Semantic web-based healthcare framework for digital healthcare in a resource-constrained environment

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DECLARATION

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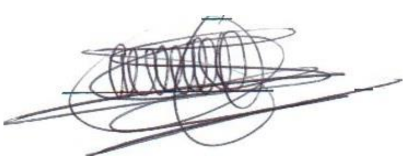
I Ludovic Tonguo, hereby declare that ‘A Semantic Web-Based Healthcare Framework for Digital Healthcare in a Resource-Constrained Environment’ is my own work and that all sources used or quoted have been indicated and acknowledged by means of complete references.

Signature **Date**



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ABSTRACT

Information and communication technology (ICT) have significantly changed our daily life during the last 20 years. ICTs have advanced through research interventions to the point that they now impact every aspect of our daily lives. Among the technologies used in ICT development are artificial intelligence (AI) and the Semantic Web. As opposed to the Semantic Web, which organises web pages so they can be directly read by computers that are connected to the network, artificial intelligence (AI) focuses on creating computer systems that mimic human behaviour. Research on the use of Web 3.0 technology in rural South Africa's healthcare system is still lacking. The Semantic Web and artificial intelligence are combined in Web 3.0. This study project demonstrates how Web 3.0 might help underprivileged communities in Dutywa Health District, Eastern Cape, receive healthcare. The semantic web directs the computer to access legitimate data, which matures into AI when the information is used. Semantic Web can help public healthcare overcome information overload caused by a lack of facilities and qualified medical workers. Fragmented medical clinical information impedes acute care. To model a Semantic Web-Based Healthcare Framework for rural healthcare, this research study uses a Design Science Methodology. Protégé, an Apache Jena Fuseki Server, is used to design and deploy a prototype to the framework for proof of concept. In order to demonstrate the effectiveness of the Semantic Web-Based Healthcare Framework development, its development is compared to the BioMedLib Search Engine using economic projections. The assessment demonstrates that the suggested Semantic Web-Based Healthcare Framework is efficient, furthermore, over time, the Semantic Web-Based Healthcare Framework will have a respectable Return on Investment.

Keywords: Web 3.0, Ontology, Semantic Web, Resource Constrained Environment, Knowledge Management, Expert System

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DEFINITION OF TERMS

5G	Fifth Generation
AIDS	Acquired Immune Deficiency Syndrome
ALM	Application Lifecycle Management
API	Application Programming Interface
AR	Augmented Reality
BioMedLib	Biomedical Library
BT	Bioterrorism
CAES	College of Agriculture and Environmental Sciences
CDA	Clinical Document Architecture
CHC	Community Healthcare Centre
DICOM	Digital Imaging and Communications in Medicine
DL	Description Logic
DS	Design Science
DSR	Design Science Research
DSRG	Design Science Research Guidelines
DSRM	Design Science Research Methods
DSRP	Design Science Research Process
EBM	Evidence-Based Medicine
ECHRC	Eastern Cape Health Research Committee
E-HEALTH	Electronic Health
EHR	Electronic Health Record
GIS	Geographic Information System
GPRS	General Packet Radio Service
GRERC	General Research Ethics Review Committee
GSM	Global System for Mobile

HCLS	Healthcare / Life Sciences
HCLSKB	Healthcare / Life Sciences Knowledge Based
HIT	Healthcare Information Technology
HIV	Human Immunodeficiency Virus
HKM	Healthcare Knowledge Management
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IBM	International Business Machines
ICD	International Classification of Diseases
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IR	Information Retrieval
IRI	Internationalized Resource Identifier
IS	Information System
ISM	Integrated Service Management
ISO	International Standards Organization
IT	Information Technology
ITU	International Telecommunication Union
JADE	Java Agent Development Framework
Jena	Java framework to construct Semantic Web Applications
JESS	Java Expert System Shell
KM	Knowledge Management
LinkedCT	Linked Clinical Trials
LOD	Linked Open Data
LOINC	Logical Observation Identifiers Names and Codes
MDG	Millennium Development Goals
MeSH	Medical Subject Headings
NCD	Non-Communicable Disease
OWL	Web Ontology Language
PACS	Picture Archive and Communication System
PHC	Primary Health Care

PubMed	Public/Publisher MEDLINE
RACER	Core Reasoning Agent for the Semantic Web
RCE	Resource-constrained Environment
RDF	Resource Description Framework
RDFS	Resource Description Framework shema
RDI	Research Development and innovation
SKOS	Simple Knowledge Organization System
SNOMED	Systematized Nomenclature of Medicine
SPARQL	Simple Protocol and RDF Query Language
SQL	Structure Query Language
SSA	Sub-Saharan Africa
SW	Semantic Web
SWBHF	Semantic Web-Based Healthcare Framework
TB	Tuberculosis
UML	Unified Modeling Language
UNISA	University of South Africa
URI	Universal Resource Identifier
VR	Virtual Reality
W3C	World Wide Web Consortium
WHO	World Health Organization
WWW	World Wide Web
XML	Extensible Markup Language

Chapter 1: Introduction

1.1 Background Introduction

Information and Communication Technology (ICT) serve as a vehicle to strengthen the socio-economic impact and provide solutions to a country in almost all domains. It is therefore important to invest on research, development and innovation in this area. Business models and consumer experiences are influenced by ICT more rapidly than ever before (Kundishora, 2014; Musingafi and Zebron, 2017). As the world evolves and technology become a fundamental part of our lives, ICT has become the catalyst underpinning the knowledge economy. Its potential to contribute to South Africa's envisioned growth path is therefore substantial. The impact of ICT is equally necessary in healthcare for the advancement of processes, delivery of services, and in necessitating all round convenience.

Noted advantages of ICT in healthcare include increased efficiency, enhanced quality and safety, improved healthcare monitoring and reporting, reduced healthcare costs, advanced health information exchange, improved access to healthcare knowledge and education as well as public and personalized medicine (Ariani, Koesoema and Soegijoko, 2017).

Remote rural and marginalized communities can reap benefits rooted in the principles of connected healthcare services, eHealth and its sub-categories of telemedicine, telecare, telehealth, m-health, routine health management information, consumer health informatics, and virtual healthcare amongst others, to improve efficiency in healthcare service delivery (Suriah, 2015; Ariani, Koesoema and Soegijoko, 2017; Lena Otto, Lorenz Harst, Hannes Schlieter, Bastian Wollschlaeger, 2018). This study adopts connected healthcare principles, Semantic Web (Web 3.0) and knowledge management as enabler of healthcare service delivery in the clinics of Eastern Cape Dutywa Health District.

Connected health as a concept refers to providing healthcare in a collaborative manner where Information Technology (IT) will aim to connect different systems, devices, and stakeholders (Bandara, 2015). This will bring together the different entities to create a connected health ecosystem, thus making this service efficient and effective for users.

1.2 Healthcare Data and Knowledge Management

LeSueur (2017) acknowledges that, healthcare data tends to reside in multiple places, be from different source systems, like EMRs or HR software, be from different departments, like radiology or pharmacy and finally, with data coming from all over an organization.

The structure of data in healthcare are generally in different formats (e.g., text, numeric, paper, digital, pictures, videos, multimedia, etc.) rendering data analysis useless. Furthermore, the researchers (LeSueur, 2017; Jayaratne, Nallaperuma, Silva, Alahakoon, Devitt, *et al.*, 2019) claim that, the integration of these data into a single, central system, such as a corporate data warehouse (CDW), makes all data available and actionable. LeSueur (2017) acknowledges that radiology uses images, old medical records exist in paper format, and hundreds of rows of textual and numerical data can be held in today's EMRs, and sometimes the same data exists in different systems and formats. This is the case of evidence from insurance and clinical data. A broken arm of a patient looks like a medical record picture, which appears in the claims details as ICD-9 code 813.8 (Adibuzzaman, DeLaurentis, Hill and Benneyworth, 2017). Moreover, it appears the future holds even more sources of data, like patient-generated tracking from fitness monitors and blood pressure sensor devices (LeSueur, 2017). Evidence-based practice and new research is coming out every day. Oftentimes, healthcare data can have inconsistent or variable definitions. A Knowledge Management and healthcare data cohort is a thought towards the right direction in attempting to interconnect disparate healthcare systems (Tharmalingam et al., 2016).

There exists several definitions of the knowledge management principle (KM) to date. In order to demonstrate the breadth and depth of thinking in the field, Girard and Girard (2015), examined, selected, and categorised the existing KM definitions by discipline in their study. Relevant KM definitions for our study are in the disciplines of content management, development, education, engineering, finance, government, health, information management, science and technology, systems thinking, and statistics. The definitions of knowledge management (KM) and the disciplines they belong to are listed in Table 1.1. The KM definitions listed in Table1.1 were chosen because they closely align with the focus of this study.

Table 1.1: Knowledge Management principles and related **disciplines** (Girard and Girard, 2015)

Knowledge Management Discipline	Knowledge Management Definitions					
Content Management	Knowledge management is the practice of ensuring that insights, results, and learning are captured within an organization and made available to staff to identify, use, update, adopt, and integrate into business processes. Knowledge management and innovation and research initiatives are often aligned with training and learning ("Knowledge Management, Elcom,"). Australia	The term knowledge management describes how knowledge is generated, stored, controlled and delivered within a company ("Knowledge Management, Bitfarm Archiv,"). Germany				
Development	Knowledge management is explicit and systematic process management that allows for the detection, creation, storage, sharing, and use of essential individual and collective information resources. The concrete expression of this is the integration of information management and organizational training(Serrat, 2009). Internation	Knowledge management is a systematic method and strategy to find, collect, organizing, distill and present data, information and Knowledge for a specific purpose and to support a particular organization or group (D. King, 2005). USA.	Knowledge management (KM) is an umbrella term that encompasses the many unique but related facets of information and experience creation, organization, sharing and use ("What is Knowledge Management (KM)?,") USA	Knowledge Management is how organizations develop, identify, improve and recycle information to achieve organizational objectives ("Knowledge Management in ADB," 2004, p. 13). International	Knowledge management is a discipline that encourages an organized approach to creating, recording, storing, accessing and using information resources of an organization. These resources include structured databases, written information such as policy and procedural documents and, most significantly, the implicit knowledge and expertise in the individual employees ' heads ("What is Knowledge management?," 2012). International	Knowledge Management (KM) is a systematic process management that facilitates the identification, development, processing, sharing and use of essential individual and collective knowledge resources for the benefit of the actors involved.("Glossary:Knowledge Management and Sharing," 2012). International
Education	[KM] is a set of practices to improve the use and sharing of information and data in decision-making (Petrides & Nodine, 2003). USA	Knowledge management is the organization's strategic planning, motivating, organising and control of people, processes and systems to ensure that its knowledge-related resources are strengthened and used effectively (W. R. King, 2009, p. 6). USA	The knowledge management process begins by identifying and classifying the types of knowledge that currently exist in the organization, followed by understanding where and how the knowledge exists.(Little, 2010). USA	The systematic process of finding, selecting, organizing, distilling and presenting information in a way that enhances the understanding of an employee in a particular area of interest ("Knowledge management - glossary, Knowledgepoint," 2007). Australia	Knowledge management: The process of capturing, organizing, storing information and experiences of workers, and making it available to others and groups within an organisation. Through storing these items in a central or distributed digital environment (often in a database called a knowledge base), KM aims to help a company gain competitive advantage ("knowledge management,	

					An e-learning glossary," 2014). United Kingdom									
Engineering	Knowledge Management is about the protection, development and exploitation of knowledge assets (Katsoulakos & Zevgolis, 2004). Cyprus	Knowledge management is a process by which an organization collects, organizes, analyzes and communicates knowledge that is important to its business environment and operational disciplines. ("Knowledge Management, CA,"). Australia												
Finance	The process of creating, institutionalizing and distributing knowledge between individuals in order to improve and organize business processes and practices ("knowledge management - Investment & Finance Definition," 2010). USA	[This is] 1. Use of the organization's knowledge of the company for competitive advantage 2. Coordination and use of the organization's knowledge resources of a company to build benefits and competitive advantages ("knowledge management," 2009). International												
Government	[KM is] the constant challenge to identify, rescue, create, access, develop, preserve, disseminate, promote, use and reuse knowledge in order to answer to our audiences delivering an excellent service (Kraft & Donoso, 2012). Chile	A trans-disciplinary approach to improving organisational outcomes and learning through maximising the use of knowledge. It involves the design, implementation and review of social and technological activities and processes to improve the creating, sharing and applying or using of knowledge. Knowledge management is concerned with innovation and sharing behaviours, managing complexity and ambiguity through knowledge networks and connections, exploring smart processes and deploying people-centric technologies ("Recordkeeping In Brief 26 - An introduction to knowledge management for records managers," 2009). Australia	Knowledge Management is: Discipline that seeks to improve the performance of individuals and organizations by maintaining and leveraging present and future value of knowledge assets, encompassing both human and automated activities (Knowledge Management Glossary, NASA Wiki, 2014). USA	Knowledge Management is: Process an organization uses to optimize its intellectual capital to achieve organizational objectives (Knowledge Management Glossary, NASA Wiki, 2014). USA	Knowledge Management (KM)— A systematic process of finding, selecting, organizing, distilling and presenting information which involves the design, review and implementation of both social and technological processes to improve the application of knowledge (Knowledge Management: Glossary of Terms, 2012, p. 5). India	Knowledge management (KM) is generally defined as a set of new, widely applicable organizational practices in the knowledge economy. Knowledge management deals with any set of intentional practices and processes designed to maximize knowledge usage, i.e. to improve allocative efficiency in knowledge output, distribution and use (Young, 2013, p. 3). International								
Health	The word [information management] is used by the WHO to explain how the secretariat uses technology to create, record, store, retrieve, use and share knowledge ("Department of Knowledge Management and Sharing (KMS),"). International	Knowledge management is a set of principles, tools and practices that allow people to build knowledge and communicate, translate and apply what they know to create value and improve efficiency ("WHO knowledge management glossary," 2006). International												
Information management	A Knowledge Management System is one that provides the user with the needed explicit information in exactly the form required, when the user needs it. (McKenna, 1997). USA	KM is a newly emerging, interdisciplinary business model that discusses all aspects of the company's knowledge, including knowledge development, codification, sharing, and how these activities facilitate learning and innovation (Hernadez, Liang, Prescott, & Kirch, 1999). USA	The ability of an organization to manage, store, value, and distribute knowledge (Liebowitz & Wilcox, 1997). USA											
Information Technology	KM is the process	[KM is] organizing an	KM is the overall task of managing	Knowledg e	Expertise manageme	Knowledge management	Knowledg e	Enterprise knowledge	A generic word to make use of	Knowledge manageme	[Knowledge management	IT Knowledg	Knowledge Management: The	

	through which organizations generate value from their intellectual and knowledge-based assets (Levinson, 2007). USA	organization's information and knowledge holistically (Koenig, 2012). USA	the processes of knowledge creation, storage and sharing, as well as the related activities (Kucza, 2001). Finland	management (KM) is a business process that formalizes the management and use of an enterprise's intellectual assets. KM promotes a collaborative and integrative approach to the creation, capture, organization, access and use of information assets, including the tacit, uncaptured knowledge of people ("knowledge management. Gartner IT Glossary.,"). USA	nt seeks to gather, evaluate, store and share information and knowledge within an organization. Knowledge management's primary purpose is to improve efficiency by reducing the need for knowledge rediscovery ("knowledge management. IT Process Wiki,"). Germany	is the name of a concept in which a company collects, organizes, shares and analyzes its knowledge of resources, documents and human skills consciously and comprehensively. ("Knowledge Management, TechTarget,"). USA	Management (KM) is the method of creating and sharing information with ITS staff when responding to and resolving incidents TS ("knowledge management, ITS "). USA	management (EKM) is a relatively broad concept in IT that refers to any technologies or systems that handle the organization of information into processes that create knowledge within a company ("Enterprise Knowledge Management, Technopedia,"). Canada	the human knowledge that resides within an organization more efficiently. Knowledge management is the basis to information management in the 21st century. It is primarily an industry where specialized groupware and business intelligence (BI) products provide a wide range of solutions ("knowledge management, PC Magazine Encyclopedia, "). USA	nt is the practice of knowledge identification, creation, communication, socialization, measurement and improvement to support strategic goals (Mar, 2013). USA	is] a method for simplifying and improving the process of knowledge creation, sharing, distribution, capture and understanding in a company (Gottschalk, 2005, p. 1). USA	e Management's objective is to create, maintain and provide users and IT support groups with concise and actionable information in order to resolve service disruptions quickly and to respond satisfactorily to customer requests. (McGlynn, 2013). United Kingdom	process responsible for sharing perspectives, ideas, experience and information, and for ensuring that these are available in the right place and at the right time. The knowledge management process enables informed decisions, and improves efficiency by reducing the need to rediscover knowledge ("knowledge management, Axelos Common Glossary," 2012). United Kingdom

Statistics	Management of knowledge involves activities related to the organization's capture, use and sharing of knowledge. It involves managing both external connections and knowledge flows within the company, including methods and procedures to search for external knowledge and to establish closer relationships with other companies (suppliers, competitors), customers or research institutions. In addition to knowledge gaining practices, knowledge management includes methods for sharing and using knowledge, including the establishment of value systems for sharing knowledge and codification practices ("knowledge management. OECD Glossary of Statistical Terms," 2005). International Organization	
Science and Technology	Knowledge management is the conversion of tacit knowledge into explicit knowledge and sharing it within the organization (Uriarte, 2008, p. 13). Japan	Knowledge management is the process through which organizations generate value from their intellectual and knowledge-based assets (Uriarte, 2008, p. 13). Japan
Systems Thinking	Knowledge Management consists of all the activities required to develop, maintain, and evolve the environment described above, and support its interaction with people (Bellinger, 2009). USA	

Consequently, knowledge management (KM) means a strong link to organizational strategy and goals which requires information management that is useful for some reason and creates value for the enterprise (Gonzalez and Martins, 2017).

KM explores where and in what ways knowledge exists; what the organization needs to know; how to promote a culture conducive to learning, sharing and knowledge-creation; how to make the right knowledge available to the right people at the right time; how to best produce or acquire new relevant knowledge; how to handle all these factors in order to improve the organizational efficiency (Dube, 2017).

Therefore, KM needs to create and provide the right learning tools, people, knowledge, structures (teams, etc.), culture, etc. It must understand the value and applications of the new knowledge that has been created; it must store this knowledge and make it readily available at the right time to the right people; and it must continually evaluate, apply, refine and remove organizational knowledge in conjunction with concrete long-and short-term factors.

1.3 Problem Statement

Healthcare workers (physicians, nurses, junior medical doctors with no field experience and students from medical university schools) are constantly on the lookout for online healthcare information and education, hence the need for a drastic shift from the traditional way of conducting healthcare affairs. This shows that the Web is used in the public healthcare, though not as part of everyday business. The challenge that public healthcare workers still encounter is the quality of information and the reliability of Web healthcare sources and resources they are browsing (Li, James and McKibben, 2016). This provides information overload entailing both reliable and unreliable data source, useful and not so useful data for the case at hand. Healthcare workers end up with excess information, which requires them to manually make sense of which information is required at a given instance.

Resource-constrained environments in developing countries (Mph, Bach and Bsch, 2012) are disadvantaged in many ways ranging from poor communication networks, poor road infrastructure and poor access to government services, to acquisition of basic needs. Consequently, medical centres in resource-constrained environments are very few and are poorly facilitated making them impossible to handle medical cases of the many patients that depend on them (Fanta, 2015; Ouma, Herselman and Vangrauen, 2015). Researchers, noted that, apart from lack of facilities and medical personnel, medical centres in resource-constrained environments also experience fragmented and inaccessible clinical information (Adams, Bakalar and Boroch, 2008; Patel, 2012; Munsamy, Parrish and Steel, 2014). All this burden can affect negatively on patients' treatment or can result in patient deaths. Regardless of all the efforts from the South African Department of Health (DoH) to address all the challenges facing rural healthcare, there is still a huge gap in terms of the quality of service delivery between public and private healthcare.

It is with this understanding that we envision the design and development of a Semantic Web-Based Healthcare Framework that will support healthcare workers in a resource-constrained environment. The decentralization that comes with the Semantic Web technologies will enable a better functioning of the public healthcare system and ensures participation of all the stakeholders involved in the healthcare ecosystem (i.e., Government, healthcare personnel & providers, and patients). The framework was piloted at Eastern Cape Province clinics and health centres in Dutywa's Health District, a rural, remote area, with the administration of interviews and survey questionnaires to doctors. The interview questionnaires were a foundational component towards the framework design and pilot development. In rural areas, the majority of the people still do not receive quality public healthcare services as compared to urban areas because of poor infrastructure and shortage of resources.

Since healthcare data and knowledge is central to clinical decisions, the framework also attempt to address the challenge of applying healthcare knowledge to existing healthcare provider environments in order to improve decision making, the quality of patient care services, the quality, efficiency and efficacy of healthcare delivery system specifically in rural, marginalized areas. It is projected that there will be a reduction in the healthcare costs in the long run as well.

1.4 Aim of the Research

The aim of this study was to design a Semantic Web-Based Healthcare Framework (SWBHF) for healthcare in a resource-constrained environment, that provides support to healthcare workers through the use of healthcare data and knowledge management principles. Furthermore, this study proposes a prototype of the designed SWBHF. The principles of KM were selected to mitigate healthcare information overloading in resource-constrained environments, specifically in clinics and hospitals in Dutywa Health District in the Eastern Cape Province of South Africa. Abidi (2008) acknowledges that, healthcare knowledge management (HKM) can be characterized as the systematic creation, modeling, sharing, operationalization and translation of healthcare knowledge to improve the quality of patient care with a goal to promoting and providing optimal, timely, effective and pragmatic healthcare knowledge to healthcare professionals (and even to patients and individuals) where and when they need it to help them make high quality, well-informed and cost-effective patient care decisions. KM is based on the idea that an organization's most valuable resource is its knowledge which may be enshrined in its people and processes, as well as information systems (computer based or other) and can be used to support the knowledge ecosystem.

The goal of this research is to provide a reference Semantic Web-Based Healthcare Framework that can be adopted and possibly be customized to fit a particular public healthcare setting in South Africa and beyond by leveraging ICT capabilities.

1.5 Research Aim, Objectives and Questions

The key research question of this study is:

How can a Semantic Web-based Healthcare Framework (SWBHF) for improving knowledge sharing, searching and efficiency in resource-constrained healthcare environments be designed and modeled?

To answer the main research question, the following sub-questions have to be answered:

- What is the state of art of the Semantic Web for healthcare regarding healthcare knowledge sharing and information overloading improvements?

- What are the challenges that hinder the implementation a SWBHF in a resource-constrained environment in South Africa?
- How can a Semantic Based Healthcare Framework be designed and developed

To achieve our goal and answer our research questions, the following objectives were addressed:

- To investigate the state of the art of semantic web technologies practice in healthcare.
- To identify the challenges that hinder the implementation of SWBHF in a resource-constrained environment in South Africa.
- To model the Semantic Web-Based Healthcare system based on our designed Framework by means of a prototype development

1.6 Motivation of the Study

In the digital world the interconnection of things and data causation plays an integral role in ICT and has the potential to transform business and government, driving entrepreneurship, innovation and socio-economic impact (i.e., reducing the costs of medical treatment and healthcare), more so in the African context.

The World Bank and the African Development Bank, with the support of the African Union substantiates this in its eTransform Africa report, which identifies best practices in the use of ICTs in key sectors of the African economy (i.e., health, education, poverty reduction, and in achieving the Millennium Development Goals) (World Bank , 2013). In addition to the highlighted activities, ICTs evidently play a defining role in enhancing and integrating healthcare in Africa. This is for enabling efficient service delivery to the multitudes, hence building a competitive ICT industry that promotes cutting edge innovation. Technology paired with solid strategies, custom-designed to align with countries' unique priorities, needs, and resources, holds an incredible promise for the healthcare industry.

