs of developing countries, an ideal infrastructure or system is required. Unlike HEIs in developed countries, most HEIs in developing countries do not have appropriate infrastructure or systems to effectively and efficiently manage their research information. Moreover, they do not have proper research data management plans, hence, research information management is carried out haphazardly (Tsang 2014; Biddick 2012).

First and foremost, an ideal system for managing research information in HEIs should be tailored to the needs of a specific institution and serve HEIs to fulfil government and relevant funders requirements. In the study of Nurminen (2014) and Laitinen *et al.* (2000), it is noted that most HEIs in Finland have succeeded by building their own systems for managing research information. Due to requirements changes, which may be unforeseen, the system for HEIs should afford flexibility to accommodate immediate and future changes in the requirements of different stakeholders. As most HEIs in developing countries are constrained in terms of resources (Mundial 2000), especially financial resources, low development and maintenance

costs are essential. Consequently, HEIs in developing countries need to use their available resources economically to develop cost-effective systems for research information management.

Since the use of internet in developing countries has impressively increased (Nyirenda-Jere and Biru 2015) and changed how knowledge is produced, managed and disseminated, it is recommended that the system of HEIs should be web-based. Web-based systems come with many benefits including unlimited accessibility and cost effective development. Furthermore, they are cross-platform compatible, fairly standardized, and easier to maintain. The system should allow quick and easy data entry and be stimulating and pleasurable to use. According to Baguma *et al.* (2013) this could be achieved through adapting the system to needs of HEIs as far as research information management is concerned.

Of course, in South Africa, the government has attempted to support the management of research information in HEIs through a proprietary system called RIMS (RIMS 2011). However, there are numerous problems that are associated with this system. Even though RIMS is not relevant to precise needs and context of a specific HEIs in developing countries, the system is inflexible to support the changing requirements of HEIs, complex to use as it comprises interfaces that are not appealing and require users to perform many steps to achieve a simple task, inadequate in terms of features desired by some HEIs, and highly costly to maintain due to licensing and frequent versioning.

Consequently, it is apparent that HEIs in developing countries need to develop ideal research information management systems which satisfy the aforesaid attributes. It is noted that the development of an optimal system for HEIs in developing countries will require proper communication of requirements between stakeholders and developers. Yusufu and Yusufu (2008) states that software requirements specification has direct impact on the quality, maintenance, economic and success of system development. Many studies show that systems whose requirements are not properly specified often become ineffective and fail to satisfy the users.

2.8. Formal methods for specifying requirements of information systems

Typically, there are two methods that are used for specifying system requirements, namely, formal methods and informal methods. The literature reveals that requirements specification using formal methods are more precise than those produced using informal methods such as scenarios, natural language and use cases (Escalona and Koch 2004). In addition, the use of

formal methods for requirements specification helps to decisively impart specifics and characteristics of a system at the early stages of software development because most users or clients are usually not certain about the requirements of the system, especially in the requirement elicitation stage (Sharma 2016; Batra 2013). According to Sommerville (2009), considering formal methods for requirements specification forces an analysis of the system requirements at an early stage and guarantees that errors are corrected instead of modifying a delivered system which may be costly. As we know that attaining correctness at early stages of system development reduces rework costs (Hall and Chapman 2002).

Formal methods are based on mathematics and logic and usually they are supported by various tools and techniques for verifying the essential properties of the desired system (Pandey and Srivastava 2015; Woodcock *et al.*, 2009). Batra (2013) and Latif *et al.* (2007) write that formal methods facilitate the development of reliable software systems, especially critical systems, by providing the feature of abstraction and unambiguous description mechanisms. They are exceptionally good for verifying system requirements and checking quality parameters such as correctness, completeness, and consistency (Pandey and Srivastava 2015). Formal methods are presented using a formal specification language and they are based on set theory and first order predicate calculus (Batra 2013). They involve the writing of formal descriptions, using a formal specification language, and analysing those descriptions. According to Batra (2013), formal methods can be applied in different phases of software development processes.

Formal methods have been mostly applied and used in the process of developing safety-critical systems (Gerhart *et al.*, 1994; Richard *et al.*, 2002; Dondossola 1998) and real-time control systems. The correctness and completeness of such system is very crucial because they impact on human life and failure of any component of such systems could lead to loss of life (Groote *et al.*, 2011; Barnes, 2011; Barroca and McDermid 1992; Rushby 1989). However, relatively recently, there has been a growing trend towards the application of formal methods for industrial hardware and software development. Heitmeyer (2007) highlights that companies such as Intel, IBM, and Motorola use formal methods in their hardware and software development to detect flaws in their product design. Bjørner and Havelund (2014) writes that formal methods have not gained wide use because of the lack of customers who demand "provably correct" software, and the lack of candidates from HEIs who are properly educated in this regard. Nevertheless, the strength of formal methods in software development cannot be abandoned.

2.8.2. Benefits of modelling information systems using formal methods

Formal methods have the capability of bridging the semantic gap – the gap that exists between user needs and software implementation efforts in software development (Gurupur *et al.*, 2014; Scheithaur *et al.*, 2008). Bibi *et al.* (2014) provides various benefits that can be realised through the application of formal methods in software development and they include:

1. Formal methods reduce cost. This point is supported by El-Gendy and El-Kadhi (2005) who pointed out that formal methods are less error prone, more cost-effective and time-effective compared to informal methods.
2. Formal methods maximize automation through use of automated tools. These automated tools produce models effortlessly which can be verified quickly and in a convenient way, hence speeding the development. Knäblein and Sahm (2010) states that better verification quality can be achieved with 70 percent less time and effort as compared to informal methods.
3. Formal methods reduce defects at an early stage (Batra 2013). According to Knäblein and Sahm (2010) and Lamsweerde (2000), formal specification produces accurate requirements and designs, reducing the chances of unintentional fault injections.

Sharma (2016) refers to the use of formal methods as essential on the grounds that they help in guaranteeing the accuracy of the system. In addition, formal methods are profoundly crucial for the wellbeing of basic frameworks and exceedingly dependable frameworks because here even a minor slip-up is agonizing (Batra 2013). Moreover, they ensure that the implementation of software system as well as hardware satisfy the requirements specification (Batra 2013).

There are several studies in the software development domain which have employed formal methods. For instance, Bakri *et al.* (2013) used Z formal language to specify an inventory system. Tchantchane (2005) also used the Z formal language to specify the critical transactions of removing an item from stock and placing a new order and generating invoices. Sivasubramanian (2016) also employed Z language in the process of actualizing a knowledge management system (KMS). Latif *et al.* (2007) provides yet another example where the Z language was applied to specify various elements of multimedia systems, namely; text, still images, moving images and audio.

2.8.3. An overview of formal methods for specifying requirements of information systems

There are many formal methods that have been proposed by various researchers and are used for different purposes in system development projects. Clarke and Wing (1996) writes that some formal methods such as Z and Larch focus on specifying the behaviour of sequential systems where states are described in terms of rich mathematical structures such as sets, relations, and functions. The state transitions are given in terms of pre- and post-conditions. They further state that other methods such as communicating sequential processes (CSP), calculus of communicating systems (CCS), Statecharts, Temporal Logic and I/O automata, focus on specifying the behaviour of concurrent systems where states typically range over simple domains like integers or are left un-interpreted; and behaviour is defined in terms of sequences, trees, or partial orders of events. There are still others such as RAISE and LOTOS which wed two different methods, one for handling rich state spaces and one for handling complexity due to concurrency. However, they all have one common property which is the use of the mathematical concepts of abstraction and composition (Sharma and Singh 2013). They all also offer the benefit of clearly understanding the system being specified. This section provides an overview of some formal methods particularly those that have been used in software development elsewhere.

2.8.3.1. The Zermelo-Fraenkel Z specification language

Z is a constructive model-based specification language which was first suggested by Abrial and later developed at the University of Oxford and accepted as a British Standards Institution (BSI) standard in 1981 (Pandey and Srivastava 2015). According to Sharma and Singh (2013) Z notation is based on typed set theory and first-order logic. Z is popular especially in developing critical systems where the reduction of errors and quality of software is extremely important (Pandey and Srivastava 2015). However, more recently Z was used to specify a knowledge management system (KMS) (Sivasubramanian 2016). Sharma and Singh (2013) explicates that Z provides a construct, called a schema, to describe a specification's state and operations. They further explain that a schema groups variable declarations with a list of predicates that constrain the possible value of variables. A specification in Z is presented as a collection of schemas which can be combined and used in other schemas. Schema is defined as a diagrammatic notation for displaying the predicates that are used in defining operations and invariants (Pandey and Srivastava 2015). The main building blocks of Z notation are basic type definition, axiomatic definition and schema definition (Pandey and Srivastava 2015). As

it is the case with many programming and specification languages, Z has its own concepts. Some of the Z notation concepts presented in the works of Pandey and Srivastava (2015) and Sharma and Singh (2013) and relevant for this research are listed as follows:

1. Data invariant

   A data invariant is a condition that is true throughout the execution of the system.

2. State

   In Z specification, the state is represented by the system's stored data.

3. Operation

   The operation is an action that takes place within a system and reads or writes data.

4. Condition

   A condition is defined as the prerequisite for an operation to take place. There are three types of conditions that are associated with an operation. The first is an *invariant* which defines what is guaranteed not to change. The second is a *precondition* which defines the circumstances in which a particular operation is valid. The third one is a *post-condition* which is a post-condition of an operation defining what is guaranteed to be true upon completion of an operation. This is defined by its effect on data.

According to Sommerville (2009), a formal description in Z language is included as small, easy-to-read chunks (called *schemas*) that are distinguished from associated text using graphical highlighting. Furthermore, schemas are used to introduce state variables and to define constraints and operations on the state. Schemas themselves can be manipulated using operations such as schema composition, schema renaming and schema hiding. In situations where a schema defines an operation, preconditions and post-conditions maybe set out to define the state before and after the operation. The difference between these pre- and post-conditions defines the action specified in the operation schema.

2.8.3.2. Object Constraint Language

Object constraint language (OCL) is an expression language which describes constraints on object-oriented language and other modelling artefacts (Sharma and Singh 2013). Sharma and Singh (2013) assert that OCL is part of unified modelling language (UML) and plays an important role in the analysis phase of software lifecycles. OCL was developed as part of UML to implement some additional constraint on the objects since UML and other traditional graphical models like class models are not adequate for precise and unambiguous specification. In other words, UML does not allow us to specify behaviour well in terms of how activities

transform one state to another and to specify that one attribute or object be derived from another, that is that the values are extracted from another attribute (Hvannberg 2001). According to Sharma and Singh (2013), OCL was developed mainly for average business or system modellers. They posit that OCL's expressive nature makes it affordable to use unlike the traditional formal methods that require one to have a good grip on mathematics.

2.8.3.3. B method

B is a formal method for specifying, designing and coding software systems (Cansell and Méry 2004). It covers the complete software life cycle, from requirements specification, through design (refinement) to implementation, code generation and maintenance (Yusufu and Yusufu 2008). B was originally developed by Jean-Raymond Abrial in France and the UK (Kaur *et al.*, 2012). It is based on Zermelo-Fraenkel set theory with the axiom of choice, the concept of generalised substitution and on structuring mechanisms (Cansell and Méry 2004). It combines the use of abstract state machines (ASM) with features inherited from both Z and VDM (Almeida *et al*., 2011). Like Z and VDM, the B formal method is a model-oriented specification language and a specification in B is a mathematical model of the required behaviour of the system (Yusufu and Yusufu 2008). However, B is more focussed on refinement to code rather than just the formal specification (Kaur *et al.*, 2012). Thus, the concept of refinement is the key notion for modelling software systems incrementally in B (Cansell and Méry 2004).

Almeida *et al.* (2011) state that the systems modelled in B are perceived as transition systems and their basic unit is called an abstract machine. They further state that in B specifications and programs are represented using a dedicated notation for the abstract machines. Each abstract machine defines the structure of its internal state, the properties that the state must always comply with and the expected operations. The properties are defined in a first-order logic extended with a set theory. Almeida *et al.* (2011) further state that in B, the important principle is that each specified operation must preserve the machine invariants. This satisfies the property called internal consistency.

2.8.3.4. Abstract State Machines

According to Damoah *et al.* (2014), abstract state machines (ASM) provide freedom of abstraction by which evolving algebras use universes, dynamic functions and states as static algebras to support the software lifecycle phases from initial specifications to executable code, through stepwise refinement. Almeida *et al.* (2011) state that in ASM, the notions of state and

state transformation are central. They further state that a system is described in this formalism by the definition of states and by a finite set of state transition rules, which describe the conditions under which a set of transformations or modifications of the machine's internal state take place. These transitions are not necessarily deterministic in the sense that the formalism considers configurations in which several transitions are eligible for a certain state of the machine.

2.8.3.5. Vienna Development Method

Vienna Development Method (VDM) is a formal language developed at the IBM laboratories in Vienna (Müller 2009). VDM is a constructive or model-based specification formal method that is based on propositional and predicate calculus and the logic of partial functions which is used to circumvent the problem of standard first order logic (Misic and Velasevic 1997). A specification in VDM consists of a mathematical model built from simple data types like sets, lists and mappings, along with operations which change the state of the model. The general principle of VDM as a formal method is that of refinement. Refinement is the process of converting abstract specifications into more concrete representations through a mathematically justified series of steps (Geer 2011). Therefore, at each step in the process, VDM provides rules for satisfying proof obligations and retrieving more abstract representations.

2.8.4. Preference for Zermelo-Fraenkel Z specification language to model research administration and management system

After a review of some formal languages, the Z language was chosen for describing and modelling the components of a web-based research administration and management system (RAMS). There are four major reasons that were considered for the choice of Z as a language to use for specifying the components of the web-based RAMS. The first reason for the choice of the Z language is that it is the most revered language in formal methods (Latif *et al.*, 2007) and has been widely used by many researchers (Bakri *et al.*, 2013); therefore, there is rich literature about the language for reference. The second reason is that with Z it is easier to present the formal specification as small, easy to read portions known as schemas. Schemas are easy to distinguish from associated text through graphical representation. Without the use of schemas Z formal specifications would be difficult and tedious to read especially where large mathematical formulae are involved. The third reason is that Z has a wide range of tools for producing the formal specifications. The variety of Z tools are provided free of charge and can be obtained from the internet. The fourth reason is the robustness in terms of the models

produced as requirements errors are significantly reduced. As is common with many formal methods, more time is invested at an early stage to get rid of the incompleteness and inconsistences in the requirements.

2.9. Chapter Summary

Research has become one of the major activities of HEIs worldwide. Increasingly important is research information that emanates from the published research as it has become one of the major sources of funding for HEIs and a source of knowledge for economic growth of nations. Governments and funders in many countries are supporting research in HEIs and are mandating the publicising of findings from funded research for sustained and continued funding. However, many HEIs globally are facing problems managing research information. Although initiatives have been reported in developed countries to address the problem, in Africa HEIs lack resources to acquire or build appropriate systems for managing research information. Of course, there is a notable initiative in South Africa where the government has attempted to support the management of research information in HEIs through a proprietary system called RIMS. However, there are numerous problems that are associated with RIMS. Even though RIMS is not relevant to precise needs and context of a specific HEI in South Africa, the system is inflexible to support the changing requirements of HEIs, complex to use as it comprises interfaces that are not appealing and require users to perform many steps to achieve a simple task, inadequate in terms of features desired by some HEIs, and high maintenance costs due to licensing and frequent versioning.

This study aimed at developing an optimal web-based research administration and management system (RAMS) for managing research at the Durban University of Technology (DUT). The Z specification language is applied to specify the requirements of RAMS to build an optimal system. The next chapter presents the methodology employed in this research.

CHAPTER 3: METHODOLOGY

This chapter provides an explanation of the design science research methodology (DSRM) as the main method used in this study, and how it is employed to achieve an optimal web-based research administration and management system (RAMS). The chapter begins by presenting an overview of the design science research (DSR) as the philosophical approach adopted in this study. Thereafter, a description of the six activities of the DSRM is presented with linkage to how they were followed in this study. The chapter also presents the formal specifications of the proposed RAMS within the third activity of the DSRM model. The chapter concludes with a summary of what has been covered.

3.1. Research Approaches in Information Systems

This study falls into the information systems (IS) field since it addresses the problem of managing research information in HEIs. It appears lucidly that the prime goal of the IS discipline is to address the problems of people, organizations and technologies (Hevner *et al.*, 2004). This discipline continues to develop rapidly and change constantly (Niehaves and Bernd 2006) as the world continues to face more problems. Thus, there are several paradigms that have emerged with the purpose of tackling diverse aspects of research problems within the IS discipline. The study of Niehaves and Bernd (2006) mentions six examples of paradigms that exist in the IS discipline, namely: positivism, interpretivism, behavioural science research, design science research, critical research paradigm and non-critical research paradigm.

To put this research into context, a review of these paradigms was carried out with an objective of finding the most appropriate for this study. Consequently, the design science research was found to be fitting because it focuses on building innovative technology systems (Marshall and McKay 2005) for addressing critical problems of people and organisations through the construction, utilization, and evaluation of artefacts that provide the utility to transform and existing situation into a preferred one (Olugbara and Ndhlovu 2014; Hevner and Chatterjee 2010; Venable *et al*., 2011). The DSR was useful in gaining an insight into problems that are faced by South African higher education institutions, specifically Durban University of Technology, concerning research information management, and developing an optimal web-based RAMS which could be a solution to those identified problems.

3.2. Design Science Research

Design science research has been solidified over the years and it is one of the paradigms that characterise the IS discipline due to its wide adoption (Niehaves and Bernd 2006) "as evidenced by the DSR special issues in leading IS journals such as *MIS Quarterly* and *European Journal of Information Systems*" (Iivari 2012). Many authors have defined DSR from different perspectives. For instance, Vaishnavi and Kuechler (2004) defines DSR as research that creates knowledge in the form of constructs, techniques, methods, models, and well-defined theory for creating artefacts that satisfy given sets of functional requirements. They further elucidate that DSR "involves the creation of new knowledge through design of novel or innovative artefacts (things or processes) and analysis of the use and/or performance of such artefacts along with reflection and abstraction- to improve and understand the behaviour of aspects of IS". Hevner *et al.* (2004) defines DSR as a problem-solving paradigm that has its roots in the engineering and sciences of the artificial. Frank (2006) states that DSR focusses on developing new innovative artefacts to extend the boundaries of human problem solving and organizational capabilities. Hevner and Chatterjee (2010) and Venable *et al.* (2011) define DSR as a paradigm that addresses critical problems of the people and organizations through the construction, utilization and evaluation of a system, with the goal of transforming the present situation to a better one. Nevertheless, what can be deduced from the aforesaid definitions is that the focal point of DSR is creation of artefacts that address problems.

According to Hevner *et al*. (2004) there are various types of design science artefacts in DSR, namely, constructs (terminology; symbols), models (concepts; abstractions; representations), methods (procedures; algorithms; practices) and instantiations (the implemented systems). Peffers *et al*. (2008) argue that social innovations or some properties of technical, social or informational resources can also be considered as artefacts. Vaishnavi and Kuechler (2004) posits that human/computer interfaces also fit as artefacts. In this study the artefact to be built is an instantiation called RAMS.

Literature informs us that one important aspect about DSR artefacts is evaluation of the artefacts. Artefact evaluation is an integral part of DSR because it "provides feedback for further development and (if done correctly) assures the rigour of the research" (Venable, Pries-Heje and Baskerville 2016). Hevner *et al*. (2004), writes that artefacts can be evaluated using quantitative metrics or qualitative comparisons with other designs. The evaluation of an artefact is mainly concerned with ascertaining artefact's suitability and ability to solve the identified problems. Hevner *et al*. (2004) introduced a conceptual model for understanding, executing,

and evaluating research in the IS discipline. The model which they introduced examines the relations between environment, information systems research and the knowledge base. They state that the environment defines the problem space which consists of people, organisations and technology. IS research focusses on building and utilisation of artefacts to solve the identified problems in the environment. The knowledge base is comprised of the foundations and methodologies established based on the research that has been conducted. The foundations consist the theories, models and tools derived from previous IS research and from other disciplines. Methodologies on the other hand provide guidelines to be used in justifying and evaluating the resulting artefact to meet the identified business need. This is where behavioural science and design science complement each other as behavioural science research seeks truth while the goal of design science is utility of the resulting artefact. Research rigor is achieved through use of the pool of previous knowledge and methodologies.

According to Hevner *et al.* (2004), research in IS discipline comprises of two phases: development and justification of theories explaining or predicting the target phenomena and building and evaluation of the artefact needed to solve certain problems. The research makes continuing additions to the knowledge base and provides applications to satisfy the business needs of the environment. The authors assert that building and application of an artefact provides researchers in the IS discipline with concrete understanding of a design problem and its viable solution. Based on this concept, Hevner *et al.* (2004) proposed seven guidelines that researchers in the IS domain could follow in carrying out design science research. The seven guidelines are presented below with a brief explanation against each guideline.

1. Design as an artefact: Design science research must produce a viable artefact such as a construct, a model, a method or and instantiation.
2. Problem relevance: The solutions achieved in design science must address important and relevant problems in the IS discipline.
3. Design evaluation: The utility, quality, and efficacy of the resulting artefact must be rigorously demonstrated via well-executed evaluation methods.
4. Research contributions: design science research must provide clear and verifiable contributions in the design artefact, foundations and design methodologies areas.
5. Research rigor: design science research should depend on rigorous methods in building and evaluating the design artefact.
6. Design as a search process: the search for an effective artefact must utilise available means to reach desired ends while satisfying laws in the problem environment.

7. Communication of research: The results of design science research should be effectively communicated to both technology-oriented and management-oriented audiences.

3.3. Design Science Research Methodology

There are several design science research frameworks and procedural models which have been conceived with the purpose of achieving a systematic development of design science artefacts (Peffers *et al*., 2007). These frameworks can be considered as mental models for demonstrating and evaluating design artefacts in IS domain. However, there is lack of commonly accepted framework for design science research and a template for its representation (Peffers *et al*., 2007; Frank 2006). The lack of a commonly accepted framework prompted Peffers *et al*. (2007) to review the previously proposed design science principles in seven representative papers, and subsequently unified them by appropriately combining their elements to achieve a commonly accepted methodology called design science research methodology (DSRM). The DSRM incorporates principles, practices and procedures to carry out design science research in the IS discipline and facilitates multiple entry points in the development process. Due to its consensus building approach, the DSRM has been widely accepted in the IS and other related publication channels (Hevner and Chatterjee 2010). Figure 3.1 below gives a visual representation of the DSRM process model which shows the six consecutive activities that constitute it. The details of how the DSRM was employed to accomplish this study are presented below under each activity of the model developed by Peffers *et al*. (2008).
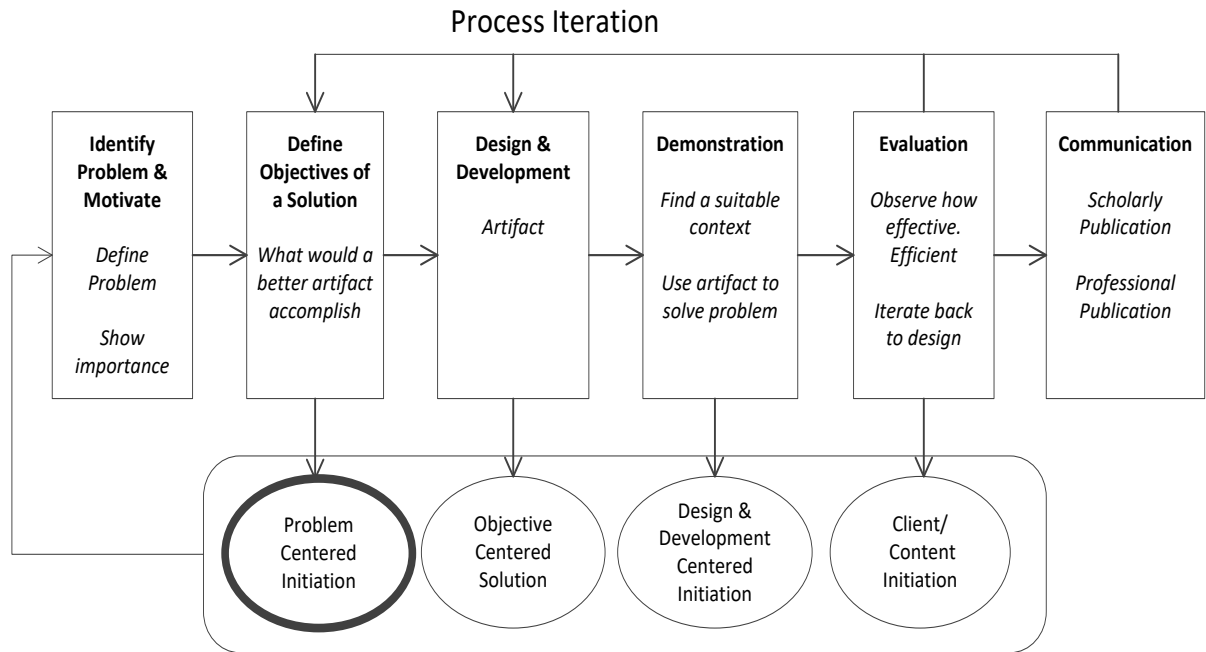
Figure 3.1: Process Model showing the activities of DSRM adopted from Peffers *et al.* (2008)

3.3.1. Activity 1: Problem identification and motivation

The first activity of the DSRM model is concerned with the definition of the specific research problem and justifying the value of a solution to the problem. The research study originated because of the various problems the users (researchers and staff in the Research and Postgraduate Office) at Durban University of Technology (DUT) are facing regarding existing technology for managing research information. A business analysis phase of the Agile Web Engineering Process life-cycle (Macdonald and Welland 2001) was essential to discover the real problems to be addressed by the proposed system. Therefore, to gain a clear understanding of the problems regarding research information management in HEIs, the researcher conducted context-free interviews with researchers, and staff in the Research and Postgraduate Office at DUT. The researcher also examined documents that are related to management of research information which were obtained from the Research and Postgraduate Office at DUT. Moreover, a comprehensive review of literature around the subject of research information management was carried out which provided rich information. The context-free interviews and examination of relevant documents were primarily intended to elicit an understanding of activities regarding research information management at DUT and the insight into the characteristics of what a successful and apposite solution could be. It was found that the major

problems were related to the use, functionality and costs associated with the current RIMS system.