Semantic Web in healthcare can be used not only to improve the quality of web mining results, but also to enhance the functions, services and the interoperability of medical information systems and standards in the healthcare field. Mining this sort of web-based information to achieve useful results is a beneficial method as it can provide related information quickly to support healthcare providers. A creative and future solution is the use of Semantic Web technology such as Resource Description Framework (RDF) and Web Ontology Language (OWL) to organize and describe information sources such as symptoms, illnesses, genes, geographical location of diseases and other medical procedural information. This eventually promotes semantic health information searching and sharing, efficiency and responsiveness (De Choudhury, Morris and White, 2014).

It is therefore paramount for African countries to develop and implement robust national strategies that pair technology with solid healthcare strategies supported by various regulations and policies. This mechanism will help realize the design for an integrated digital health system that connects everything from patient electronic health records to mobile phone health applications, resulting in real-time, high-quality data that can be used to improve health for all. In the long run, African countries can learn from each other through a network of digital health systems. The semantic web together with knowledge management principles are a big enabler towards realizing the design of this healthcare framework. This study responds to the South African ICT RDI Roadmap cluster that talks of "*The Service Economy opportunities, that is, enabling improved, lower cost and more convenient access and consumption of physical and digital services". It also responds more to the South African eHealth strategy 2012-2017 which emphasize on the effective monitoring of healthcare service delivery and overall performance of health systems that requires functional health information systems capable of producing real time information for decision making.*

ICT has emerged as a critical enabling mechanism to achieve the stated undertaking. This research adopts proven semantic web-based technologies for healthcare to work, scale and extend them to fit the South African healthcare context. This research develops a Semantic Web-Based Healthcare Digital Framework for resource-constrained environments, to support healthcare providers (physicians and nurses) specifically junior doctors and nurses to strengthen digital healthcare systems and build local capacity so that everyone, from government officials to healthcare workers to patients, can make more informed decisions, leading to healthier South Africa. To arrive at the framework, design science research was identified as a suitable approach to designing an artifact. A business model that informs the framework is developed. The proposed framework is an attempt to also assist healthcare software engineers, application developers, amongst other technical experts involved in healthcare development, to implement custom-made healthcare systems for resource-constrained environments in developing countries.

1.7 Methodology

This study adopts the Design Science Research (DSR) paradigm as it harnesses the thinking on how design science is defined, theorised, and actualised in the Information Systems (IS) field (Nunamaker, Chen and Purdin, 1991; Hirschheim and Klein, 2003; Hevner, March, Park, and Ram, 2004; Peffers, Tuunanen and Rothenberger, 2008) and education. Hirschheim and Klein (2003), offered a concise definition of design and development research as the "disciplined investigation conducted in the context of the development of a product or program for improving either the thing being developed or the developer" (Hirschheim and Klein, 2003; Richey and Klein, 2014). Design Science Research (DSR) combines a focus on the information technology (IT) artefact with a high priority on its relevance in the application domain (Walls, Widmeyer and Sawy, 1992; March and Smith, 1995; Iivari, Hirschheim and Klein, 1998).

DSR aims to improve theories that explain or anticipate on organizational and human phenomena surrounding the analysis, design, implementation and use of IS. Such theories finally inform researchers and practitioners of the interactions between organizations, technology, people and that must be managed if an information system is to achieve its stated purpose, namely, improving the effectiveness and efficiency of an organization (Peffers, Rothenberger, Tuunanen and Vaezi, 2008; Hevner and Chatterjee, 2015).

This study attempts to address both aspects of DSR, that is, improving the thing being developed or the developer, since it is an attempt at improving the way healthcare services are delivered using ICT principles to design an artefact and develop a model.

A literature search is used as the secondary data collection technique in this study. Journal articles, conference papers and books related to the topics of healthcare in a resource-constrained environment, application of the Semantic Web in healthcare, adaptation of the Semantic Web to resource-constrained environment healthcare delivery and healthcare ontologies are targeted. The primary data collection was a series of questionnaires and interviews. Primary data was collected from doctors and nurses in three selected hospitals in Dutywa Health District.

1.8 Research deliverables

The deliverables of this research are:

- A Semantic Web-Based Healthcare Framework for the design and implementation of healthcare information systems in a resource-constrained environment in developing countries.
- At least one research output
- A Master's Dissertation

1.9 Delimitations of the study

The study focuses on improving healthcare knowledge searching, sharing in addition to information overloading of healthcare workers in clinics and hospitals in Dutywa Health District in the Eastern Cape Province of South Africa through designing a SWBHF and prototype development. Only one province was used for this research. However, the framework can be customized for use in the other provinces of South Africa that are resource-constrained healthcare environments and certainly customized for other African countries. The designing of the SWBHF will not cover hospital financial systems, administrative systems, electronic devices and patient portals.

1.10 Ethical Considerations

All participants involved in the research were treated with respect and integrity as stipulated in the Research Ethics Policy of the University of South Africa (UNISA). The application, informed consent form and data collection instruments have been forwarded to and accepted by the General Research Ethics Review Committee (GRERC) of the College of Agriculture and Environmental Sciences (CAES). No insecure groups or data administrators/users were concerned, and the researcher maintained secrecy. Each research participant had to sign an informed consent form. The approval from CAES and Eastern Cape Health Research Committee (ECHRC) is attached as Appendix A and B.

1.11 Chapter Outline

This research applies the DSR approach throughout the study (see Chapter 4). The research approach describes a process to be followed, from problem identification and motivation and structuring through to the design and development of the artifact, and communication of results (Peffers, Rothenberger, Tuunanen and Vaezi, 2008). This process speaks to the research design, and the outline of this dissertation as captured in the structure of the dissertation is outlined in Table 1.2, indicating the description of each chapter.

Table 1.2: Structure of the dissertation

Chapter No	Title	Description
1	Introduction	This chapter presents the background to the study, research context, research problem statement, research objectives and deliverables.
2	Background	This chapter provides a background of the phenomenon being studied
3	Literature Review	This area of study includes a literature review about healthcare in a resource-constrained environment, Semantic Web, the state of the art of the Semantic Web in healthcare and some related cases where the Semantic Web was successfully used in the healthcare.
4	Research Methodology	This chapter is about the research methods and approaches, research design and data collection techniques.
5	Model Design and Development	The goal of this chapter is to design a Semantic Web-based Healthcare Framework that supports healthcare providers in a resource-constrained environment and provides details of how the artefact was designed and instantiated for the purpose of the selected clinics at Dutywa health district in Eastern Cape case study.

6	Model Prototyping and Evaluation	Chapter 4 centred around the model design and development of the Semantic Web-based Healthcare Framework discussion that supports healthcare workers in a resource - constrained environment. The research presented a model design using the UML diagram approach to show the system's architectural blueprints, which include activities, actors, business processes and reusable software components. This chapter is a prototype of the model and its evaluation.
7	Summary, Conclusion and Future Work	The contribution of the research, the recommendations and a conclusion are included in this chapter

1.12 Conclusion

This research study outlines the design of a SWBHF that will support healthcare providers in a resource-constrained environment. It presents the problem statement, the research aims, and objectives and the research method followed. It also highlights the structure of the whole dissertation. The next chapter discusses the literature review.

Chapter 2: Background

2.1 Introduction

This chapter provides an overview of the south African healthcare landscape, the current challenges in public healthcare, and semantic web in healthcare.

2.1.1 The Healthcare Landscape

The world is endowed with limited resources. The health system has budgetary constraints, but the need for high-quality medical care seems to never end. Every day, healthcare authorities in South Africa must weigh the best value for healthcare spending against the best patient care. These are challenging decisions. The clarity, openness, and evidence-based methods used to prioritise healthcare can significantly improve the calibre and honesty of the choices made by our legislators. The Constitution of South Africa recognises the existence of health disparities in the nation and adopts a universal health coverage (UHC) approach to healthcare. The National Health Insurance (NHI) White Paper from 2015 made this strategy clear, although it was already implied in the 1994 nationwide free primary healthcare programme and the 1996 expanded healthcare plan for expectant mothers and children. Known as the benefits package, the NHI mechanism seeks to achieve universal health coverage (UHC) by 2025 by providing all South Africans with access to a comprehensive platform of high-quality healthcare services. Nevertheless, the 2015 NHI White Paper suggests creating an NHI Benefits Advisory Committee to do so, although it does not yet include information about the package or the procedures necessary to ascertain its contents, as mentioned in the 2016 South African Health Review.

South Africa's healthcare system "is divided between the public and private sectors, with significant inequities evident between the two systems," according to Alberts et al. (2015, p. 4). The National Department of Health (2011) reports that the public health system, which has inadequate funding, serves the remaining population, with nearly half of all national spending going towards the private sector, which only serves 16.2% of the population. For the majority of Black Africans, the relatively large public health sector provides free primary healthcare services (PHC) as well as secondary and tertiary healthcare at state-owned hospitals. Meanwhile, the private sector offers top-notch facilities for those who can afford healthcare out-of-pocket or for the insured minority (Coovadia, Jewkes, Barron, Sanders and Mcintyre, 2009; Delobelle, 2016; DoC, 2017). Due to this, the public health sector is primarily dependent on general tax funds, which account for 11% of the government budget, which is then distributed and spent by the nine provinces in accordance with their respective requirements and goals.

Healthcare delivery has been impacted by the migration of healthcare workers from rural to urban, public to private, and secondary to postsecondary institutions. This has, in turn, compromised the quality of treatment and exacerbated health inequalities, particularly in distant and rural areas (Aitken and Kemp, 2003). Many of these issues have their roots in certain aspects of South Africa's past, where segregationist policies perpetuated health disparities.

It is obvious that prior to implementation, a fair, trustworthy, and evidence-based method will need to be used to establish the standards for new technology and services to be included in the NHI healthcare platform. A health technology assessment (HTA) system can assist in identifying and enlightening decisions regarding financing health services and technologies, as demonstrated by global experience (Hofman, McGee, Chalkidou, Tantivess, & Culyer, 2015; South African National Department of Health, 2015; Barron & Padarath, 2017; Siegfried, Wilkinson & Hofman, 2017).

The Internet serves as a vast global network that facilitates direct and transparent communication between computers of all types, hence enabling the delivery of healthcare services. According to, it is described as a worldwide network and a "Information Super-highway" (Kelly, Campbell, Gong, & Scuffham, 2020; Carson and Bonk,1999).

It is described as having the ability to broadcast globally, a way to distribute information, and a way for people to collaborate and communicate with their computers from anywhere in the world (Phelps, 2005). The most significant technological innovation of our day is the Internet. The Internet is a well-liked resource for healthcare information for both consumers and practitioners (Lima-Pereira, Bermúdez-Tamayo and Jasienska, 2012;

Xiao, Sharman, Rao and Upadhyaya, 2014). It has been acknowledged by many as a crucial tool for the reform of medical treatment (Ajuwon, 2006; Terry, 2016).

One of the fundamental uses of the Internet is as an encyclopedic information resource (Hughes, Joshi, Lemonde, & Wareham, 2009; Smith, 2020; Battineni, Baldoni, Chintalapudi, Sagaro, Pallotta, Nittari, & Amenta, 2020). According to Ajuwon (2006), 60–80% of WWW users have accessed healthcare information, which is among the most sought-after pieces of information on the Internet. In addition, the Internet has the power to inform and empower patients by encouraging patient autonomy and self-help while also offering information on healthcare and its services. Following the same line of reasoning, the majority of people who use the Internet to research healthcare issues claim that it has an influence of some kind.

In the 1980s, the McMaster Medical School in Canada coined the term "Evidence-Based Medicine," which is often referred to as "Healthcare Clinical Guidelines". Sackett, a cofounder of Evidence-Based Medicine (EBM), defines EBM as the deliberate, explicit, and prudent application of the best available research to medical decisions that are made with the patient's best interests in mind (Sackett, Rosenberg, Grey, 1996). In order to apply EBM, one must combine professional clinical experience with the best clinical data that can be gleaned from the systematic analysis of previous studies. EBM differs from other methods of providing appropriate and high-quality medical information in that it relies heavily on human input to add expert knowledge. This is especially useful for downstream processes like evaluating a study's methodology and customising the information for a consultation.

EBM is a medical practice approach that integrates the best available information from the medical literature to make decisions. Usually, controlled clinical trials provide this kind of proof (Subbiah, 2023; Shortlife, 2014).

According to Shortliffe (2014), new methods are needed to choose which clinical information should be used for decisions in light of the increasing amount of data available in digital libraries and information retrieval (IR) systems. This is stated in his book, "Biomedical Informatics: Computer Applications in Health Care and Biomedicine Fourth Edition". This method is guided by the EBM philosophy, which can be seen as a collection of instruments to assist in clinical decision making. It makes it possible to combine the greatest clinical knowledge with clinical experience, or "art" (Haynes, Devereaux, and Guyatt, 2002). Additionally, EBM increases the clinical applicability and relevance of the medical literature.

Healthcare is being revolutionised by the ongoing advancements in information and communication technology (ICT). This necessitates a dramatic shift towards the use of fully integrated IS, particularly in resource-constrained situations (Kapur, 2001). The movement towards cyberspace interaction will be crucial in facilitating the delivery of healthcare services to South Africa's underprivileged areas by creating a channel for industry and government cooperation. These advancements are expected to drive up Internet usage, which is already being used more and more for healthcare delivery and information (Powell, Darvell, and Grey, 2003; Carley, Horner, Body, & Mackway-Jones, 2020). Studies indicate that medical professionals are cognizant of the opportunities presented by Internet technology; thus, it is necessary to be mindful of the risks associated with it as well (Powell et al., 2003; Carley et al., 2020).

According to Kitchens, Harle, and Li (2014), people are increasingly using the Internet to supplement or replace traditional sources of healthcare information, making online searches for health information nearly universal. As a result, there is a critical need to comprehend the quality of online healthcare information. According to the authors of this paper, more people ask Google questions about healthcare issues than they do their doctors, and consumers of healthcare tend to focus their searches on information about illnesses, medical issues, treatments, and procedures (Ajuwon, 2006). Moreover, we would anticipate that people would be better educated and able to make better healthcare decisions if this behaviour also leads users to high-quality knowledge. However, there is reason to be concerned about the influence on people's attitudes and decisions if these searches typically turn up inaccurate or unsupported healthcare information. Therefore, it's critical to understand whether customers who search for information typically find trustworthy and relevant sources about healthcare.

Online access to healthcare information may benefit patients by increasing their knowledge of their conditions and lowering feelings of isolation and loneliness. This is especially helpful for patients who are bedridden and immobile due to severe illnesses (Tonsaker and Bartlett, 2014).

According to Moretti, Oliveira, and Silva (2012), there is a significant risk associated with using the Internet in the healthcare industry since consumers and healthcare professionals may not be aware of the guidelines for identifying quality standards. Many specialists draw attention to the fact that much of the material about illnesses and therapies that may be found online is either scientifically insufficient or lacking. In light of this, authors recommend that healthcare websites employ certificates of approval from specialised authorities that are granted according to certain standards.

According to Ouma and Herselman (2009), there was a time when people got all of their healthcare information from their doctors. It is also recognised that patients actively seek out information about healthcare on the Internet these days, so when they visit their doctors, they already know something about the ailment that is bothering them (Ouma and Herselman, 2009). The shift has affected not just medical professionals but also other e-health stakeholders. Doctors are often looking for information about research and education on the internet. There is a need for a significant departure from the conventional approach to managing healthcare affairs because pharmaceutical companies sell their products online, clinics and hospitals purchase their products online, and insurers are billed via the Internet (Powell, Darvell and Grey, 2003; Ouma and Herselman, 2009; Suziedelyte, 2012; Atkin, 2016). Thus, it is imperative that hospitals embrace the usage of the Internet. The issue that still faces e-health policymakers and consumers (e-doctors, e-patients, e-nurses, e-researchers, e-communities) is the accuracy and dependability of the healthcare websites and resources they visit, whether they are public health websites, private healthcare providers, or legally registered or recognised medical healthcare businesses (Ouma and Herselman, 2009).

Health Information Technologies

Studies demonstrate that the application of health information technologies (HITs) has the potential to revolutionise the healthcare sector. Enforcing the use of HITs appears to be a crucial tactic in long-term cost reduction and control of healthcare without sacrificing the standard of treatment provided to patients (Gardner, Cooper, Haskell, Harris, Poplau, Kroth, & Linzer, 2019: Garavand, Mohseni, Asadi, Etemadi, Moradi-Joo, & Moosavi, 2016). HITs can help close the growing gap between the demand and supply of healthcare services by processing, storing, retrieving, and sharing healthcare data and knowledge for use in decision-making and communication within the healthcare industry (Mostert-Phipps, Pottas, and Korpela, 2013). In order to promote the acceptance and effective use of HITs in the South African healthcare system, the authors of this study set out to determine the variables that needed to be taken into consideration. The healthcare industry in South Africa still uses paper-based information management systems, despite the fact that many scholars have suggested HIT techniques including electronic health records, electronic medical records, and telemedicine, among others. This is especially true when it comes to the management of medical records.

Reviews indicate that South Africa has not advanced far enough towards achieving several of the healthcare goals, or has perhaps gone backwards.

Resource-constrained context

In studies based on resource-constrained situations, Patel, (2012); Alberts, Botha and Fogwill, (2015); and Fanta, (2015), the writers paint a picture of how these communities suffer due to a lack of enough infrastructure to supply services. Consequently, medical facilities in settings with limited resources are impacted, rendering it unfeasible to manage medical problems for the numerous people who rely on them. The researchers observed that medical centres in resource-constrained areas face fragmented and unavailable clinical information in addition to a shortage of facilities and medical professionals (Mmamolefe R. Kgasi and Kalema, 2014). Due to an increase in medical errors, this fragmented and inaccessible clinical information may have a negative impact on the cost and quality of healthcare delivered, ultimately jeopardising patient safety (Keeton, 2011). In contrast, precise and comprehensive patient data is necessary for medical researchers, healthcare administrators, patients, and policymakers to make well-informed decisions regarding various healthcare matters (Ouma, Herselman, and Vangrauen, 2011; Sibte and Abidi, 2008; Mmamolefe, Kgasi and Kalema, 2014; Mohlameane and Ruxwana, 2014; Munsamy, Parrish, and Steel, 2014).

In settings with limited resources, attracting, developing, and keeping healthcare professionals are difficult issues (Munsamy, Parrish, and Steel, 2014). In areas with the greatest need for healthcare, the number of physicians, nurses, and other allied healthcare professionals is low and frequently nonexistent (Ouma, Herselman, and Vangrauen, 2011; Munsamy, Parrish, and Steel, 2014).

2.1.2 Current Challenges in Public Healthcare

The South African health system is divided into two parts: public and private. The former is handled through different provincial government health departments. The public health sector is organised into primary, secondary, and tertiary health services, which are delivered through a variety of health institutions located within and supervised by various provincial departments and overseen by the National Department of Health (Malakoane, Heunis, Chikobvu, Kigozi, & Kruger, 2020).

With the goal of improving service delivery and strengthening the performance of the public health system, the South African government has been implementing strategies, plans, policies, and charters ever since democracy was established. Yet, as the burden of disease rose, public health programme performance and results continued to be subpar (Malakoane et al., 2020). There is abundant evidence that a number of issues that have a detrimental influence on healthcare quality have lowered the standard of care in South Africa (Maphumulo & Bhengu, 2019). As a result, this industry faced significant health system difficulties, such as unfavourable employee attitudes, protracted wait times, dirty facilities, medicine stock-outs, inadequate infection control, and jeopardized patient and worker safety (Department of Health, 2017).

Service delivery

According to research, stakeholders believed that the inefficiency of the health system was primarily caused by fragmentation of health care supply. Fragmentation of healthcare services was recognised as a serious concern in the face of increased illness burden. Health services that are fragmented lead to complex, impersonal health systems that are difficult to navigate.

According to a study by Malakoane et al. (2020), the public health system's low performance in terms of quality of care and health outcomes was mostly caused by a lacklustre leadership team and service fragmentation at the implementation level. Other studies (Muhwava, Murphy, Zarowsky & Levitt, 2018; Benatar, 2013) conducted in South Africa have also noted leadership deficiencies and the fragmentation of public healthcare services. A study conducted in Gauteng revealed that roughly 75% of randomly selected participants said they were no longer using public healthcare services because they felt the quality had decreased.

Health workforce

One of the main issues leading to unequal healthcare services was the discrepancy in the distribution of qualified health professionals (Furlanetto, Pinho, & Parreira, 2015). An Ethiopian study found that in order to speed up healthcare reform initiatives, a dedicated and driven health personnel was required (Manyazewal, Oosthuizen, & Matlakala, 2016). An additional study conducted in Ethiopia revealed that job discontent and low motivation among public healthcare employees at public hospitals could have an effect on the health system as a whole. Raising skill levels as a result of receiving high-quality training raises the standard of care, which raises the health system's efficacy (Manyazewal & Matlakala, 2017). Malakoane et al. (2020), discovered in South Africa that while the burden of sickness was increasing, the number of health professionals was dropping in the Free State. This showed that the health system needs to be strengthened in terms of HRH in order to deliver healthcare services to the public.

Information

To generate, store, and distribute health information within healthcare systems, such as electronic patient records, clinical databases, financial and administrative systems, a variety of tools and know-how are available in the field of health information technology. Nevertheless, operational issues with DHIS2 were found after a study and meta-synthesis of 20 research conducted in 11 different countries (Ngafeeson, 2015). These issues included inadequate money and HRH, unfulfilled training needs, incorrect data, inadequate data security, and inadequate stakeholder communications (Dehnavieh, Haghdoost, Khosravi, Hoseinabadi, Rahimi, Poursheikhali, & Aghamohamadi, 2019). According to reports from stakeholders in South Africa, Malakoane et al. (2020) found that the necessary computer hardware and DHIS software were frequently not appropriately provided at the local level. When patient records were kept manually, there were file losses, duplications, and lengthy wait periods for patients. The process of looking for files for follow-up visits was laborious and often led to the opening of new files when the old ones could not be located. Because there was a shortage of computer gear and connectivity, the manual process of recording patient prescriptions for medications at clinic pharmacies and medicine stock was also necessary.

A thorough examination of the healthcare landscape revealed additional challenges, such as those relating to money, infrastructure, knowledge and research evidence, human skills and development, leadership and governance, security and interoperability, and sociocultural and technological environments. Before creating or implementing any m-health or e-health systems in developing nations, these factors must be taken into account.

Uma and Herselman (2009), conducted a case study on how five rural hospitals in Kenya adapted to the shift in technology. The researchers looked at the advantages of using ICT infrastructure and e-health as well as the difficulties that hospitals in developing nations faced in using ICT technologies. The findings show that due to a number of issues, the ICT infrastructure already in existence is insufficient for e-health initiatives. Consequently, Ouma and Herselman (2009) have proposed the model in Figure 2.1 as a way to give suggestions on how to address the numerous difficulties.

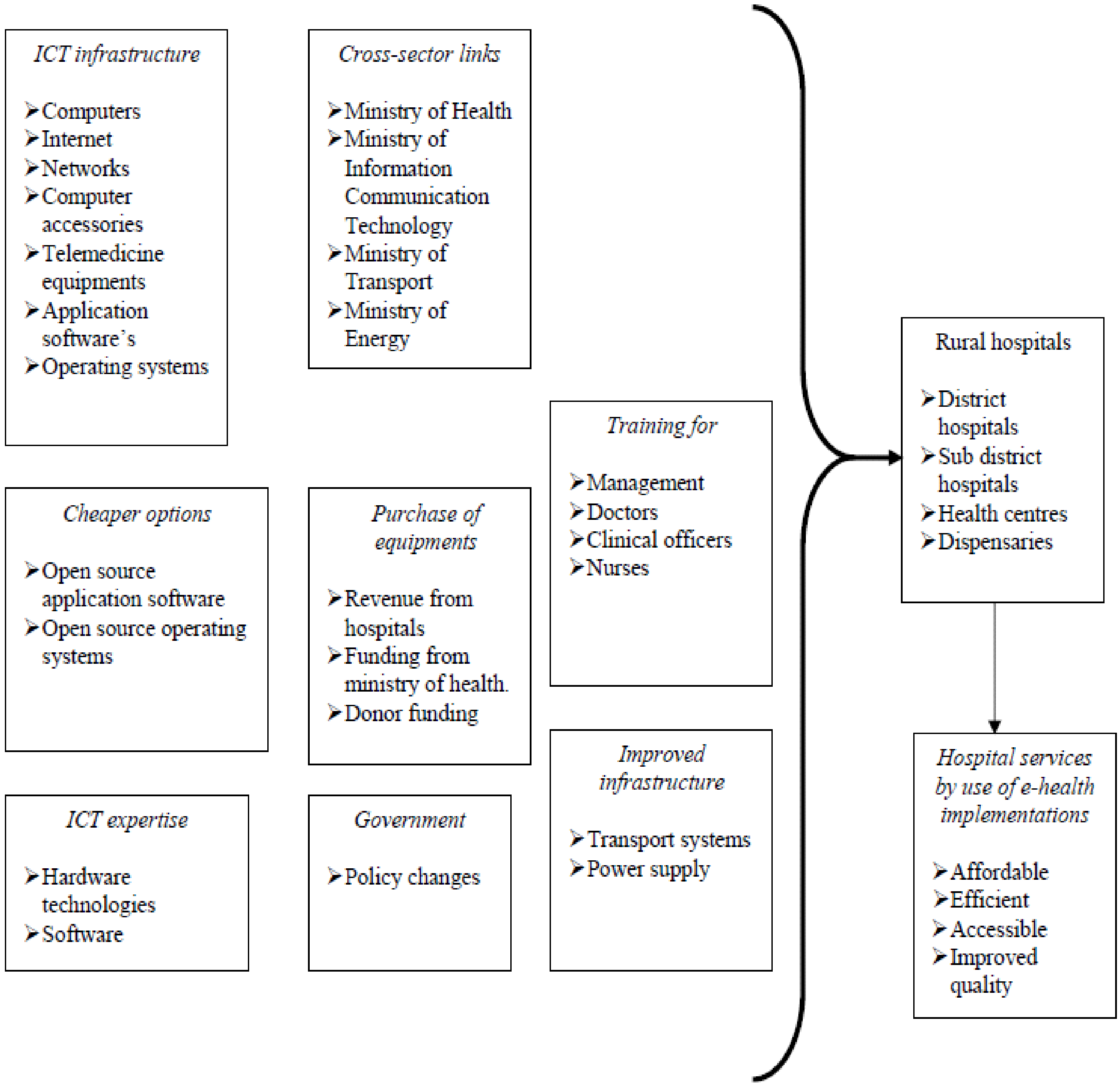

Figure 2.1 Proposed model for rural areas (Ouma and Herselman, 2009)

2.1.3 Healthcare Data and Benefits of Knowledge Management

The development and maintenance of organisations depend heavily on knowledge management (Kashyap & Piersson, 2018). According to research, companies can only reap the benefits of knowledge management if they make technological investments in addition to highlighting and supporting other organisational components like culture and management (Salloum, Al-Emran & Shaalan, 2018; Salloum, Al-Emran & Shaalan, 2017; Mouzaek, Alaali, Salloum, & Aburayya, 2021).

While knowledge management (KM) systems use information technology (IT) to manage the creation, storage, sharing, and use or reuse of knowledge, Sharma (2016) notes that the healthcare industry poses unique challenges to the application of KM, including system complexity, the impact of medical errors, the significant growth in medical knowledge, and rising healthcare costs. According to Anderson and Mcdaniel (2000), Reinhardt, Hussey, and Anderson (2004), and Orr and Sankaran (2007), as referenced by Sharma (2016), the healthcare system is one of the most complex systems in society since it contains dynamic professionals who collaborate to provide care to humans.

Semantic Web technology is a huge success for knowledge management (KM) solutions since KM approaches and solutions have demonstrated the advantages of ontologies and related techniques. Since high level representation of knowledge using ontologies enables strong searches and knowledge modification, retrieval, and discovery, many knowledge management frameworks are built on top of them (Buranarach, Supnithi and Chalortham, 2010; Morr and Subercaze, 2014; Hasoneh, 2018).

A logic-oriented architecture called the Healthcare Semantic Web is used to connect and represent diverse information resources. There are several ways to acquire information about healthcare: explicit, experiential, and tacit (Abidi and Helen Chen, 2006). Using the Semantic Web and mining technologies, like Web Ontology Language (OWL) and Resource Description Framework (RDF), to structure and describe information sources, like symptoms, diseases, genes, disease locations, and other medical procedures, has the following advantages:

Medical Error Reduction

According to Hussain and Abidi (2009), KM can help reduce medical errors and their associated costs by giving practitioners choice support. To achieve this goal, case-based reasoning, rule-based reasoning, and/or the semantic web and mining in the healthcare industry can be applied (Jain, Jain, Bhojak, Bhilwar and Mamatha, 2012; Veterinary, Akter, Veterinary and Modelling, 2018). Medical mistake reduction has already been acknowledged as a benefit of knowledge management (KM) and the Semantic Web (Wang, Zhou, Tian, Qian, and Li, 2014).

Cooperation and Innovation

To offer high-quality care in a complicated industry like healthcare, collaboration between the many healthcare providers is essential (Morr and Subercaze 2014; Sinyegwe 2014). Coordinated inter-professional care strategies are necessary because research (Vahidi, Mirhashemi, Noorbakhsh, & Taleghani, 2018; Elhauge, 2010) has demonstrated that a lack of collaboration in the healthcare system is a major contributor to many medical errors. Therefore, by implementing KM systems, healthcare actors can achieve joint diagnosis.

In addition to collaboration, there exists an opportunity for innovation, which has been acknowledged by scholars and led to the establishment of knowledge-sharing networks (Sharma, 2016). Additionally, as the health industry is driven by innovation, it is critical to manage clinical knowledge (Buchan, 1997) employing paradigms like distributed knowledge management (Mogens Kühn Pedersen and Larsen, 2001). Ultimately, collaboration and creativity depend on identifying knowledge-sharing channels and the organisational elements that shape them (Donaldson, Lank, and Maher, 2005; Currie & Suhomlinova, 2006).

Quality of Care

One of the main objectives of all health research is to increase the quality of care; therefore, finding, collaborating with, and developing the expertise of clinicians is essential to discovering and improving information exchange and, consequently, the quality of care. Strategies for knowledge management (KM) have been shown to enhance treatment quality (Sibte and Abidi, 2001; Morr, 2010; Akachi & Kruk, 2017; Bombard, Baker, Orlando, Fancott, Bhatia, Casalino, & Pomey, 2018).

Cost Reduction

Collaboration influences the quality of care, which is thought to be the primary goal of providing healthcare, but it also affects costs because it makes knowledge sharing possible. The goal of local health information agencies, according to Lamont (2007), is to "increase cost-effective use of health resources by sharing information among a coalition of providers, payers, employers, and other stakeholders" (Driver, 2001; Firestone and Mcelroy, 2005; Lamont, 2007; Tortorella, Fogliatto, Espôsto, Mac Cawley, Vassolo, Tlapa, & Narayanamurthy, 2022; Guzman, Gitelis, Linn, Ujiki, Waskerwitz, Umanskiy, & Muldoon, 2015).

Error reduction is another benefit of KM-based decision-making. The high cost of medical errors has also occasionally served as a driving force behind the implementation of knowledge management (KM) in the healthcare industry (Firestone and Mcelroy, 2005). KM will remain a clear benefit that has not yet been completely investigated in this setting (EARDLEY & KAMALANATHAN, 2015; Olasunkanmi, Adu, & Apena, 2019).

Knowledge Organization and Organizational Learning

The day-to-day operations of the health organisation, for administrators as well as professionals, heavily rely on knowledge. This includes organisational structure and leadership, financial management, risk management, quality management, information management, and organisational structure and planning (Garman, Burkhart and Strong, 2006; Olasunkanmi, Adu, & Apena, 2019; Evans, Brown, & Baker, 2017). It is the primary source of information that practitioners need to practise appropriately. According to Choudhry, Fletcher, and Soumerai's (2005) systematic review, practitioners' understanding is not constant and varies with time. This is evident in the correlations between clinical experience and quality of care. "Physicians who have been in practice longer may be at risk of providing lower-quality care," stated Choudhry et al. (2005). As a result, knowledge management (KM) becomes essential to guaranteeing practitioners' use of evidence-based practice and managers' organisational development.

Understanding (1) knowledge creation and transfer, (2) knowledge demands, (3) responsibilities of healthcare professionals, (4) information seeking behaviour, (5) knowledge organisation, and (6) knowledge sharing behaviour are crucial for utilising knowledge management. Understanding the creation and transmission of information is crucial for making use of it (Chen-Wei Yang, Huang, S.R. and Yang, Fang, 2007; Bate Robert, 2002; Ansell, 2007).

However, information that cannot be acquired is useless. Therefore, it should be recognised in order to make healthcare knowledge more accessible. It should also be recognised in order to identify healthcare professionals' knowledge demands (Burnett, Williams, 2005), roles in knowledge management (KM), and information-seeking behaviours (Dawes M., 2003).

Ultimately, knowledge management's ultimate objective is to transform a health organisation into a learning organisation capable of producing new information, creating knowledge systems, and using knowledge to inform organisational decisions (Sharma, 2016) Understanding information is necessary for organisational learning (Driver, 2001; Sharma, 2016). Other strategies that support organisational learning include the use of organisational memory (Sibte and Abidi, 2001; Lahaie, 2005), which facilitates concept sharing and organisation among community members to support collaborative work, and knowledge environments like Healthcare Enterprise Memory, which Sibte and Abidi (2001) proposed. In order to address language and cultural variations in the learning organisation, knowledge management (KM) may be used in terminology translation in a multicultural, multilingual, and international integrated healthcare team. This is important to ensure that cooperation occurs clearly (Kisilowska, 2006).

2.1.4 The Electronic Health (E-Health) System

The World Health Organisation describes eHealth as the application of information and communication technologies (ICTs) to health in order to monitor public health, treat patients, conduct research, teach students, and track diseases. This concise definition encompasses a wide range of topics, including: "Routine health management information (e.g., web-based surveillance systems, electronic disease registers, electronic district healthcare information systems), Electronic health records (allowing for the sharing of patient data between points of care), Healthcare knowledge management (KM) (e.g., best practice guidelines managed and accessed electronically), mHealth (e.g., use of mobile devices such as cell phones to share information or to collect aggregate or patient data), Telemedicine (e.g., use of ICTs to provide care at a distance), Virtual healthcare (e.g., teams of professionals working together via ICTs), and Vital registration (the use of computerised systems for registration of deaths or births) (e.g., use of high-performance computing to handle large volumes of data)" (National Department of Health, 2016, p. 7; De Pietro & Francetic, 2018; Katurura, & Cilliers, 2018).

2.1.4.1 Benefits of e-Health

Through electronic patient record sharing, remote patient monitoring, and remote diagnosis, e-Health is thought to help lower healthcare costs and alleviate the shortage of medical professionals (Ouma and Herselman, 2009; Mmamolefe, Kgasi and Kalema, 2014; Fanta, 2015).

WHO and ITU (2012), as quoted by Fanta (2015), state that e-Health solutions were introduced to address some of the healthcare challenges in both developed and developing countries. Fanta (2015) also emphasises that although the healthcare industry is information-intensive, e-Health systems are thought to be helpful in raising the standard of care by offering current patient data. According to WHO and ITU (2012), the following are some of the advantages of e-Health systems:

- Better access to medical treatment, particularly in isolated and rural areas without access to medical professionals
- Better quality and safety in healthcare services;
- More efficiency in the delivery of healthcare

- Better health information and education accessibility;
- enhanced healthcare monitoring and reporting

2.2 State of the Art: Towards the Utilization of Semantic Web in Evidence-Based Healthcare Medicine and Clinical Guidelines

An improvement on the current Web, the Semantic Web allows machines and humans to collaborate more effectively by giving information a clear meaning. It is a network of data that machines may process both directly and indirectly. (Denaux et al., 2011; Orlandi and Passant, 2011a; Zolhavarieh, Parry, & Bai, 2017; Berners-Lee, Hendler, and Lassila, 2001).

This portion of the study goes into detail on how the Semantic Web can be used to integrate evidence-based healthcare through the use of ontology. It also demonstrates how an ontological approach can be used to revisit the conceptual underpinnings of EBM and to enable more efficient knowledge-based information retrieval in the literature.

Berners-Lee (2001), the man who created the World Wide Web, believes that one day computers will be able to do more than just display content from the Web.

2.2.1 Semantic Web Technology Stack

The evolution of Semantic Web technologies is illustrated in figure 2.2. The Semantic Web technological architecture consists of a number of technologies to achieve its objectives. A subset of the technologies (URI/IRI, XML, RDF, RDFS, OWL, SPARQL, RESOURCES, and a few more) are used by the majority of applications, as seen in figure 2.2 as components of the stack. The following cutting-edge and significant Semantic Web technologies are covered:

Resource

"Anything that has an identity, be it a retrievable digital entity (such as an electronic document, an image, or a service), a physical entity (such as a book), or a collection of other resources" is what Allemang and Hendler (2011, p. 338) define as a resource.

Uniform Resource Identifier

A character string known as a Uniform Resource Identifier (URI) is used to identify physical or abstract resources on the Web (Yu, 2011; Abraham and Araya, 2013; Kumar and Dwivedi, 2014).

Extensible Markup Language (XML)

An arbitrary data can be stored, sent, and rebuilt using the file format and markup language known as Extensible Markup Language. It specifies a set of guidelines for document encoding in a machine- and human-readable format (Abraham and Araya, 2013; Malhotra, Younesia, Gundel, Muller, Henekac and Hofmann-Apitius, 2014; Ziminski and Demurjian, 2016).

Resource Description Framework

The Resource Description Framework (RDF) is a general framework for expressing linked data on the internet. RDF statements are used to describe and exchange metadata, allowing for standardised data sharing based on relationships. RDF is used to combine data from several sources (Decker, Mitra and Melnik, 2000; Hogan, Umbrich, Harth, Cyganiak, Polleres and Decker, 2012b; Jain and Singh, 2013; Dia, Togbe, Boly, Kasi-Aoul, & Metais, 2018).

The Web Ontology Language (OWL)

The World Wide Web Consortium's Web Ontology Language (OWL) is a Semantic Web language meant to convey rich and sophisticated knowledge about things, groups of things, and relationships between things. OWL is a computational logic-based language, which means that knowledge stated in OWL may be used by computer programmes to check consistency or make implicit knowledge explicit. Ontologies, which are OWL documents, can be published on the World Wide Web and may refer to or be referenced to by other OWL ontologies. OWL is a component of the W3C's Semantic Web technology stack, which also includes RDF, RDFS, SPARQL, and others (Espinoza-Arias, Garijo, & Corcho, 2020; Hogan & Hogan, 2020).

Simple Knowledge Organization System (SKOS)

Knowledge organisation systems (KOS) such as thesauri, categorization schemes, subject heading systems, and taxonomies can be used within the Semantic Web architecture. SKOS is the field of work that develops specifications and standards to allow this use. SKOS offers a standardised method for leveraging the Resource Description Framework (RDF) to define knowledge organisation systems. This data can be sent between computer programmes in an interoperable manner by encoding it in RDF. RDF also makes it possible to apply knowledge organisation systems in decentralised, distributed metadata applications. Decentralised metadata is more commonplace in situations where service providers aim to enhance metadata gathered from many sources (Smith, 2022; Zeng, & Mayr, 2019).

SPARQL (Simple Protocol and RDF Query Language)

SPARQL Protocol and RDF Query Language (SPARQL) is a query language for searching triplestores. It converts graph data into tabular data with rows and columns. Consider a SPARQL query to be a Mad Lib—a series of sentences with blanks in them. The database will use this query to discover every set of matched statements that fill in the blanks correctly. The capacity to build complicated queries that reference several variables at once is what makes SPARQL so powerful (Wang, Wang, Liu, Chen, Zhang, & Qi, 2018).

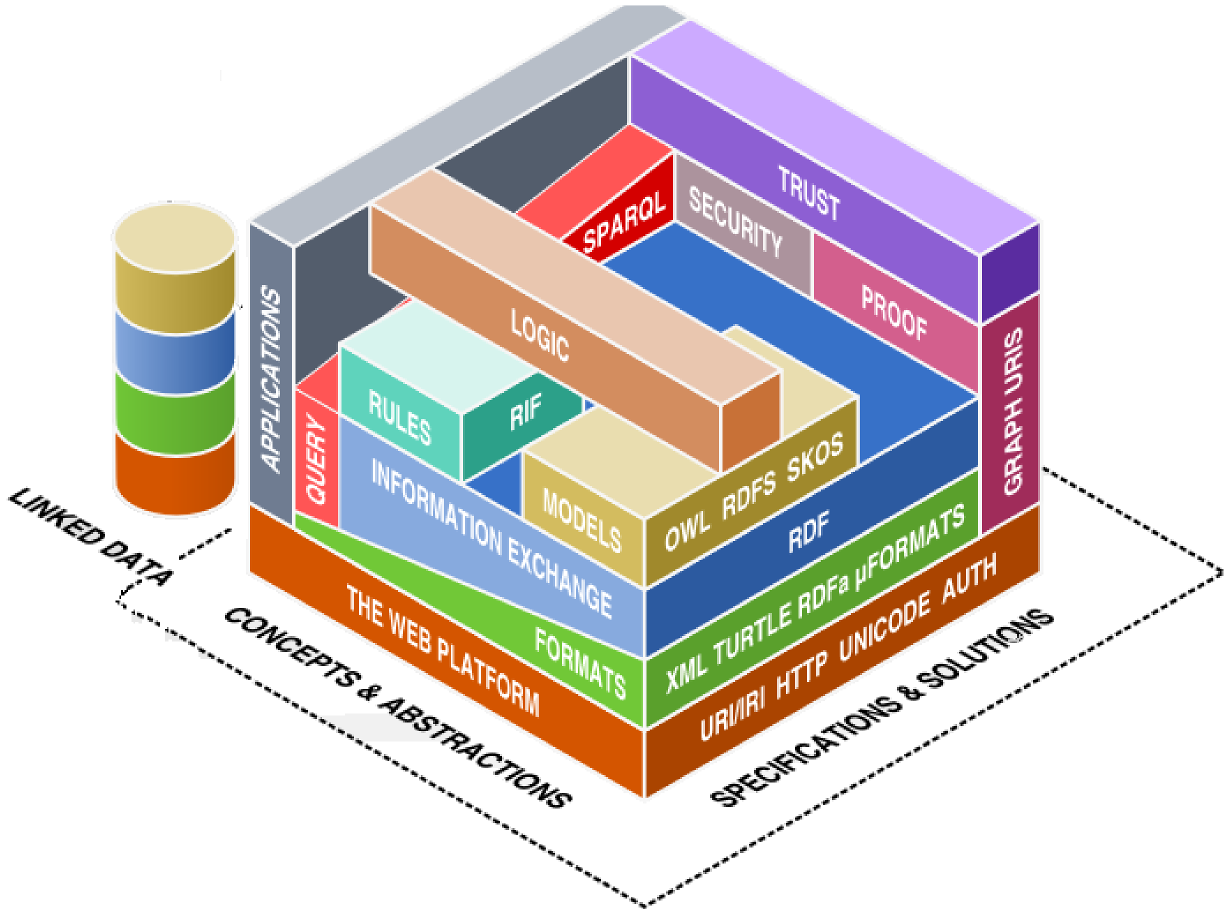

Figure 2.2: The Semantic Web Technology Stack (Cardillo, 2011, p. 41)

2.2.2 Overview of Semantic Web of Evidence-Based Medical Information

Based on an integrated Web-based ontology on EBM that is currently incorporated into the RDF/RDFS framework, the facilitation of integrated information from distributed and heterogeneous sources is detailed. Healthcare professionals must navigate a quickly evolving, unstructured, and qualitatively diverse knowledge environment in order to get the data they need to make decisions. In order to stay current with important medical publications, healthcare providers are reportedly need to review 19 articles every day (Pisanelli, Zaccagnini, Capurso and Koch, 2003; Grütter and Eikemeier, 2016; Veterinary, Akter, Veterinary and Modelling, 2018). According to Pisanelli et al. (2003), a new paradigm has arisen to guarantee the calibre of knowledge reported in literature and, eventually, to lessen the "noise" of less relevant publications. Healthcare practitioners are more inclined to accept clinical research based on this method in their practice, as this paradigm revolves around the idea of "best evidence."

Therefore, choosing and using the evidence is a continuous process that doctors who are looking for crucial clinical data on diagnosis, therapy, prognosis, and other clinical difficulties engage in throughout their lives. Clinical entropy, unjustifiable variability, and quality standards between healthcare providers should all be restricted by clinical assumptions based on "evidence" (Pisanelli, Zaccagnini, Capurso and Koch, 2003; Huang, Teije and Harmelen, 2017).

Huang et al. (2017) created RDF-based terminologies (a lightweight ontology) to express clinical evidences in order to meet the evidence-orientation criterion. These concepts can then be utilised to describe different types of evidence information in clinical guidelines.

The following sections make up the semantic representation of evidence-based clinical guidelines:

- Heading. The guidelines' heading section gives a brief summary of the data, including the provenance, version number, published date, and title.
- Body. The primary explanation of the recommendations and the supporting data are given in the body portion of the document. A collection of guideline items, or evidence-based guideline statements, with the supporting documentation and RDF/OWL representations for each guideline statement are included in the body section.

    - Evidence description. It offers the official evidence description, including the evidence level and references, using the Dublin core format—the industry standard for metadata representation of publications.
    - Guideline description. Using Semantic Web technologies, like RDF and OWL, to structure and represent information sources, like symptoms,

diseases, genes, geographical locations of diseases, and other medical procedural information, is a novel and promising approach. It gives the RDF/OWL description of the guideline statement.

Healthcare professionals from different countries can share XML-based ontologies and exchange information by using semantic web technology. By relying on semantic-based information, they can also more easily access the knowledge and information needed to effectively prescribe medications and medical procedures to prevent and/or treat dangerous diseases, as well as to recommend affordable medical options to patients. Semantic Web technologies can be used to structure this type of data in a way that makes it easier for machines to understand and interpret. If this is done correctly, the ontology can then be put into an inference engine to efficiently apply new findings to patient treatment protocols or other healthcare-related operations.

2.3 Semantic Web/Web 3.0 in Healthcare

According to Aziz and Madani (2015), Web 2.0 applications in healthcare have been extensively adopted by numerous online health-related professionals and healthcare organisations due to its ability to facilitate easy cooperation and strong information exchange. Web 2.0 is typically connected with information sharing, interoperability, and collaborative technologies on the WWW such blogs, wikis, Facebook, and podcasts. According to Kuehne, Blinn, Rosenkranz, and Nuettgens (2011), "Health 2.0, considered as the increasing use of Web 2.0 technologies and tools in electronic healthcare, promises new ways of interaction, communication, and participation for healthcare." The following crucial areas of healthcare—diagnosis, treatment, and prevention—are where Health 2.0 may help to improve patient safety. Eysenbach (2008) claims that a plethora of applications are accessible with Health 2.0 to track patients' health issues and assist patients and healthcare providers. For further details, refer to figure 2.3, which discusses the Medicine 2.0 Map and includes a few examples of modern sample apps and services.