During the interviews, most users reported that the system was too complex to use and that the interface was not appealing. Moreover, RIMS does not adapt well to devices with small screens such as smart phones hence requiring users to use the system on desktop computers for good display. This was said to be a limitation to users particularly researchers who wanted to provide information about their publications into the system and access the information regardless of where they are. It was also found that RIMS is inflexible to promptly support the changing requirements of HEIs because it is a proprietary system; and proprietary systems are incapable of immediately housing any changes in the requirements due to their restrictions in accessing source code. RIMS lacked some crucial components needed by DUT and due to its proprietary nature, it was not possible to promptly implement those components.

Apart from the inflexibility, RIMS is also costly to maintain as the license to use the system must be renewed for the agreed period at even higher cost. Considering these problems, the researcher conducted a literature review of the existing systems that have been used in HEIs elsewhere to solve similar problem of managing research information, with the objective of learning how those systems were built to solve the identified problems. The information about some of the existing systems that were reviewed has been presented in the preceding chapter. This study was initiated to build an optimal web-based RAMS that could improve the management of research information in HEIs in South Africa. The proposed RAMS has attractive interfaces and adapts well to devices with different screen sizes. Moreover, RAMS is simple to use and provides the needed functionalities that greatly improve the activities of research information management for staff in the Research and Postgraduate Office at DUT.

3.3.2. Activity 2: Define the objectives for a solution

The second activity of the DSRM model deals with establishment of objectives of a solution from the problem definition and knowledge of what is possible and feasible. After identifying the problems that are associated with the current system at DUT, this study aimed at developing an optimal web-based RAMS. It was envisaged that the proposed system should be simple, appealing to the user and adaptable to devices with different screen sizes. Moreover, the system should essentially satisfy the requirements of the HEI. To achieve this aim, four main objectives were established to guide the study. The first objective was to deduce the requirements of the proposed system from users (researchers and staff in the Research and

Postgraduate Office). Successful elicitation of requirements is a vital process in systems development as it directly leads to user acceptance of the developed system, that is if the system satisfies users' requirements.

Well-defined requirements are crucial for the successful development and delivery of the apposite system, without which developers would not know what to develop and users would not know what to expect. Moreover, it would be extremely difficult to validate that the system meets the requirements of the users. To ensure that the right requirements were elicited, the researcher mainly employed context-free interviews and observation techniques to gather the requirements. Additionally, documents related to research information management at the case study institution were analysed. The researcher was also privileged to practically use the existing system for managing research information at DUT which helped gain an appreciation of the problems of the system and insight as to how best the proposed system could be designed and developed to solve the problems experienced and avoid reinventing the wheel. A literature review of the systems for managing research information that have been implemented in some HEIs in other countries also provide important insight regarding the essential features that could be relevant to the proposed system.

The second objective was to model the elicited requirements of the proposed research administration and management system in form of a formal specification. Requirements specification is important as it helps to communicate the problem to be solved between developers and users in an unambiguous manner. It ensures that all uncertainties on requirements are cleared and a consensus is reached between users and developers before development starts. Johansson and Rolandsson (2012) affirms that the requirements specification can serve as "a channel of communication, conveying the characteristics of the system between the developers and users". Escalona and Koch (2004) states that the requirements specification stage is crucial to assure the quality of the resulting software.

There are many techniques for specifying system requirements such as scenarios, natural language, use case modelling and formal methods (Escalona and Koch 2004). This study opted to use formal methods to specify requirements of RAMS because specifications produced using formal languages are more precise than those produced using natural languages and use cases (Escalona and Koch 2004). Moreover, use of formal methods for requirements specification forces an analysis of the system requirements at an early stage and guarantees that any errors are corrected at this stage instead of modifying a delivered system which is costly (Sommerville 2009). Therefore, the attention to correctness at early stages pays off in reduced

rework costs (Hall and Chapman 2002). Use of formal methods also helps to decisively impart specifics and characteristics of a system at the beginning of a systems project since at this stage most users or clients are usually not exact about requirements for the system (Sharma 2016; Batra 2013). Therefore, formal methods ensure that the implementation of a software product should satisfy the requirements specification (Batra 2013). In this study the Z formal specification language was used to specify the requirements of RAMS. The specification for RAMS is presented in section 3.3.3.1 of this chapter.

The third objective was to design, develop and implement an optimal web-based research administration and management system for managing research information in HEIs. The last objective was to evaluate the web-based research administration and management system to ensure the system fulfils the needs of the HEI. The evaluation of RAMS is covered in detail in chapter four of this dissertation.

3.3.3. Activity 3: Design and development

The third activity of the DSRM model is concerned with the design and development of an artefact. It includes determining the artefact's desired functionality and its architecture and then creating the actual artefact. According Peffers *et al*. (2007) and Hevner *et al*. (2004) the potential artefacts of IS are constructs, models, methods, or instantiations. The artefact that was developed in this study is an instantiation- a web-based system called research administration and management system (RAMS).

The design and development of RAMS followed a planned and systematic approach using the Agile Web Engineering (AWE) process life-cycle for the construction of web-based applications that was developed in 2001 by Macdonald and Welland (2005). A visual representation of the AWE Process life-cycle is shown in Figure 3.2 below.
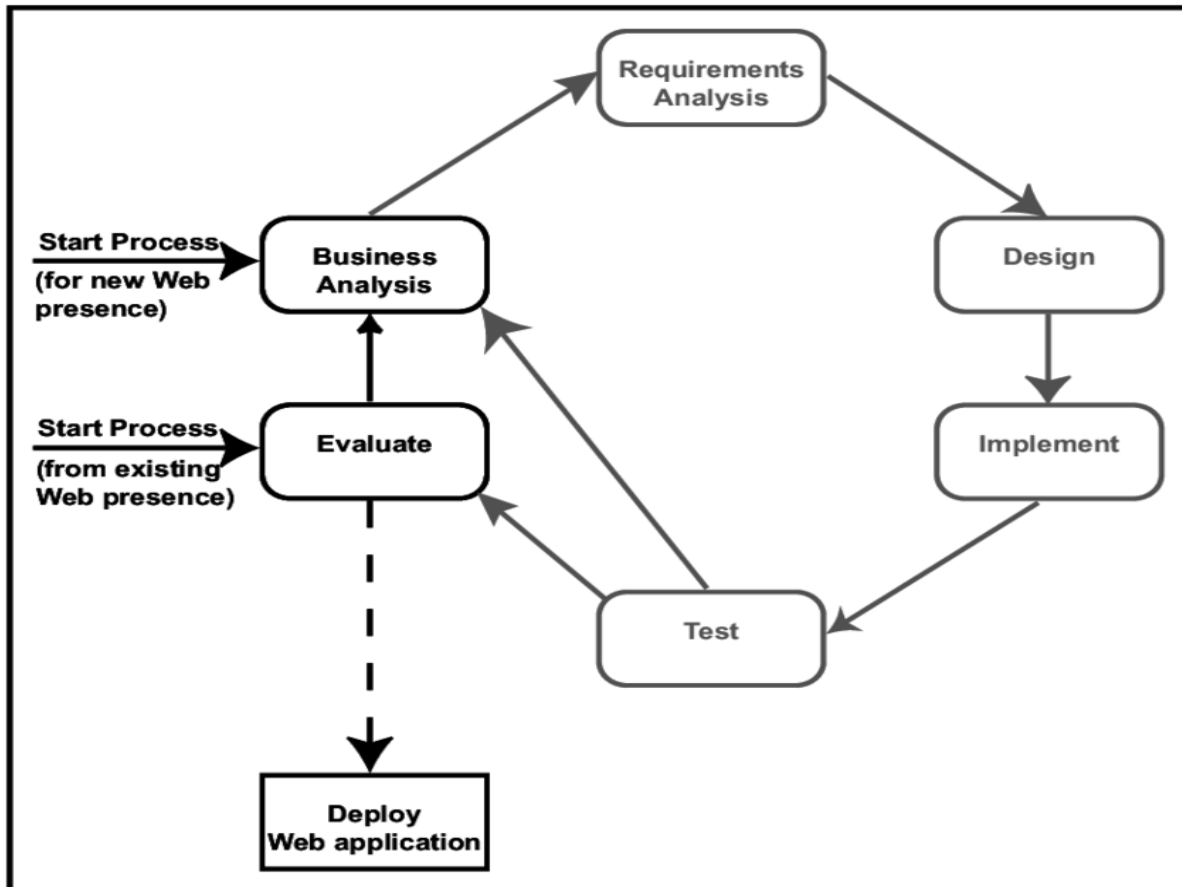
Figure 3.2: The Agile Web Engineering Process life-cycle (Adopted from Macdonald and Welland 2001)

AWE is an iterative and incremental process that ensures early and continuous delivery of valuable software and offers the ability to support changing requirements, even late in development, and the delivery of working software frequently (Macdonald and Welland 2001). It provides a roadmap that allows web-based activities to deliver solutions that satisfy end-users, who are ultimately the litmus test for success (Macdonald and Welland 2005). The AWE Process life-cycle is separated into seven phases, with one main deliverable- the web application that meets clearly defined business objectives. In this study the design and development activity of the DSRM included the two phases of the AWE process life-cycle namely, requirements analysis and design. The business analysis phase was applied in the problem identification activity of the DSRM. The implementation, testing and evaluation phases of the AWE Process are covered in detailed in chapter 3 of the dissertation.

3.3.3.1 Requirements analysis

The Requirements analysis phase of AWE Process is essentially about defining what the proposed solution will do and what constraints are to be placed upon the proposed solution

(Macdonald and Welland 2001). As explained in section 3.3.2, the requirements of RAMS were deduced through context interviews the researcher conducted with researchers and staff in the Research and Postgraduate support office at DUT, examination of documents related to research information management and the literature review. Table 3.1 presents some of the functional and non-functional requirements of RAMS.

Table 3.1: Functional and Non-functional requirements of RAMS

Functional requirements	Non-functional requirements
The system shall manage publications	The system shall be secure
The system shall manage researchers	The system shall be usable
The system shall manage collaborations	The system shall be reliable
The system shall manage research grants	The system shall be available
The system shall manage communication	The system shall deliver satisfactory performance
The system shall harvest publications from online sources	The system shall be scalable
The system shall allow authorized users to review, change, or update their publications	
The system shall allow generation of formatted reports of outputs	
The system shall allow generation of a uniform CV for researchers in pdf format	
The system shall automate the process of conference funding application	
The system shall allow users to register into the system	

The functional requirements of RAMS were modelled as a formal specification using the Zermelo-Fraenkel Z formal language. Ahmad *et al.* (2012) states that the use of formal methods for requirements specification leads to unambiguous, consistent and verified system. Consequently, the Z specification language was chosen to specify the requirements of RAMS as it provides the ability to describe how things change in the system. The Z specification language makes it very easy to specify sequences and bags of which in other modelling

languages like UML is impossible to make this distinction when specifying relationships (Hvannberg 2001). Moreover, UML does not allow us to specify behaviour well in terms of how activities transform one state to another and to specify that one attribute or object be derived from another, that is that the values are extracted from another attribute (Hvannberg 2001). A brief comparison of UML and Z is presented in table 3.1. The resulting specifications for RAMS are presented in the subsections below.

Table 3.2: Comparison of UML and Z

Criteria	Specification languages	
	Z	UML
Completeness	More precise and unambiguous specification (Sharma and Singh, 2013)	Not enough for precise and unambiguous specification (Sharma and Singh, 2013)
Verifiability	The specification in Z can be proved to be correct using preconditions and post conditions (Li, 2000).	Specification in UML cannot be proved to be correct (Li, 2000).
Redundancy	The specification in Z is precise without redundancy (Li, 2000).	The specification in UML represents a piece of knowledge more than once from different views (Li, 2000).
Reusability	Easy to reuse parts of the respective models to represent other models (Li, 2000).	Not very easy to reuse parts of the respective models to represent other models (Li, 2000).
Consistency	More consistent because of well-defined rules for analysing and transforming specifications (McDermid and Barroca, 1993).	Less consistent (McDermid and Barroca, 1993).
Effectiveness	Most effective as a form of communication and for agreeing and documenting (design) decisions (McDermid and Barroca, 1993).	Less effective as a form of communication and for agreeing and documenting (design) decisions (McDermid and Barroca, 1993).
Reliability	Effectively improves system reliability and reduce defect in developing the System (Bakri *et al.*, 2013).	Reliability not guaranteed

3.3.3.1.1 Formal specifications for RAMS

3.3.3.1.1.1 Type declarations

The process of specifying the requirements of RAMS started with the declaration of the variable types to be used within the specifications. Presented below is the declaration part for the specifications followed by their explanations.

[*TEXT*, *PASSWORD*, *DATE*, *EMAIL*, *WEBADDRESS*, *FILEPATH*, *COUNTRY*, *ADDRESS*, *TELEPHONE*, *CELLPHONE*, *FAX*, *YEAR*, *ISBN*, *DOI*, *URL*, *ACCESSION*, *ISSN*, *RANGE*, *PROJECT_ID*, *CESM*, *AMOUNT*, *PROJECT_NUMBER*, *PATENT_NUMBER*]

USER_ROLE::= *admin | manager |researcher | assistant*

GENDER::= *male | female*

RACE::= *black_african | indian | coloured | white | other*

RANK::= *professor | associate_prof | director | lecturer | senior_lecturer | assistant_lectuter*

RESPONSE::= *USER_ADDED_SUCCESSFULLY | RECORD_SUCCESSFULLY_ADDED | RECORD_ALREADY_EXISTS | NO_RECORDS_FOUND | DELETION_SUCCESSFUL*

IDTYPE::= *passport_number | south_african_id*

TITLE::= *assoc_prof | doctor | miss | mr | mrs | prof | sir*

AUTHOR::= *lastname | initials*

ROLE::= *Principal_Investigator | Co_Investigator | Research_Assistant | Supervisor | Manager | otherpi*

3.3.3.1.1.2 Explanations for the declarations

[*TEXT*]: is a descriptive text item that contains one or more characters.

[*PASSWORD*]: is a primitive type for an encrypted password.

[*DATE*]: is primitive type for the date.

[*EMAIL*]: is a type for email address.

[*WEBADDRESS*]: is a type for a website URL address.

[*FILEPATH*]: is a type for a path to a file or image. Indicates that value of a file or image is stored in database as a path to a specific file or image.

[*COUNTRY*]: is a type for country.

[*ADDRESS*]: is a descriptive type for address.

[*TELEPHONE*]: is a type for a telephone number. Indicates that the value should the format for a telephone number.

[*CELLPHONE*]: indicates that the value should conform to the format for cell phone number format.

[*FAX*]: indicates that the value entered should conform to the format for fax number.

[*YEAR*]: indicates that the value should be a year.

[*ISBN*]: indicates that the value should be an ISBN.

[*DOI*]: indicates that the value should be a document object identifier.

[*URL*]: indicates that the value should be a link.

[*ACCESSION*]: indicates that the value is an accession number.

[*AMOUNT*]: is the quantity of money.

[*ISSN*]: indicates that the value should be the issn of an article.

[*RANGE*]: indicates that value should be a range showing the start number and end number.

USER_ROLE: This represents different types of users of the system: *admin* the administrator of the system, *manager* is the research manager, *researcher* represents various individuals who conduct research, *assistant* is an individual who handles the entry of data into the system.

*GENDE*R: This represents the sexes of users of the system. These can only be *male* or *female*.

RACE: This represents the races of users of the system. These can be *black African*, *Indian*, *coloured*, *white,* or *other* races.

RANK: This represents the positions of individuals in the institution. These can be *professor*, *associate professor*, *director*, *lecturer, senior lecturer*, *assistant lecturer*.

IDTYPE: This represents the identifications of users of the system: *passport number* for foreigners, *South African IDs* for South African citizens.

TITLE: This represents the identifying designation signifying status or function: these can be *Associate professor, Doctor, Miss, Mr, Mrs, Professor, Sir*.

AUTHOR: This represents the author of a publication which be stored as *last name* and *initials* in the system.

ROLE: This represents the different roles that individuals can assume in a project. These can be *Principal Investigator, Co-Investigator, Research Assistant, Supervisor, Manager*, other roles.

RESPONSE: this contains the values ensuring a robust system.

- *USER_ADDED_SUCCESSFULLY*: indicates successful operation of adding a user into the system.
- *RECORD_SUCCESSFULLY_ADDED*: indicates the successful entry of a record into the system.
- *RECORD_ALREADY_EXISTS*: indicates that a record with same characteristics has already been entered the system and therefore no two records of same characteristics can exist in the system.
- *NO_RECORDS_FOUND*: indicates that requested record was not found in the system.

3.3.3.1.1.3 Basic definitions for RAMS

3.3.3.1.1.3.1. Basic definition for user in RAMS

The following schema is the definition of *MEMBER* which defines user in RAMS.

_MEMBER_____

$Id : \mathbb{N}_1$
mem_id, *username*, *fname*, *lname*, *biography*, *institution* : *TEXT*
password : *PASSWORD*
role : *USER_ROLE*
title : *TITLE*
dob : *DATE*
gender : *GENDER*
id_type : *IDTYPE*
race : *RACE*
nationality : *COUNTRY*
rank : *RANK*
telephone : *TELEPHONE*
fax : *FAX*
cellphone : *CELLPHONE*
email : *EMAIL*
address : *ADDRESS*
website : *WEBADDRESS*
photo : *FILEPATH*

_____

The *MEMBER* schema defines a user. The rest of this specification assumes that no two elements of the set of all possible users are the same. This condition will be satisfied because the *mem_id* will be unique for each user in the system. The uses of the different fields in *MEMBER* are as follows:

➢ **Id:** this is an auto incrementing positive natural number starting from 1 upwards.

➢ **Mem_id:** this is a unique id or employee number for the employee.

➢ **Username:** is the chosen name of the user for logging into the system.

➢ **Password:** is a secret password used by the user to login to the system.

➢ **Fname:** is the first name of the user.

➢ **Lname:** is the surname of the user.

➢ **Role:** defines the user as either admin, manager, researcher or assistant.

- ➤ **Title:** defines designation status as either *Associate professor, Doctor, Miss, Mr, Mrs, Professor, Sir*.
- ➤ **Dob:** is the date of birth.
- ➤ **Gender:** defines sex either male or female.
- ➤ **Id_type:** is the nationality id either passport number or South African id.
- ➤ **Race:** identifies the race of the user.
- ➤ **Nationality:** identifies the country of origin of the user.
- ➤ **Rank:** is current relative status of the user in the institution.
- ➤ **Telephone:** is the office landline number.
- ➤ **Fax:** is the facsimile number.
- ➤ **Cellphone:** is the mobile number of the user.
- ➤ **Email:** is the email address of the user.
- ➤ **Address:** is the address where user is found
- ➤ **Institution:** is the name of the organisation
- ➤ **Biography:** is a brief account of a user's academic life
- ➤ **Website:** is the website link address
- ➤ **Photo:** is the image of the user. Preferably of 100 x 100 pixels PNG format.

3.3.3.1.1.3.2 Basic definition for research interest areas

The following schema is the definition of the *RESEARCHAREA* which defines research interest area in RAMS.

RESEARCHAREA
$Id : \mathbb{N}_1$
$title : TEXT$
$description : TEXT$
$date : DATE$
$publications : \mathbb{N}_1$
$sponsor : TEXT$

The schema for *RESEARCHAREA* defines the interest areas for the researchers. The uses of different fields are as follows:

- ➤ **Id:** is the unique auto incrementing natural number from 1 upwards.
- ➤ **Title:** is the name of the research interest area.
- ➤ **Description:** is the brief description of the interest area.

- ➤ **Date:** is the when the research interest area started.
- ➤ **Publications:** is the number of publication that emanated from the area.
- ➤ **Sponsor:** defines the name of sponsor if there has been any sponsor in the area.

3.3.3.1.1.3.3 Basic definition for creative art

The following schema is the definition of *CREATIVEART* that is a placeholder for the definition of creative art in RAMS.

<u>*CREATIVEART*</u>
Id : $\mathbb{N}_1$
Title : *TEXT*
Description : *TEXT*
Year : *YEAR*
Institution : *TEXT*

The uses of different fields of CREATIVEART are as follows:
- ➤ **Id:** is a unique auto incrementing natural number from 1 upwards.
- ➤ **Title**: is the name of the creative art.
- ➤ **Description:** is the brief explanation of the creative art.
- ➤ **Year:** is the year of creation of the art.
- ➤ **Institution:** is the name of the organisation.

3.3.3.1.1.3.4 Basic definition for an award

The following schema is the definition of the *AWARD* in RAMS. It is a placeholder for awards in RAMS.

<u>*AWARD*</u>
Id : $\mathbb{N}_1$
award_name : *TEXT*
organisation : *TEXT*
value : *AMOUNT*
year : *YEAR*
description : *TEXT*

The uses of the different fields of *AWARD* are as follows:
- ➤ **Id:** is the unique auto incrementing natural number from 1 upwards.

- ➢ **Award_name:** is the name of the award.
- ➢ **Organisation:** is the name of the awarding organisation.
- ➢ **Value:** is the amount received for the award.
- ➢ **Year:** is the year the awards was received.
- ➢ **Description:** describes the award.

3.3.3.1.1.3.5 Basic definition for a book

The following schema is a definition of *BOOK* in RAMS.

BOOK
_____

Id : $\mathbb{N}_1$
authors, *exauthors* : *AUTHOR*
internal_authors : $\mathbb{N}_1$
external_authors : $\mathbb{N}$
year, *report_year* : *YEAR*
title, *place_of_publication*, *publisher*, *editor*, *edition* : *TEXT*
isbn : *ISBN*
pages : $\mathbb{N}_1$
doi : *DOI*
url : *URL*
accession : *ACCESSION*
file : *FILEPATH*

The uses of the different fields of *BOOK* are as follows:
- ➢ **Id:** is the auto incrementing natural number from 1 upwards.
- ➢ **Authors:** stores the names of internal authors.
- ➢ **Exauthors:** stores the names of external authors.
- ➢ **Internal_authors:** stores the number of internal authors from 1 upwards.
- ➢ **External_authors:** stores the number of external authors from 0 upwards.
- ➢ **Year:** is the year the book was published.
- ➢ **Report_year:** is the year of reporting about the book.
- ➢ **Title:** is the name of the book
- ➢ **Place_of_publication:** stores the name of the place where book was published.
- ➢ **Publisher:** stores the name of the publisher of the book.
- ➢ **Editor:** stores the name of editor of the book.
- ➢ **Edition:** is the edition of the book.