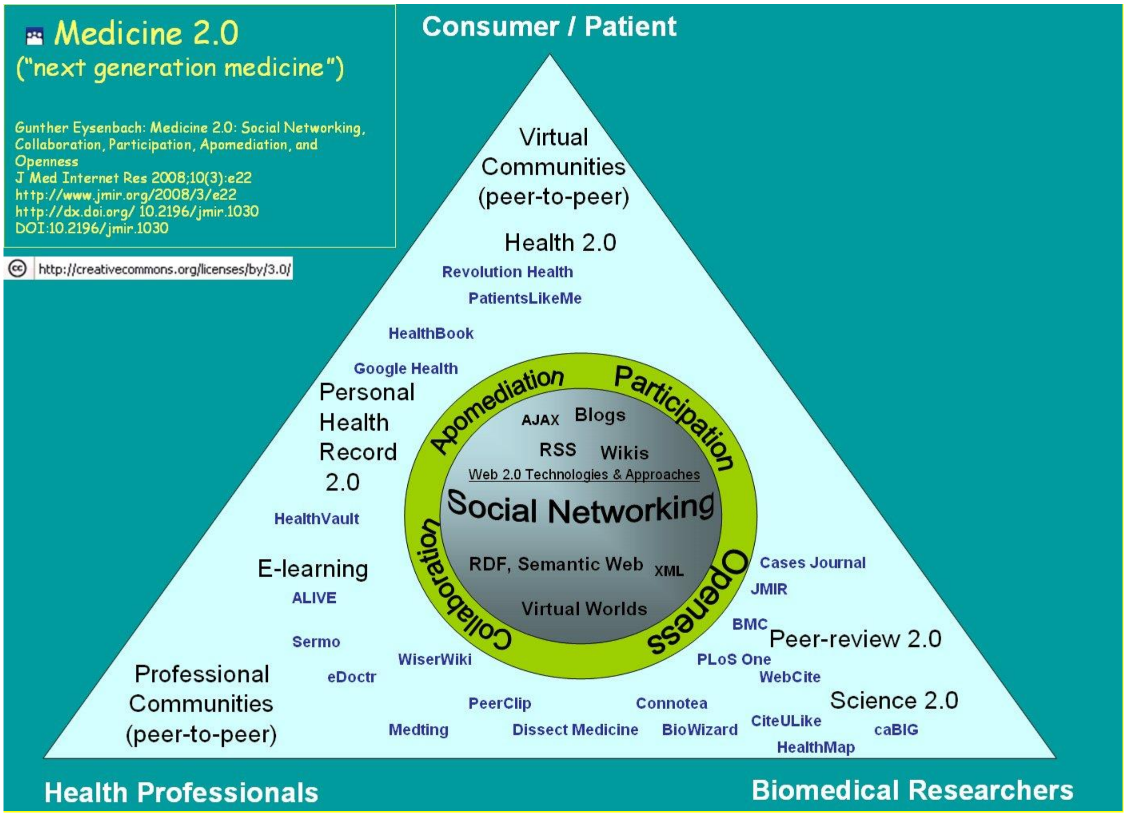

Figure 2.3: Medicine 2.0 Map (Eysenbach, 2008, p. 4)

Some examples of the adaptation of Web 2.0 tools in healthcare as listed by (Aziz and Madani, 2015):

• HealthMap: Using RSS feeds integrated with Google Earth, the programme gathers data to investigate outbreaks of various conditions.

• SecondLife: Online patients can go to a health information island to get actual medical advice regarding illnesses and ailments from actual doctors.

• Flu Wiki: By keeping an eye on the transmission of influenza infections, local public health officials can plan ahead for epidemics and outbreaks. Physicians' online habits are changing as a result of Web 2.0's unorganised information accessibility, leading to improved methods for information retrieval.

According to Aghaei, Nematbakhsh, and Farsani (2012), "Web 3.0," sometimes referred to as the Semantic Web, would use metadata—data about data—to allow computers to speak with one another, enabling increased connectedness between data and its applications. Metadata will become a massive database thanks to Web 3.0, which will then organise it into more relevant information. The idea of Web 3.0 "will be an important challenge for the doctors in healthcare organisations, since greater personalisation and the treatment of patients' health problems is relying on the usage of the latest technologies," according to Aziz and Madani (2015, p. 5). The cost of medical care will go down as a result of employing this method and giving patients access to search for health information. For instance, the integration of epidemiological records with Google Earth's three-dimensional functionality can offer a warning system for emerging diseases and natural disasters.

Moreover, Health 3.0 is a health-related extension of the concept of Web 3.0, whereby the users' interaction with the data and information available on the web is personalised to optimise their experience (Ilioudi, Lazakidou, Glezakos and Tsironi, 2012; Wikipedia, 2019). According to Wikipedia (2019), the primary objective of Health 3.0 is "Digital Healing," which entails patients using social media to get validation, confidence, and support from others. Web 3.0 is being applied in medicine and healthcare, as evidenced by the Cochrane Library and PubMed, two reliable resources in health informatics. Wikiproteins compile genetic data, and scientific literature has embraced Semantic Web technologies as the sole means of importing data from various sources, including PubMed and the National Library of Medicine (Aziz and Madani 2015; Mons et al., 2008).

According to Almaida (2017), Web 4.0 is linked to "automatic reasoning, sustained by the advances in AI and the large-scale use of linked agents." "WebView" is a new Web 4.0 application that allows for quick reviews of patient reports and photographs from system software using any HTML5 web browser (Aziz and Madani, 2015). A well-designed reporting system for radiology, obstetrics, cardiology, and gynaecology as well as voice recognition software and electronic health records, hospital information systems, and laboratory information systems could all be integrated into this application (Choudhury, 2014; Aziz and Madani, 2015; Lowry, Ramaiah, Patterson, Brick, Gibbons and Paul, 2015). It will also offer sophisticated clinical image management. A robust Picture Archive and Communication System (PACS) imaging archive, excellent imaging review workstations, an integrated clinical database, thorough analysis, and reporting are all features of this application's reporting system (Aziz and Madani, 2015). Figure 2.4 illustrates how a distributed system will be used to actualize Web 3.0 improvements in the healthcare industry. Since each node has the ability to keep a duplicate of the data, there is no centralization in any area of the network. Node instructs other nodes on what to do. Rather, each node has the ability to validate all data, meaning that it can verify any information that has been previously entered into the network or application by any user. This development is extremely complex technically. For example, all nodes on the network have complete access to the data even if one of them is offline.

All of the aforementioned components—Science, Technology, and Compassion—will interact with the Web. To provide evidence-based healthcare, it shouldn't be or, since the Web ought to be conscious of how people think and feel. This will affect how healthcare treatments turn out. It will be the most disruptive phase of the Web's evolution, with enormous effects.

Compassion + Science + Technology

Figure 2.4: Decentralised nodes in Web 3.0. Source: computes.com

Table 2.2: The advantages and disadvantages of Web 3.0 (Benjatikul, 2014)

Advantages	Disadvantages
The integration known as web 3.0 might be considered the most recent developments in artificial intelligence.	There aren't many PCs that can support Web 3.0.
Web 3.0 leverages user behaviour, mashups, semantic web, and widgets to focus on the individual user.	Web 3.0 will shortly be dropped.

Web 3.0 uses data web technologies to pull reusable and publishable data records as XML and RDF.	The web 3.0 requires current technology, which is not yet ready.
Web 3.0 is a step towards a fully semantic web, allowing for improved application operations, data integrations, and links across online sites.	Too complicated
The application of technology in web 3.0 is demonstrated by the prediction of hit songs based on music web sites, since it focuses on the interaction of people in an organic manner.	The government invests heavily in the development of Web 3.0.

examples of case studies already in existence where academics have made an effort to create and develop healthcare-related Web-enabled solutions. This demonstrates the value and advantages of an entirely automated and integrated healthcare system for effective community service delivery.

2.3.1 Case example 1

Open Services Lifecycle Collaboration framework based on Linked Data

IBM's Rational Group combines a suite of software and distributed commercial solutions using this technology by employing Linked Data as an architectural style. The group was able to address difficulties that were previously challenging to handle with other architectural styles of software integration that they had previously researched thanks to the read/write functionality of linked data. Although other classes, like IBM Tivoli, follow suit in areas like Integrated Service Management (ISM), the IBM Rational technologies are mostly implemented in the Application Lifecycle Management (ALM) arena. It is anticipated that knowledge obtained from reading and writing linked data will be highly significant and useful in the IT sector for resolving system integration issues. Linked Data, as defined by Tim Berners-Lee, is founded on the same concepts that made the WWW so popular. It functions using resource formats and protocols as opposed to various application interfaces. Hypertext transfer protocol (HTTP) or hypertext manipulation language (HTML) is used in a web of pages. Linked Data employs RDF and HTTP. Both make use of universal resource identifiers (URIs) to identify resources that make it simple to express any kind of relationship between resources, regardless of their domain. When considering Application Lifecycle Management (ALM) domain integration, applying linked data requires considering certain domain resources, such as requirements, problems and areas for improvement, and access to these resources instead of tools. With the IBM design, the tools became the primary notion rather than the applications. Their architecture was redesigned with a collection of resources from several application domains as the focal point, with apps acting as mere handlers of HTTP requests for those services. The different resource categories required and their relationships are modelled in this study using RDF. As a result, a modification request becomes an exposed asset in the form of an RDF that can be linked to the issue that has to be fixed and a check that can be used to confirm the intended change. The concepts of Linked Data allow change management, defect management, and test management programmes to access resources directly rather than connecting to one another through several interfaces.

Key Benefits of Using Semantic Web Technology

The benefits of Semantic Web technology are as follows:

- RDF provides a data model that is very flexible, enables interoperability and extensibility.
- Following the basic principles of the WWW, Linked Data enjoys the same characteristics that is, distributed, scalable, reliable, extensible, simple, and equitable.
- RDF provides a foundation for rich capabilities such as impact analysis, reporting, and deep querying across multiple domains.

2.3.2 Case example 2

The research team in this case study presented a knowledge-based public health awareness system and illustrated the value of knowledge-intensive approaches in integrating heterogeneous data, mitigating the effects of syndrome uncertainty, aberration detection, and incomplete and low-quality surveillance data, and visualising complex information structures in the public sector. A concise explanation of the fundamental ideas and connections in public health's comprehension of the circumstance serves as the foundation for this approach. This representation is based on the mental model of global consumers, or decision-makers in public health, and is designed to be relevant to the processes and actions involved in comprehending the state of public health. It is also optimised for performance effectiveness. In order to describe domain expert knowledge in machine-interpretable and computable problem-solving modules that can then guide users and computer systems in screening and investigating the root cause of the event through the most appropriate syndrome and outbreak data, the system uses the RDF and additional layers of more concise languages. In contrast to conventional frameworks, which base procedures on statistical approaches, the methodology bases the analysis of public health data on specialised domain expertise.

Preliminary data from this initiative show enhanced results in cross-domain investigation of the underlying causes of public health events, identification of the syndrome and aberration, information visualisation for information access, and information integration (Mirhaji, Richesson, Richesson and Turley, 2004).

2.3.3 Case Example 3

Public health situation awareness: toward a semantic approach

Innovations in commercial semantics are addressing the fundamental issues in the healthcare and life sciences (HCLS). In research and clinical contexts, as well as in production environments for data access, interpretation, semantic incorporation, analysis, and testing, semantic tools and related implementation and evaluation methodologies are frequently utilised to create findings for personalised medicine. The framework for interoperable semantic software is built on W3C standards such as the RDF and OWL. While many essential data storage and access requirements can be met by traditional approaches to relational data storage and federation, these approaches frequently fall short when faced with dynamic changes and the innate complexity of data integration requirements for high-throughput learning and science (HCLS) research. Semantic integration techniques guarantee uniformity, harmonise diverse terminologies and synonyms, and offer broad, adaptable platforms for data integration as well as an interactive knowledge base for pertinent network analysis. The article describes how to effectively incorporate information from all sources—experimental, internal, external, medical, and public—using a novel semantic strategy. Predictive functional biology-based decision support for complex translation research and personalised medicine applications can benefit from the ensuing visual exploration of the integrated graphic environment and the creation of distinctive marker patterns or molecular signatures (Stanley, Mcmanus, Ng, Gombocz, Eshleman and Rockey, 2011).

2.3.4 Case Example 4

Composing a Safer Drug Regimen for each Patient with Semantic Web Technologies

Together with signs and symptoms, the research and design team has created an ontology of medical disorders that is patient-friendly in terms of language and how it arranges and retrieves terms and concepts. The structured and interoperable structure of this ontology is made possible by the semantic web languages RDF and OWL, which facilitate collaborative production, maintenance, and access from a wide range of applications. The goal of the effort is to bring together payers, researchers, pharmaceutical companies, physicians, chemists, and clinicians in a cooperative network. In order to enable data accessibility in a way that is both useable and meaningful across these diverse subcommunities, it is crucial that the information made available through Semantic Web technologies fulfils the necessary requirements (Schweber, 2007). Shared access is made possible through XML serialisations of RDF(S) and OWL that employ web-centric resource identifiers, and shared meaning is enabled by the formal semantics of these ontological languages.

2.3.5 Case Example 5

HCLS 2.0/3.0: Health care and life sciences data mashup using Web 2.0/3.0

Data mashup in the domains of HCLS is possible thanks to Web 2.0 advancements; compare this possibility with the growing popularity of semantic mashup outcomes. Two examples of data mashups are displayed. The Web 2.0 tools and websites Yahoo! Pipes, Dapper, Google Maps, and GeoCommons are made possible. In the initial setup for DNA microarray research, Dapper and Yahoo! Pipes were utilised to accomplish a difficult data integration task. In the second setup, a geographic information system (GIS) interface was created using Yahoo! Pipes, Google Maps, and GeoCommons to enable the integration and visualisation of many public health data categories, such as cancer incidence and pollution prevalence. On the other hand, was Semantic Web, the mainstream Web 3.0 technology that enables more powerful web-based data integration to provide useful benefits to HCLS research through this combination (Cheung, Yip, Townsend and Scotch, 2008).

2.3.6 Case Example 6

SemanticDB: A Semantic Web Infrastructure for Clinical Research and Quality Reporting

Semantic Web technologies have the potential to transform healthcare data management by boosting interoperability and reusability while minimising the need for duplicate data collection and storage. Cleveland Clinic financed a programme to investigate and improve this skill from 1998 to 2010. SemanticDB, the result of this endeavour, is a set of software tools and information resources meant to enable the collecting, storage, and use of the diverse data required for clinical research and health-care quality reporting. SemanticDB comprises three primary parts: 1) a repository for information fueled by a meta-model which enables the handling and integration of information in XML format and converts data to RDF automatically; 2) an inferential, natural language query interface designed to identify patients who meet specific inclusion and exclusion criteria; and 3) a data development pipeline using inferences. The Cleveland Clinic's Heart and Vascular Institute has been using this system since 2008 to support a variety of clinical investigations. In 2009, the Cleveland Clinic received authorization to submit data generated by this system to national quality control databases that are funded by the American College of Cardiology and the Society of Thoracic Surgeons (D. Pierce, Booth, Ogbuji, Deaton, Blackstone and Lenat, 2012).

2.3.7 Case Example 7

Semantic web for integrated network analysis in biomedicine

A survey was carried out to evaluate the practicality and cutting edge application of Semantic Web technology for knowledge reflection, integration, and analysis across diverse biomedical networks. The study offers a novel conceptual framework—semantic graph mining—that enables researchers to use ontology reasoning to graph mining in network data analysis. Semantic graph mining can be used to analyse disease-caused genes, cross-talks in the Gene Ontology category, drug effectiveness, and herb-drug interactions, as demonstrated in four case studies (Chen, Ding, Wu, Yu, Dhanapalan and Chen, 2009).

2.3.8 Ontologies

The Semantic Web Ontologies are data topologies that offer a regulated vocabulary of ideas, each with a semantics that is machine-processable and well specified (Sadeghineko & Kumar, 2022; Zamazal, 2020). The primary uses of ontologies are in the systematic classification of knowledge-related vocabulary, the property-based definition of vocabulary relations, and the ability to provide a hierarchical explanation of the meaning of vocabulary and relations. The primary goal of developing an ontology is to facilitate clear communication between individuals, groups, and software systems (Sadeghineko & Kumar, 2022; Zamazal, 2020; Rhayem, Mhiri, & Gargouri, 2020).

2.3.8.1 Types of Ontologies

Ontologies can be classified based on the domain they represent or the degree of detail of knowledge they offer (Bodenreider & Burgun (2005). Ontologies were categorised into the following groups by Bodenreider & Burgun (2005):

General Ontologies

Intermediate-level detail knowledge is represented by this type of ontology. The top tiers of this type of ontology typically reflect conceptions of space and time and offer ideas to which all concepts in ontologies currently in use are inevitably related (Fernández-López, Gómez-Pérez, & Suárez-Figueroa, 2013).

Domain Ontologies

Through a theory of the domain it represents, this type of ontology reflects knowledge about a specific area of the universe of knowledge as well as the underlying reality. For instance, the domain ontology can only concentrate on medical information (McDaniel, & Storey, 2019).

In some fields, ontologies have been employed as a source of knowledge; two examples are the Unified Medical Language System (UMLS) and Medical Subject Headings (MeSH). Medical ontology knowledge bases like UMLS and MeSH are designed to aid medical information systems in comprehending the meanings of terminology, concepts, and relationships in the biomedical and health domain (Jing, 2021; Brody, 2020).

2.4 Integration of Heterogeneous Health Data Using Semantic Web

The Semantic Web is expected to bring several benefits to the healthcare industry, including the ability to assemble heterogeneous data using clear semantics, simplify annotation and result sharing, convey rich and well-defined data aggregation and search models, facilitate unexpected data recycling, and use logic to deduce additional insights (Cardillo, 2011; Jamoulle, Stichele, Cardillo, Roumier, Grosjean and Darmoni, 2015; Peng & Goswami, 2019; Haque, Arifuzzaman, Siddik, Kalam, Shahjahan, Saleena, & Hossain, 2022).

W3C founded the Interest Group for the Semantic Web for Health Care and Life Sciences (HCLSIG) to advance, induce, and encourage the use of Semantic Web technologies for biological science, translational medicine, and healthcare. These professions, which rely on the interoperability of information from many domains and procedures to facilitate decision-making, would greatly benefit from Semantic Web technologies. The HCLS Knowledge Base combines, publishes, and links biological data from fifteen distinct biomedical data sources using contemporary Web technologies (HCLSKB, 2016). The knowledge base contains entries from Medical Subject Headings (MeSH), Allain Brain Atlas, and PubMed. Using the concepts of the Semantic Web and Linked Data principles, initiatives like DailyMed (DailyMed, 2019) and LinkedCT (Hassanzadeh, Kementsietsidis, Lim, Miller, and Wang, 2009) have provided and will continue to supply health-related information. Currently, Datahub (datahub.io) has hundreds of tagged datasets in the health category, and this figure is likely to increase in the years to come. In the same line, the proposed model of this study has added another layer to the integration of heterogeneous health data by establishing a direct connection to the consumer-patient model. When it comes to business engagement, the connections between stakeholders in the traditional healthcare paradigm frequently avoid the patient entity. Thus, the SWBHF provides an aspect of patient-centric approach which will contribute to the ever-innovating healthcare web semantic field.

Table 2.3 Representative Datasets published using Semantic Web (Zenuni, Raufi, Ismaili and Ajdari, 2015)

Data source	Number of triples (statements)	Description
CardioSHARE	N/A	Clinical data on heart diseases and other data in the biomedical domain
Bio2RDF	~11 billion	Data from multiple sources
HCLS Knowledge Base	N/A	Data from multiple sources, like from PubMed, clinical trials, etc.
WHOsGHO RDF	~3 million	Data from WHO statistics
LinkedCT	~7 million	ClincialTrials.gov represented in RDF
DailyMed	~100000	Data about marketed drugs

2.5 Summary

There has been discussion of the background related to the Semantic Web-Based healthcare study. The state of the healthcare system in South Africa provided insight into its problems. In addition to prior work in the healthcare domain, case studies illustrating the diverse applications of semantic web-based technologies provided an intriguing perspective for selecting the best tools for our proposed framework.

Chapter 3: Literature Review

3.1 Introduction

The literature covered in this chapter is essential in setting the foundation for our proposed SWBHF for evidence-based healthcare in resource-constrained settings. The study employs a methodical assessment of prior research, an essential undertaking for any scholarly investigation (Webster and Watson, 2002). Methodological research emphasises the need to find what is already known in the corpus of knowledge prior to commencing any research investigation (Hart, 1998). Hart (1998) asserts that in order to ensure that pertinent facts related to the study are analysed, the literature review must address the most important questions as depicted in figure 3.1.

Figure 3.1: Source: Hart (1998)

A strong foundation for knowledge advancement is established by a good literature review (Webster and Watson, 2002; Randolph, 2019). This promotes theory development, highlights gaps in the literature, and draws attention to areas that require more research.

These ideas make it evident that a good literature review needs to have the following qualities: a) Methodologically assess and synthesise high-quality literature; b) establish a solid foundation for the research topic; c) establish a solid foundation for the research methodology selection; and d) demonstrate that the work being proposed adds something new to the body of knowledge or advances the body of knowledge in the research field (Randolph, 2019).

Chapters one and two have provided background information on the study topic, problem statement, research questions, research objectives, and deliverables. A brief description of resource constraints and associated difficulties is provided in this study of the literature. The WWW and the Semantic Web (Web 3.0) and its related technologies, the application of the Semantic Web in the healthcare domain, the definition and advantages of electronic health (e-Health), evidence-based healthcare in resource-constrained environments, and the related work on SWBHF and healthcare are also given. The Semantic Web approach takes an innovative turn. Web 3.0 allows researchers who think that technology can be used to dramatically improve the way that services are provided to society while also advancing sustainable economic development to accelerate development by bypassing less creative and expensive technologies and moving directly to more sophisticated ones (Kreiser, Nauerz, Bakalov, König-Ries and Welsch, 2009).

3.2 The Evolution of the Web as a Connected Ecosystem

The Web has been since its origin a leading-edge technology. Its development is notable through the phenomenal evolution it has experienced overtime. This section discusses the origins of the Web towards the direction in which it connects things to efficiently work in harmony in achieving an end goal, enabling interoperability and the integration of business processes in an external environment.

3.2.1 Web 1.0

Web 1.0, which is defined as the web of information connections was initiated between 1989 and 2005. Since printed media, such as books and news, was used in an online setting for the web's initial implementation, Gruwell (2007) notes that the web initiative at the time was primarily concerned with protocols, open standard markup languages like HTML and XML, web browsers, web development platforms and tools, web-centric software languages like Java and JavaScript, the creation of the first websites, the commercialization of the Web, and Web business models. During 1999-2001, the dotcom boom gained hype, with a number of investors having interest and willingness to finance dotcom startups. This saw entrepreneurs, many of whom without well founded and well-thought of ideas, used the popularity of the dotcom hype to get money from the investors (Gruwell, 2007). The unfortunate happened in 2001, which caused disappointments and disillusions in the web and its prospects (Choudhury, 2014).

3.2.2 Web 2.0: The Beginning of the Social Web

Web 2.0 came into existence as the second generation of the web. It gained momentum and popularity in 2004 when Dale Dougherty defined it as a read-write web. It referred to the changes in the ways people utilize the web and not to a new technology. A second generation of Internet-based services that encourages online collaboration and sharing among users (Choudhury, 2014), opening limitless possibilities for contributing, collaborating, and connecting. Gruwell (2007) reports that the major themes of Web 2.0 include: social networking; social bookmarking; media sharing (social media); folksonomies; lightweight collaboration (e.g., wikis); mash-ups; etc. The amount of data made available in one minute on the Web is massive and the future growth is staggering.

3.2.3 Web 3.0

The third generation of Internet-based services that together make up what could be called the Intelligent Web or web of data are referred to by Kujur Pranay et al. (2015) as the semantic Web, a term coined by Tim Berners-Lee, the creator of the World Wide Web. Web 3.0 addresses the problem of abundance of data and scarcity of meaning. Web 3.0 was developed as a revision of the Semantic Web with the notion of defining structured data and links them to more effective discovery, automation, integration, and reuse across various applications (Choudhury, 2014).