- ➤ **Isbn:** stores the ISBN number of the book.
- ➤ **Pages:** stores the number of pages of the book.
- ➤ **Doi:** stores the document object identifier (if any) of a book that is available on the internet.
- ➤ **url:** stores the link address to the book that is available on the internet.
- ➤ **File:** stores the path to the book that has been uploaded to the system.

3.3.3.1.1.3.6 Basic definition for book chapter

The following schema is a definition of *BOOKCHAPTER* in RAMS.

BOOKCHAPTER

$Id : \mathbb{N}_1$
authors, *exauthors* : *AUTHOR*
internal_authors : $\mathbb{N}_1$
external_authors : $\mathbb{N}$
year, *report_year* : *YEAR*
title : *TEXT*
book_title : *TEXT*
place_published : *TEXT*
publisher : *TEXT*
pages : $\mathbb{N}_1$
editor : *TEXT*
edition : *TEXT*
isbn : *ISBN*
doi : *DOI*
url : *URL*
accession : *ACCESSION*
file : *FILEPATH*

The uses of the different fields of *BOOKCHAPTER* are as follows:
- ➤ **Id:** is the auto incrementing natural number from 1 upwards.
- ➤ **Authors:** stores the names of internal authors.
- ➤ **Exauthors:** stores the names of external authors.
- ➤ **Internal_authors:** stores the number of internal authors from 1 upwards.
- ➤ **External_authors:** stores the number of external authors from 0 upwards.
- ➤ **Year:** is the year the book was published.
- ➤ **Report_year:** is the year of reporting about the book.
- ➤ **Title:** is the name of the chapter.

- ➢ **Book_title:** is the name of the book the chapter appears in.
- ➢ **Place_of_publication**: stores the name of the place where book or chapter was published.
- ➢ **Publisher:** stores the name of the publisher of the book or chapter.
- ➢ **Editor:** stores the name of editor of the book chapter.
- ➢ **Edition:** is the edition of the book.
- ➢ **Isbn:** stores the ISBN number of the book.
- ➢ **Pages:** stores the number of pages of the book chapter.
- ➢ **Doi:** stores the document object identifier (if any) of a book chapter that is available on the internet.
- ➢ **url:** stores the link address to the book chapter that is available on the internet.
- ➢ **File:** stores the path to the book chapter that has been uploaded to the system.

3.3.3.1.1.3.7 Basic definition for conference paper

The schema below is a definition of the *CONFERENCE* in RAMS. The uses of the different fields are as follows:

- ➢ **Id:** is the auto incrementing natural number from 1 upwards.
- ➢ **Authors:** stores the names of internal authors.
- ➢ **Exauthors:** stores the names of external authors.
- ➢ **Internal_authors:** stores the number of internal authors from 1 upwards.
- ➢ **External_authors:** stores the number of external authors from 0 upwards.
- ➢ **Year:** is the year the conference took place.
- ➢ **Report_year:** is the year of reporting about the conference paper.
- ➢ **Title:** is the name of the conference paper.
- ➢ **Conference_name:** is the name or title of the conference.
- ➢ **Venue:** is the location where the conference took place.
- ➢ **Date:** stores the actual date of the conference.
- ➢ **Place_published:** stores the name of the place where conference was published.
- ➢ **Publisher:** stores the name of the publisher of conference paper.
- ➢ **Editor:** stores the name of editor of conference paper.
- ➢ **Volume:** is the volume number of the conference paper.
- ➢ **Issue:** stores the issue number of conference paper.
- ➢ **Issn:** stores the ISSN number of the Conference.
- ➢ **Pages:** stores the number of pages of the conference paper.

- ➢ **Doi:** stores the document object identifier (if any) of a conference paper that is available on the internet.
- ➢ **url:** stores the link address to the conference paper if it is available on the internet.
- ➢ **File:** stores the path to the conference paper that has been uploaded to the system.

```
 CONFERENCE
 Id : ℕ₁
 authors, exauthors : AUTHOR
 internal_authors : ℕ₁
 external_authors : ℕ
 year, report_year : YEAR
 title, conference_name, venue : TEXT
 date : DATE
 place_published, publisher, editor : TEXT
 volume : ℕ₁
 issue : ℕ₁
 issn : ISSN
 pages : ℕ₁
 doi : DOI
 url : URL
 accession : ACCESSION
 file : FILEPATH
```

3.3.3.1.1.3.8 Basic definition for journal

The following schema is a definition of JOURNAL in RAMS.

$\underline{JOURNAL}$_____

$Id : \mathbb{N}_1$

authors, *exauthors* : *AUTHOR*

internal_authors : $\mathbb{N}_1$

external_authors : $\mathbb{N}$

year, *report_year* : *YEAR*

title : *TEXT*

journal_name : *TEXT*

volume : $\mathbb{N}_1$

issue : $\mathbb{N}_1$

cesm : *CESM*

issn : *ISSN*

page_range : *RANGE*

doi : *DOI*

url : *URL*

file : *FILEPATH*

Below is a function called *cesm* that maps the different Classification of Education Subject Matter (CESM) categories to their integer values which are stored in the system. CESM is a standard way required by the Department of Education for higher education institutions in South Africa to classify different areas of learning within their institutions for consistency the when submitting annual data returns (http://www.gov.za/documents/classification-educational-subject-matter).

> *cesm* = {(*Agriculture Agricultural Operations and Related Sciences* ↦ 1),
> (*Architecture and the Built Environment* ↦ 2),
> (*Visual and Performing Arts* ↦ 3),
> (*Business Economics and Management Studies* ↦ 4),
> (*Communication Journalism and Related Studies* ↦ 5),
> (*Computer and Information Sciences* ↦ 6), (*Education* ↦ 7),
> (*Engineering* ↦ 8),
> (*Health Professions and Related Clinical Sciences* ↦ 9),
> (*Family Ecology and Consumer Sciences* ↦ 10),
> (*Languages Linguistics and Literature* ↦ 11), (*Law* ↦ 12),
> (*Life Sciences* ↦ 13),
> (*Physical Sciences* ↦ 14), (*Mathematics and Statistics* ↦ 15),
> (*Military Sciences* ↦ 16), (*Philosophy, Religion and Theology* ↦ 17),
> (*Psychology* ↦ 18), (*Public Management and Services* ↦ 19),
> (*Social Sciences* ↦ 20)}

The uses of the different fields of *JOURNAL* are as follows:

- ➢ **Id:** is the auto incrementing natural number from 1 upwards.
- ➢ **Authors:** stores the names of internal authors.
- ➢ **Exauthors:** stores the names of external authors.
- ➢ **Internal_auhtors:** stores the number of internal authors from 1 upwards.
- ➢ **External_authors:** stores the number of external authors from 0 upwards.
- ➢ **Year:** is the year the journal article was published.
- ➢ **Report_year:** is the year of reporting about the journal article.
- ➢ **Title:** is the name of the journal article.
- ➢ **Journal_name:** is the name of the journal in which the article is published.
- ➢ **Volume:** is the volume number of the journal article.
- ➢ **Issue:** stores the issue number of journal article.
- ➢ **Cesm:** stores the integer value of the classification of the education subject matter from the function *cesm*.
- ➢ **Issn:** stores the ISSN number of the journal article.
- ➢ **Page_range:** stores the range of page numbers (start and end).
- ➢ **Doi:** stores the document object identifier (if any) of a journal article that is available on the internet.
- ➢ **url:** stores the link address to the journal article if it is available on the internet.
- ➢ **File:** stores the path to the journal article that has been uploaded to the system.

3.3.3.1.1.3.9 Basic definition for a project

The following schema is a definition of *PROJECT* in RAMS.

___*PROJECT*_____
| *Id* : $\mathbb{N}_1$
| *Pid* : *PROJECT_NUMBER*
| *Title* : *TEXT*
| *Role* : *ROLE*
| *Project_sponsor* : *TEXT*
| *Project_amount* : *AMOUNT*
| *Start_date* : *DATE*
| *Finish_date* : *DATE*
| *Piname* : *TEXT*
| *Otherpi* : *TEXT*
|_____

The uses of the different fields of *PROJECT* are as follows:

- **Id:** is a unique auto incrementing natural number form 1 upwards
- **Pid:** stores a unique identifier of a project. It is used to uniquely identify a project in RAMS.
- **Title:** is the name of the project.
- **Role:** is defines the function a user performs in the project.
- **Project_sponsor:** stores the name of the funder of the project.
- **Project_amount:** stores the value of the quantity of money for the project.
- **Start_date:** stores the date for the commencement of the project.
- **Finish_date**: stores the date for the end of the project.
- **Piname:** stores the name of the principal investigator.
- **Otherpi:** stores the names of the other principal investigators if any.

3.3.3.1.1.3.10 Basic definition for a patent

The following schema is a definition of PATENT in RAMS.

PATENT

$Id : \mathbb{N}_1$
$Title : TEXT$
$Patent\_date : DATE$
$Patent\_number : PATENT\_NUMBER$
$Granting\_country : COUNTRY$
$Inventor : TEXT$
$Invention\_name : TEXT$
$Abstract : TEXT$

The uses of the different fields of *PATENT* are as follows:
- **Id:** is a unique auto incrementing natural number from 1 upwards.
- **Title:** defines the name of the patent.
- **Patent_date:** stores the date the patent was granted.
- **Patent_number:** stores a unique number of a patent.
- **Granting_country:** stores the name of the country where the patent was granted from.
- **Inventor:** stores the name(s) of innovators.
- **Invention_name:** stores the name of the innovation for which the patent was granted.
- **Abstract:** describes the innovation.

3.3.3.1.1.3.11 Basic definition for research grant

The following schema is a definition of *RESEARCHGRANT* in RAMS.

RESEARCHGRANT
_____

Id :$\mathbb{N}_1$
Name_of_grant : *TEXT*
Sponsor : *TEXT*
Amount : *AMOUNT*
Partners : *TEXT*
Grant_holder : *TEXT*
Year : *YEAR*
Description : *TEXT*

The uses of the different fields of *RESEARCHGRANT* are as follows:

➢ **Id:** is a unique auto incrementing natural number from 1 upwards.

➢ **Name_of_grant:** stores the title of the research grant.

➢ **Sponsor:** stores the name of the sponsor.

➢ **Amount:** stores the value of the quantity of money for the grant.

➢ **Partners:** stores the names of collaborators.

➢ **Grant_holder:** stores the name(s) of the grant holders.

➢ **Year:** is the year the grant was won.

➢ **Description:** describes the grant.

3.3.3.1.1.3.12 Basic definition for technical report

The following schema is a definition of *TECHNICALREPORT* in RAMS.

TECHNICALREPORT
_____

Id : $\mathbb{N}_1$
Author : *TEXT*
Year : *YEAR*
Title: *TEXT*
File : *FILEPATH*

The uses of the different fields of *TECHNICALREPORT* are as follows:

➢ **Id:** is a unique auto incrementing natural number from 1 upwards.

➢ **Author:** stores the names of the author(s).

- **Year:** stores the year in which the report was published.
- **Title:** stores the name of the report.
- **File:** stores the path to the report if the report is uploaded to the system.

3.3.3.1.1.3.13 Basic definition of Collaboration

The following schema is a definition of *COLLABORATION* in RAMS.

COLLABORATION
$Id : \mathbb{N}_1$
Collaborator_name : *TEXT*
Specialisation_area : *TEXT*
Collaboration_type : *TEXT*
Institution : *TEXT*
Address : *ADDRESS*
Country : *COUNTRY*
Email : *EMAIL*
Cellphone : *CELLPHONE*
Telephone : *TELEPHONE*
Website : *WEBADDRESS*
Photo : *FILEPATH*

The uses of the different fields of *COLLABORATION* are as follows:

- **Id:** is a unique auto incrementing natural number from 1 upwards.
- **Collaboration_name:** stores the title of the collaborator(s).
- **Specialisation_area:** stores the area of specialisation of the collaborator.
- **Collaboration_type:** stores the type of collaboration the collaborator is involved in.
- **Institution:** stores the name of the organisation of the collaborator.
- **Address:** stores the address of the collaborator where he is found.
- **Country:** stores the country where the collaborator lives.
- **Email:** stores the email address of the collaborator.
- **Cellphone:** stores the mobile number of the collaborator.
- **Telephone:** stores the landline number of the collaborator.
- **Website:** stores the website link of the collaborator.
- **Photo:** stores the path to the image of the collaborator if the image is uploaded.

3.3.3.1.1.4. Defining the building blocks for RAMS

3.3.3.1.1.4.1. Definition of Members

The following is the definition of Members. Members represents all users of RAMS.

_Members_____
$Member : \mathbb{P}\ MEMBER$
_____

$\forall\ x, y : Member \bullet x.mem\_id = y.mem\_id \wedge x.cellphone = y.cellphone \Leftrightarrow x = y$

In the above schema, *Member* is a set of *MEMBER*. In the predicate part, we state that each user must have a unique *mem_id* and *cellphone*. Therefore, no two users can have the same *mem_id* and *cellphone* number. The same can also be defined as below.

_User_____
$Mem : \mathbb{P}\ MEMBER$
_____

$\forall\ x, y : Mem \bullet x.mem\_id \neq y.mem\_id \wedge x.cellphone \neq y.cellphone \Leftrightarrow x \neq y$

3.3.3.1.1.4.2 Definition of Projects

The following is the definition of Projects which represents all the projects in RAMS.

_Projects_____
$Project : \mathbb{P}\ PROJECT$
_____

$\forall\ p, q : Project \bullet p.Id = q.Id \wedge p.Pid = q.Pid \Leftrightarrow p = q$

In the above schema, *Project* is a set of PROJECT. In the predicate, we define the constraint that no two projects can have the same project number *Pid*. We also set that no two projects should have one *Pid*. Each project has unique project id and project number.

3.3.3.1.1.4.3 Definition of Books

The following is the definition of Books which represents all books in RAMS.

```
┌─ Books ─────────────────────────────────────────────────────
│ Book : ℙ BOOK
│ Member : ℙ MEMBER
│ Added_by_Member : Members ↔ MEMBER
│ Has_author_Member : Members ↔ MEMBER
├──────────────────────────────
│ ∀ x, y : Book • x.Id = y.Id ∧ x.isbn = y.isbn ⇔ x = y
│ ran Added_by_Member ⊆ Member
│ ran Has_author_Member ⊆ Member
└─────────────────────────────────────────────────────────────
```

In the above schema, *Book* is a set of *BOOK*. No two books can have the same *Id* and *isbn*. A book is added into the system by a member belonging to set of *Member* which is itself a set of MEMBER.

3.3.3.1.1.4.4 Definition of Journals

The following is the definition of Journals. Journals represents all the journals in RAMS.

```
┌─ Journals ──────────────────────────────────────────────────
│ Journal : ℙ JOURNAL
│ Member : ℙ MEMBER
│ Added_by_Member : Members ↔ MEMBER
│ Has_author_Member : Members ↔ MEMBER
├──────────────────────────────
│ ∀ x, y : Journal • x.Id = y.Id ∧ x.issn = y.issn ⇔ x = y
│ ran Added_by_Member ⊆ Member
│ ran Has_author_Member ⊆ Member
└─────────────────────────────────────────────────────────────
```

In the above definition, Journal is a set of *JOURNAL*. No two journals can have the same *Id* and *issn*. A journal is added by a member from a set of *Members*. A journal has author(s) who can be from a set of *Members*.

3.3.3.1.1.4.5 Definition of Book chapters

The following is the definition of Chapters. Chapters represents all the chapters in RAMS.

$\underline{Chapters}$

$Chapter : \mathbb{P} \; BOOKCHAPTER$
$Member : \mathbb{P} \; MEMBER$
$Added\_by\_Member : Members \leftrightarrow MEMBER$
$Has\_author\_Member : Members \leftrightarrow MEMBER$

$\forall \; x, y : Chapter \bullet x.Id = y.Id \land x.isbn = y.isbn \Leftrightarrow x = y$
ran $Added\_by\_Member \subseteq Member$
ran $Has\_author\_Member \subseteq Member$

In the above definition, Chapter is a set of *CHAPTER*. No two chapters can have the same *Id* and *isbn*. A Chapter is added by a member from a set of *Members*. A chapter has author(s) who can be from a set of *Members*.

3.3.3.1.1.4.6 Definition of Conference

The following is the definition of Conferences which applies to all conferences in RAMS.

$\underline{Conferences}$

$Conference : \mathbb{P} \; CONFERENCE$
$Member : \mathbb{P} \; MEMBER$
$Added\_by\_Member : Members \leftrightarrow MEMBER$
$Has\_author\_Member : Members \leftrightarrow MEMBER$

$\forall \; x, y : Conference \bullet x.Id \neq y.Id \land x.issn \neq y.issn \Leftrightarrow x \neq y$
ran $Added\_by\_Member \subseteq Member$
ran $Has\_author\_Member \subseteq Member$

In the above definition, Conference is a set of *CONFERENCE*. No two conference papers can have the same *Id* and *issn*. A conference paper is added by a member from a set of *Members*. A conference paper has author(s) who can be from a set of *Members*.

3.3.3.1.1.4.7 Definition for Awards

The following is the definition of Awards. Awards represents all awards in RAMS.

_Awards_____

Award : ℙ *AWARD*

Member : ℙ *MEMBER*

Added_by_Member : *Members* ↔ *MEMBER*

_____

∀ x, y : Award • x.Id ≠ y.Id ⇔ x ≠ y

ran *Added_by_Member* ⊆ *Member*
_____

In the above definition, Award is a set of *AWARDS*. Each award has a unique Id. An award is added by a member from a set of *Members*.

3.3.3.1.1.4.8 Definition of Patents

The following is the definition of Patents which represents all patents in RAMS.

_Patents_____

Patent : ℙ *PATENT*

Member : ℙ *MEMBER*

Added_by_Member : *Members* ↔ *MEMBER*

Owned_by_Member : *Members*↔ *MEMBER*

_____

∀ x, y : Patent • x.Id ≠ y.Id ∧ x.Patent_number ≠ y.Patent_number ⇔ x ≠ y

ran *Added_by_Member* ⊆ *Member*

ran *Owned_by_Member* ⊆ *Member*
_____

In the above definition, Patent is a set of *PATENT*. No two patents can have the same *Id* and *Patent_number*. A patent is added by a member from a set of *Members*. A patent is owned by member from a set of *Members*.

3.3.3.1.1.4.9 Definition of Creative arts

The following is the definition of Arts. Arts here represents all creative arts in RAMS.

```
  Arts
  Art : ℙ CREATIVEART
  Member : ℙ MEMBER
  Added_by_Member : Members ↔ MEMBER
  Has_inventor_Member : Members↔ MEMBER

  ∀ x, y : Art • x.Id = y.Id ⇔ x = y
  ran Added_by_Member ⊆ Member
  ran Has_inventor_Member ⊆ Member
```

In the above schema definition, *Art* is a set of *CREATIVEART*. No two creative arts can have the same *Id.* A creative art is added by a member from a set of *Members*. A creative art has inventor who can be from a set of *Members*.

3.3.3.1.1.4.10 Definition of Grant

The following is the definition Grants which applies to all grants in RAMS.

```
  Grants
  Grant : ℙ RESEARCHGRANT

  ∀ x, y : Grant • x.Id = y.Id ⇔ x = y
```

In the above schema definition for a grant, *Grant* is a set of *RESEARCHGRANT* and no two grants can have the same *Id*.

3.3.3.1.1.4.11 Definition of Technical report

The following is the definition of TechnicalReports which is applicable to all technical reports in RAMS.

```
  TechnicalReports
  Technical_report : ℙ TECHNICALREPORT

  ∀ x, y : Technical_report • x.Id = y.Id ⇔ x = y
```

In the above schema definition for a technical report, *Technical_reportt* is a set of *TECHNICALREPORT* and no two technical reports can have the same *Id*.

3.3.3.1.1.4.12 Definition of Collaboration

The following is the definition of Collaborations. Collaborations represents all collaborations in RAMS.

_Collaborations_____

Collaboration: $\mathbb{P}$ _COLLABORATION_

$\forall\ x,\ y : Collaboration \bullet x.Id = y.Id \Leftrightarrow x = y$

In the above schema definition for collaboration, _Collaboration_ is a set of _COLLABORATION_ and no two collaborations can have the same _Id_.

3.3.3.1.1.4.13 Definition for Research Area

The following is the definition of Interests. RInterests represents all research interest areas in RAMS.

_RInterests_____

Area : $\mathbb{P}$ _RESEARCHAREA_
Member : $\mathbb{P}$ _MEMBER_
_Added_by_Member_ : _Members_ $\leftrightarrow$ _MEMBER_

$\forall\ x,\ y : Area \bullet x.Id \neq y.Id \Leftrightarrow x \neq y$
ran _Added_by_Member_ $\subseteq$ _Member_

In the above definition, _Area_ is a set of _RESEARCHAREA_. Each Area has a unique Id. An area is added by a member from a set of _Members_.

3.3.3.1.1.5 Definition of RAMS

RAMS is comprised of several components. Some of the major components are as follows:

1. Members: represents all the users of the system
2. Books: represents a book publication
3. Chapters: represents a chapter publication
4. Conferences: represents a conference paper
5. Journals: represents a journal publication
6. Patents: represents any patented work
7. Grants: represents the grants acquired by researchers within the HEI
8. Arts: represents any creative art work in the HEI

9. TechnicalReports: represents technical reports by researchers in the HEI

10. Awards: represents award presented to researchers in the HEI

11. Collaboration: represents the partnerships with other researchers in research work

12. RInterests: represents the research interest area of a researcher.

The components are defined in the schema as shown below.

RAMS

Members
Books
Chapters
Conferences
Journals
Awards
Patents
Grants
Arts
TechnicalReports
Collaborations
RInterests

3.3.3.1.1.6 Initialisation of RAMS

The following is the initialisation of Research Administration and Management System (RAMS). The initial state of the system contains no data. Therefore, all the sets and relations have been initialized to empty sets.

```
  InitRAMS
  Δ RAMS

  Members = ∅
  Books = ∅
  Chapters = ∅
  Conferences = ∅
  Journals = ∅
  Awards = ∅
  Patents = ∅
  Arts = ∅
  TechnicalReports = ∅
  Collaborations = ∅
  Grants = ∅
  RInterests = ∅
```

3.3.3.1.1.7 Operations in RAMS

3.3.3.1.1.7.1 Adding a new member

The operation below is a manipulation operation that adds a new member to the system. It ensures that the new member does not already exist in the system. If the member already exists in the system, the new record is not added and an error message will be displayed. If the member does not already exist in the system, the new member will be added and a message of successful operation will be displayed.

AddNewMember
_____

ΔMembers
empid?, uname?, name?, surname? : TEXT
passwd? : PASSWORD
urole? : USER_ROLE
salutation? : TITLE
bdate? : DATE
sex? : GENDER
identity? : IDTYPE
rc? : RACE
origin? : COUNTRY
grade? : RANK
tel? : TELEPHONE
faxno? : FAX
cell? : CELLPHONE
e_mail? : EMAIL
p_address? : ADDRESS
inst? : TEXT
bio? : TEXT
response!, success! : RESPONSE
site? : WEBADDRESS
pic? : FILEPATH
_____

∃x : Member • x.mem_id = empid? ∨x.id_type = identity?
⇒ response! = RECORD_ALREADY_EXISTS
Member' = Member ∪ { x : MEMBER | x.mem_id = empid? ∧
x.username = uname? ∧ x.password = passwd? ∧ x.fname = name? ∧ x.lname = surname? ∧
x.role = urole? ∧ x.title = salutation? ∧ x.dob = bdate? ∧ x.gender = sex? ∧ x.id_type = identity? ∧
x.race = rc? ∧ x.nationality = origin? ∧ x.rank = grade? ∧ x.telephone = tel? ∧ x.fax = faxno? ∧
x.cellphone = cell? ∧ x.email = e_mail? ∧ x.address = p_address? ∧ x.website = site? ∧
x.institution = inst? ∧ x.biography = bio? ∧ x.photo = pic? }
⇒ response! = USER_ADDED_SUCCESSFULLY

3.3.3.1.1.7.2 Adding a new book

The manipulation operation below adds a new book into the system. It ensures that the new
book does not already exist in the system. If the book already exists in the system, the new
record is not added and an error message will be displayed. If the new book does not already

exist in the system, the new record will be added and a message of successful operation will be displayed.

┌─ *AddNewBook* ───
│ Δ*Books*
│ *author?, exauthor?* : *AUTHOR*
│ *internal?* : $\mathbb{N}_1$
│ *external?* : $\mathbb{N}$
│ *yr?, ryear?* : *YEAR*
│ *t?, place?, pub?, ed?, edtn?* : *TEXT*
│ *bisbn?* : *ISBN*
│ *page?* : $\mathbb{N}_1$
│ *bdoi?* : *DOI*
│ *url_address?* : *URL*
│ *access?* : *ACCESSION*
│ *success!, response!* : *RESPONSE*
│ *doc?* : *FILEPATH*
├──
│ $\exists x$: *Book* • *x.title = t?* ∧ *x.year = yr?* ∧ *x.isbn = bisbn?*
│ ⇒ *response! = RECORD_ALREADY_EXISTS*
│ *Book' = Book* ∪ { *x* : *BOOK* | *x.authors = author?* ∧ *x.exauthors = exauthor?* ∧
│ *x.internal_authors = internal?* ∧ *x.external_authors = external?* ∧
│ *x.year = yr?* ∧ *x.report_year= ryear?* ∧ *x.title = t?* ∧ *x.place_of_publication = place?* ∧
│ *x.publisher = pub?* ∧ *x.editor = ed?* ∧ *x.edition = edtn?* ∧ *x.isbn = bisbn?* ∧ *x.pages = page?* ∧
│ *x.doi = bdoi?* ∧ *x.url = url_address?* ∧ *x.accession = access?* ∧ *x.file = doc?* }
│ ⇒ *success! = RECORD_SUCCESSFULLY_ADDED*
└──

3.3.3.1.1.7.3 Adding a new book chapter

The manipulation operation below adds a new chapter of a book into the system. It ensures that the new chapter does not already exist in the system. If the chapter already exists in the system, the new record is not added and an error message will be displayed informing the user that the information already exists in the system. If the new chapter does not already exist in the system, the new record will be added and a message of successful operation will be displayed.

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AddNewChapter

Δ_Chapters_

author?, exauthor? : AUTHOR

internal? : $\mathbb{N}_1$

external? : $\mathbb{N}$

yr?, ryear? : YEAR

chaptitle?, btitle?, place?, pub?, ed?, edtn? : TEXT

isbnno? : ISBN

page? : $\mathbb{N}_1$

chapdoi? : DOI

_url_address? : URL_

access? : ACCESSION

success!, response! : RESPONSE

doc? : FILEPATH

$\exists x$: _Chapter • x.title = chaptitle?_ $\wedge$ _x.year = yr?_ $\wedge$ _x.isbn = isbnno?_

$\Rightarrow$ _response! = RECORD_ALREADY_EXISTS_

Chapter' = Chapter $\cup$ { _x : BOOKCHAPTER | x.authors = author?_ $\wedge$ _x.exauthors = exauthor?_ $\wedge$
_x.internal_authors = internal?_ $\wedge$ _x.external_authors = external?_ $\wedge$ _x.year = yr?_ $\wedge$
_x.report_year= ryear?_ $\wedge$ _x.title = chaptitle?_ $\wedge$ _x.book_title = btitle?_ $\wedge$ _x.place_published = place?_ $\wedge$
 x.publisher = pub? $\wedge$ _x.editor = ed?_ $\wedge$ _x.edition = edtn?_ $\wedge$ _x.isbn = isbnno?_ $\wedge$ _x.pages = page?_ $\wedge$
x.doi = chapdoi? $\wedge$ _x.url = url_address?_ $\wedge$ _x.accession = access?_ $\wedge$ _x.file = doc?_ }
$\Rightarrow$ _success! = RECORD_SUCCESSFULLY_ADDED_

3.3.3.1.1.7.4 Adding a new conference paper

The manipulation operation below adds a new conference paper into the system. It ensures that the new conference record does not already exist in the system. If the record already exists in the system, is not added again and an error message will be displayed. If the new record does not already exist in the system, it will be added and a message of successful operation will be displayed.

$\underline{\text{AddNewConference}\underline{}}$

Δ*Conferences*

author?, exauthor? : *AUTHOR*

internal? : $\mathbb{N}_1$

external? : $\mathbb{N}$

yr?, ryear? : *YEAR*

t?, conference?, ven? : *TEXT*

confdate? : *DATE*

place?, pub?, edt? : *TEXT*

vol?, cissue? : $\mathbb{N}_1$

cissn? : *ISSN*

page? : $\mathbb{N}_1$

cdoi? : *DOI*

url_address? : *URL*

access? : *ACCESSION*

success!, response! : *RESPONSE*

doc? : *FILEPATH*

$\underline{}$

$\exists x$: *Conference* • *x.title = t?* $\wedge$ *x.year = yr?* $\wedge$ *x.date = confdate?*

$\Rightarrow$ *response! = RECORD_ALREADY_EXISTS*

Conference' = Conference $\cup$ { *x* : *CONFERENCE* | *x.authors = author?* $\wedge$ *x.exauthors = exauthor?* $\wedge$

x.internal_authors = internal? $\wedge$ *x.external_authors = external?* $\wedge$

x.year = yr? $\wedge$ *x.report_year= ryear?* $\wedge$ *x.title = t?* $\wedge$ *x.conference_name = conference?* $\wedge$

x.venue = ven? $\wedge$ *x.date = confdate?* $\wedge$ *x.place_published = place?* $\wedge$ *x.publisher = pub?* $\wedge$

x.editor = edt? $\wedge$ *x.volume = vol?* $\wedge$ *x.issue = cissue?* $\wedge$ *x.issn = cissn?* $\wedge$ *x.pages = page?* $\wedge$

x.doi = cdoi? $\wedge$ *x.url = url_address?* $\wedge$ *x.accession = access?* $\wedge$ *x.file = doc?* }

$\Rightarrow$*success! = RECORD_SUCCESSFULLY_ADDED*

3.3.3.1.1.7.5 Adding a new journal

The manipulation operation below adds a new journal record into the system. It ensures that the new record does not already exist in the system. If the record already exists in the system, it is not added and an error message will be displayed. If the new record does not already exist in the system, it will be added and a message of successful operation will be displayed.

```
AddNewJournal
ΔJournals
author?, exauthor? : AUTHOR
internal? : ℕ₁
external? : ℕ
yr?, ryear? : YEAR
t?, journal? : TEXT
vol?, jissue? : ℕ₁
jissn? : ISSN
pagerange? : RANGE
jdoi? : DOI
jurl? : URL
success!, response! : RESPONSE
doc? : FILEPATH

∃x : Journal • x.title = t? ∧ x.year = yr?
⇒ response! = RECORD_ALREADY_EXISTS
Journal' = Journal ∪ { x :JOURNAL | x.authors = author? ∧ x.exauthors = exauthor? ∧
x.internal_authors = internal? ∧ x.external_authors = external? ∧
x.year = yr? ∧ x.report_year= ryear? ∧ x.title = t? ∧ x.journal_name = journal? ∧
x.volume = vol? ∧ x.issue = jissue? ∧ x.issn = jissn? ∧ x.page_range = pagerange? ∧
x.doi = jdoi? ∧ x.url = jurl? ∧ x.file = doc? }
⇒success! = RECORD_SUCCESSFULLY_ADDED
```

3.3.3.1.1.7.6 Adding a new award

The manipulation operation below adds a new award into the system. It ensures that the new record does not already exist in the system. If the record already exists in the system, it is not added and an error message will be displayed. If the new record does not already exist in the system, the new record will be added and a message of successful operation will be displayed.

```
AddNewAward
ΔAwards
award? : TEXT
org? : TEXT
val? : AMOUNT
yr? : YEAR
success!, response! : RESPONSE
desc? : TEXT

∃x : Award • x.award_name = award? ∧ x.year = yr? ∧ x.organisation = org?
⇒ response! = RECORD_ALREADY_EXISTS
Award' = Award ∪ { x : AWARD | x.award_name = award? ∧ x.organisation = org? ∧
x.value = val? ∧ x.year = yr? ∧ x.description = desc? }
⇒ success! = RECORD_SUCCESSFULLY_ADDED
```

3.3.3.1.1.7.7 Adding a new creative art

The manipulation operation below adds a new creative art record into the system. It ensures that the new record does not already exist in the system. If the record already exists in the system, it is not added and an error message will be displayed. If the new record does not already exist in the system, it will be added and a message of successful operation will be displayed.

```
AddNewArt
ΔArts
t? : TEXT
desc? : TEXT
yr? : YEAR
success!, response! : RESPONSE
inst? : TEXT

∃x : Art • x.Title = t? ∧ x.Year = yr?
⇒ response! = RECORD_ALREADY_EXISTS
Art' = Art ∪ { x : CREATIVEART | x.Title = t? ∧ x.Description = desc? ∧ x.Year = yr? ∧
x.Institution = inst? }
⇒ success! = RECORD_SUCCESSFULLY_ADDED
```

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3.3.3.1.1.7.8 Adding a new technical report

The manipulation operation below adds a new record for technical report into the system. It ensures that the new record does not already exist in the system. If the record already exists in the system, it is not added and an error message will be displayed. If the new record does not already exist in the system, it will be added and a message of successful operation will be displayed.

AddNewTecnicalReport
ΔTechnicalReports
auth? : TEXT
yr? : YEAR
title? : TEXT
success!, response! : RESPONSE
doc? : FILEPATH

∃x : _Technical_report • x.Title = title? ∧ x.Year = yr?_
⇒ _response! = RECORD_ALREADY_EXISTS_
_Technical_report' = Technical_report ∪ { x : TECHNICALREPORT | x.Author = auth? ∧ x.Year = yr? ∧ x.Title = title? ∧ x.File = doc? }_
⇒ _success! = RECORD_SUCCESSFULLY_ADDED_

3.3.3.1.1.7.9 Adding a new project

The manipulation operation below adds a new record for project into the system. It ensures that the new record does not already exist in the system. If the record already exists in the system, it is not added and an error message will be displayed. If the new record does not already exist in the system, it will be added and a message of successful operation will be displayed.

```
AddNewProject
ΔProjects
projectno? : PROJECT_NUMBER
title? : TEXT
role? : ROLE
sponsor? : TEXT
amount? : AMOUNT
sdate? : DATE
fdate? : DATE
piname? : TEXT
success!, response! : RESPONSE
other? : TEXT

∃x : Project • x.Title = title? ∧ x.Start_date = sdate? ∧ x.Finish_date = fdate? ∨ x.Pid = projectno?
⇒ response! = RECORD_ALREADY_EXISTS
Project' = Project ∪ { x : PROJECT | x.Pid = projectno? ∧ x.Title= title? ∧ x.Role = role? ∧
x.Project_sponsor = sponsor? ∧ x.Project_amount = amount? ∧ x.Start_date = sdate? ∧
x.Finish_date = fdate? ∧ x.Piname = piname? ∧ x.Otherpi = other?}
⇒success! = RECORD_SUCCESSFULLY_ADDED
```

3.3.3.1.1.7.10 Adding a new patent

The manipulation operation below adds a new record of a patent into the system. It ensures that
the new record does not already exist in the system. If the record already exists in the system,
it is not added and an error message will be displayed. If the new record does not already exist
in the system, it will be added and a message of successful operation will be displayed.

_AddNewPatent_____

ΔPatents
title?, innovator?, abstract?, invention? : TEXT
pdate? : DATE
patentno? : PATENT_NUMBER
country? : COUNTRY
success!, response! : RESPONSE
_____

$\exists x : Patent \bullet x.Title = title? \lor x.Patent\_number = patentno? \land x.Patent\_date = pdate?$
$\Rightarrow response! = RECORD\_ALREADY\_EXISTS$
Patent′ = Patent ∪ { x : PATENT | x.Title = title? ∧ x.Patent_date= pdate? ∧
x.Patent_number = patentno? ∧ x.Granting_country = country? ∧
x.Inventor = innovator? ∧ x.Invention_name = invention? ∧
x.Abstract = abstract?}
⇒success! = RECORD_SUCCESSFULLY_ADDED
_____

3.3.3.1.1.7.11 Adding a new grant

The manipulation operation below adds a new record of a grant into the system. It ensures that the new record does not already exist in the system. If the record already exists in the system, it is not added and an error message will be displayed. If the new record does not already exist in the system, it will be added and a message of successful operation will be displayed

_AddNewGrant_____

ΔGrants
grant?, sponsor?, partner?, gholder?, desc? : TEXT
amount? : AMOUNT
yr? : YEAR
success!, response! : RESPONSE
_____

$\exists x : Grant \bullet x.Name\_of\_grant = grant? \land x.Year = yr? \land x.Grant\_holder = gholder?$
$\Rightarrow response! = RECORD\_ALREADY\_EXISTS$
Grant′ = Grant ∪ { x : RESEARCHGRANT | x.Name_of_grant= grant? ∧
x.Sponsor= sponsor? ∧ x.Amount = amount? ∧ x.Partners = partner? ∧
x.Grant_holder = gholder? ∧ x.Year= yr? ∧ x.Description = desc?}
⇒success! = RECORD_SUCCESSFULLY_ADDED
_____

3.3.3.1.1.7.12 Add new collaboration

The manipulation operation below adds a new record of a collaboration into the system. It ensures that the new record does not already exist in the system. If the record already exists in the system, it is not added and an error message will be displayed. If the new record does not already exist in the system, it will be added and a message of successful operation will be displayed.

AddNewCollaboration
ΔCollaborations
name?, area?, type?, inst? : TEXT
address? : ADDRESS
country? : COUNTRY
email? : EMAIL
cell? : CELLPHONE
tel? : TELEPHONE
site? : WEBADDRESS
success!, response! : RESPONSE
pic? : FILEPATH

$\exists x : Collaboration \bullet x.Collaborator\_name = name? \wedge x.Cellphone = cell?$
$\Rightarrow response! = RECORD\_ALREADY\_EXISTS$
$Collaboration' = Collaboration \cup \{ x : COLLABORATION \mid x.Collaborator\_name = name? \wedge$
$x.Specialisation\_area = area? \wedge x.Collaboration\_type = type? \wedge x.Institution = inst? \wedge$
$x.Address = address? \wedge x.Country = country? \wedge x.Email = email? \wedge x.Cellphone = cell? \wedge$
$x.Telephone = tel? \wedge x.Website = site? \wedge x.Photo = pic? \}$
$\Rightarrow success! = RECORD\_SUCCESSFULLY\_ADDED$

3.3.3.1.1.7.13 Add a new research interest

The manipulation operation below adds a new record of a research interest area into the system. It ensures that the new record does not already exist in the system. If the record already exists in the system, it is not added and an error message will be displayed. If the new record does not already exist in the system, it will be added and a message of successful operation will be displayed.

```
AddNewResearchArea
ΔRInterests
t? : TEXT
desc? : TEXT
date? : DATE
sponsor? : TEXT
success!, response! : RESPONSE
pub? : ℕ₁

∃x : Area • x.title = t?
⇒ response! = RECORD_ALREADY_EXISTS
Area' = Area ∪ { x : RESEARCHAREA | x.title = t? ∧ x.description = desc? ∧ x.date = date? ∧
x.publications = pub? ∧ x.sponsor = sponsor?}
⇒ success! = RECORD_SUCCESSFULLY_ADDED
```

3.3.3.1.1.8 Query operations for viewing records and displaying error messages

3.3.3.1.1.8.1 View Projects

The operation below lists records of projects. If the records do not exist a message is displayed
notifying that records are not found.

```
ViewProject
ΞRAMS
pname? : TEXT
project : ℙ PROJECT
Project : ℙ PROJECT
result!, records : PROJECT
response! : RESPONSE
pnum? : PROJECT_NUMBER

project = {x : Project | x.Pid = pnum? ∨ x.Title = pname? }
records = (μ x : Project | x.Pid = pnum? ∨ x.Title = pname? )
result! = records
{records} = ∅ ⇒ response! = NO_RECORDS_FOUND
```

3.3.3.1.1.8.2 View Journals

The operation below lists records of journals. If there are no records matching a criterion, a
message is displayed notifying that records are not found.

*ViewJournal*_____

$\Xi RAMS$

author? : *AUTHOR*

year? : *YEAR*

title? : *TEXT*

response! : *RESPONSE*

result!, *records* : *JOURNAL*

_____

records = (μ *x* : *Journal* | *x.authors* = *author*? $\vee$ *x.title* = *title*? $\vee$ *x.year* = *year*?)

result! = *records*

{*records*} = $\emptyset$ $\Rightarrow$ *response*! = *NO_RECORDS_FOUND*

_____

3.3.3.1.1.8.3 View Books

The operation below lists records of books. If the records do not exist in the system, a message is displayed notifying that records are not found.

*ViewBook*_____

$\Xi RAMS$

author? : *AUTHOR*

year? : *YEAR*

title? : *TEXT*

records : *BOOK*

response! : *RESPONSE*

result! : *BOOK*

_____

records = (μ *x* : *Book* | *x.authors* = *author*? $\vee$ *x.title* = *title*? $\vee$ *x.year* = *year*?)

result! = *records*

{*records*} = $\emptyset$ $\Rightarrow$ *response*! = *NO_RECORDS_FOUND*

_____

3.3.3.1.1.8.4 View Book Chapters

The operation below lists records of book chapters. If the records do not exist a message is displayed notifying that records are not found.

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_ViewChapter_____

ΞRAMS
author? : AUTHOR
year? : YEAR
title? : TEXT
records : BOOKCHAPTER
response! : RESPONSE
result! : BOOKCHAPTER
_____

records = (μ x : Chapter | x.authors = author? ∨ x.title = title? ∨ x.year = year?)
result! = records
{ records } = ∅ ⇒ response! = NO_RECORDS_FOUND
_____

3.3.3.1.1.8.5 Viewing Conference records

The operation below lists records of conference papers. If the records do not exist a message is displayed notifying that records are not found.

_ViewConference_____

ΞRAMS
author? : AUTHOR
year? : YEAR
title? : TEXT
records : CONFERENCE
response! : RESPONSE
result! : CONFERENCE
_____

result! = (μ x : Conference | x.authors = author? ∨ x.title = title? ∨ x.year = year?)
records = (μ x : Conference | x.authors = author? ∨ x.title = title? ∨ x.year = year?)
{ records } = ∅ ⇒ response! = NO_RECORDS_FOUND
_____

3.3.3.1.1.8.6 View Patents

The operation below lists records of patents. If the records do not exist a message is displayed notifying that records are not found.

ViewPatents

$\Xi RAMS$
title? : TEXT
inventor? : TEXT
response! : RESPONSE
records : PATENT
result! : PATENT

records = (μ x : Patent | x.Title = title? ∨ x.Inventor = inventor?)
result! = records
{ records } = ∅
⇒ response! = NO_RECORDS_FOUND

3.3.3.1.1.8.7 Viewing Grants records

The operation below lists records of grants. If the records do not exist a message is displayed notifying that records are not found.

ViewGrants

$\Xi RAMS$
grant? : TEXT
sponsor? : TEXT
name? : TEXT
year? : YEAR
response! : RESPONSE
records : RESEARCHGRANT
result! : RESEARCHGRANT

records = (μ x : Grant | x.Name_of_grant= grant? ∨ x.Sponsor = sponsor? ∨
x.Grant_holder = name? ∨ x.Year = year?)
result! = records
{ records } = ∅
⇒ response! = NO_RECORDS_FOUND

3.3.3.1.1.8.8 Viewing Technical reports

The operation below lists records of technical reports. If the records do not exist a message is displayed notifying that records are not found.

```
ViewTechnicalReports
ΞRAMS
author? : TEXT
year? : YEAR
title? : TEXT
response! : RESPONSE
records : TECHNICALREPORT
result! : TECHNICALREPORT

records = (μ x : Technical_report | x.Author= author? ∨ x.Year = year? ∨ x.Title = title?)
result! = records
{ records } = ∅
⇒ response! = NO_RECORDS_FOUND
```

3.3.3.1.1.8.9 View Creative arts

The operation below lists records of creative arts. If the records do not exist in the system, a message is displayed notifying that records are not found.

```
ViewCreativeArts
ΞRAMS
title? : TEXT
year? : YEAR
response! : RESPONSE
records : CREATIVEART
result! : CREATIVEART

records = (μ x : Art | x.Title = title? ∨ x.Year = year?)
result! = records
{ records } = ∅
⇒ response! = NO_RECORDS_FOUND
```

3.3.3.1.1.8.10 View Awards

The operation below lists records of awards. If the records do not exist in the system, a message is displayed notifying that records are not found.

80

ViewAwards

ΞRAMS

title? : *TEXT*

year? : *YEAR*

response! : *RESPONSE*

records : *AWARD*

result! : *AWARD*

records = (*μ x* : *Award* | *x.award_name* = *title?* ∨ *x.year* = *year?*)

result! = *records*

{ *records* } = ∅

⇒ *response!* = *NO_RECORDS_FOUND*

3.3.3.1.1.8.11 View Collaborators

The operation below lists records of collaborators. If the records do not exist in the system, a message is displayed notifying that records are not found.

ViewCollaborators

ΞRAMS

name? : *TEXT*

country? : *COUNTRY*

inst? : *TEXT*

response! : *RESPONSE*

records : *COLLABORATION*

result! : *COLLABORATION*

records = (*μ x* : *Collaboration* | *x.Collaborator_name* = *name?* ∨ *x.Country* = *country?*

∨ *x.Institution* = *inst?*)

result! = *records*

{ *records* } = ∅

⇒ *response!* = *NO_RECORDS_FOUND*

3.3.3.1.1.8.12 View research interests

The operation below lists records of research interest areas. If the records do not exist in the system, a message is displayed notifying that records are not found.

_ViewResearchArea_____

ΞRAMS

title? : TEXT

sponsor? : TEXT

response! : RESPONSE

records : RESEARCHAREA

result! : RESEARCHAREA

_____

records = (µ x : Area | x.title = title? ∨ x.sponsor = sponsor?)

result! = records

{ records } = ∅

⇒ response! = NO_RECORDS_FOUND

_____

3.3.3.2 Design

After the elicitation and specification of requirements, the design decision for the proposed system was reached. RAMS is based on the client-server architecture organised in presentation tier, application tier and data tier. The presentation tier comprises all components that are responsible for presenting information in a web user interface. It encompasses the web-browser based representation of all information that can be accessed in RAMS. Clients in the send their requests over the secure hypertext transfer protocol (HTTPS) to the web server which then respond with the queried data over the same HTTPS to the client.