The major factors that triggered the widespread use of AI-based technologies in Web 2.0 are natural language processing; machine learning; rules-based inferences; personal agents; web mining amongst others to enable a more effective use of the data on the Web for personalisation. Web 2.0 has been primarily focused on the advancement of the Web's front-end and the users' experience whereas Web 3.0 is primarily focused on significant improvement of the Web's backend (Gruwell, 2007) and will form the basis of the Web 3.0: Semantic markup and web services.

This third Web generation addresses organizational challenges of applications presenting information on the web to provide context to data, and, therefore, understand what is relevant and what is not. Additionally, Keller et al. (2006) argue that by examining interoperability, the Semantic Web promises to make information machine-understandable and facilitate the seamless integration of heterogeneous applications.

3.2.4 Web 4.0 and the Future of the Internet

Aziz and Madani (2015) state that the revolution of Web 1.0 through Web 3.0 generated the dream of having an interaction of a symbiotic web between users and machines in terms of the Ultra Intelligent Electronic Agent, Web 4.0 (also called WebOS). In addition, Aziz and Madani mentioned that it will possibly be tremendous and powerful interfaces that are mind controlled using Web 4.0, where the machines would be smarter in building more commanding interfaces in reading, writing, execution and concurrency. Furthermore, the authors acknowledge that this generation of the web will be as a middleware that will function as an important component of the operating system, and it will infer a massive web of intelligent interactions that will be like the human brain. Moreover, Web 4.0 will ensure global transparency governance, distribution, participation, collaboration into key communities such as industry, political, social and other communities (Aghaei, Nematbakhsh, & Farsani, 2012)

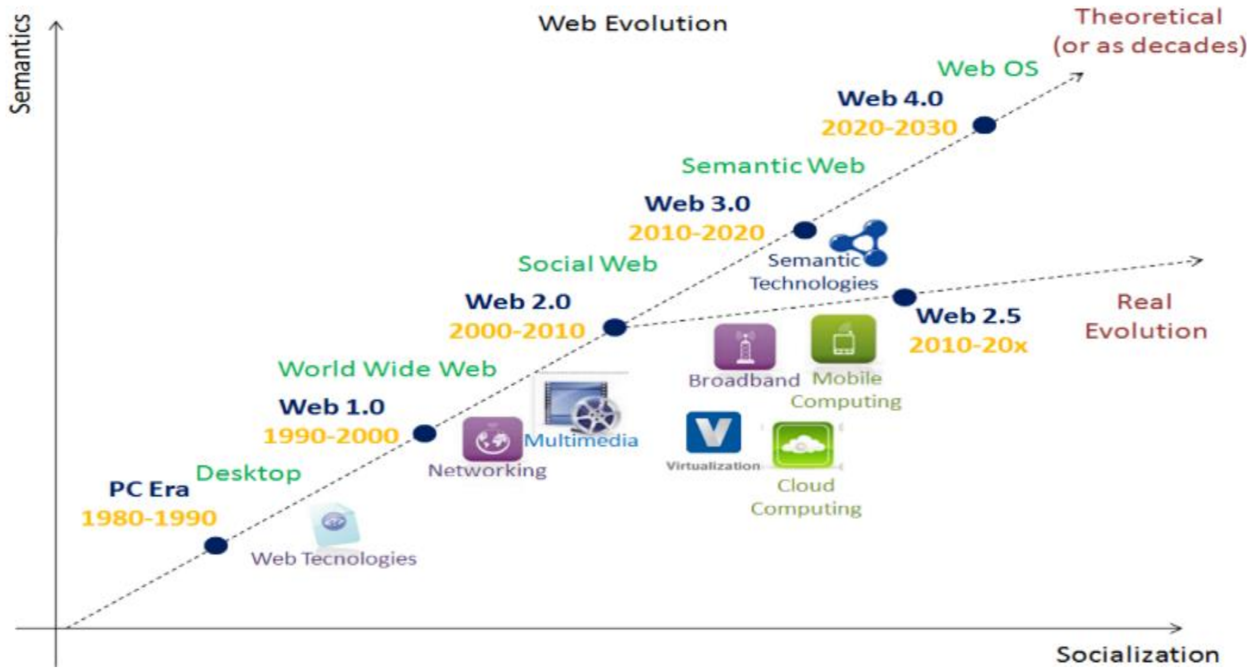

Figure 3.2 Web evolution (Gruwell, 2007)

The figure 3.2 depicts the evolution and development of the Web, the technologies involved at each stage and the period in years. In addition, Figure 3.2 indicates that, despite its incomplete realisation, we have now entered the Web 3.0 Era. The introduction background forms a foundation and limitation of technology concepts (ICT, KM, the Web, and healthcare data) and the area (healthcare) that will enlighten our study. As far as the Web is concerned, our study will concentrate on the Web 3.0 / Semantic Web in attempting to come up with a way to elevate healthcare service delivery in resource-constrained environments of South Africa. There are many ways in which resource-constrained environment in developing countries are affected, ranging from poor communication networks, poor road connectivity and or infrastructure, limited access to government services and to basic needs. Medical centers in resource-constrained environments are therefore very few and are poorly managed, making it impossible to deal with medical cases of the many patients who rely on them due to a drastic shortage of trained and experienced physicians and nurses (Patel, 2012; Chitrakar, 2015; Fanta, 2015).

3.3 Related Research Work on Semantic Web and Healthcare Domain

This section covers research on the Semantic Web and healthcare that can be implemented or reused in resource-constrained environments in developing nations, with a focus on South Africa's Eastern Cape Province's Dutywa Health District.

3.3.1 **Semantic Web-based E-Health as a component for a multi-purpose communication centre**

In his research, Hlungulu (2010) used ICTs that were set up in Dwesa as part of the Siyakhula Living Lab (SLL) project to help the community's health standards. Additionally, by creating a practical web application, this project aims to encourage community members to use the ICTs that have been deployed in Dwesa.

The main objective of this project was to leverage semantic web technologies as part of the e-Health system's data layer to establish multiple information repositories for isiXhosa traditional medicine knowledge and indigenous knowledge[Figure3.3].

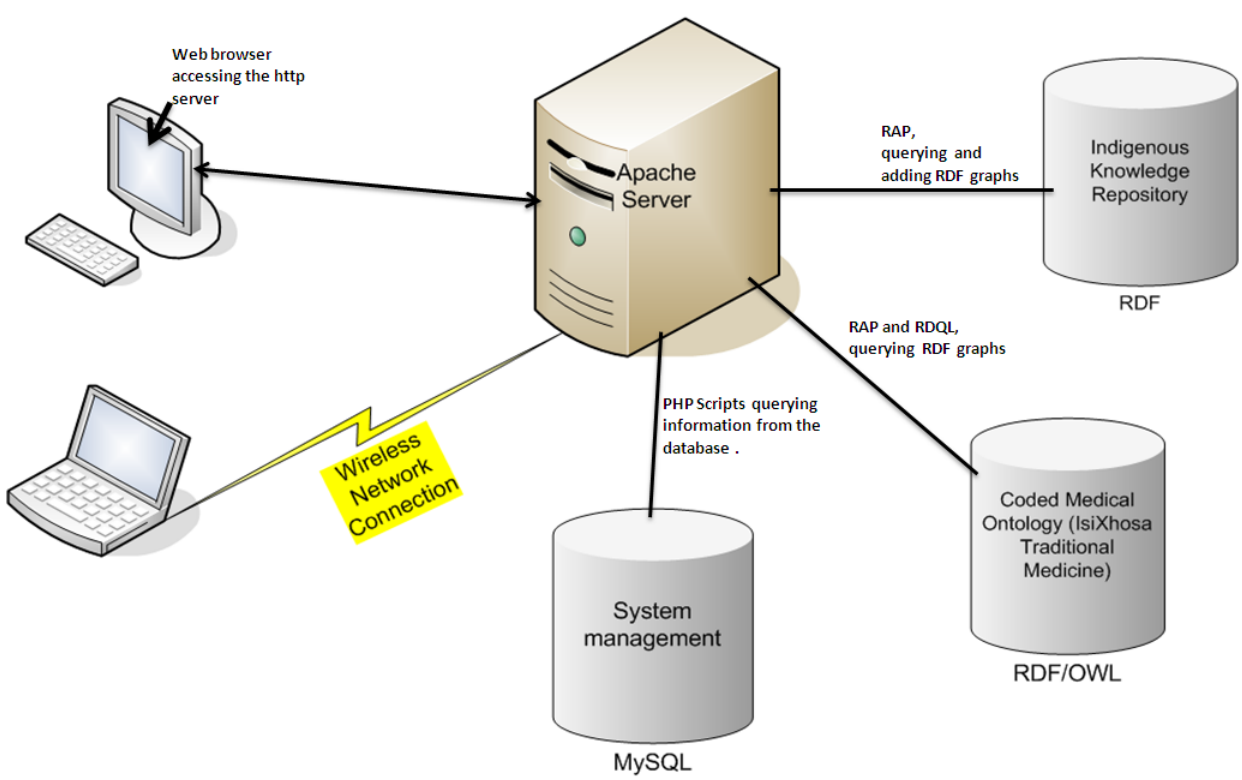

Figure 3.3: SLL e-Health system architecture (Hlungulu, 2010)

The findings of this study serve as the foundation for ongoing efforts to use the semantic web to improve access to healthcare for rural populations. The coded medicinal ontology that is produced is limited to isiXhosa Traditional Medicine and cannot be expanded, which is how this Semantic Web-based E-Health Component differs from our suggested approach.

3.3.2 Adaptation of Semantic Web to Rural Healthcare Delivery

In response to the challenges associated with delivering healthcare in remote locations, Abur and Soroyewun (2010) offer a theory regarding the usage of the Semantic Web in this context. Database, Data Transfer Mechanism (DTM), Medical Inference Engine (MIE), and User Interface are the four (4) levels that make up the authors' proposed semantic health paradigm [Figure 3.4].

The result paper presents a conceptual model (Semantic health model) of using the Semantic Web to locate necessary information regarding health matters, thereby facilitating healthcare delivery in rural areas. The model addresses the challenge of providing high-quality healthcare services at reasonable costs while the elderly population and the associated chronic disease increase. By facilitating intelligent access to dispersed information, the Semantic Web will allow software products, or agents, to act as a middleman between the demands of users and the accessible information sources.

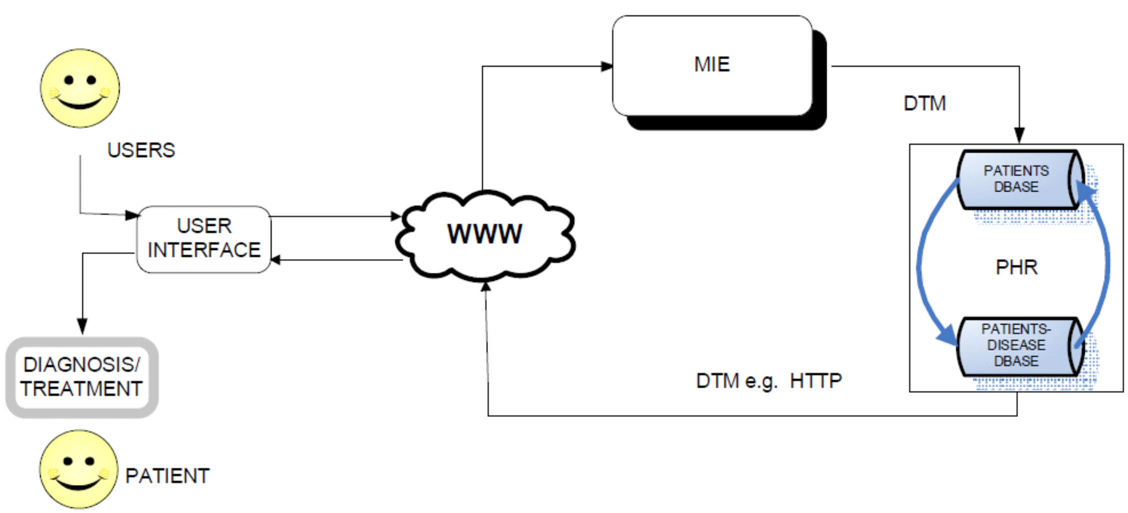

Figure 3.4 Semantic Web Health Model (Abur and Soroyewun, 2010)

3.3.3 Finnish Health on Semantic Web

A nationwide semantic publishing system called HEALTHFINLAND [Figure 3.5] was created to give Finns access to current, accurate healthcare information. There are three components to the system: 1) a tool-equipped, centralised health ontology infrastructure; 2) a semantic content production platform centred on various distributed health organisations; and 3) an intelligent semantic portal that organises and offers intuitive and health information that supports end-user viewpoints. (Hyv, 2001; Suominen and Hyv, 2010; Hyv, Viljanen, Eetu, Kauppinen, Ruotsalo, et al., 2007; Keskimaki, Tynkkynen, Reissell, Koivusalo, Syrja, Vuorenkoski, & Karanikolos, 2019). Modern semantic web technology is applied by the HEALTHFINLAND system to the problems of publishing, aggregating, and locating national health information. The framework demonstrates how semantic web technologies can be used to address issues with distributed content production, discovery, linking, aggregation, and reuse in health information at the national level from the perspectives of end users, content producers, and computer processing.

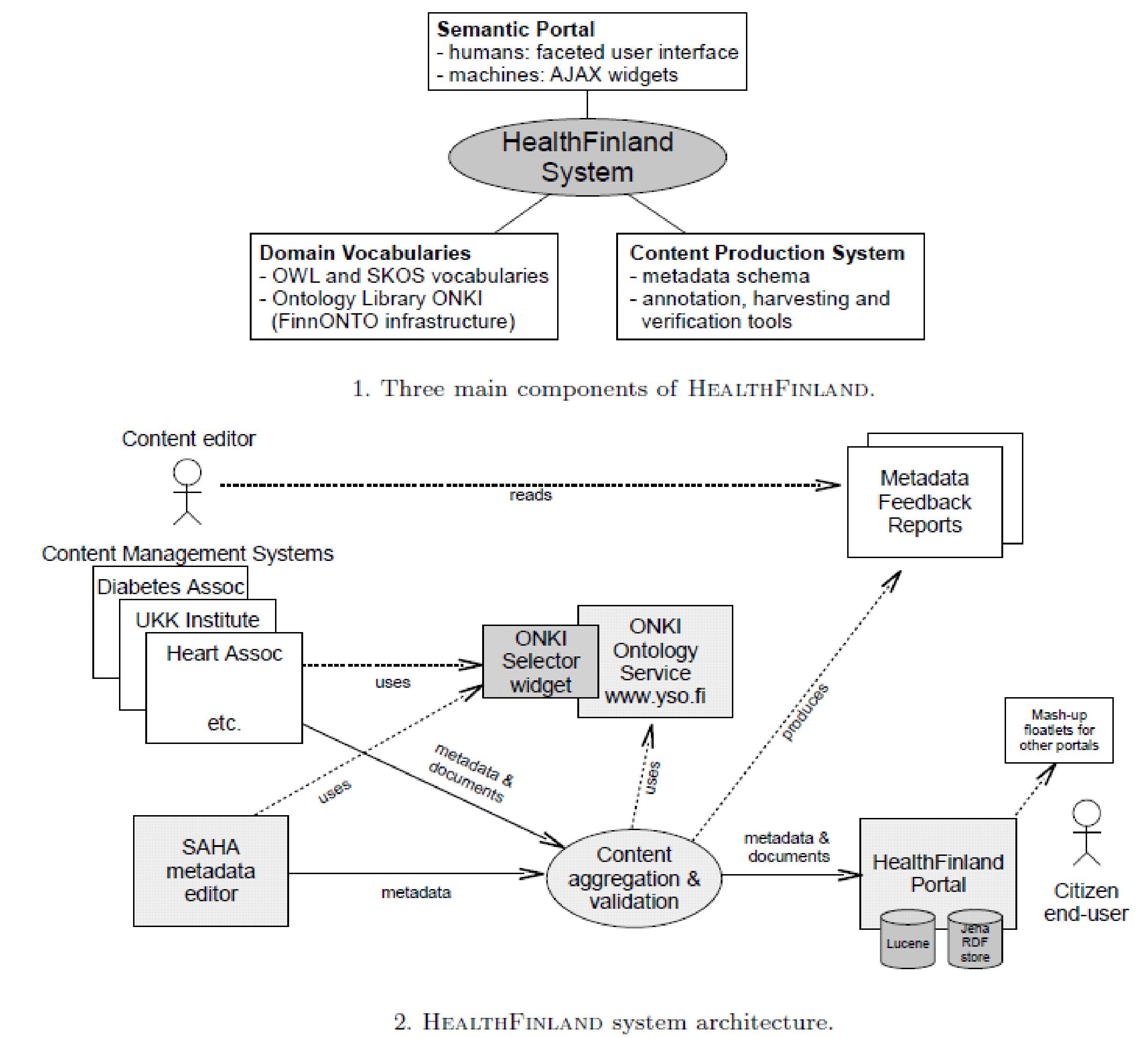

Figure 3.5 HealthFinland Semantic Web-Based Framework (Suominen and Hyv, 2010)

An intriguing step towards understanding the challenges associated with providing ICT-enabled healthcare in rural locations is the HealthFinland Semantic We Based Framework project.

3.3.4 A Generic Framework for Developing Semantic Web-based Applications

Kumar and Dwivedi (2014) introduced the generalised design of an agent-based framework for the semantic web that allows the organisation and development of semantic web applications for any domain and its corresponding features[Figure 3.6].

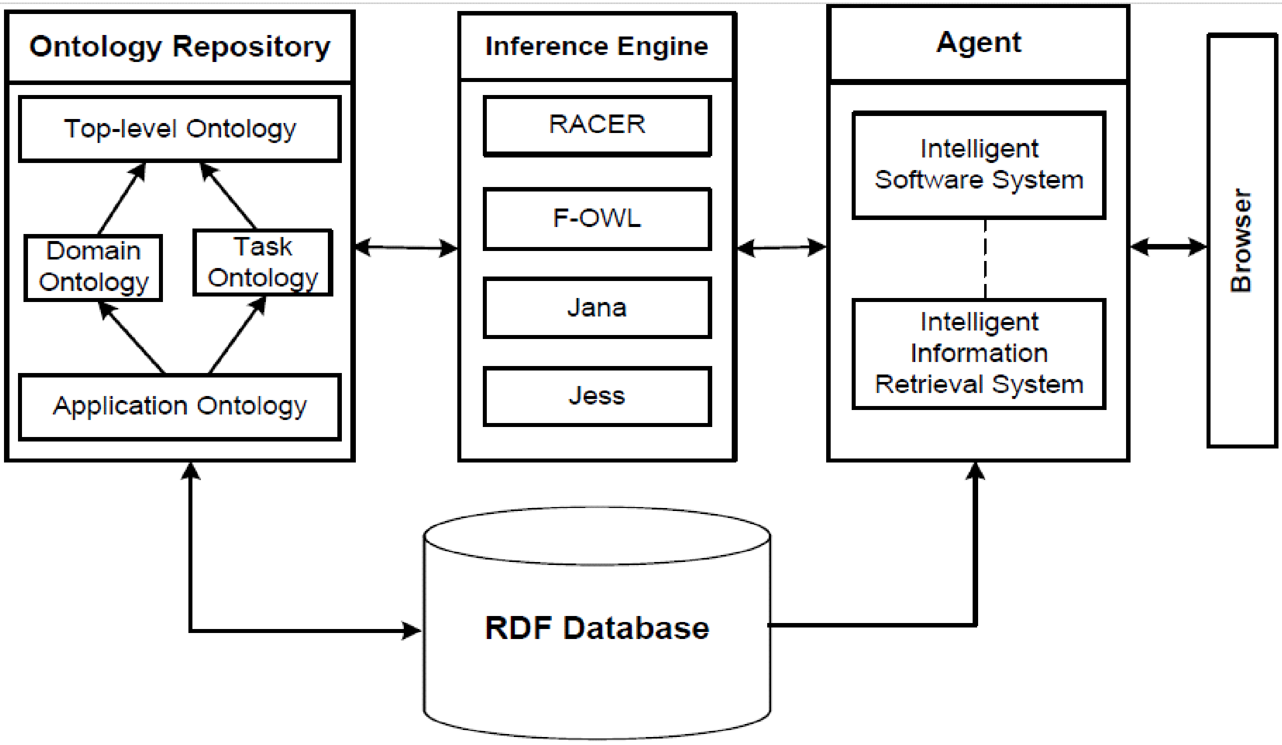

Figure 3.6 Generic Architecture of Semantic Web-Based Framework for any Domain. (Kumar and Dwivedi, 2014)

In order to achieve the suggested goals and objectives and to try to address the research issues, the SWBFH architecture incorporates certain elements from the generic architecture.

3.3.5 A Semantic Web-Based Framework to Support Knowledge Management in Chronic Disease Healthcare

An ongoing project that highlights the necessity of healthcare knowledge management (KM) to assist clinical information systems and decision support systems (DSS) in order to improve the quality of care for patients with chronic diseases is described by Buranarach et al. (2009). The authors suggested using knowledge engineering and ontology-based modelling and acquisition to create a useful method for gathering professional judgement for use in developing clinical practice guidelines. A knowledge management platform that facilitates the integration of knowledge with patient databases and endorsed publications is being built with the Semantic Web-Based Framework [Figure 3.7].

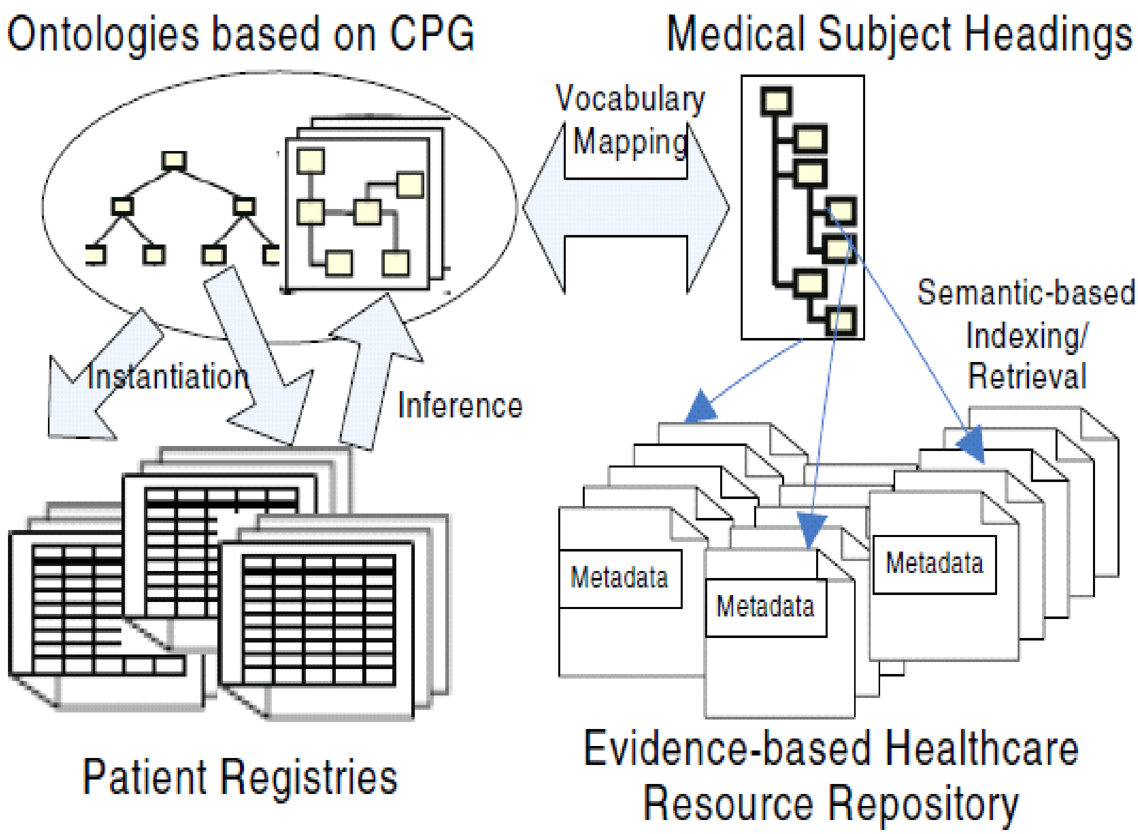

Figure 3.7 Knowledge resources in ontology-based healthcare KM framework (Buranarach, Supnithi, Chalortham, Khunthong, Varasai and Kawtrakul, 2009)

Semantic web research has been attempted to support healthcare knowledge management in chronic disease healthcare in this linked effort.