The application tier comprises in general all components that are responsible for the logistics of RAMS. This tier consists of a web server which communicates with the presentation tier and data tier to process the incoming queries and move data between presentation and data tier. The application tier coordinates the application, processes commands, makes logical decisions and evaluations on the queries received from the presentation tier. The application tier is written in PHP and is capable of handling simultaneous connections thus allowing several users to interact with RAMS. The data tier is where information is stored and retrieved from a MySQL database and then passed back to application tier for processing and then eventually to the presentation tier for viewing by the user. Generally, the data tier comprises all components responsible for the persistent, sustainable storage and management of data in RAMS. Figure 3.3 shows the simplified architecture of RAMS.
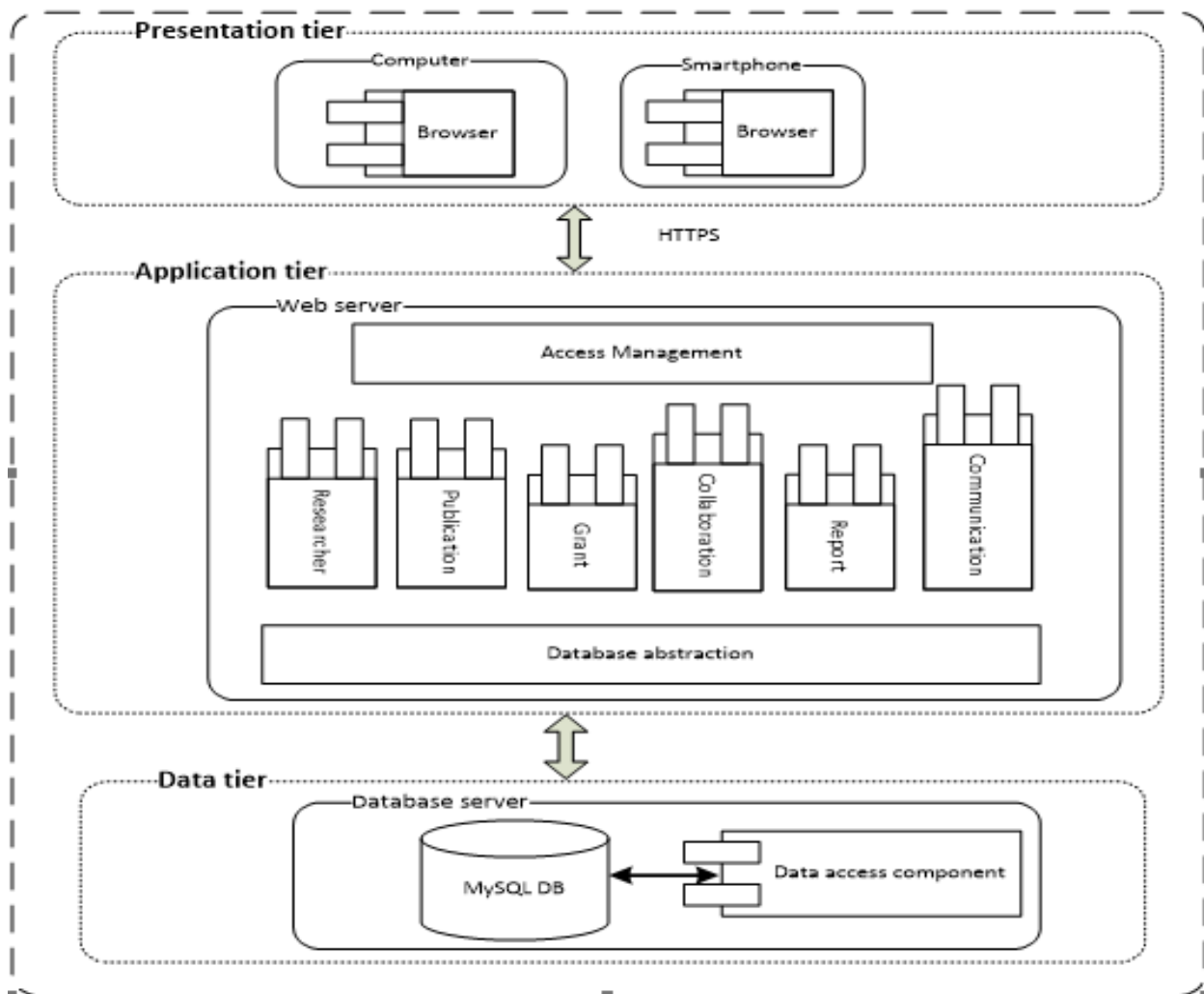
Figure 3.3: Client-Server architecture of RAMS

The resulting artefact was developed using responsive web technologies which have gained momentum with the emergent of HTML5 and CSS. These technologies made it possible to design a research administration and management system that has user interface that adapts to devices with various screen resolution sizes. The responsive web technologies are essential as they allow the system to be accessible on both PC and mobile devices such as smart phones. This gives the freedom to users who use mobile devices to use the system at their convinience as the system adapts to these devices. Therefore the users are not tethered in one place in order to use the system. The responsive technology greatly improves presentation on mobile browsers by hiding certain user interface contents. Use of responsive technologies to design web applications have recently gained preference. The primary contributing factor is the increasing support that the technology receives from JavaScript web frameworks such as *Bootstrap* (Bootstrap 2017), *JQuery UI* (The jQuery Foundation 2017) and *Less Framework* (Korpi 2017). These frameworks adopt a fluent grid concept to layout contents on diverse

screen resolutions. The development task for RAMS utilised PHP as the main scripting language in conjunction with JavaScript.

3.3.4. Activity 4: Demonstration

The fourth activity of the DSRM model focuses on demonstrating the use of the artefact to solve one or more instances of the problem. After successful creation, the research administration and management system was deployed for use in the production environment at the case study institution to demonstrate how the system accomplished the different research information management activities. The selected set of users were authorised to use the system and try out all the different functionalities of the system and report their perceptions and any issues found through a personal messaging component built within the system. The feedback from the users led to several iterations of the design and development process.

3.3.5. Activity 5: Evaluation

The fifth activity of the DSRM model is the evaluation of the resulting artefact. It involves comparing the objectives of a solution to actual observed results from use of the artefact in the demonstration. After deployment of the research administration and management system, the researcher observed the users as they performed research information management activities with the system. The research administration and management system proved to be effective for managing the activities pertinent to the Research and Postgraduate Office. However, the system did not include the functionality for automatically harvesting publication information from online sources such as google scholar, web of science, etc. Due to time constraints, this functionality was not implemented in RAMS and it is anticipated that prospects of future research on the system should address this requirement. The evaluation results of the developed system are presented in detail in chapter 4 of this dissertation.

3.3.6. Activity 6. Communication

The last activity of the DSRM model involves communicating the problem and its importance, the artefact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences such as practicing professionals, when appropriate (Peffers *et al*., 2007). The results of this study are communicated in form of the developed artefact called RAMS which is built for managing research information in HEIs. This dissertation is also regarded as means of communicating the problem that the study intended to solve and how the

solution was realised. Additionally, a journal article will be produced from this work which will report on the work accomplished in this study.

3.4. Chapter Summary

This chapter has presented the design science research paradigm that was adopted for this research study. The chapter has also shown how the DSRM was utilised to carry out the research study by highlighting the activities that were accomplished. This chapter has also presented the formal specifications for the research administration and management system. The next chapter presents the implementation and evaluation results of the proposed research administration and management system.

CHAPTER 4: EXPERIMENTATION AND RESULTS

In conformity with the evaluation step of the DSRM, which aims to observe and measure how well the resulting artefact supports a solution to the identified problems, this chapter reports on the implementation and evaluation of the proposed research administration and management system (RAMS) that could be used for managing research information in HEIs. The developed RAMS serves to legitimise its conception as a proposed solution to the identified problems. The chapter begins by presenting implementation of RAMS followed by its functional description. Thereafter evaluation of RAMS and results are presented. Lastly, a summary of the chapter is presented.

4.1. Implementation of RAMS

The proposed RAMS is aimed at managing research information in HEIs by improving the effectiveness and efficiency of the research information management processes. Therefore, the successful implementation and use of RAMS in a real-life environment of the intended users in HEIs should demonstrate its relevance and provide proof of its conception. The developed RAMS is a simple web-based application that is easy to use and adapts to devices with different screen sizes. Accordingly, RAMS is accessible through mobile devices such as smart phones, allowing users (researchers and staff in Research and Postgraduate Office) to use the system regardless of where they are provided the device has an internet connection. Additionally, RAMS is compatible with different browsers.

The proposed system houses several modules that are germane to research information management, namely, Manage Publications, Manage Researchers, Manage Grants, Manage Collaborations, Manage Reports and Manage Communication. The "Manage Publications" module deals with all functionalities (adding, viewing, editing, deleting) that are related to management of research outputs which include books, book chapters, conference papers, journal articles and patents. The "Manage Researcher" module provides the user (researchers and staff in Research and Postgraduate Office) with functionalities for adding, updating, deleting of their personal, professional and academic information. This module also allows the user to view his or her profile which is created automatically by the system based on the user's information available in the system. Within the manage researcher module is where the user can also automatically generate his or her curriculum vitae. The "Manage Grants" module is where researchers can add, view, edit, and delete information about their awards, projects and research grants. The "Manage Collaborations" module provides functionalities for the

researcher to add, view and edit information about other researchers he or she collaborated with, specifically from other institutions.

The "Manage Reports" module handles functionalities for generating several types of reports from RAMS. This module is only accessible to users in the Research and Postgraduate Office as they are the ones responsible for reporting on research activities within the HEI. The "Manage Communication" module provides a means where users within the HEI can network with each other to discuss important issues. Within this module, a researcher can also add and view information about the students under his or her supervision. For the purposes of testing the system by users and evaluation, the proposed RAMS was hosted on a server and can be accessed at http://www.dutresearch.co.za.com. The back-end database used for RAMS is MySQL database server. MySQL was chosen because it is open source and free, and has many other advantages as listed at https://www.mysql.com/why-mysql/topreasons.html. Additionally, MySQL database is capable of handling large amounts of data and allows speedy and concurrent access to data by multiple users in real time.

4.2. Functional description of RAMS

The proposed RAMS was built mainly to support research information management activities of researchers and staff in the Research and Postgraduate Office at Durban University of Technology (DUT). However, the system can also be useful to other HEIs with similar needs as those of DUT. RAMS comprises important modules for managing research information. The modules are accessible for use by the user when the user is successfully authenticated by providing his or her username and password. Therefore, before a user can make use of the modules in RAMS, he or she must be registered into the system by providing a username and a password which are used for authentication during login to the system. Moreover, the registration process allows the users to provide detailed information about themselves which is used by the system to generate a profile for the user.

Figures 4.1 and Figure 4.2 below show the screen where the user logs into the system by supplying username and password. Figure 4.1 specifically shows the login screen when viewed on devices with large screen sizes. The screen in Figure 4.1 also provides an option for users who are not registered into the system to register by clicking on the "Register" button located on the top right of the screen. Figure 4.1 also shows the main modules of RAMS on the left panel which can only be used if the user successfully logs into the system, except those in red colour which are for public viewing. Figure 4.2 shows the login screen when viewed on

smart phone and Figure 4.3 when the toggle button is clicked on a smart phone which reveals the modules in RAMS. Figure 4.4 shows the user registration screen.
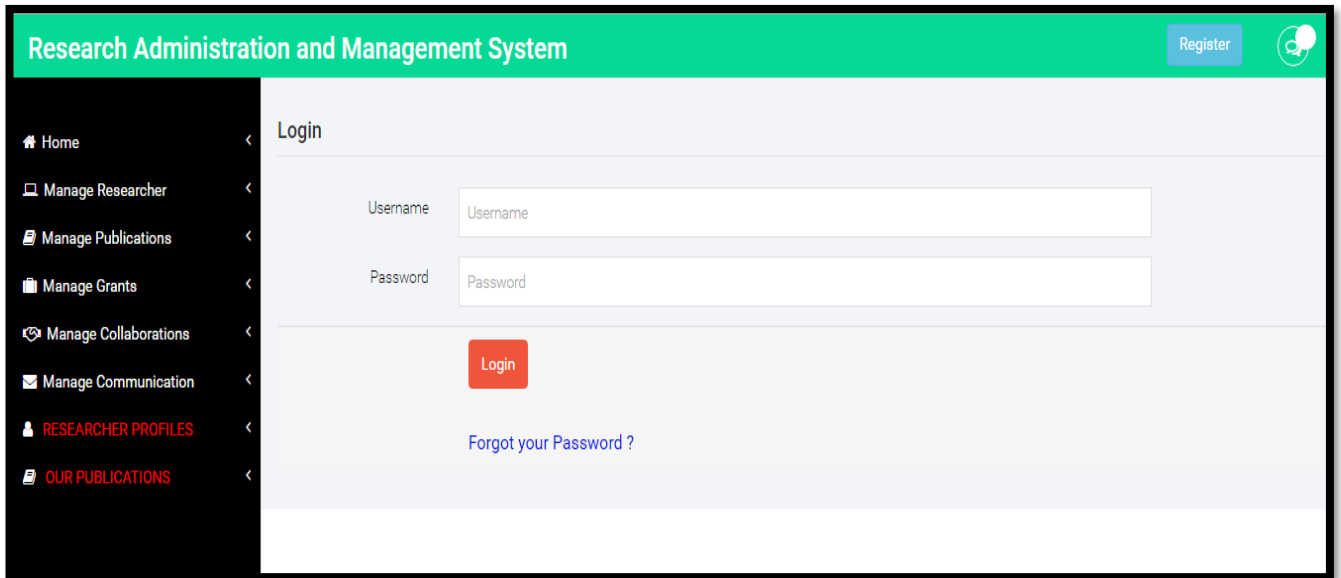
Figure 4.1: Login screen when viewed on
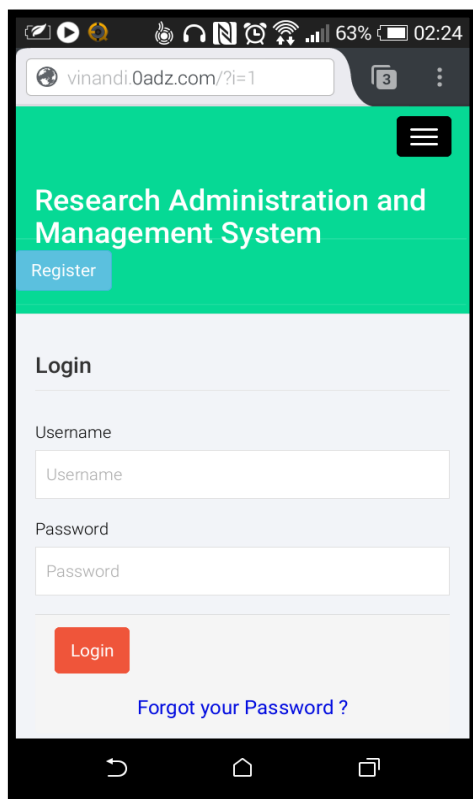
Figure 4.2: Login screen when viewed on smart phone
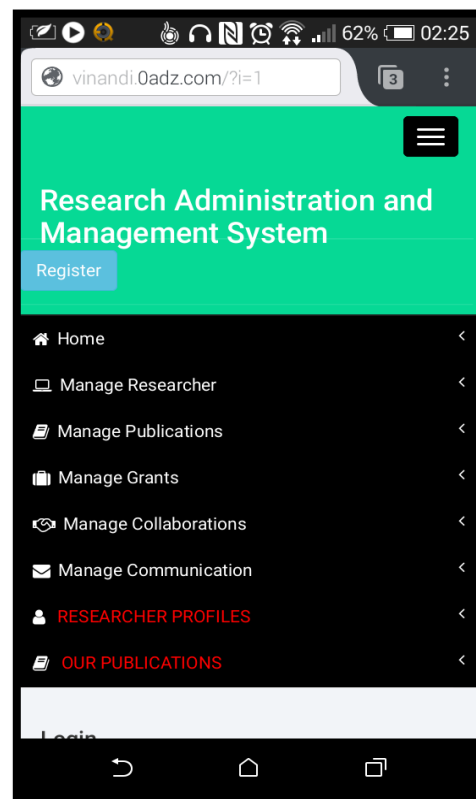
Figure 4.3: Login screen on smart phone when toggle button is

Figure 4.4: User registration screen

Once the user has successfully logged into the system, a screen shown in Figure 4.5 is displayed showing the profile of the user and all the modules which now are ready for use, allowing the user to perform several functions provided in RAMS. On this screen, the user can select different functionalities provided under Manage Researcher, Manage Publications, Manage Grants, Manage Collaboration and Manage Communication. For instance, the user can add, view, edit and delete information about their personal, professional and academic details by selecting functionalities under Manage Researcher. RAMS then uses the information of the user supplied in the system to automatically generate a profile and CV for the particular user with a single click for each. The CV module in RAMS is essential because it ensures a consistent and uniform format for CVs for all researchers within the HEI. Additionally, RAMS allows the researchers to add, view, edit and delete information about their published work. The system ensures that whenever a researcher is adding publication information, a Microsoft word or pdf copy of the publication must be uploaded for verification of the publication authenticity by staff in the Research and Postgraduate Office who can then approve it for subsidy or not. The system also provides access to the uploaded and verified publications by other researchers.
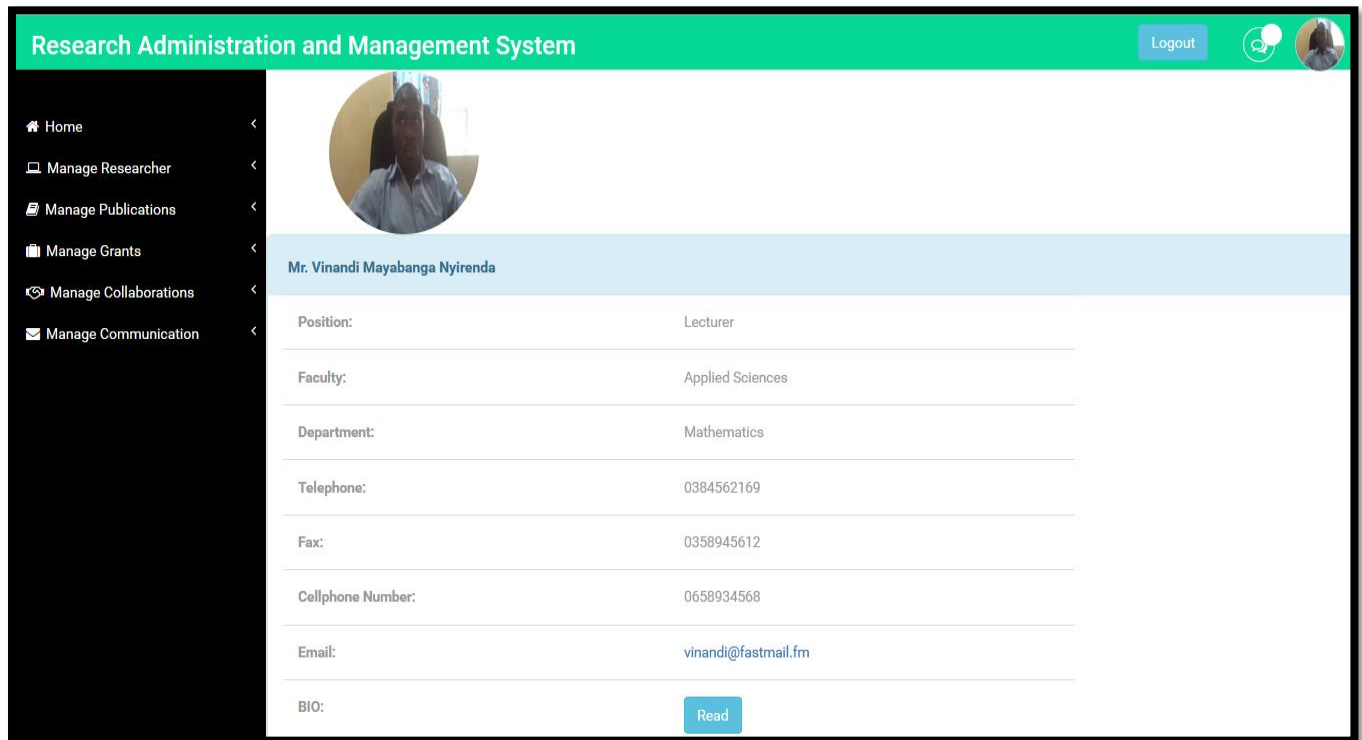
Figure 4.5: Main operation screen in

4.2.1. Manage Researcher module

The "Manage Researcher" module has functionalities for managing information of users which include; Personal Details, Qualification Records, Employment Records, Professional Registrations, Research Interests and Curriculum Vitae. The functionalities under the "Manage Researcher" module are shown in Figure 4.6 below. When the user clicks on 'Personal Details' in figure 4.6, a screen is displayed as shown in Figure 4.7 where the user can add and edit his or her personal information, department, faculty, qualification, biography, contacts etcetera. These actions can be accomplished by simply clicking on the specific item that needs to be edited or on the red pen symbol in Figure 4.7 which will open a page where the items can be edited.
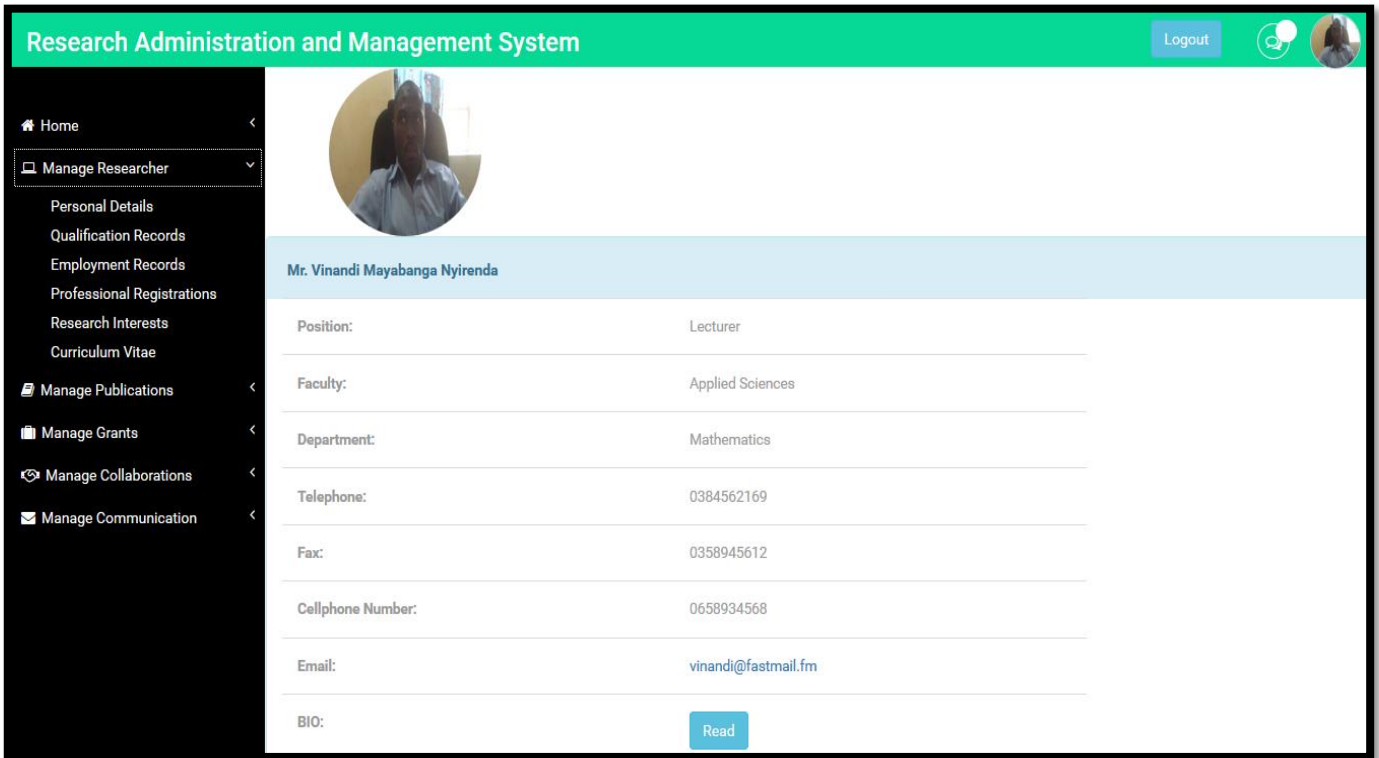
Figure 4.6: Functionalities on the Manage Researcher
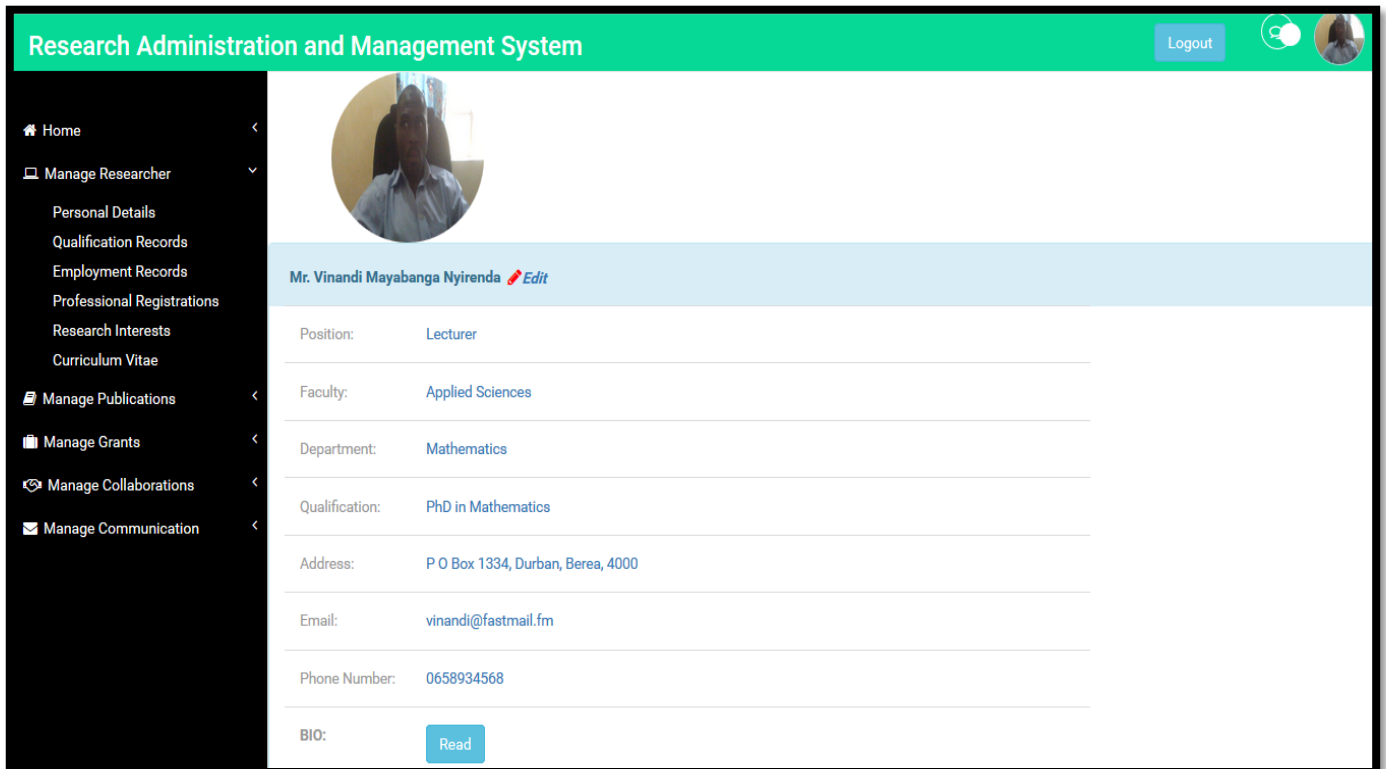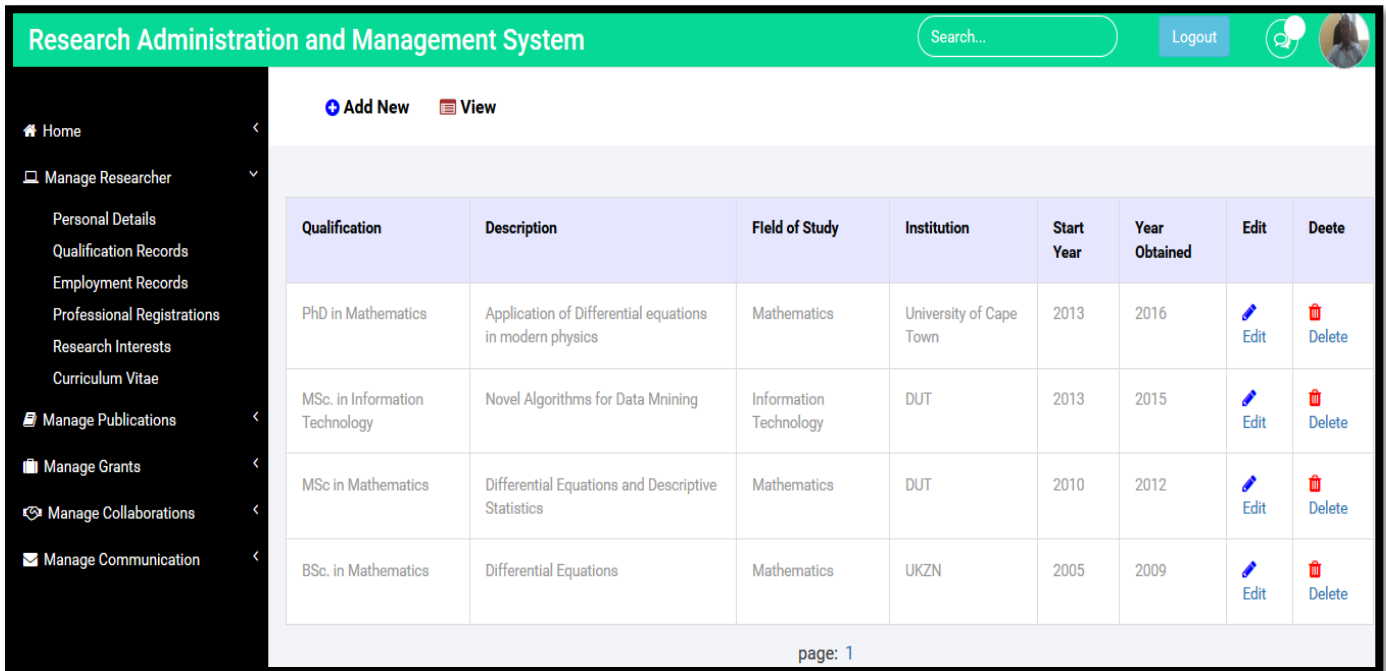
Figure 4.7: Profile Items that can be edited

4.2.1.1. Qualification records

To add, view and edit qualification records, the user clicks on "Qualification records" under manage researcher module which opens a screen as shown in Figure 4.8 below showing the qualification records and actions that the user can take, namely, add, edit, view, and delete.

Figure 4.8: Screen for qualification records

When the user clicks on "Add New" in Figure 4.8, a form shown in figure 4.9 below will be displayed where details of the new qualification can be entered. Clicking on "Edit" within Figure 4.8 displays a screen shown in Figure 4.10 where a selected qualification record can be edited. When the user clicks on "Delete" in Figure 4.8, he or she will be requested to confirm the delete action as shown in Figure 4.11, and if confirmed, the selected record will be deleted from the system.

Figure 4.9: Add new qualification

Figure 4.10: Edit qualification

Figure 4.11: Confirm delete

4.2.1.2. Employment records

To view, add, edit and delete employment records, the user clicks on "Employment Records" under the "Manage Researcher" module. A screen shown in Figure 4.12 below is displayed where actions for adding, editing, and deleting can be selected and performed in a similar manner to the ones shown for adding, editing, and deleting a qualification record.
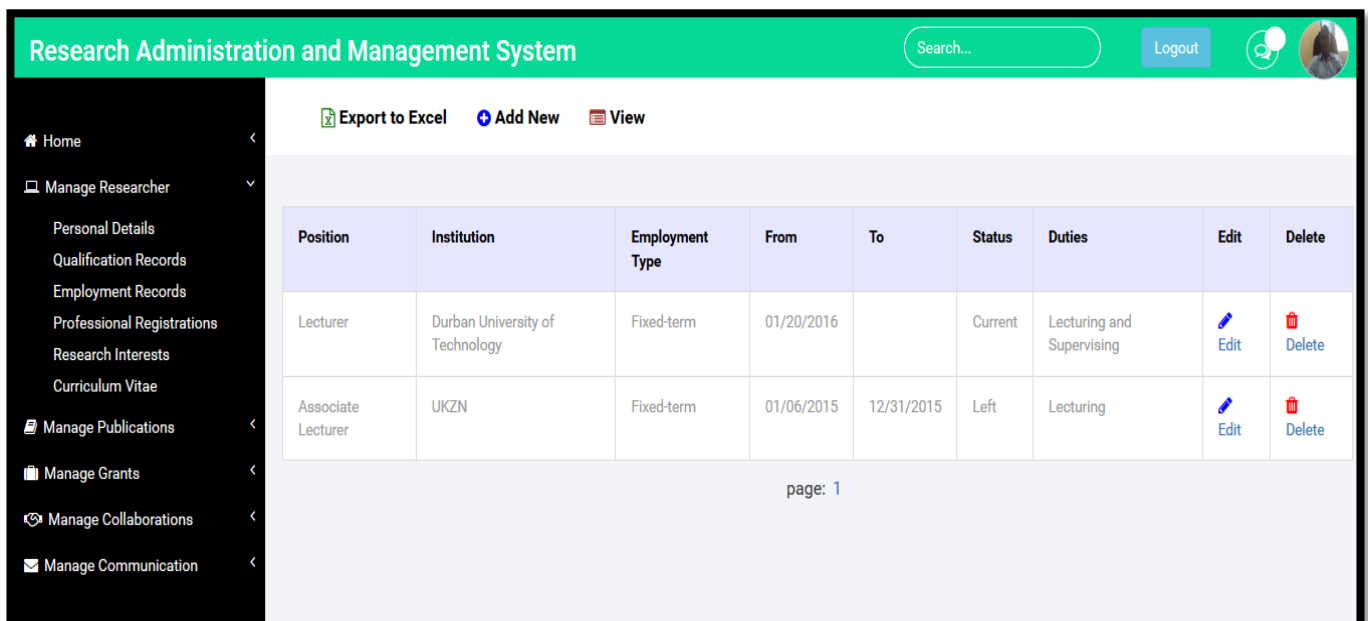
Figure 4.12: Employment records

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4.2.1.3. Professional registrations

To view, add, edit and delete professional records, the user clicks on "Professional Records" under "Manage Researcher" and a screen shown in Figure 4.13 is displayed where functionalities for adding, editing, and deleting a professional record can be selected. The functions are performed in similar manner as of those for qualification records.
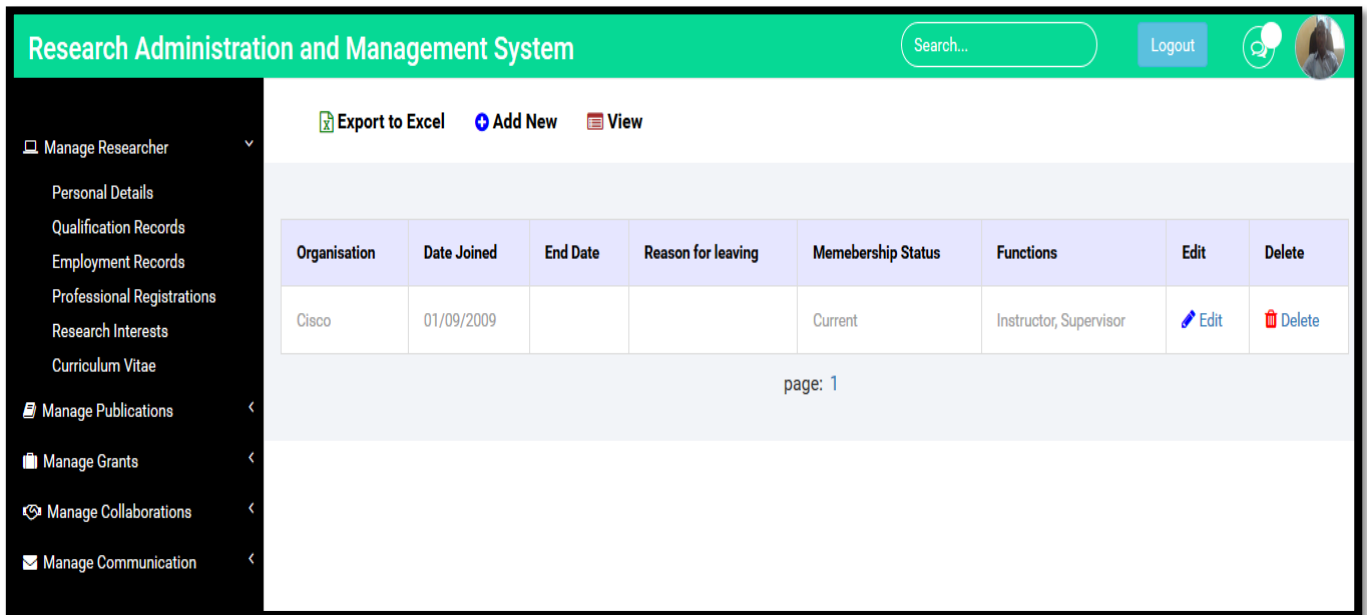
Figure 4.13: Professional records

To view, add, edit and delete research interest records, the user clicks on "Research Interests" under "Manage Researcher" and a screen shown in Figure 4.14 is displayed where functionalities for adding, editing and deleting a record can be selected. These functions can be performed in similar manner to those for qualification record shown above.

Figure 4.14: Research interests

If the user clicks on "Curriculum Vitae" under "Manage Researcher", the system will automatically generate a curriculum vitae for the user in pdf format.

4.3. Manage Publications

The "Manage Publications" module is where all functionalities for viewing, adding, editing, and deleting research outputs are found. These functionalities are discussed in the following subsections.

4.3.1. Book records

To perform functions for viewing, adding, editing and deleting book records from the system, the user clicks on "Books" under "Manage Publications" and a screen is displayed as shown in Figure 4.15 below showing details of books of a particular user. If the user clicks on "Add new" in figure 4.15, a form is displayed as shown in Figure 4.16 where details of a book can be entered. If the user clicks on "Edit" in Figure 4.15, a screen is displayed as shown in Figure 4.17 where the details of the selected book can be edited. If the user clicks on "Delete" in Figure 4.15, he or she will be requested to confirm the deletion of the selected record as shown in Figure 4.18, and if the user clicks on ok, the record will be deleted from the system. Clicking on "Export to excel" in Figure 4.15 generates an excel sheet containing records of books of a particular user.

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Figure 4.15: Book records

Figure 4.16: Add new book record

Figure 4.17: Edit book record

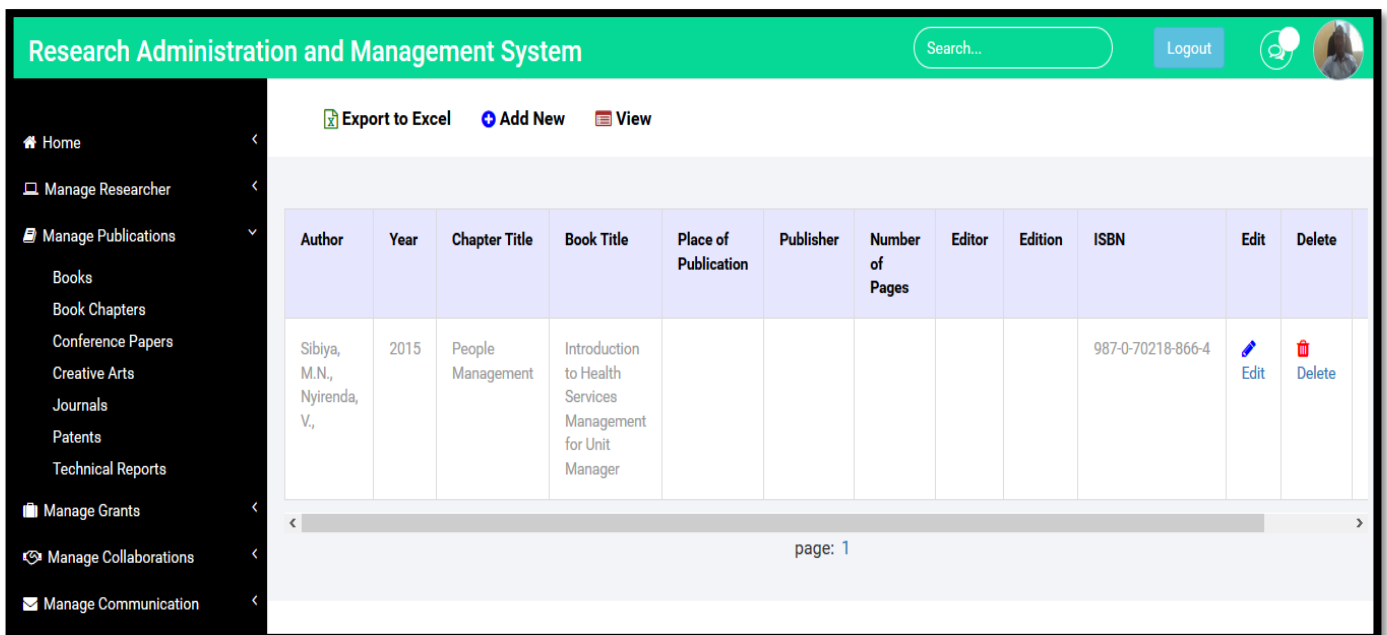**Figure 4.18: Confirm delete**

4.3.2. Book chapter records

To perform functions for viewing, adding, editing and deleting book chapter records from the system, the user clicks on "Book Chapters" under "Manage Publications" and a screen is displayed as shown in Figure 4.19 below showing details of book chapters of a particular user. If the user clicks on "Add New" in Figure 4.19, a form is displayed as shown in Figure 4.20 where details of a book chapter can be entered. If the user clicks on "Edit" in Figure 4.19, a screen is displayed as shown in Figure 4.21 where the details of the selected book chapter can be edited. If the user clicks on "Delete" in Figure 4.19, he or she will be requested to confirm the deletion of the selected record as shown in Figure 4.22, and if the user clicks on ok, the record will be deleted from the system. Clicking on "Export to excel" in Figure 4.19 generates an excel sheet containing records of book chapters of that particular user. The user can also download book chapters that he/she uploaded into the system by clicking on download which can be viewed by scrolling the bottom scroll bar in Figure 4.19.

Figure 4.19: Book chapter records

Figure 4.20: Add new book chapter
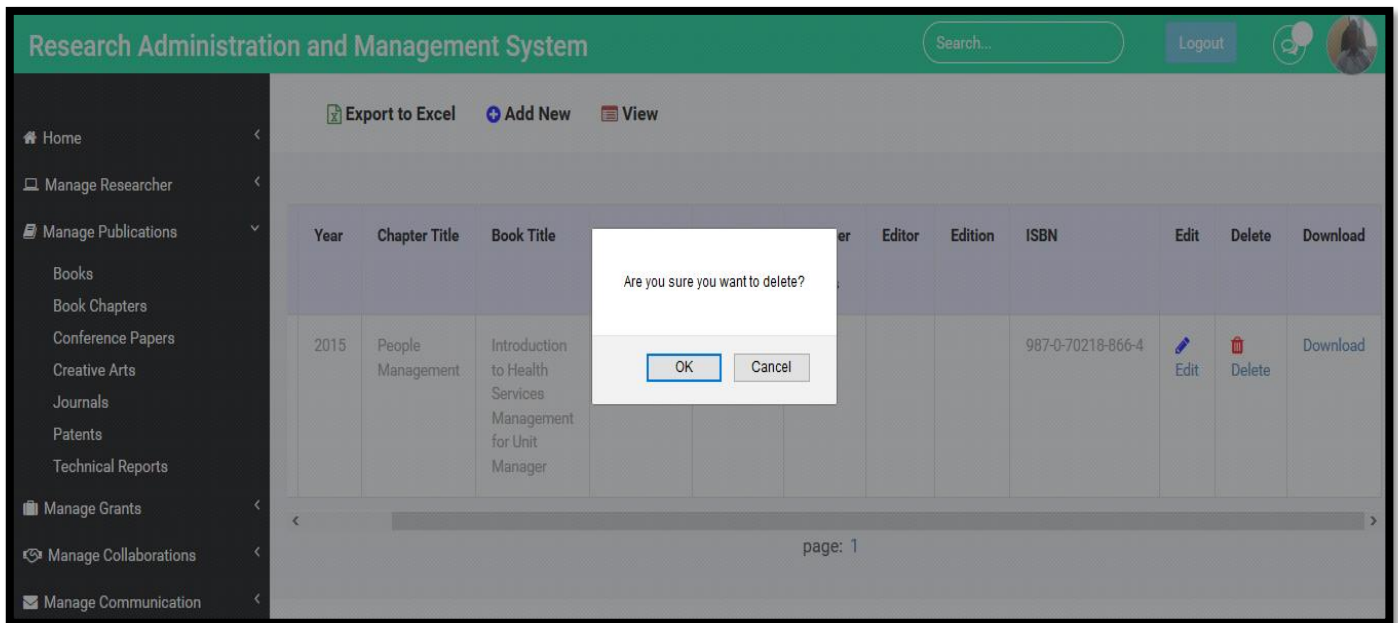
Figure 4.21: Edit book chapter

Figure 4.22: Confirm delete

4.3.3. Conference records

To perform functions for viewing, adding, editing and deleting records of conference proceedings from the system, the user clicks on "Conference Papers" under "Manage Publications" and a screen is displayed as shown in Figure 4.23 below showing the details of conference records of a particular user. If the user clicks on "Add New" in Figure 4.23, a form is displayed as shown in Figure 4.24 where details of a conference paper can be entered. If the user clicks on "Edit" in Figure 4.23, a screen is displayed as shown in Figure 4.25 where the details of the selected conference paper can be edited. If the user clicks on "Delete" in Figure 4.23, he or she will be requested to confirm the deletion of the selected record as shown in Figure 4.26, and if the user clicks on ok, the record will be deleted from the system. Clicking on "Export to excel" in Figure 4.23 generates an excel sheet containing records of conference papers of that particular user. The user can also download conference papers that he/she uploaded into the system by clicking on download which can be viewed by scrolling the bottom scroll bar.

Figure 4.23: Conference records

Figure 4.24: Add new conference paper

Figure 4.25: Edit Conference paper

Figure 4.26: Confirm delete

4.3.4. Journal records

To view, add, edit and delete records of journals from the system, the user clicks on Journals under Manage Publications, and a screen is displayed as shown in Figure 4.27 below showing the details of journal records of a particular user. If the user clicks on "Add New" in Figure 4.27, a form is displayed as shown in figure 4.28 where details of a journal can be entered. If the user clicks on "Edit" in Figure 4.27, a screen is displayed as shown in Figure 4.29 where the details of the selected journal article can be edited. If the user clicks on "Delete" in Figure 4.27, he or she will be requested to confirm the deletion of the selected record as shown in Figure 4.30, and if the user clicks on ok, the record will be deleted from the system. Clicking on "Export to excel" in Figure 4.27 generates an excel sheet containing records of journal papers of that particular user. The user can also download journal papers that he/she uploaded into the system by clicking on download. Additionally, the user can generate a Microsoft word document containing a list of his or her journal papers.