3.3.6 A Semantic Web-Based Healthcare Framework for the interoperability and exploitation of clinical models and EHR data

Legaz-garcía, Martínez-costa, Menárguez-tortosa, and Fernández-breis (2016) present how an OWL-based framework facilitates the interoperability and exploitation of archetypes, EHR data, and ontologies by utilising EHR and Semantic Web technologies [Figure 3.8]. Additionally, it makes clinical data usable for later use. The Archetype Management System (ArchMS) has this framework implemented. Legaz-garcía et al. also detail the application of ArchMS in a real-world investigation within the field of colorectal cancer.

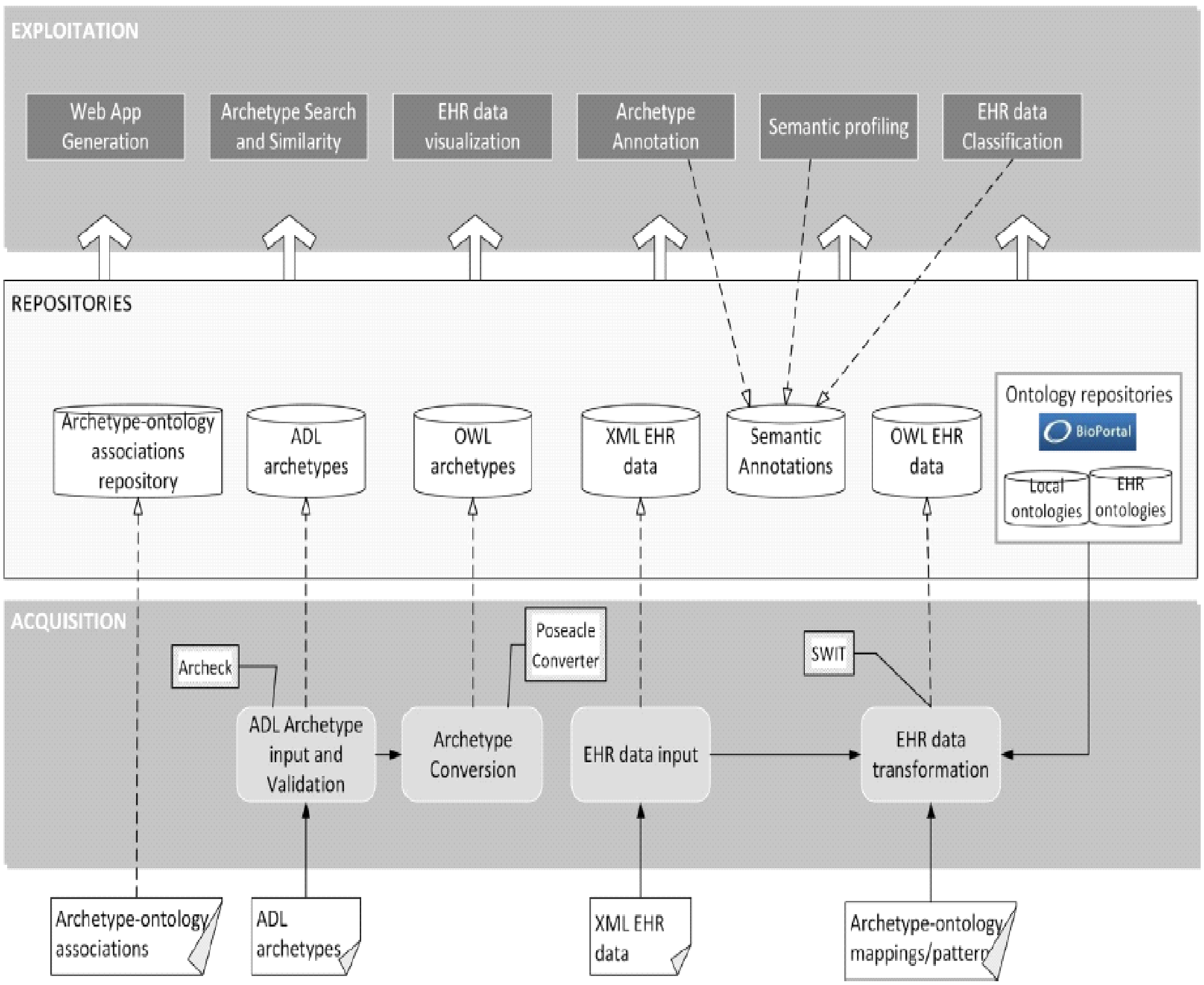

Figure 3.8 ArchMS architecture overview, including three layers (from bottom to top): acquisition (light grey rounded-corner rectangles), repositories (white cylinders) and exploitation (grey rectangles).(Legaz-garcía, Martínez-costa, Menárguez-tortosa and Fernández-breis, 2016)

3.3.7 A Review of Interoperability Standards in E-health and Imperatives for their Adoption in Africa

In this research study, Adebesin et al. (2010) assert that healthcare information systems' capacity for information sharing and exchange (interoperability) is crucial for promoting the efficacy and calibre of healthcare services (Figure 3.9). However, they go on to say that standardisation is the solution to the fragmentation that the healthcare system is currently facing. Making sense of the landscape of e-health interoperability standards is one of the many reasons that e-health standardisation can be challenging. This study paper, which is specifically targeted at the African health informatics community, gives an overview of e-health interoperability and emphasises the importance of standardisation in achieving it.

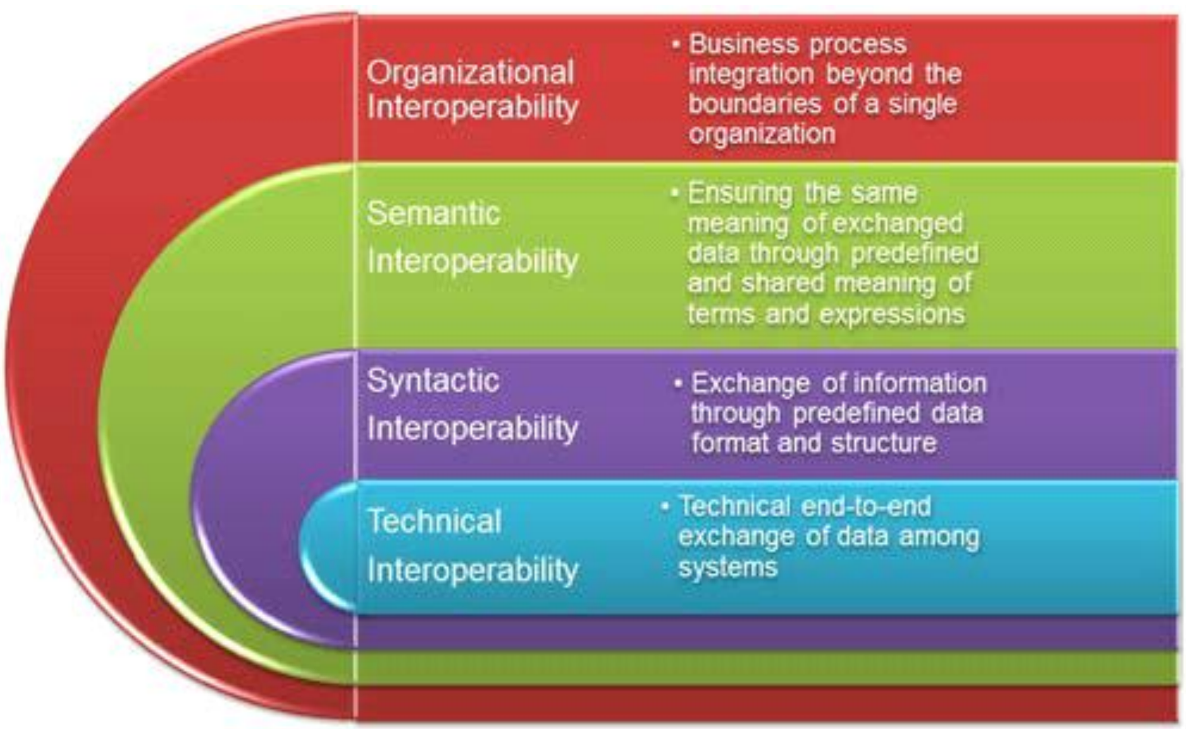

Figure 3.9 Levels of interoperability (Van Der Veer and Wiles, 2008; WHO and ITU, 2012)

Table 3.1 Standards and interoperability level mappings (Adebesin, Foster, Kotzé, Greunen and CSIR Meraka Institute, 2010).

	Interoperability level			
Standard	Technical	Syntactic	Semantic	Organizational
Identifiers				
ISO/TS 22220:2011		X	X	
ISO/TS 27527:2010		X	X	X
Messaging / information exchange				
HL7 V2.X		X	X	
HL7 V3		X	X	
DICOM		X	X	
SDMX-HD		X		
Structure and content				
ASTM E2369-12		X	X	
HL7 CDA		X	X	
HL7/ASTM CCD		X	X	
HL7 CRS		X	X	
ISO 21090		X	X	
Clinical terminology and coding				
SNOMED		X	X	
LOINC		X	X	
ICD		X	X	
ICPC-2		X	X	
CPT		X	X	
Electronic health record				
ISO 18308:2011		X	X	X
System functional models				
HL7 EHR-System Functional Model, Release 1.1	X	X	X	X
Security and access control				
ISO/TS 22600				X

Table 3.1 Provides mapping of these standards to the relevant interoperability level(s).

3.4. Resource constrained environment

Anderson, Anderson, Borriello, & Kolko, (2012) use a broad definition of resource-constrained situations, such as low-income neighbourhoods and places with limited bandwidth. Certain contexts (such as societies where people are averse to technology or inexperienced with it altogether, or places where power and network access are expensive and rare) impose particular limits. In this study, Dutywa is considered as resource constrained environment as it fits the definition of Anderson et al. (2012).

3.4.1 Dutywa

Dutywa, often spelt Idutywa, is a town in the Eastern Cape region of South Africa's Mbashe Local Municipality. It was established as a military fort in 1858 as a result of a conflict between the locals and a raiding force from Natal Colony. It takes its name from the Dutywa River, which is a Mbhashe River tributary. The name translates to "place of disorder" in Xhosa. On July 16, 2004, the spelling was formally changed from "Idutywa" to "Dutywa". The Settlement, which was formerly a part of the Transkei bantustan, was planned out in 1884 and became a municipality in 1913. Thabo Mbeki, who was elected president of South Africa in 1999, was born there. On the N2 road, it lies 35 miles north of Gcuwa, historically known as Butterworth. Agriculture and education are the main sources of economic contributions to this community.

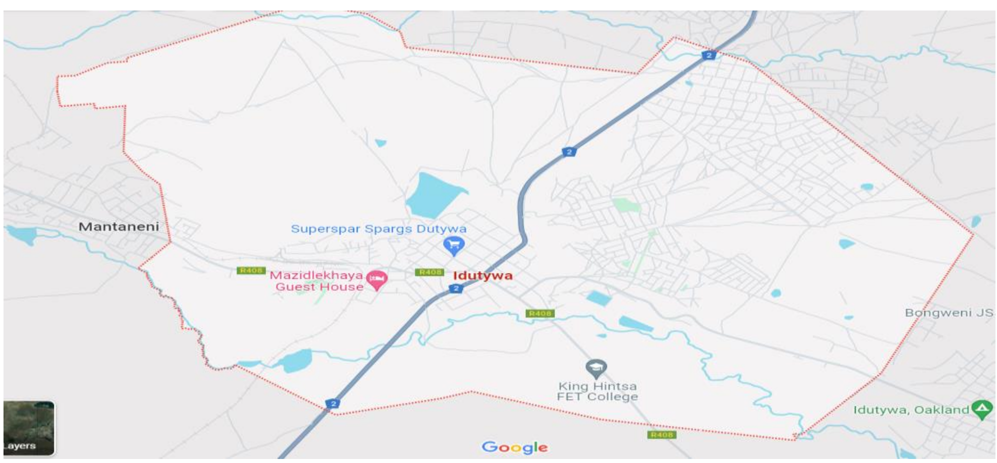

Figure 3.10 Dutywa Map

3.5 Summary

Since the literature study chapter will serve as a foundation for comparison with the suggested prototype, it is an important place to start. The earlier studies referenced in this chapter highlight the importance of conducting research on semantic web-based concepts in order to develop creative applications for them as a means of delivering services.

Chapter 4: Research Methodology

4.1 Introduction

In this chapter, the explanation of the research approach used in investigating how to design a Semantic Web-Based Healthcare Framework for Digital Healthcare in a resource-constrained environment takes place. This chapter begins by highlighting the variety of research approaches that can be used in Information Systems, demonstrating the importance of the decision on which research approach is to be adopted in order to answer research questions. The chapter then addresses the various philosophical viewpoints (i.e., paradigms) in IS research and provides the justification for DSR selection. Next, it explores the DSR model showing its nature, concepts, theories, and production styles. In addition, the approach to design science employed is discussed, including its variations and processes.

4.2 Choice of Research Methodology

A research methodology consists of the combination of the processes, methods, and tools that are used in conducting research in a particular domain (Nunamaker et al., 1990). Basically, the methodology is, essentially, the steps that will be taken in order to derive reliable and valid answers to the questions (Ellis and Levy, 2010).

March and Smith (1995); Peffers (2008); Hevner and Chatterjee (2015) state that two paradigms characterise much of the research in the IS discipline: behavioral science and design science. The behavioral science paradigm seeks to develop and verify theories that explain or predict human or organizational behavior and the design science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artefacts (Hevner, 2011; Gregor and Hevner, 2013; Holzweißig, 2013; Vaishnavi and Kuechler, 2014). Both paradigms are foundational to the IS discipline, positioned as it is at the confluence of people, organizations, and technology.

The research methodology used in this dissertation is the one of DSR methodology (Hevner and March, 2004) because the goal is to design a new artefact. While routine design is the application of existing knowledge to organizational problems, design science involves finding new solutions to previously unsolved problems or better and more efficient solutions to previously solved problems (March and Smith, 1995).

4.3 Research Paradigm in Information Systems

The set of beliefs or the underlying philosophical perspectives and assumptions which guide the actions and the activities that researchers conduct throughout the research process can be defined as a paradigm (Guba and Lincoln, 1994; Bellami, 2001).

Denzin and Lincoln (1998) propose three questions that are deemed important in defining a paradigm as they reflect the underlying beliefs of researchers: What is the nature of reality that is addressed, or what is assumed to exist (ontology); what is the nature of valid or true knowledge (epistemology); and what is the best approach, or set of guidelines, that helps in generating the desired knowledge and understanding in a valid and reliable manner (methodology). Some other researchers (e.g., Mingers, 2001) considered axiology or ethics; that is what is of value or considered right, as an important aspect as well.

Traditionally in IS research, three major paradigms can be distinguished as positivist, interpretive, and critical (Orlikowski and Baroudi, 1991; Baskerville and Myers, 2004). These paradigms can be summarized as follows:

- The research in IS is considered interpretative if the knowledge of reality is gained through social constructions such as language, consciousness, shared meanings, documents, tools, and other artefacts (Coleman, 2010). Walsham (2006, p. 4-5) claimed that the aim of interpretive research is at the "understanding of the context of the information system and the process whereby the information system influences and is influenced by the context".

- The research study is viewed as positivist if there is an evidence of hypotheses generation, operational or quantifiable measures of research variables such as the dependent and independent variables, testing of the formulated propositions, and finally the drawing of inferences and conclusions about the examined phenomenon from a sample representing the research population (Orlikowski and Baroudi, 1991).

Therefore, positivists commonly assume that reality is objectively given and thus can be measured independently of the researcher and the employed instrument (Baskerville, Pries-Heje and Venable, 2009).

- The research is classified as critical if the main aim of the research is one of a social critique seeking to assist in eliminating the causes of unwarranted alienation and domination; and hence improves the opportunities for appreciating human potentials (Hirschheim and Klein, 1994). This kind of research assumes that "social reality is historically constituted and that is produced and reproduced by people" (Avison, 2005). Baskerville and Myers (2004) argued that critical researchers assume that social reality is historically constituted and that it is produced and reproduced by people.

However, within the last two decades, a fourth paradigm, the one of design science has emerged and is established in IS research, aiming to improve the relevance of the IS discipline. The summary of this paradigm is as follows:

- The DSR paradigm has its roots in the sciences and engineering. It is fundamentally a problem-solving paradigm (Simon, 1996). DSR seeks to enhance human knowledge with the creation of innovative artefacts. These artefacts embody the ideas, practices, technical capabilities, and products through which information and computing technology and systems (abbreviated here as the field of IS) can be efficiently developed and effectively used (Vaishnavi and Kuechler, 2014; Hevner and Chatterjee, 2015). Artefacts are not exempt from natural laws or behavioral theories. Vaishnavi and Kuechler (2014) argue that, DSR is yet another "lens" or set of synthetic and analytical techniques and perspectives (complementing the positivist and interpretive perspectives) for performing research in IS.

A summary of research paradigms in information systems is provided in the following table (i.e., Table 4-1).

Table 4.1 Research Paradigms in IS **Compiled after** (Peffers, 2008; Hevner, 2011; Vaishnavi and Kuechler, 2014)

Basic beliefs	Research Paradigms			
	Positivist	Interpretative	Critical	Design
Ontology	A single reality, knowledge, probabilistic	Multiple realities, socially constructed	Reality is historically constituted.	Multiple, contextually situated alternative world states, socio-technologically enabled
Epistemology	Objective, dispassionate, detached observer of truth	Subjective, i.e. values and knowledge emerge from the researcher-participant interaction	Reality is shaped by its social context, knowledge is grounded in social and historical practices, facts and values are entwined.	Knowing through making: objectively constrained construction within a context, iterative circumscription reveals meaning
Methodology	Observation, quantitative, statistical	Participation, qualitative, hermeneutical, dialectical	Assumptions, beliefs, and values shape and shaped by the investigation.	Developmental, measure artefactual impacts on the composite system
Axiology	Truth: universal and beautiful, prediction	Understanding: situated and description	Descriptive and situated knowledge and understanding of phenomena	Descriptive and situated knowledge and understanding of phenomena

Considering a well-established difference amongst the research paradigms in IS and the nature of the research question tackled in this research, the DSR paradigm is a good candidate. This research aspires to answer the best approach to designing a SWBHF to support healthcare providers in resource-constrained environments by achieving their strategic goals and objectives. This issue is highly pertinent to healthcare workers (i.e., physicians, nurses, junior medical doctors with no field experience and students from medical university schools) as their current practices regarding medical decision making do not seem to be effective given the poor quality of information and the reliability of the health web sources and resources they are browsing. This information is web content belonging to public healthcare, private healthcare providers or registered and/or recognized medical/healthcare companies as emphasized by (Ouma and Herselman, 2009) which is synonymous to information overload as discussed in chapter one. In trying to move from this state into an improved one, this research develops an artefact in the form of SWBHF. However, the manner in which the DSR paradigm is employed in this research, along with the methods and approach used, are fully discussed in the coming sections.

4.4 The Design Science Research Paradigm & Artefacts

The research paradigm followed in this research, concerned itself with the designing of a SWBHF to support healthcare providers in resource-constrained environments, is that of design science (Hevner and March, 2004). This research aims, by utilizing DSR, at producing a technology-oriented utility (i.e., SWBHF). This SWBHF identifies and categorizes the key concepts, relationships, and rules in the Semantic Web-based in the healthcare domain and produces a clear understanding of them. This is highly pertinent in an effort to leverage the ability of the Semantic Web in the healthcare industry (i.e., designing, evaluating, and improving their existence and future web-based capabilities in healthcare in an innovative manner).

DSR has been gaining growing attention in IS and computing disciplines recently, although not new. It has been acknowledged that the DSR paradigm is yet another lens or set of analytical perspectives that could usefully complement the behavioral science pattern, which is the mainstream of IS research within the cycle of IS research. (March and Smith, 1995; Hevner and March, 2004; Vaishnavi and Kuechler, 2014) (see Figure 4-1). The increasing interest in DSR has been coupled with that of design theory which has lately been emphasized by (Gregor and Jones, 2007; Gregor, 2010; Gregor and Hevner, 2013). Within IS, DSR has been impacted by Simon's idea of the science of the artificial (Simon, 1996), and other disciplines such as engineering, architecture, and computer science (Baskerville and Myers, 2004; Baskerville, Pries-Heje and Venable, 2009). The term design implies creating something new that does not exist in the natural (Vaishnavi and Kuechler, 2014). Nevertheless, DSR extends the notion of design to include aspects related to systematic creation of knowledge about and within design (Baskerville and Myers, 2004). In the discipline of IS, DSR seeks to significantly improve aspects related to analysis, design, implementation, management, and use of information systems by the creation of useful artifacts (Hevner and March, 2004).

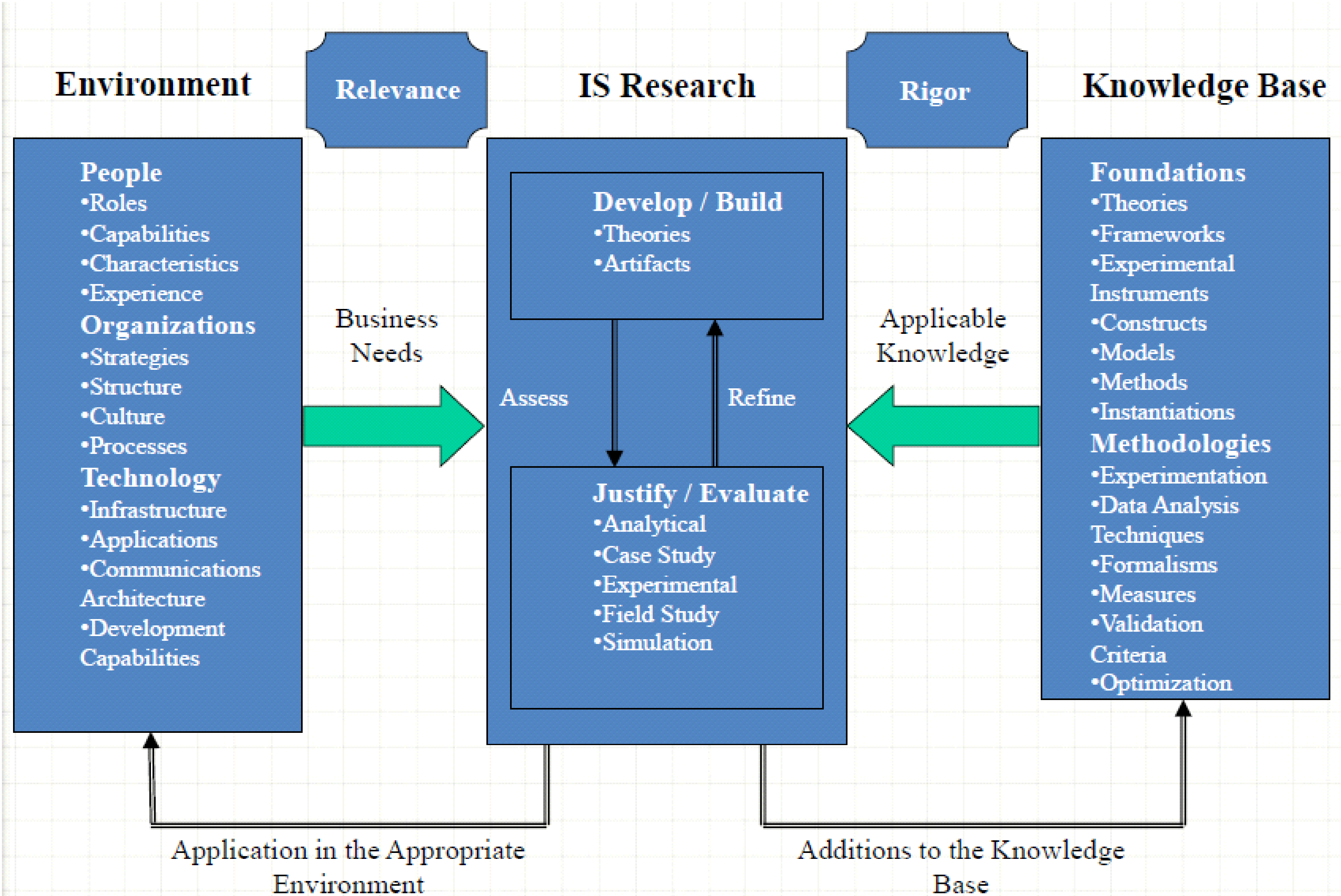

Figure 4.1: Information System Research Framework (Hevner and March, 2004)

Therefore, while humans could change their lifestyles through the introduction of these novel artefacts, organizations might change the ways in which they do business so as to exploit the opportunities that emerged due to these artefacts. In the context of this research, whilst the SWBHF is the main artefact, the design of a SWBHF artefact that would meet strategic goals and objectives of healthcare providers, e.g., healthcare workers (physicians, nurses, junior medical doctors with no field experience and students from medical university school) is the tackled “wicked problem”.