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Figure 4.27: Journal records

Figure 4.28: Add new journal

Figure 4.29: Edit journal record
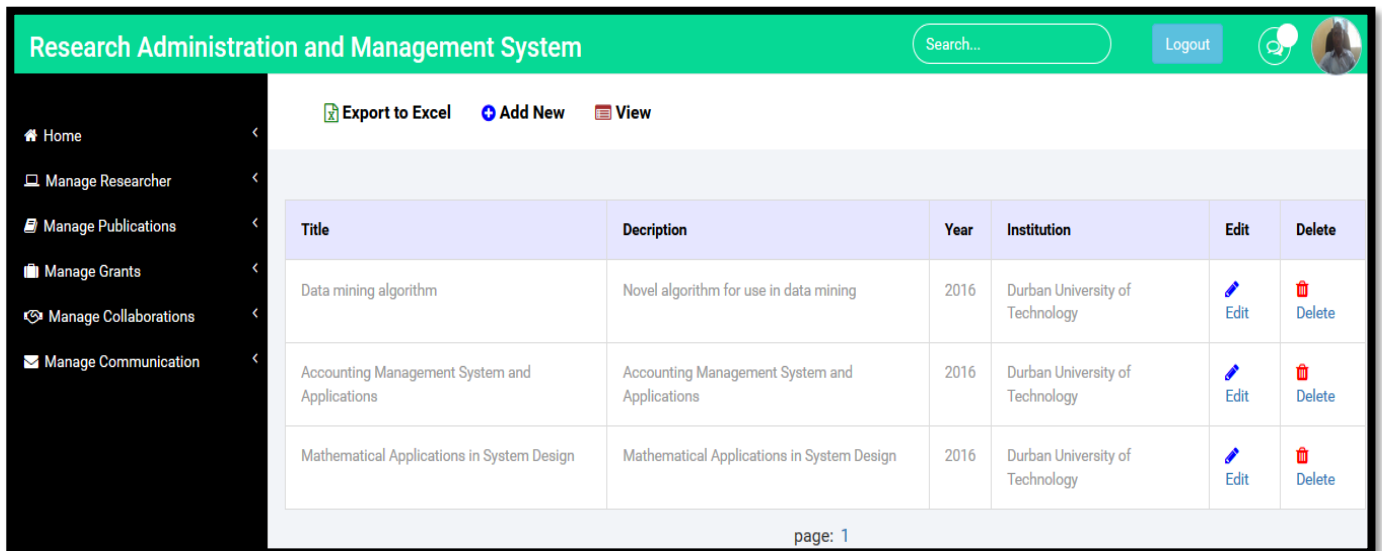
Figure 4.30: Confirm delete

4.3.5. Creative Arts

To add, edit and delete records of creative arts from the system, the user clicks on "Creative Arts" under "Manage Publications", and a screen is displayed as shown in Figure 4.31 below showing records of creative arts of a particular user. If the user clicks on "Add New" in Figure 4.31, a form is displayed as shown in Figure 4.32 where details of a creative art can be entered. If the user clicks on "Edit" in Figure 4.31, a screen is displayed as shown in Figure 4.33 where the details of the selected journal can be edited. If the user clicks on "Delete" in Figure 4.31, he or she will be requested to confirm the deletion of the selected record as shown in Figure 4.34, and if the user clicks on ok, the record will be deleted from the system. Clicking on "Export to excel" in figure 4.31 generates an excel sheet containing records of creative arts of that particular user.

Figure 4.31: Creative arts

Figure 4.32: Add new creative art

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Figure 4.33: Edit Creative art

Figure 4.34: Confirm delete

4.4. Advantages of using Z language for specifying the requirements of RAMS

Considering the complexity of developing large systems such as systems for managing research information and the fact that the system should satisfy the requirements of the intended users, the application of the Z language was vital to specify the requirements of RAMS. The Z language allowed the researcher to provide mathematically sound frameworks for RAMS in a

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systematic rather than in an ad hoc manner. The use of the Z language provided a means to define RAMS as a collection of different sets on which several operations are defined. Moreover, using Z language allowed to present RAMS as a procedural abstraction using schemas which use high-level mathematical structures like arbitrary sets and functions to only describe what is to be done, thus allowing us not to worry about how these are to be implemented.

The general benefit derived from the use of the Z language for specifying the requirements of the proposed RAMS is that it allowed the researcher and the intended users to have a common understanding about the requirements of the system before the actual development. It helped to clarify several aspects of the system behaviour that otherwise could not be obvious in an informal specification. Thus, the Z specification served as proof that the implementation of RAMS satisfies the specification and further proving the properties of RAMS without necessarily running the system.

4.5. Evaluation

Design science research (DSR) is focused on creation of information technology (IT) artefacts to solve identified organisational problems (Hevner *et al.*, 2004). However, Shrestha *et al.* (2014) argues that "if the research has an exclusive focus on the "design" of the artefact, then there is a lack of evidence that the artefact achieves its purpose to solve a class of problems". They state that unless DSR artefacts are rigorously evaluated, the outcomes could be viewed as merely unconfirmed propositions. Therefore, evaluation of design artefact is a key activity in DSR as it provides feedback for further development and assures the rigour of the research (Venable *et al*., 2016). Furthermore, evaluation of DSR artefact provides an answer to the crucial question of "how well the artefact performs?" (Shrestha *et al*., 2014). Moreover, evaluation helps to establish that an artefact worked or did not work, and to determine how and why it worked or not (Pries-Heje *et al.*, 2008). Hevner *et al.* (2004) states that "the evaluation of the artefact provides feedback information and a better understanding of the problem in order to improve both the quality of the product and the design process". According to Venable *et al.* (2012) a key purpose of DSR evaluation is to determine whether or how well the developed artefact achieves its purpose. Therefore, thorough evaluation of the DSR artefact is crucial (Hevner *et al.*, 2004). To achieve thorough evaluation of the DSR artefact, the choice of an appropriate approach(es), method(s) and strategy or a combination of strategies is vital. The

following sections considers the evaluation approaches, evaluation methods and evaluation strategies in DSR literature.

4.5.1. Evaluation approaches

Several authors have proposed different approaches for evaluating artefacts in the general information systems (IS) research and in DSR. According to Pries-Heje *et al.* (2008), in the general IS research the evaluation is generally regarded in the *ex ante* and *ex post* perspectives. An *ex ante* evaluation assesses candidate systems or technologies before they are chosen, acquired, implemented, designed or constructed. On the other hand, an *ex post* evaluation assesses a chosen and developed system or technology after it has been acquired, designed, constructed, or implemented (Venable *et al.*, 2016). An *ex ante* evaluation operates as a cost benefit analysis (Pries-Heje *et al.*, 2008). However, both *ex ante* and *ex post* refer only to timing, and therefore they address the question of "when to evaluate" (Venable *et al.*, 2016). In DSR, according to Pries-Heje *et al.* (2008), evaluation approaches are classified as artificial evaluation and naturalistic evaluation. Artificial evaluation evaluates a solution technology in a contrived and non-realistic way (Olugbara and Ndhlovu, 2014). It assesses the efficacy of the technology artefact (Venable *et al.*, 2016). On the other hand, naturalistic evaluation explores the performance of a solution technology in its real environment involving real users to accomplish real tasks (Olugbara and Ndhlovu, 2014; Pries-Heje *et al.*, 2008; Venable *et al.*, 2012; Venable *et al.*, 2016). Therefore, naturalistic evaluation embraces all the complexities of human practice in real organisations (Venable *et al.*, 2016).

The literature also distinguishes two other types of evaluation approaches as formative evaluation and summative evaluation. Formative evaluation is carried out during the process of development and implementation of the IS with the goal of acquiring feedback and suggesting ways of improvement to help in the development of the change, innovation or intervention (Chen *et al.*, 2011). On the other hand, summative evaluation is carried out after the process of development and implementation is finished and aims to gather information and feedback to assess the effects, effectiveness, impacts and outcomes of the developed IS (Chen *et al.*, 2011).

4.5.2. Evaluation methods

Literature defines various methods that can be used to accomplish the evaluation activity in DSR with the approaches mentioned above. For instance, Pries-Heje *et al.* (2008) mentions case studies, field studies, surveys, ethnography, phenomenology, hermeneutic methods and

action research as some of the methods for naturalistic evaluation. Artificial evaluation methods include laboratory experiments, field experiments, simulations, criteria-based analysis, theoretical arguments, and mathematical proofs (Pries-Heje *et al.*, 2008). Hevner *et al.* (2004) mentions observational, analytical, experimental, testing and descriptive methods for artefact evaluation.

According Hevner *et al.* (2004), observational methods include case study where the artefact is studied in the business environment, and field study where the use of the artefact is monitored in multiple projects. Analytical methods include static analysis, architecture analysis, optimisation and dynamic analysis. Experimental methods include controlled experiments and simulations. The testing methods include functional (black box) and structural (white box) testing. The descriptive methods include informed argument and scenarios.

4.5.3. Evaluation strategies

Precise and clearly communicated strategies to guide DSR researchers to evaluate artefacts have been lacking in literature for some time (Venable *et al.*, 2016). Pries-Heje *et al.* (2008) proposed a framework for building evaluation strategies. The framework distinguishes evaluation of DSR artefact in three dimensions, each with two aspects. The first dimension is about differentiating between the two categories of artefacts, namely, design process and design product. Design process is defined as a sequence of expert activities that produces an innovative product (Hevner *et al.*, 2004). Design product is defined as the set of activities, tools, methods, and practices that can be used to guide the flow of production. The second dimension is associated with time of the evaluation which can be *ex ante* or *ex post*. The third dimension is related to the approach or form of evaluation which can be artificial or naturalistic. In general, the DSR evaluation framework by Pries-Heje *et al.* (2008), shown in figure 4.35, proposes a strategy to evaluate the DSR artefact based on three questions as follows:

1. What is to be evaluated?
2. When is it evaluated?
3. How is it evaluated?
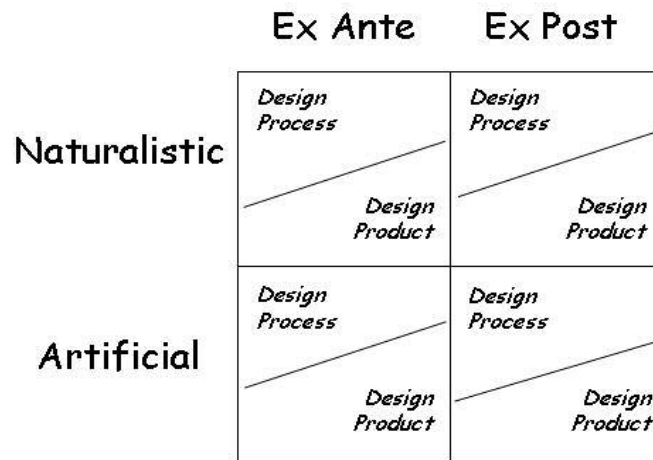
Figure 4.35: Strategic DSR evaluation framework (Pries-Heje *et al.*, 2008)

More recently, Venable *et al.* (2016), designed the framework for evaluation in design science (FEDS) framework to help DSR researchers to decide on appropriate strategies for evaluating the outcomes of the build activity in DSR. The FEDS framework creates a bridge between the evaluation goals and evaluation strategies. The design of the FEDS framework took into consideration two important dimensions. The first dimension concerns the functional purpose of the evaluation which can be formative evaluations where the functional purpose is to improve the outcomes of the process under evaluation, or summative evaluations, of which the functional purpose is to judge the extent that the outcomes match expectations. This dimension basically answers the question "Why to evaluate?". The second dimension relates to the paradigm or form or approach of the evaluation which can be artificial evaluations or naturalistic evaluations. The basic question addressed in this dimension is "How to evaluate?" The FEDS framework in figure 4.36 below shows four different evaluation strategies proposed by Venable *et al.* (2016), that the evaluations can take, progressing from left to right.
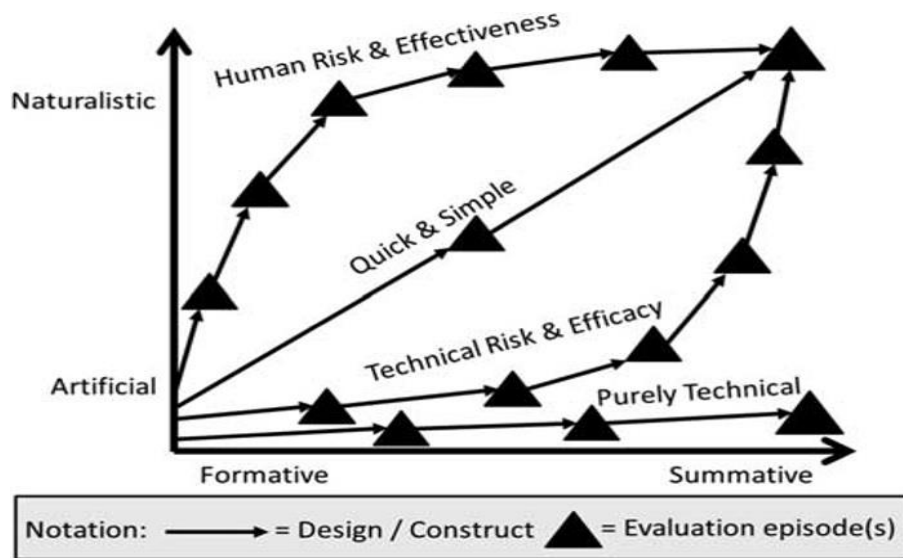
Figure 4.36: FEDS framework (Venable *et al.,* 2016)

The FEDS framework evaluation strategies proposed by Venable *et al.* (2016) are explained as follows:

1. Human Risk and Effectiveness strategy

   This strategy emphasises formative evaluations early in the process which could either be artificial or formative evaluation, but progresses quickly to more naturalistic formative evaluations and more summative evaluations near the end.

2. Quick and simple strategy

   This strategy conducts relatively little formative evaluations and progresses quickly to summative and more naturalistic evaluations.

3. Technical Risk and Efficacy strategy

   This strategy emphasises artificial formative evaluations iteratively early in the process, but progressively moving towards summative artificial evaluations.

4. Purely Technical strategy

   The Purely Technical strategy is used when an artefact is purely technical, without human users.

Based on the FEDS framework developed by Vinable *et al.* (2016), this research adopted the Human Risk and Effectiveness evaluation strategy to evaluate the developed RAMS.

4.5.4. Evaluation procedure

In this study the evaluation started by utilising the strategic evaluation framework proposed by Pries-Heje *et al.* (2008) to provide a clear definition of the artefact under evaluation and the context for the evaluation (Shrestha *et al.*, 2014). The framework is articulated based on questions as follows:

1. What was evaluated? In this research the developed artefact is an instantiation- a system called research administration and management system (RAMS), which is considered a design product was evaluated.

2. When did the evaluation take place? In this study the evaluation was mainly conducted *ex post* because the artefact was evaluated after it was constructed and demonstrated.

3. How was it evaluated? The evaluation of RAMS was principally naturalistic because it was conducted using a real artefact in real organisation involving real users to solve real problems. However, artificial evaluation was also conducted to ensure the efficacy of the developed artefact.

Considering the above arguments, the approaches utilised to accomplish the evaluation task in this research were artificial and naturalistic, but mainly naturalistic evaluation, because the main purpose of the developed artefact was to enable researchers and staff in the Research and Postgraduate Office in HEIs to effectively manage research information. Therefore, it was deemed proper to evaluate the system in the real environment with real users to solve real problems. The artificial evaluation was conducted in a lab setting by the developer to ensure the efficacy of the developed artefact, especially the components that are more vital such as "Manage Report" component in RAMS. The report component in RAMS is vital because it enables staff in the Research and Postgraduate Office to gain a consistent overview of the research activity in different faculties within the HEI. Based on the overview of the research activity, the research manager can be informed about whether progress is being made or not in terms of research output in the HEI. The report component also helps staff in the Research and Postgraduate Office to prepare formatted reports for submission to the Department of Higher Education and Training for disbursement of government subsidies to the HEI. Artificial evaluation used the Technical Risk and efficacy strategy proposed by Venable *et al.* (2016) in the FEDS framework, with more artificial summative evaluations to rigorously determine the efficacy of the developed artefact. The naturalistic evaluation was appropriate to evaluate the usability of the developed system with real users in real setting. The main strategy used for conducting naturalistic evaluation was the Human Risk and Effectiveness strategy proposed by

Venable *et al.* (2016), and involved more naturalistic summative evaluations to determine the usability of the developed artefact.

In terms of the chosen characteristics to be evaluated, in this research, the evaluation was built around the usability characteristic. Usability is one of the key characteristics that has been considered for evaluation in several systems, and various instruments have been developed for assessing the usability of a system considering different dimensions of usability. For instance, Olugbara *et al.* (2011) developed the effectiveness and user satisfaction questionnaire which they used to measure the usability of a location-based shopping recommender system. In their questionnaire, two dimensions of usability were considered, namely, effectiveness and satisfaction. Lund (2001) developed the user satisfaction and ease of use (USE) questionnaire for measuring usability that considered four dimensions of usability as usefulness, ease of use, ease of learning and satisfaction. More recently, Parhizkar and Commuzi (2017), evaluated the usability of their tool by considering four dimensions of usability, namely, usefulness, ease of use, ease of learning and satisfaction. Kortum and Sorber (2015) mentions many other popular instruments for measuring system usability. In their work, they used the SUS questionnaire that was developed by Brooke (1996). The usability evaluation in this study considered five dimensions of usability, namely, effectiveness, usefulness, ease of use, learnability and satisfaction adopted from Olugbara and Ndhlovu (2014), Olugbara *et al.* (2011), Lund (2001) and Parhizkar and Commuzi (2017) as shown in Appendix 1.

Usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (Aziz *et al.*, 2013). Therefore, conforming to this definition, it was determined that a better understanding of the usability of the proposed system could be obtained through the assessment of the proposed system by the intended users. Consequently, users were selected and they experimented with the system. The users provided feedback validating usability of RAMS in five dimensions, namely, effectiveness, ease of use, usefulness, learnability and satisfaction. Effectiveness is defined as the performance in accomplishment of tasks by some percentage of users within the system (Thuseethan *et al.*, 2014). Learnability is concerned with the ease with which new users can begin effective interaction with the system and achieve maximal performance (Munaiseche and Liando, 2016; Stasko *et al.*, 2007). Ease of use ties to a person's assessment of the mental effort involved in using the system (Downing and Liu 2014). It determines how easy the system is to use. Satisfaction is defined as the freedom from

discomfort and positive attitude towards the use of the system (Standard, 1998). Usefulness is concerned with how good a system is to achieve some desired goal (Roger 2011).

Fourteen users registered and experimented with the proposed system. The users were in two categories, namely, researchers and staff from the Research and Postgraduate Office at the case study institution, namely, Durban University of Technology. These included 10 researchers who were randomly selected but have had experience using the current system, and 4 staff from the Research and Postgraduate Office. The four staff from the Research and Postgraduate Office were chosen because they are the ones who collect and input publications data into the current system and produce the relevant reports for the HEI. The researchers were chosen to evaluate the proposed system because they also provide their information into the system and they play a critical role in the research process. Moreover, their experience with the current system was important. Initially, training was provided to all the evaluators (participants) to acquaint them with how the system works.

The four evaluators from the Research and Postgraduate Office were trained together in the Borden room within the Research and Postgraduate Office after which they were asked to enter at least two publications of each type and produce reports from the system. On the other hand, researchers were trained individually as it proved difficult to assemble them together due their busy schedules. Therefore, different training sessions with the ten researchers were conducted at their convenient time. After each training session, each researcher was requested to experiment with the system on their own by entering information about their publications, at least two journal articles, two books, two book chapters and two conferences. When the participants from both categories had experimented with the proposed system, they were also requested to rate the system usability using the questionnaire with 20 items on a scale of 1 to 5 where 1 means "Strongly Disagree", 2 means "Disagree", 3 means "Neutral", 4 means "Agree" and 5 means "Strongly Agree" as shown in Appendix 1.

4.5.5. Evaluation results

This section presents the experimentation results of the proposed application. The proposed system was tested for the effectiveness, usefulness, ease of use, learnability and satisfaction dimensions of usability. Table 4.1 shows the evaluation results. The results of the evaluation show that in general most evaluators responded positively to the evaluation statements proving that the proposed system is usable. The results also show that the proposed system addresses a relevant problem of managing research information and that it could be a suitable solution to the problem of managing research information at the case study institution. Nevertheless, a small percentage of participants provided unsatisfactory feedback. This was expected because some of the components of proposed system were not yet developed because of time limitation. It is anticipated that future work on the proposed system will involve the development of those components and further enhancements.

Figure 4.37 shows the mean responses of the participants against the 20 evaluation statements for the usability of the proposed system. The analysis shows a general increase in all responses with the minimum mean of 1.43 and a corresponding standard deviation of 0.69. The maximum mean of 4.5 occurs for two responses with standard deviations of 0.9 and 0.85. The minimum mean value occurred for statement 2 which is about the difficulty of the system to use despite the help the participants received. This result shows that almost all participants did not find the system difficult to use. The maximum mean value occurred for statements 9 and 10 which are about how simple the system is to use and how user friendly the system is respectively. This result shows that most participants found the proposed system to be simple to use as well as user friendly. It is impressive to note that most participants responded positively to all the usability dimensions. The results for each dimension of usability are presented in the subsections below.

4.5.5.1. Effectiveness

The percentage responses for statements 1, 2 and 3 of the effectiveness criteria are shown in figure 4.38. The maximum percentage of 64% occurs for statement 2 and the minimum percentage of 7% occurs for statement 2 and 3. Overall, most participants rated the system to be effective. Based on this outcome it can be deduced that the proposed system satisfies the usability criteria of effectiveness. It can also be said that the proper integration of features in the proposed system played an important role as it enabled the participants to use the system without needing any further help.

Table 4.1: Evaluation results

It	Criteria	Percentage response for item					Statistics	
It	**Effectiveness**	1	2	3	4	5	**Mean**	**STDEV**
1	I needed much help to use the system.	60%(7)	21%(3)	14%(2)	14%(2)		1.93	1.14
2	I found the system difficult to use despite help received.	64%(9)	29%(4)	7%(1)			1.43	0.65
3	I found the provided features of the system well integrated.		7%(1)	7%(1)	29%(4)	57%(8)	4.4	0.9
	Usefulness	1	2	3	4	5		
4	The system is useful.		7%(1)	14%(2)	29%(4)	50%(7)	4.2	1
5	The system makes the things I want to accomplish easier to get done.		7%(1)	29%(4)	29%(4)	36%(5)	3.9	1
6	The system does everything I would expect it to do.		7%(1)	29%(3)	29%(2)	36%(4)	3.9	1
7	The system saves me time when I use it.			36%(5)	43%(6)	21%(3)	3.9	0.8
	Ease of use	1	2	3	4	5		
8	The system is easy to use.		7%(1)		43%(6)	50%(7)	4.4	0.8
9	The system is simple to use.		7%(1)		29%(4)	64%(9)	4.5	0.9
10	The system is user friendly.		7%(1)		29%(4)	64%(9)	4.5	0.85
11	The system requires the fewest steps possible to accomplish what I want to do with it.			7%(1)	57%(8)	36%(5)	4.3	0.6
12	Using the system is effortless.	7%(1)		14%(2)	36%(5)	43%(6)	4.1	1.1
	Learnability	1	2	3	4	5		
13	The system is easy to remember how to use.	7%(1)		14%(2)	29%(4)	50%(7)	4.14	1.17
14	I learnt to use the system quickly.	7%(1)		7%(1)	21%(3)	64%(9)	4.36	1.15
15	The system is easy to learn to use.	7%(1)		7%(1)	21%(1)	64%(9)	4.43	1.16
	Satisfaction	1	2	3	4	5		
16	I am satisfied with the system.	7%(1)	7%(1)	7%(1)	36%(5)	43%(6)	4	1.24
17	The system interface is simple to use.		7%(1)		43%(6)	50%(7)	4.36	0.84
18	The system works the way that I expected.		14%(2)	29%(4)	21%(3)	36%(5)	3.8	1.1
19	The system is pleasant to use.		7%(1)	7%(1)	29%(4)	59%(8)	4.4	0.9
20	I would recommend the system to other users.		7%(1)	14%(2)	14%(2)	64%(9)	4.36	1.01

It= Item ■ Strongly Disagree ■ Disagree ■ Neutral ■ Agree ■ Strongly Agree
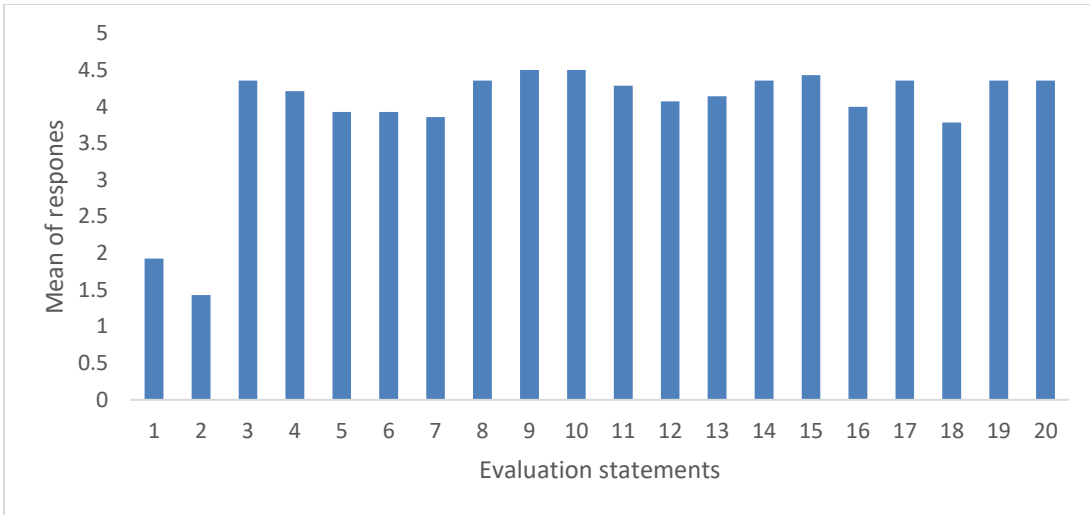
Figure 4.37: Mean of Responses
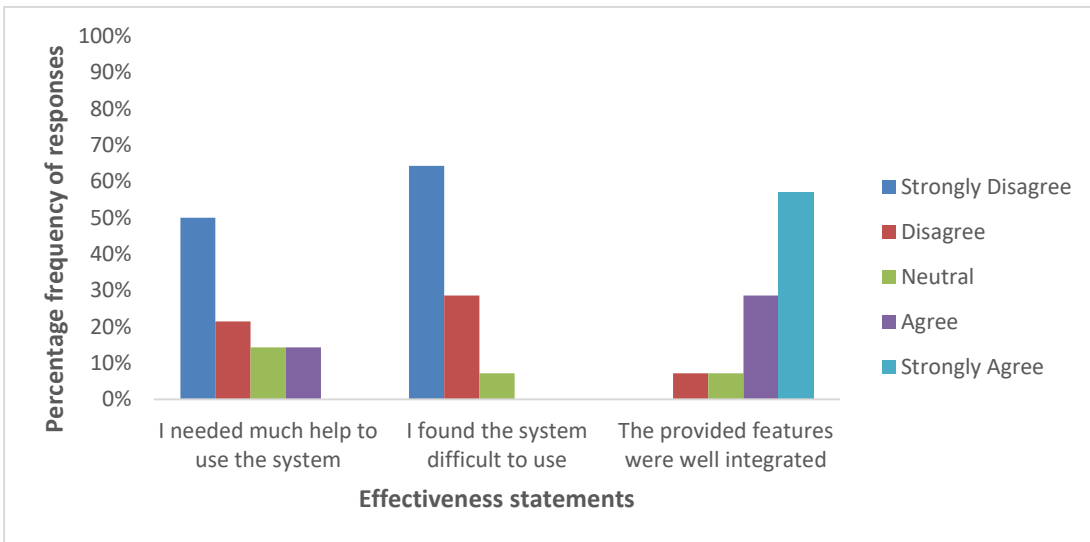
Figure 4.38: Effectiveness criteria

4.5.5.2. Usefulness

Figure 4.39 shows the percentage responses of participants for statements 4, 5, 6 and 7. The maximum percentage of 50% occurs for statement 4 and the minimum percentage of 7% occurs for statements 4, 5 and 6. Generally, most participants rated the system to be useful. Based on the definition by (Roger 2011), it can be said that this result shows that most participants found the proposed system to encompass the desired functionalities that enabled them to achieve their desired goals.
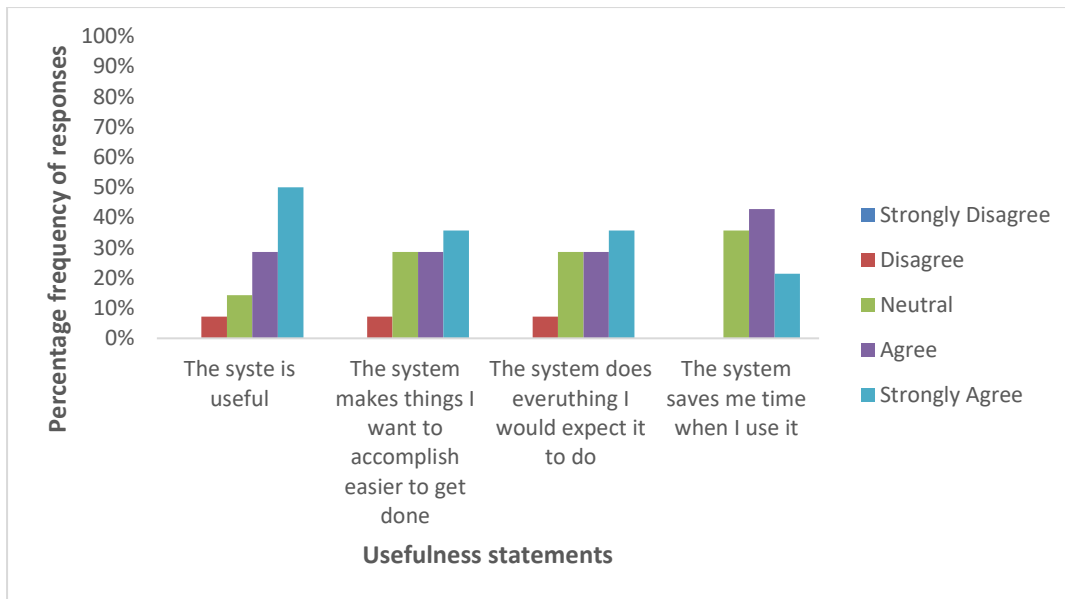
Figure 4.39: Usefulness criteria

4.5.5.3. Ease of use

The percentage responses of the ease of use criteria are presented in Figure 4.40. The maximum percentage of 64% occurs for evaluation statements 9 and 10. The minimum percentage of 7% occurs for all statements (8, 9, 10, 11, 12). The result shows that most participants were able to access and use the system with ease. This result can be attributed to the simple and intuitive design of the interfaces in RAMS and the consistency in presentation of interface elements which allow the user to navigate through the system with ease. Moreover, the interface elements are self-explanatory for the intended function. Additionally, the data entry interfaces have been designed to minimise data entry effort by the user through use of checkboxes and drop-down lists. The system also provides feedback indicating success or failure of an operation. For instance, the system provides feedback error message if a field is left empty or wrong data is entered.
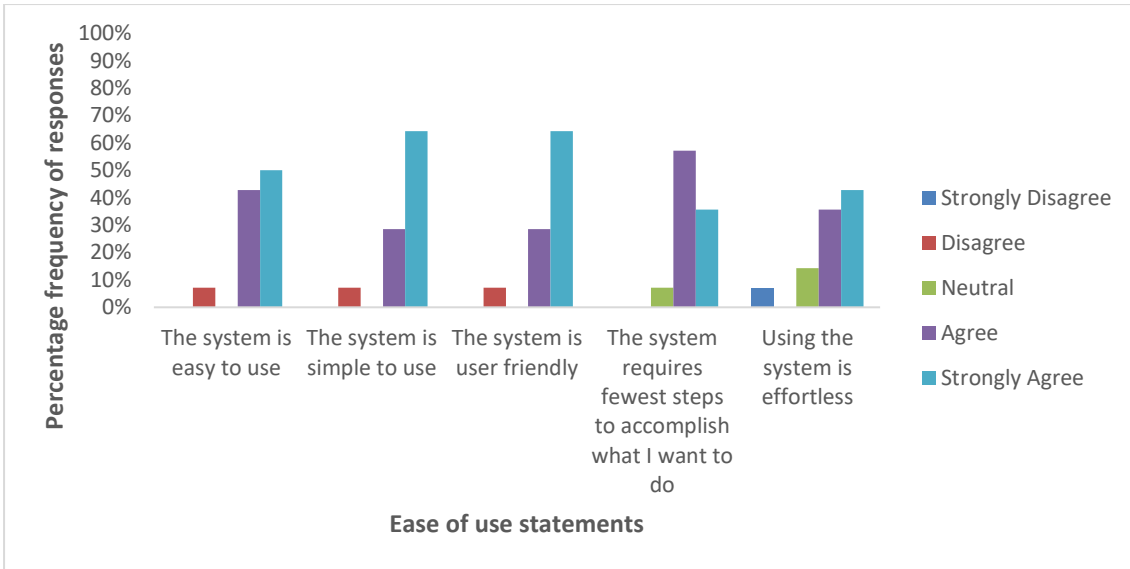
Figure 4.40: Ease of use criteria

4.5.5.4. Learnability

Figure 4.41 shows the overall percentage responses for each of the learnability statements. The maximum percentage of 64% occurs for statement 14 and 15 and the minimum percentage of 7% occurs for statements 13, 14 and 15. The results show that most participants could learn and use the system quickly and with ease and that they found the system easy to remember how to use.
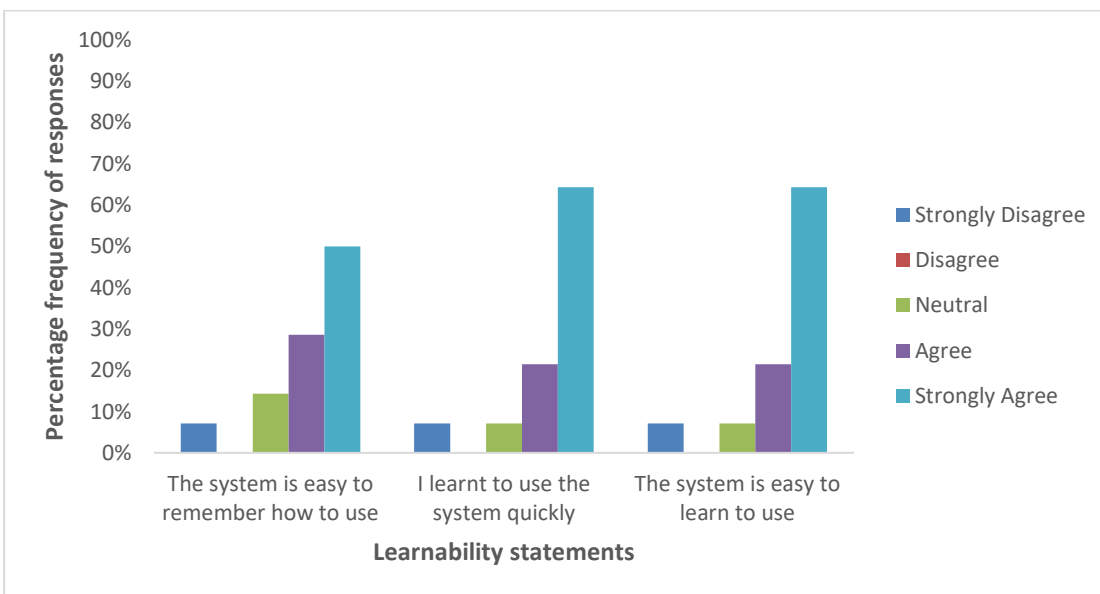
Figure 4.41: Learnability criteria

4.5.5.5. Satisfaction

The overall results of the satisfaction criteria are shown in figure 4.42 below. The maximum percentage of 64% occurs for statement 20 and minimum percentage of 7% occurs for statements 16, 17, 19 and 20. Generally, he results show that most participants were satisfied with the proposed system.
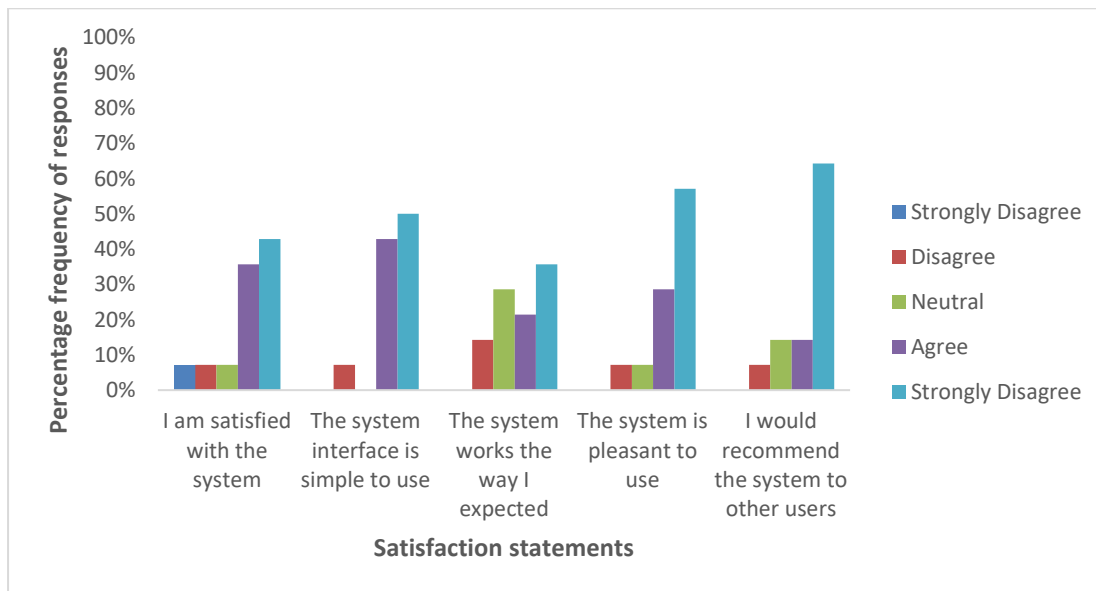
Figure 4.42: Satisfaction criteria

4.6. Chapter Summary

This chapter has presented the implementation, functional description and the evaluation of the proposed RAMS that could be used to manage research information in HEIs. The evaluation in this chapter focused on the usability of the proposed system. The evaluation was carried out through a case study involving researchers and staff in the Research and Postgraduate Office at Durban university of Technology who assessed the usability of the proposed RAMS. The assessment was done using a questionnaire with 20 questions categorised in five dimensions of usability. Overall the usability evaluation of RAMS yielded satisfactory results. Based on the evaluation feedback, it can be concluded that the proposed RAMS is indeed usable and that it achieves its main purpose. The feedback also shows that most participants considered RAMS to be easy to understand how to use and helpful in accomplishing the research information management activities. Although the results were generally positive, some possible improvements were nonetheless identified. Therefore, further development is necessary for improvements and to ensure all the desired components are implemented, as the current version

of RAMS does not include the component for harvesting publications information from online sources. The next chapter concludes the dissertation by providing the summary of the whole dissertation and the suggestions for possible future work arising from this study.

CHAPTER 5: SUMMARY, FUTURE WORK AND CONCLUSION

This chapter presents the summary of the entire study and discusses the fulfilment of each of the research objectives. A discussion on the study focussing on the contributions made is presented. The limitations of this research, as well as the lessons learnt in carrying out this study and the recommendations for possible further research work arising from the study are articulated. Lastly, concluding remarks are presented.

5.1. Overall Summary of research

This study aimed at developing an optimal web-based research administration and management system (RAMS) that could be used for managing research information in South African higher education institutions (HEIs). Through a rigorous process, a web-based system called RAMS was developed. This study emphasises use of formal methods as best practice to specify requirements of an information management system. As reported in chapter 2 of this dissertation, many authors have outlined the benefits of formal methods in software development. For instance, formal methods have the capability of bridging the semantic gap that exists between user needs and software implementation efforts in software development (Gurupur *et al.*, 2014). The semantic gap is primarily caused due to lack of communication between the users and developers of the system because most developers tend to move from requirements gathering to the development of the system, skipping the requirements specification stage. As a result, in many cases systems whose requirements were not properly specified and whose intended users were not extensively involved in the development process, fail to meet specific user needs. In this study the Z formal language was applied to specify requirements of RAMS which were rigorously reviewed by the intended users of the system ensuring that any omissions and misinterpretations were corrected and ambiguities were resolved. This dissertation has addressed the processes leading to the design and development of the proposed system. The proposed RAMS could be a solution to the many issues faced with the use of the current proprietary RIMS system as discussed in chapter 1. The proposed system is developed as a simple and intuitive application that could help in the cost-effective management of research information in HEIs.

5.2. Fulfilment of the research objectives

The overarching aim of this study was expected to be addressed through the identified objectives as stated below. The following subsections reflect on how each objective has been attained.

5.2.1. To elicit the requirements of an optimal web-based research administration and management system for HEIs.

The necessary requirements which resulted in the development of the proposed RAMS were elicited through context-free interviews the researcher conducted with researchers and staff in the Research and Postgraduate Office at the Durban University of Technology (DUT). The researcher also examined documents that are related to management of research information which were obtained from the Research and Postgraduate Office at DUT. Moreover, a comprehensive review of literature around the subject of research information management was carried out which provided rich information. The context-free interviews and examination of relevant documents were primarily intended to elicit an understanding of activities regarding research information management at DUT, the problems faced by use of the current research information management system (RIMS), and the insight into the characteristics of what a successful and apposite solution could be. Literature about some of the existing systems was also reviewed to learn about the important features. Consequently, a web-based RAMS was proposed as a possible solution to the identified problems. The proposed RAMS was developed as a possible solution to the problems faced with the use of RIMS.

5.2.2. To model the requirements of an optimal web-based research administration and management system as a formal specification

Requirements specification is an important step in the process of software development. According to Nehal (2009) requirements specifications have four major goals.

1. Assures the customer that the developer understands the problems to be solved and the software behaviour to solve the problems.
2. It helps in breaking the problem into its component parts in an orderly fashion.
3. It serves as an input to the design specification of the system.
4. It serves as a product validation check because strategies for testing and validation that can be applied to the requirements for verification can be drawn from it.

Realising the importance of high quality requirements specification, the elicited requirements for the proposed research administration and management system were modelled as formal specifications because specifications produced using formal languages are more precise than those produced using natural languages and use cases (Escalona and Koch 2004). Moreover, use of formal methods for requirements specification forces an analysis of the system requirements at an early stage and guarantees that any errors are corrected at this stage instead of modifying a delivered system which is costly (Sommerville 2009). Furthermore, the use of formal methods requirements specification leads to unambiguous, consistent and verified systems (Ahmad *et al.*, 2012). The Z formal specification language was used to specify the requirements of the proposed RAMS. The Z language was chosen because it is the most revered language in formal methods (Latif *et al.*, 2007) and has been widely used by many researchers (Bakri *et al.*, 2013); therefore, there is rich literature about the language for reference. The requirements specification for RAMS are presented in chapter 3 of this dissertation.

5.2.3. To design and implement the specification of an optimal web-based research administration and management system.

Following the requirements specification, the design and development of the system was accomplished using responsive web technologies which have gained momentum with the emergence of HTML5 and CSS3. Use of responsive technologies to design web applications have mainly gained preference because of the increasing support that the technology receives from JavaScript web frameworks such as *Bootstrap* (Bootstrap 2017), *JQuery UI* (The jQuery Foundation 2017) and *Less Framework* (Korpi 2017). These frameworks adopt a smooth grid concept to layout contents on diverse screen resolutions. These technologies made it possible to design a research administration and management system that has user interface that adapts to devices with various screen resolution sizes. This makes the system accessible on both PC and mobile devices. The responsive technology greatly improves presentation on mobile browsers by hiding certain user interface contents. The main scripting language that was used to develop the proposed system is Hypertext Preprocessor (PHP) which is a widely-used open source general-purpose scripting language that is especially suited for web-based application development and is easily embedded into HTML. The implementation and functional description of the proposed system has been covered in Chapter 4 of the dissertation.

5.2.4. To evaluate a web-based research administration and management system

The developed artefact was demonstrated and evaluated for its usability for managing research information. The results of the evaluation have been articulated in chapter 4 of the dissertation. The results of the evaluation were generally positive with some possible improvements being identified necessitating further development of the system to ensure all required components are implemented. For instance, in its current version the proposed system does not include a module for harvesting publications information from online sources such as google scholar and ORCID. This is an example of enhancements needed for further integration of the system with existing databases. The artefact has been lodged with the Technology Transfer and Innovation Directorate at Durban University of Technology.

5.3. Limitations

The major limitations in this research are as follows:

1. The study could not accomplish the development of the component for harvesting publications information from online sources due to time limitations, but this has been left as a future project which will be pursued by the researcher as part of the project to assist the DUT Research and Postgraduate Office with enhancement of the system.

2. The developed application does not interface with the system that stores human resources (HR) information. Therefore, the system does not contain records for all the employees at the case study institution. There is an option of working with the University's Information Technology Support Services (ITSS) to upload HR data to RAMS through a script. For now, researchers are required to register on the system.

3. Due to resource limitation, the study was confined only to one higher education institution in South Africa as a case study. However, the findings from the literature reveals that higher education institutions worldwide are faced with similar challenges of managing research information.

4. The evaluation in this study only used 14 participants as most participants who were approached were busy with their work engagements and could not commit to be trained to use the system and then assess its usability. However, the respondents were critical users of the system in the research administration portfolios who capture research publications for the University and are direct end users of the system. It is noted that it would have been ideal if a larger number of users assessed the usability of the system, however, the case study institution has a centralized system of reporting research

publications and hence this limited the number of willing participants from a broader DUT research base population.

5.4. Lessons learnt

There are various skills that have been attained throughout the course of carrying out this research. The most notable is the application of formal methods to specify the requirements of an information management system. The area of formal methods was quite new to the researcher and hence it presented an exciting challenge where the researcher explored the different formal languages to choose the appropriate and manageable to use in the study. Eventually, the Z language was found to be more interesting and was chosen for this study. The experience of writing formal specifications with the Z language was exciting and enriched the researcher's knowledge in system requirements specification. Moreover, the researcher gained an extensive understanding of processes of managing research information in HEIs. This study also significantly contributed to the researcher's knowledge in terms of technical skills gained through the development of the web-based RAMS. The researcher gained an extensive understanding of web technologies throughout the development process of the web-based RAMS. The researcher also gained exposure to the modern technology trends in software development and had hands on experience with web development tools. While working with web development tools the researcher learnt how to utilise a web development framework to build a web-based system that adapts to devices with different screen sizes. In addition, some of the lessons learnt have been communicated to the practitioners within the University's Research and Postgraduate Directorate to enhance and influence the development of an institutional research data management policy through the Directorate for Research and Postgraduate Support.

5.5. Future work

The robustness and relevance of any system depends on the continued improvements to it. In Likewise the developed application can be enhanced in many ways. Therefore, the following directions might be interesting and important in the future work:

1. Development and implementation of a module for harvesting publications information from online sources. As identified in this study, a comprehensive component is required for automatically collecting publications information from online sources. This will minimise the manual entry of publications information in the proposed RAMS.

2. Overall improvements to the data entry interfaces to significantly reduce the effort of entering data in the system by the users.

3. Addition of more components that are pertinent to research information management.

5.6. Concluding remarks

This chapter has concluded the current study. This study successfully developed and implemented a working web-based research administration and management system (RAMS) that could be used to cost-effectively manage research information in South African higher education institutions. The proposed system was tested by real users for usability and it demonstrated acceptable performance in solving real problems of research information management at the case study institution. Although the study was limited to the case study institution, the developed system can be used in other HEIs with similar requirements. Moreover, since the developed system is not proprietary, modifications can be made to the system to suit the requirements of specific higher education institution. In this dissertation, the importance of research information management and the importance of using cost-effective electronic systems to manage research information has been well documented. Overall, carrying out this study was an exciting challenge and a fulfilling experience. The researcher cherished the many interactions with various individuals who provided their valued input leading to the success of this study. The design and development of a functioning system that could be used for managing research information in HEIs is one of the most of the fulfilling experiences especially when the end users show how this would affect and ease their work flows. In summary, the study has satisfied its objectives and fulfilled its purpose to develop a web-based research administration and management system that could be a cost-effective solution for managing research information in higher education institutions.

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APPENDIX 1

Instrument used for evaluating usability of RAMS

	Criteria	Strongly Disagree				Strongly Agree
Statement	**Effectiveness**	1	2	3	4	5
1	I needed much help to use the system.					
2	I found the system difficult to use despite help received.					
3	I found the provided features of the system well integrated.					
	Usefulness	1	2	3	4	5
4	The system is useful.					
5	The system makes the things I want to accomplish easier to get done.					
6	The system does everything I would expect it to do.					
7	The system saves me time when I use it.					
	Ease of use	1	2	3	4	5
8	The system is easy to use.					
9	The system is simple to use.					
10	The system is user friendly.					
11	The system requires the fewest steps possible to accomplish what I want to do with it.					
12	Using the system is effortless.					
	Learnability	1	2	3	4	5
13	The system is easy to remember how to use.					
14	I learnt to use the system quickly.					
15	The system is easy to learn to use.					
	Satisfaction	1	2	3	4	5
16	I am satisfied with the system.					
17	The system interface is simple to use.					
18	The system works the way that I expected.					
19	The system is pleasant to use.					
20	I would recommend the system to other users.					