In the context of DSR, the term “wicked problems” can be described as unstructured or ill-defined (Hevner, 2011; Vaishnavi and Kuechler, 2014) decision-making activities and settings. This is because these types of decisions are normally “poorly formulated, confusing, and permeated with conflicting values of many decision makers or other stakeholders” (Baskerville, Pries-Heje and Venable, 2009; Venable, Pries-heje and Baskerville, 2016). In fact, design problems are usually difficult to define because they have no precise starting or finishing points, and thus such problems are often solved through a combination of strategies that emerge throughout the design process (Hevner, 2011; Vaishnavi and Kuechler, 2014).

In a more general sense, human and/or organizational structures may define the term "problem" as the presence of a difference between the current situation (and state-of-the-world) and the desired situation. The magnitude of the problem can be determined by the size of the gap or the difference between the current and desired states. The gap however represents the problem space which is either fulfilled or at least shrunk by the introduction of the design artefact. This definition of the term “problem” in the context of information systems DSR is consistent with Simon (1996, p.130)’s observation, that “everyone designs who devises courses of action aimed at changing existing situations into preferred ones”.

Moreover, IS and computing researchers have not yet come into agreement about what constitutes an artefact in DSR. Some argue that the IT artefacts are the only allowed outputs of IS DSR (Nunamaker, Chen and Purdin, 1991; March and Smith, 1995; Hevner and March, 2004; Vaishnavi and Kuechler, 2014). Considering that the field of IS discusses issues related to organizations, social and human aspects, technologies, and their interrelationships, it is also questioned whether pure organizational artefacts are acceptable outcomes of IS DSR, or not. (Simon, 1996; Peffers, 2008).

DSR artefacts (IT Artefacts) are essential outputs of IS research as mentioned by (Nunamaker, Chen and Purdin, 1991; March and Smith, 1995; Hevner and March, 2004; Vaishnavi and Kuechler, 2014). In their research paper on "Evaluating an Artefact in Design Science Research Methodology as was implemented in a resource-constrained environment", Herselman, Botha and Meraka (2016) state that an artifact is a man-made object created to solve a specific problem, as opposed to naturally occurring objects. The artefacts created in DSR could be either a construct, model, framework, architecture, design principle, method, instantiation or a better theory (Vaishnavi and Kuechler, 2014; Herselman, Botha and Meraka, 2016) [Table 4.2].

Table 4.2: Outputs of Design Science Research (Vaishnavi and Kuechler, 2014)

	Output of DSR	Description
1	Constructs	The conceptual vocabulary of a domain
2	Models	Sets of propositions or statements expressing relationships between constructs
3	Frameworks	Real or conceptual guides to serve as support or guide
4	Architectures	High level structures of systems
5	Design principles	Core principles and concepts to guide design
6	Methods	Sets of steps used to perform tasks how-to knowledge
7	Instantiations	Situated implementations in certain environments that do or do not operationalize constructs, models, methods, and other abstract artefacts; in the latter case such knowledge remains tacit.
8	Design theories / Better theories	A prescriptive set of statements on how to do something to achieve a certain objective. A theory usually includes other abstract artefacts such as constructs, models, frameworks, architectures, design principles, and methods.

However, instantiation is generally referred to as a material artefact, while the other types of artefacts are referred to as abstract artefacts. A design theory usually includes abstract artefacts and can also include instantiations (Vaishnavi and Kuechler, 2014).

Vaishnavi and Kuechler (2014) mentioned the DSR output own list of Sein, Henfridsson, Purao, Rossi, & Lindgren, (2011) and Purao (2002). All but one of these can be mapped directly to March Smith list. Their fifth output, Better Theories / Design Theories, is highly significant and merits inclusion in the general list of DSR outputs. This is added to the list of outputs, additional abstract artefacts such as frameworks, architectures, and design principles in this research.

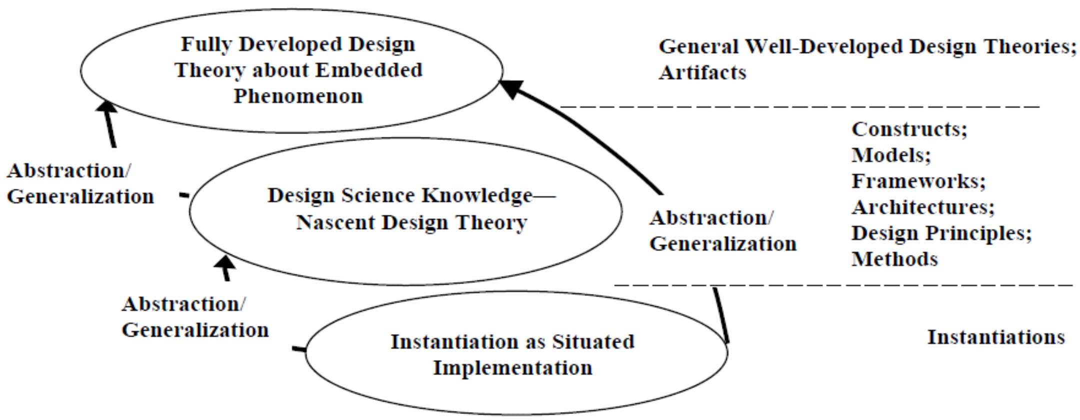

Figure 4.2. Design Science Knowledge Hierarchy **(Vaishnavi and Kuechler, 2014)**

In Figure 4.2, the multiple outputs of DSR are classified by level of abstraction and generalization; outputs at higher levels are preferred since it reflects a more general advancement of knowledge in the area.

4.5 Design Theories in Design Science

In both the natural and social / behavioral sciences, theories play a key role. Natural sciences have progressed mainly through comprehensive theory development and testing, mainly through positivist approaches. The social and behavioral sciences have also made progress through the theory development and testing (Venable, 2006). Simon (1996) established the need for the advancement of various design sciences in the Sciences of the Artificial. A design science is an inventive or creative activity that solves problems; one in which the primary products are new technologies (Simon, 1996).

In IS design science, a design theory is a prescriptive theory based on theoretical contexts that explains how an efficient and feasible design process can be carried out in a way (Gregor and Hevner, 2014). It offers guidelines or principles that can be practically followed. Because they are prescriptive, design theories vary from the theories found in natural or physical sciences that describe and forecast. The IS community's design theories focus on improving the effectiveness and usefulness of IT artifacts in solving real-world business problems (Paola, Robin, Alan and Chatterjee, 2010; Hevner and Chatterjee, 2015). Table 4.3 lists some design theories developed by design science researchers.

Table 4.3 Design Theories in IS Research

Study done by	Process
(Nunamaker et al., 1990)	The process comprises five stages: (1) Construct a conceptual framework (2) Develop a system architecture (3) Analyze and design the system (4) Build the (prototype) system, and (5) Observe and evaluate the system.
(Walls et al., 1992)	Addresses both product and process design. Four components about the design product: (1) Meta-requirements (2) Meta-design (3) Kernel theories, and (4) Testable design product hypotheses. Three components about design process: (5) Design method (6) Kernel theories, and (7) Testable design process hypotheses. Kernel theories are drawn from natural or social sciences, as above, but apply to the design method.
(March & Smith, 1995)	Design activity consists of: (1) Build (2) Evaluate (3) Theorize (4) Justify
(Alan R. Hevner, March, 2004)	Seven guidelines for Design Science in IS research: (1) Design as an Artifact (2) Problem Relevance (3) Design Evaluation (4) Research Contributions (5) Research Rigor (6) Design as a Search Process (7) Communication of the Research
(J. R. Venable, 2006)	1. Solution technology invention 2. Theory building 3. Artificial evaluation 4. Naturalistic evaluation
(Gregor, 2010; Gregor & Jones, 2007)	• The purpose and scope • Constructs • Principles of form and functions • Artifact mutability • Testable propositions • Justificatory knowledge • Principles of implementation • Expository instantiation

The IS literature around design theories is scattered and appears under different labels, such as the constructive approach (Iivari, Hirschheim and Klein, 1998), the system development approach (Nunamaker, Chen and Purdin, 1991; Gregor and Jones, 2007), and the design science approach (March and Smith, 1995; Hevner and March, 2004). The popular emphasis of these theories of design is on how to create an artifact (knowledge of design / process development) and what the artifact will look like when it is designed (principles of design). Many papers addressing theory in the sense of DSR see design theory as a prescriptive assertion that is an important outcome of a research effort (Gregor and Jones, 2007).

4.6 Design Research Methodology Applied to this study

Hevner and March (2004) provide a framework within the IS discipline for research activities in design science and a clear set of guidelines or principles to conduct and evaluate good DSR. Hevner and March (2004) argue that effective DSR must make clear contributions in the areas of artefact design, knowledge of design building, and/or methodologies for design evaluation. In addition, researchers, reviewers, and editors must use their creative abilities and judgment to determine when, where, and how each of these guidelines should be applied. For DSR to be full as emphasized by (Hevner and March, 2004), each of these seven principles should be discussed in some way.

DSR Guidelines related to our study are therefore discussed in details:

Table 4.4 Design Science Research Guidelines (DSRG) (Hevner and March, 2004)

Guideline	**Description**	**Application for SWBHF**
Guideline 1: Design as an Artifact	Design science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation	The Semantic Web-Based Healthcare Framework to support healthcare providers in a resource-constrained environment (SWBHF) is a clear artefact produced by this research. The designed framework will be used to create an intelligent web application to support health workers (physicians, nurses and junior medical doctor) exercising their duty in a resource-constrained environment.
Guideline 2: Problem Relevance	The objective of design science research is to develop technology-based solutions to important and relevant business problems.	From the literature review (Chapter 2) it is evident that there is no research conducted on SWBHF to support health workers in resource-constrained environments. This need has been recognized but not implemented in practice and is the very relevant problem addressed by this research. The designed framework (SWBHF) can also be used in other developing or developed countries with similar initiatives if need be. To confirm the problem's relevance, questionnaires and interviews **(Appendix D)** were drafted based on the health workers (physicians, nurses) seeking health information's on the internet.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.	Alan R. Hevner, March (2004) An observational method using multiple case studies and a descriptive method were used for evaluating the design process (see Chapter 5). An expert review analysis tool was used for evaluating the artefact. The purpose of the evaluation was to find out whether the designed SWBHF in this study can address the needs of users. Experts, users and designers have evaluated the product. Details of the evaluation process are discussed in Chapter 5

Guideline 4: Research Contributions	Effective DSR must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies.	The relevant SWBHF is a novel contribution to assist health informatics software engineers / systems developers, biomedical engineers and health policy makers and implementers to consider specific frameworks relevant to Semantic Web in the healthcare domain. There are also some theoretical, methodological and practical contributions which the SWBHF can have for ehealth in South Africa, sub-saharian and developing / develop countries.
Guideline 5: Research Rigor	DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.	The present study has theoretical foundations in both IS design and SWBHF in healthcare. The new framework was designed from a thorough search of the relevant literature review (see Chapter 3). The new artefact was instantiated through a case study. Evaluation of the artefact was done rigorously using multiple methods (see Chapter 5).
Guideline 6: Design as a Search Process	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.	Design is essentially a search process to discover an effective solution to a problem. Problem-solving can be viewed as utilizing available means to reach desired ends while satisfying laws existing in the environment (Simon, 1996).
Guideline 7: Communication of Research	DSR must be presented effectively both to technology-oriented, as well as management-oriented audiences.	This study provides clear information to both the researcher and healthcare workers. The research communicates and demonstrates clear benefits to the researcher and healthcare workers regarding the benefits of integrating Semantic Web technology in healthcare, specifically, healthcare in the resource-constrained environments of developing countries by utilizing a case study of a clinic in the Dutywa Health District in Eastern Cape Province of South Africa.

4.7 Design Science Research Process and Objective-centered Approach

The Design Science Research Process (DSRP) includes the following six steps: problem identification and motivation, objectives for a solution, design and development, evaluation, demonstration and communication and its application in this research is consistent with prior literature (Gengler, Rossi, Hui, Bragge, Peffers and Tuunanen, 2006; Hevner, 2007; Baskerville, Pries-Heje and Venable, 2009; Offermann and Platz, 2009).

The iterative nature of the DSRP, as introduced by Peffers (2008) and adapted for this study, is shown in Figure 4.3 by the arrows between the various steps (see Figure 4.3).

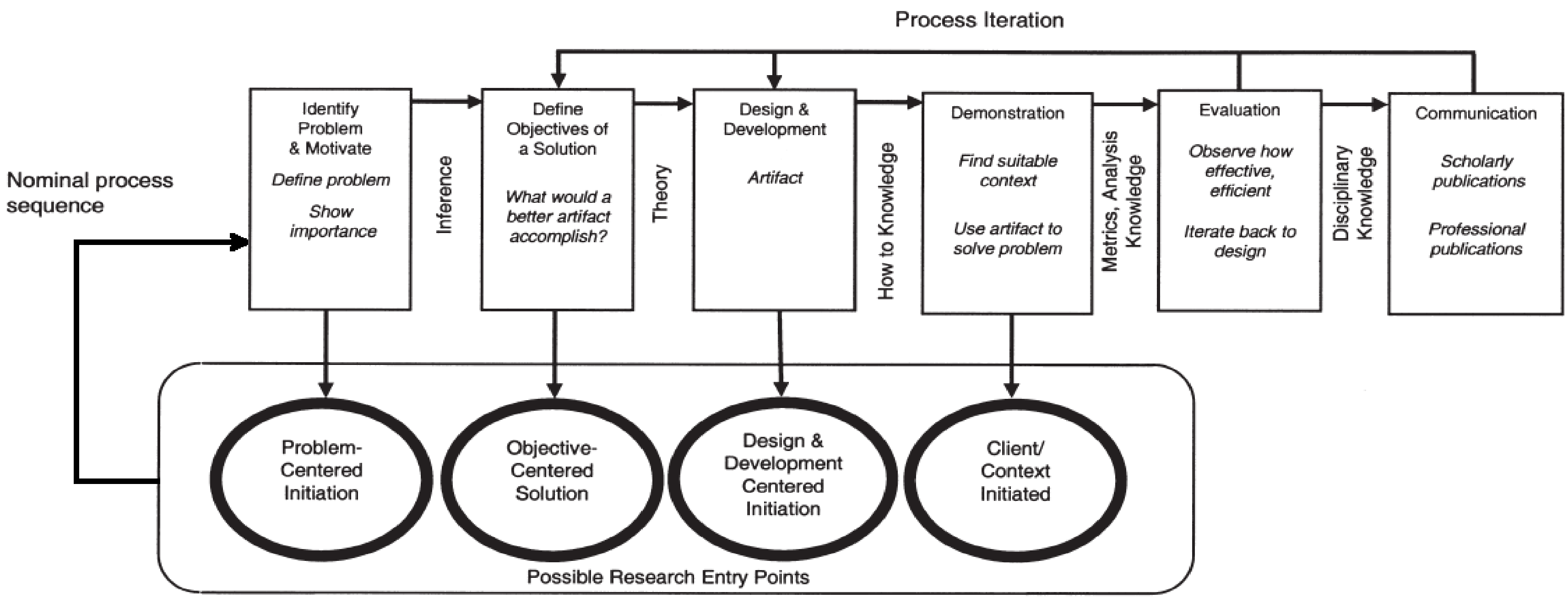

Figure 4.3: Design science research process (DSRP) model (Peffers, 2008)

The lack of a SWBHF to help software developers/software engineers developing intelligent web applications to support healthcare providers in the resource-constrained environments made searching and sharing of healthcare information on the web labor intensive. The need for a more efficient web framework to design and develop healthcare applications triggered the design of SWBHF. With this framework, healthcare personnel efficiency can be accelerated, information sharing enabled, and overloading can be improved. The risk of healthcare workers burnout can also be substantially reduced, diseases controlled, and overall healthcare system thus improved. Thus, the research pursued in this study was positioned as an objective-centered approach.

In the case of this study where a SWBHF is designed to support healthcare provision in a resource-constrained environment, the DSRM Process Model is as follows: (see Figure 4.4).

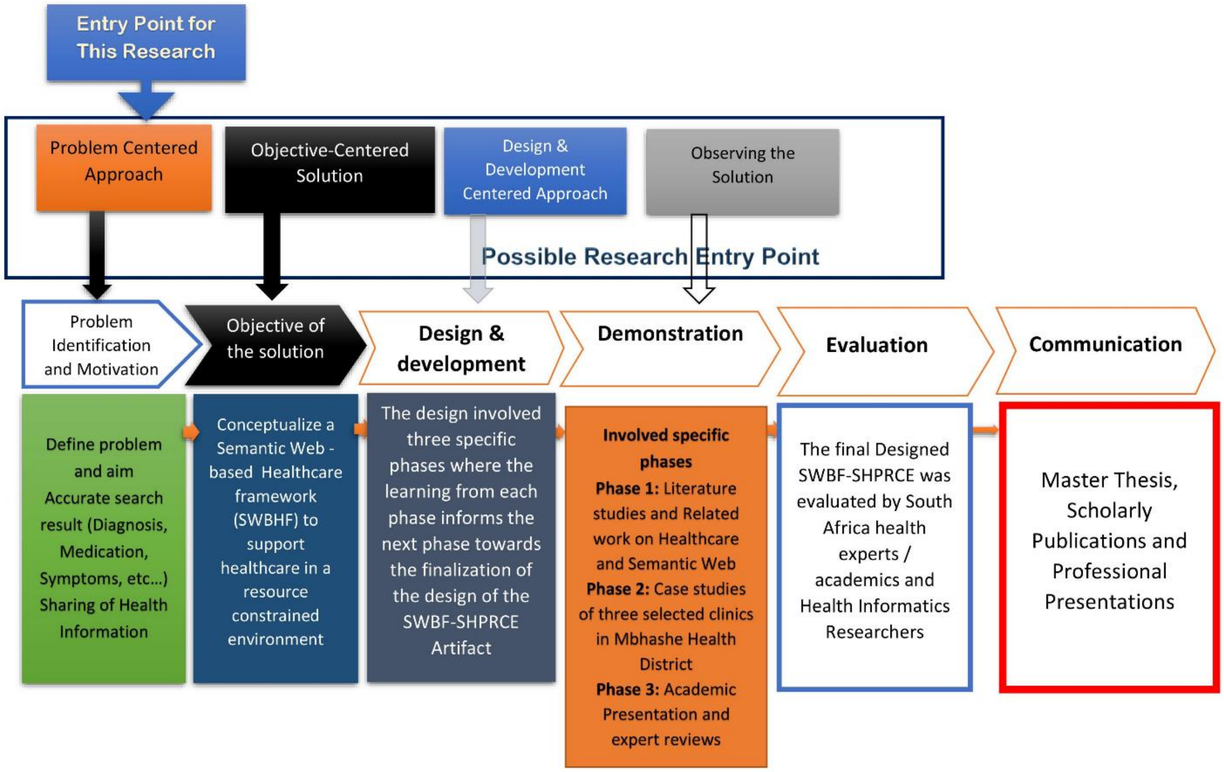

Figure 4.4: DSRP Model adapted from Peffers et al. (2008) and Herselman and Botha (2014).

Figure 4.5: DSRP Model with the multiple case studies and the deliverable from each iteration adapted from Peffers et al. (2008) and Herselman and Botha (2014).

4.8 Conclusion

This chapter identified DSR as a suitable approach for this study, as the focus is on the design of an artefact. Hevner, March (2004) research framework in the form of guideline and Peffers et al. (2008) research framework in the form of methodology were used for this study. Both frameworks are well established and are popular in IS research even though DSRG is the most cited. We also notice that the DSRM process of Peffers is gaining popularity tremendously. The next chapter provides detail on how the artefact is designed and instantiated using a case study approach.

Chapter 5: Model Design and Development

5.1 Introduction

The goal of this chapter is to design a SWBHF that supports healthcare providers in a resource-constrained environment and provides details of how the artefact was designed and instantiated for the purpose of the selected clinics in Dutywa Health District in the Eastern Cape as a case study. The framework and all the related technology are explained and how they integrate into each other. It should be noted that although the SWBHF framework identifies with the selected clinics in the Eastern Cape, this concept can be adopted for customization in other areas of the world with similar environments, particularly in Africa.

5.2 Business Benefits

This research emanates from the ICT Research Development and Innovation (ICT RDI) Roadmap and Health Strategy 2012-2017 (CSIR and DST, 2012) objective that this research attempts to respond to, as the design and development of this effort progresses from vision, to feasibility, to design and development, and evaluation (CSIR and DST, 2012) The benefits of this initiative are:

- Improved healthcare data knowledge sharing, searching and efficiency in resource-constrained healthcare environments informed by the design of a Semantic Web-based business model, hence improving healthcare information overloading. This is achieved through a case study and DSR.
- Provide data-driven decisions enabled by digital and physical world cohesion, which consequently improves the quality of life for all South Africans especially in healthcare settings.
- Improved interconnection of business process, devices and resources for healthcare through the Web. This will extend the role of the Internet in handling pure digital data to handling physical data coming from the physical world and linking patients and healthcare personnel.

- Improved ICT infrastructure access that will enable the healthcare landscape (i.e., individuals, society and the economy) to advance, and in the long run reduce healthcare costs, increase access and improve outcomes.
- Having access to the digital world, will free individuals, households and communities from the past constraints of geography, resources and ability—today and tomorrow.
- Since the piloting of this research will be in the selected clinics of the Eastern Cape Province of South Africa, that is in the Dutywa Health District, e-inclusion has been one of the challenges and this research will attempt to mitigate such factors.
- The realization of the framework development is informed by standard processes. The healthcare data will improve quality and drive better outcomes in healthcare, specifically in rural marginalized areas.

5.3 Conceptual Framework Design

The technology developed is powered by Web 3.0—the Internet of the future. It has five major significant features of the Web 3.0 blockchain. These are:

1. ***An Internet of Everything***- Smart devices that can connect and use the Internet, creating a network of devices with a purpose of connecting anything and everything to the Internet. This kind of infrastructure is not available in health now, but soon enough it will happen.
2. ***User-Centric-*** The Web 3.0 blockchain application stack is designed to be more user-centric. The semantic metadata will help the users to connect easily. The Web 3.0 IT stack is all about the users. People are now creating more content on the Web than ever. Personal blogs and vlogs are becoming extremely popular. People do not have to rely on media and corporate content makers. They are now simply following others. Thus, it creates a world where people will be more humane, and the Internet will be more user-centric.
3. ***Artificial Intelligence-*** AI will mainly work to provide better analysis and results for people. Intelligent agents will search the Internet to return results being searched for. Some of the technology giants in the world are already implementing their AI projects. The AI simply identifies a person's needs and suggests the best

option by analyzing one's behavior. Everything is interconnected. So, rather than using mass-marketing techniques, the future marketing strategy will be person based.

4. ***Semantic Web-*** The blockchain technology stack utilizes the Semantic Web. The Semantic Web simply means the method of understanding Web content the way a human being would. It relates to machine learning and AI. The Semantic Web basically tries to teach the computer to understand data and how it behaves. While Web 2.0 depends on keywords, page authority, and domain authority to rank the content, Web 3.0 browser tries to understand a Web content like a human would.
5. ***3D Graphics and Future of Contents-*** Undoubtedly, web content is now more graphical these days. People love to see and share videos and images more than they do plain text. It is more alive and soothing for the eye. In the near future, Augmented Reality (AR) and Virtual Reality (VR) will be a common thing. Different applications and games will have more life-like graphics and feel in them. Also, 3D printing will not be limited to laboratory use only. As people use 3D more and more, printing will become more available and cheaper.

5.4 Proposed Semantic Web-Based Healthcare Framework for Digital Healthcare in a Resource-constrained Environment (SWBHF)

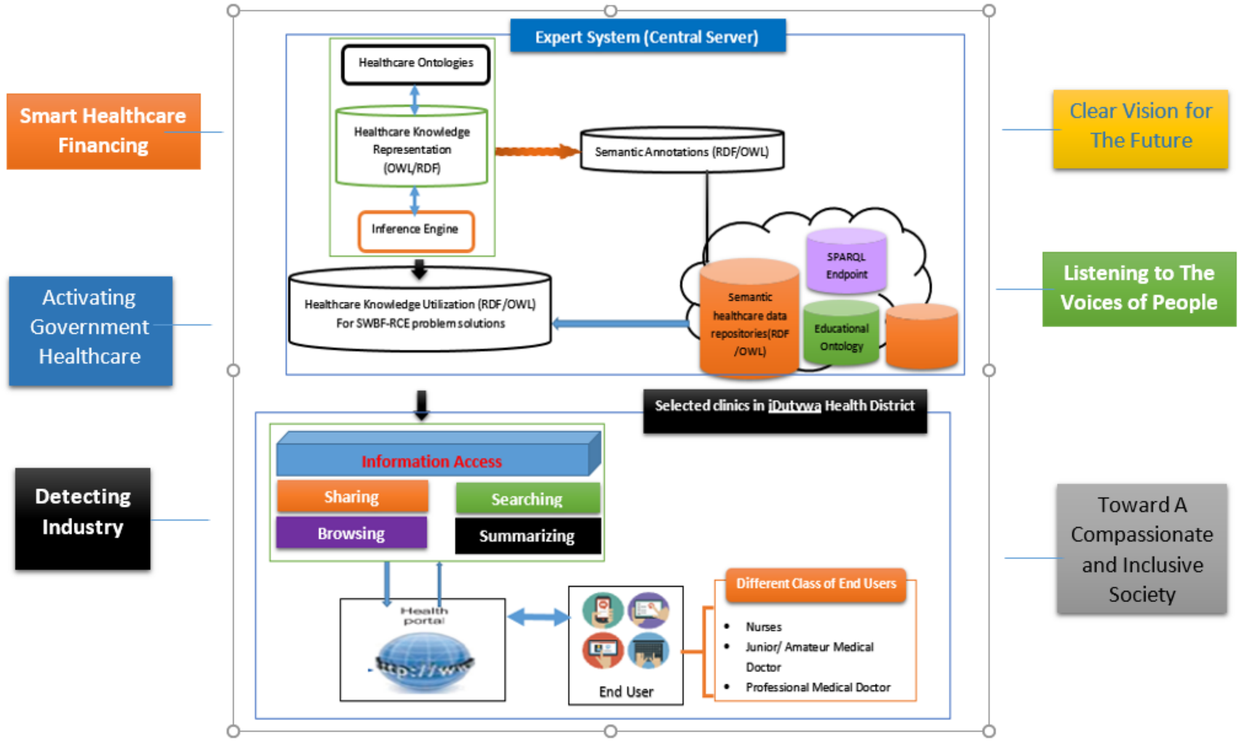

Figure 5.1: Proposed Semantic Web-Based Healthcare Framework (SWBHF)

Figure 5.1 depicts this research's contribution in the form of a SWBHF, which provides a vision for the future, i.e., innovation of a patient-centric approach. In the traditional healthcare model, the links between stakeholders often bypass the patient entity in terms of business engagement. Moving forward to Semantic Web-based enabled healthcare, it is critical to establish a direct connection to the Consumer-Patient model. Components 1-6 depicts the high-level mechanism of one of the components contained in the ICT RDI Roadmap and Health Strategy 2012-2017 (CSIR and DST, 2012) that this study responds to. These are:

1. **Clear vision for the future-** All companies and resource planners must pay attention to the growth of megatrends and the increasingly rapid pace of disruptive technologies that affect the healthcare industry's baseline standards. As capacities and practices often change slowly, there is a risk of a lack of demand-supply (ICT RDI, 2015).

2. **Smart healthcare financing**- With the challenge of evolving and rising healthcare demands facing us, a major ongoing effort is being made to review the funding mechanisms currently in place and potentially available to finance current or future healthcare systems. Among the variety of healthcare funding options, resource allocation, fund collection, and risk pooling are the fundamental roles played by the funding mechanisms within a healthcare system. The harmonization of these tasks relies on the healthcare system's management and institutional fine-tuning.
3. **Listening to the voices of the people**- In a model influenced by the consumer-patient, the role of social media becomes more and more dominant in the healthcare realm. Not only are the ramifications of this restricted to a point of view for information dissemination and advertising, it also requires an understanding of patient behaviour and values that are more interactive and better. As a result, more can be done to influence lifestyle choices and encourage healthy behaviours. Considering that the problem of increasing chronic disease treatment costs is one that health systems need to find effective ways to deal with, a new patient-centred approach is likely to improve chances of success. In addition, the challenge of increasing patient engagement stretches beyond just the aspect of social media. It also requires a greater understanding of a new model for interpreting patient behaviour and shaping this.
4. **Detecting the industry**- With many moving parts in the system, it is often easy to forget that the healthcare industry is largely dependent on the skilled staff and medical professionals who collectively drive from start to finish the entire patient experience. We are the custodians of the name and prestige of a health organisation. Manpower issues will remain on the agenda of the day, but evolving issues such as job flexibility and justice need to be addressed promptly. The fact is that if a successful triple-dividend partnership cannot be reached between the healthcare industry (employer), healthcare workers and customers (patient), then modest progress can be made for the industry.
5. **Towards a compassionate and inclusive society**- When global demand for healthcare moves from the initial prevailing emphasis on acute care to an intermediate and long-term care model, the healthcare system must represent not

only patients with chronic illness but also a subset of the elderly. This would include therapy services as well as channels for social support and healthcare. Nonetheless, the 'care' aspect of 'healthcare' will become more pronounced, and the overall approach must reflect this. It is arguable that efforts to achieve an inclusive social goal extend beyond healthcare discussion. At the same time, however, it is undeniable that any pragmatic and enlightened approach will have to include in the equation the health system. With healthcare costs increasingly escalating, it is also likely that a proportion of younger demographics will be financially affected if an adult who is a close family member suffers from a disease. Therefore, it is increasingly important for any future healthcare system to set its priorities for equal and fair access, irrespective of social status, through a variety of funding mechanisms best suited to the context. If this is not done, cultural, political and economic problems are likely to emerge in the future.

6. **Activating governmental healthcare**- Governments must continue to play an effective role in healthcare, supporting national security (universal health), quality (cost leadership), affordability (accessibility) pillars, and assuming responsibility within the health system. Instead of playing a single role as a custodian or regulator, governments are expected to play a more active role in regional collaboration (government-to-government relations) and become a mover of market collaboration (a catalyst for business-to-business partnerships). The public sector is the largest healthcare provider and payer for most markets with the majority of patients under their care and is therefore an influential stakeholder in the healthcare system.

Components 7-15 is the core Semantic Web architectural organization of the system, which acts as a vehicle in harnessing healthcare service delivery of the SWBHF. These components of the framework address the computer organization and architecture respectively. The idea of emphasizing on the organization of the system’s architecture in the proposed framework is illustrated by the “Selected clinics in Dutywa Health District” component, representing the computer system behavior as seen by the user, that is, the architecture design at the lower level. The “Expert System (Central Server)” component portrays the interaction between the hardware and software as an interface, that is, the way hardware components are connected together to form a computer system. Since we recommended that the SWBHF is essential for use to both low level users (healthcare practitioners, patients and other relevant stakeholders), high level users (system developers); it is essential to engage on how both components work in unison to achieve the required outcome that feeds to the idea of external components at large.

7. **Expert System (Central Server)**

   The expert system is a ground-breaking approach that harnesses the Semantic Web and healthcare used to support healthcare providers by mining valuable medical information (Al-Hamadani & Alwan, 2015). Semantic Web and agent-based technologies, such as (healthcare ontologies, inference Engine and healthcare knowledge representation (OWL)) are used to structure information in a more understandable and machine interpretable way to represent information sources, such as symptoms, diseases, genes, geographical location of diseases, and other medical procedural information. If this is done successfully, then healthcare ontologies attributes can be fed into an inference engine (e.g., Jena, JESS, JADE, RACER), which can effectively make new discoveries useful to the patient treatment recommendations to reduce the required time of care providers, patients and saves many medical resources (Al-Hamadani & Alwan, 2015).

8. **Healthcare / Medical Ontologies (OWL/RDF)**

   In this case study, healthcare ontology is a model of the knowledge base from a clinical domain such as heart failure syndrome. It contains all of the relevant concepts related to the diagnostics, treatment, clinical procedures and patient data. Ontologies will be designed in a way that allows knowledge inference and reasoning.

   In the case of this study, it represents a knowledge base which then becomes available to an application that needs to use and / or share the knowledge of a domain. Within health informatics, an ontology is a formal description of a health-related domain.

   The benefits of ontologies are as follows: -

- Ontologies can help build more powerful and more interoperable information systems in healthcare.
- Ontologies can support the need of the healthcare process to transmit, re-use and share patient data.
- Ontologies can also provide semantic-based criteria to support different statistical aggregations for different purposes.
- Possibly the most significant benefit that ontologies may bring to healthcare systems is their ability to support the indispensable integration of knowledge and data.

9. **Healthcare Knowledge Representation (OWL/RDF)**

   The descriptive part of the knowledge base is realized as an ontology (OWL/RDF) which conceptualizes the medical domain. Healthcare knowledge representation formalism and the types of reasoning supported are of major importance for the development of knowledge-based systems in healthcare informatics.

10. **Inference Engine**

   The inference engine is the heart of every expert system. It is the inference engine which draws conclusions by applying abstract knowledge to concrete knowledge. In this study, an inference engine is needed to process the knowledge encoded in a Semantic Web language such as OWL. The OWL language is the source of description logic (DL) and knowledge representation language, which is designed to encode the knowledge with concepts and concept hierarchies. There are a number of inference engines that exist to support OWL Language e.g., Racer by Racer Systems (open-source), Jena inference support (open-source), Pellet: OWL DL reasoner for Java (open-source), FaCT++ (open-source, in C++), and RDF4J(Sesame) supports RDFS reasoning, etc...

11. **Healthcare Knowledge Utilization (RDF/OWL)**

   The healthcare knowledge utilization will serve as the knowledge backbone responsible for maintaining the currency, quality and validity of healthcare knowledge used to develop the healthcare system.

12. **Semantic Annotations (RDF/OWL)**

Semantic annotations will be responsible for linking healthcare electronic resources to a specific ontology. Healthcare electronic resources can be healthcare text contents, healthcare images, healthcare videos, and healthcare services, etc. Ontology here is only one of the possible means to provide a formal semantic. Semantic annotation uses ontology objects to enrich resource information that tells a computer the meanings and relations of the data terms. Semantic annotation could also be used in this framework to bridge the gap between models as additional information that helps description, discovery and composition.

13. **PARQL Endpoint**

Although machine-readable data sets are mainly published for software agents, it is not always a choice to automatically extract data. Semantic information retrieval also requires users looking for answers to a complex question based on the knowledge in a dataset or database that is formally represented. While Structured Query Language (SQL) is used to query relational databases, the SPARQL Protocol and RDF Query Language (SPARQL) can be used to query databases and flat Resource Description Framework (RDF) files (Hasnain, Mehmood, e Zainab, & Hogan, 2018). RDF is a primary query language, which is much more efficient than SQL. SPARQL, is a structured language capable of querying local and online RDF files, Linked Open Data (LOD) datasets, and graph databases; building new RDF graphs based on the information in the graphs being queried; adding new RDF statements to or removing triples from a graph; causing logical consequences; and federating queries. Some Semantic Web software tools, as for programmers, provide a programmatic access SPARQL application programming interface (API).

14. **Semantic Healthcare Data Repositories (RDF/OWL)**

In this part of the framework, healthcare data repositories may include information about clinical laboratory test results, patient demographics, pharmacy information, radiology reports and images, pathology reports, hospital admission, discharge and transfer dates, ICD-9 codes, discharge summaries, and progress notes. This is where the intelligence of the web is invoked. The information is published based on the user's search context to meet their needs, meaning the web is data-driven and a Semantic Web. The main purpose of healthcare Semantic Web-enabled data repositories is to provide uniform access to multiple heterogeneous information sources that perform a single query to the set of local schemas. It also serves as a starting point of healthcare interoperability and information sharing. The Semantic Web simply tries to teach the computer to understand data and how it works, more like how the human behaves. It is connected with machine learning and AI (El Idrissi, Baïna, Mamouny, & Elmaallam, 2022).

15. **Web Browser / Information Access**

    A web browser is the final part of the framework. It acts as an interface to send and receive data requests on behalf of the end-user to the end-users' (healthcare provider and others) benefit. The web browser also serves as a user interface that allows the user to properly and conveniently interact with the system in submitting queries and giving feedback on the suitability of results returned.

5.5 Semantic Web-Based Healthcare Framework (SWBHF) Prototype Design

UML provides the graphical representation of visualization, specifying, constructing and documenting the artefacts. This research attempts to solve the problem of information overloading, shortage of healthcare workers, lack of infrastructure and resources in resource-constrained environments. It shows that developers can use this solution to develop systems custom-made for a specific resource-constrained environment.

5.5.1 Use Case Diagram

The use case diagram allows researchers to give a description of the possible usage scenarios (use cases) that a system is developed for. It expresses what a system should do but does not address any realization details such as data structures, algorithms, etc.…. Figure 5.2 illustrates a use-case diagram that shows actions that can be performed by a user (healthcare workers. e.g., physicians, nurses, junior medical doctors with no field experience and students from medical university school, amateurs) in the system in trying to address information overloading through sharing and searching for health information during a medical intervention. Moreover, healthcare workers can also edit knowledge-based stores into semantic healthcare data. The system also allows knowledge engineers to constantly update the domain ontologies (healthcare ontologies) on the health district server as well as local clinic servers.

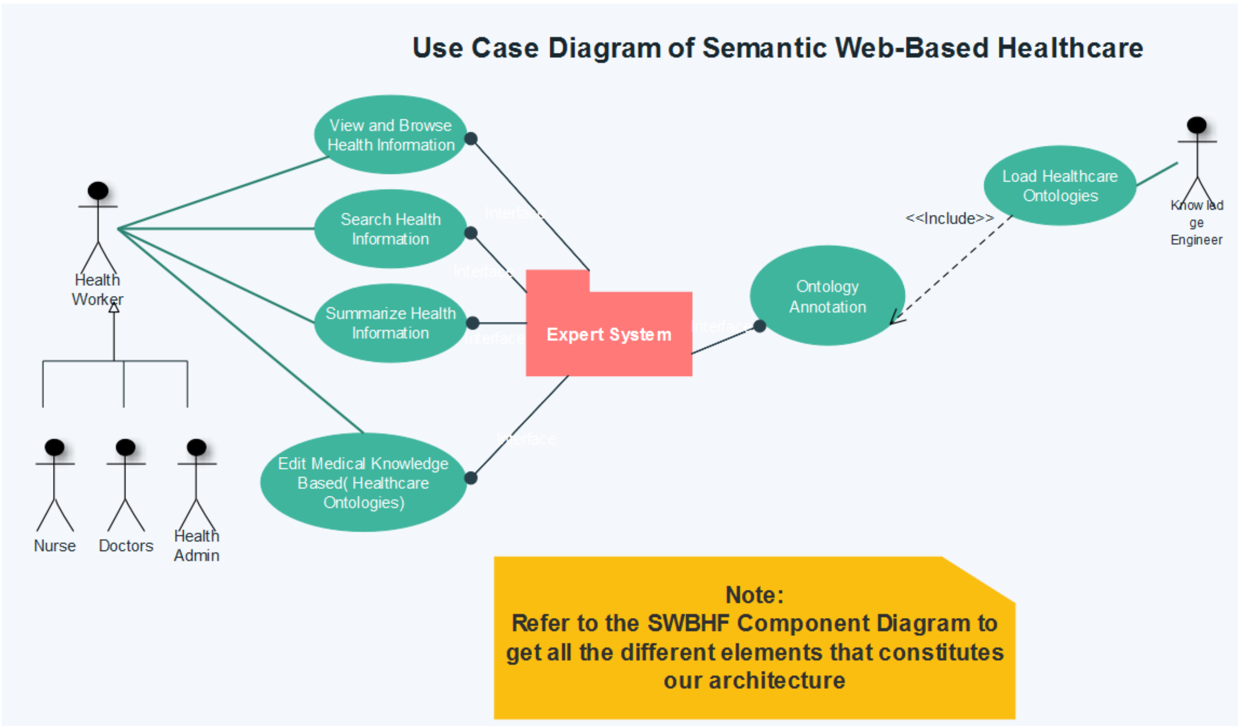

Figure 5.2: Use case diagram of SWBHF for digital healthcare in RCE

5.5.2 Sequence Diagram

Figure 5.3 is the sequence diagram of how healthcare workers mitigate information overloading by searching and sharing healthcare information extracted from the knowledge bases of medical ontologies. Retrieval of healthcare information is performed through the following steps:

1. Healthcare workers formulate the search information and enter it into the Expert System.
2. The Expert System uses an agent-based information retrieval to connect to the knowledge based and SPARQL queries are run.
3. After the running of the query, the information is retrieved and returned to the Expert System.

4. The Expert System ranks the results according to the most suitable information ready for clinical decision support.
5. The ranked result is displayed to the healthcare worker via a web browser.

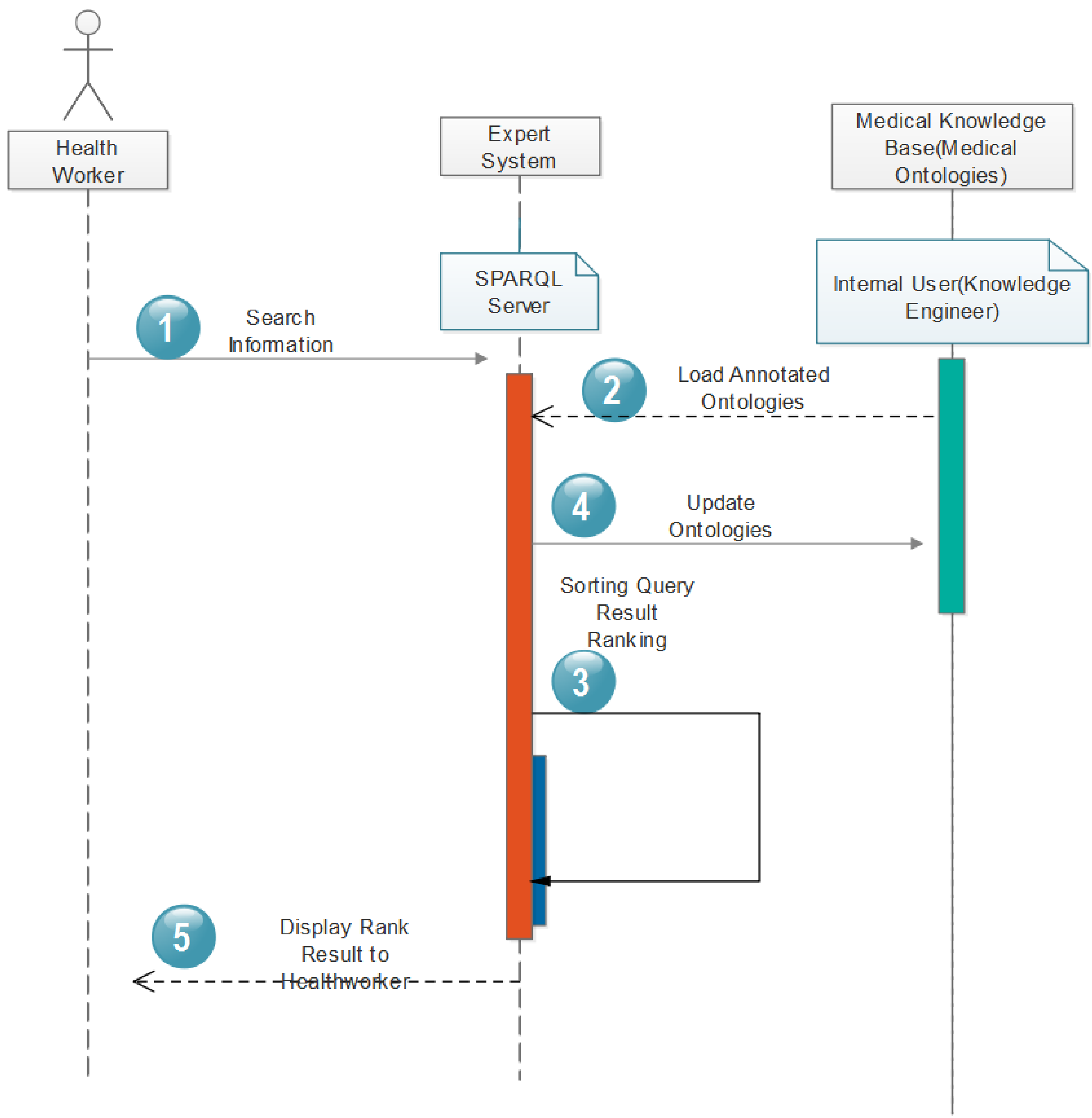

Figure 5.3: Sequence Diagram of SWBHF

5.5.3 Activity Diagram

The activity diagram focuses on modelling the procedural processing aspects of a system. It specifies the control flow and data flow between various steps of the actions required to implement an activity. The flow gives meaning like a start activity, the decisions that may occur, and a finished activity.

Figure 5.4 shows the activity diagram of the SWBHF. The flow of the events starts with healthcare workers seeking for health information. The healthcare worker enters the laboratory test, disease information or treatment information, etc. into the Expert System. The rule-based inference engine e.g., Jena, JESS, JADE, etc. which is Java API for the Semantic Web suggests the potential disease associated that will undergo a query using SPARQL Protocol and RDF Query Language (SPARQL). The row(s) that satisfy the query are selected, ranked and displayed to the user (healthcare workers).

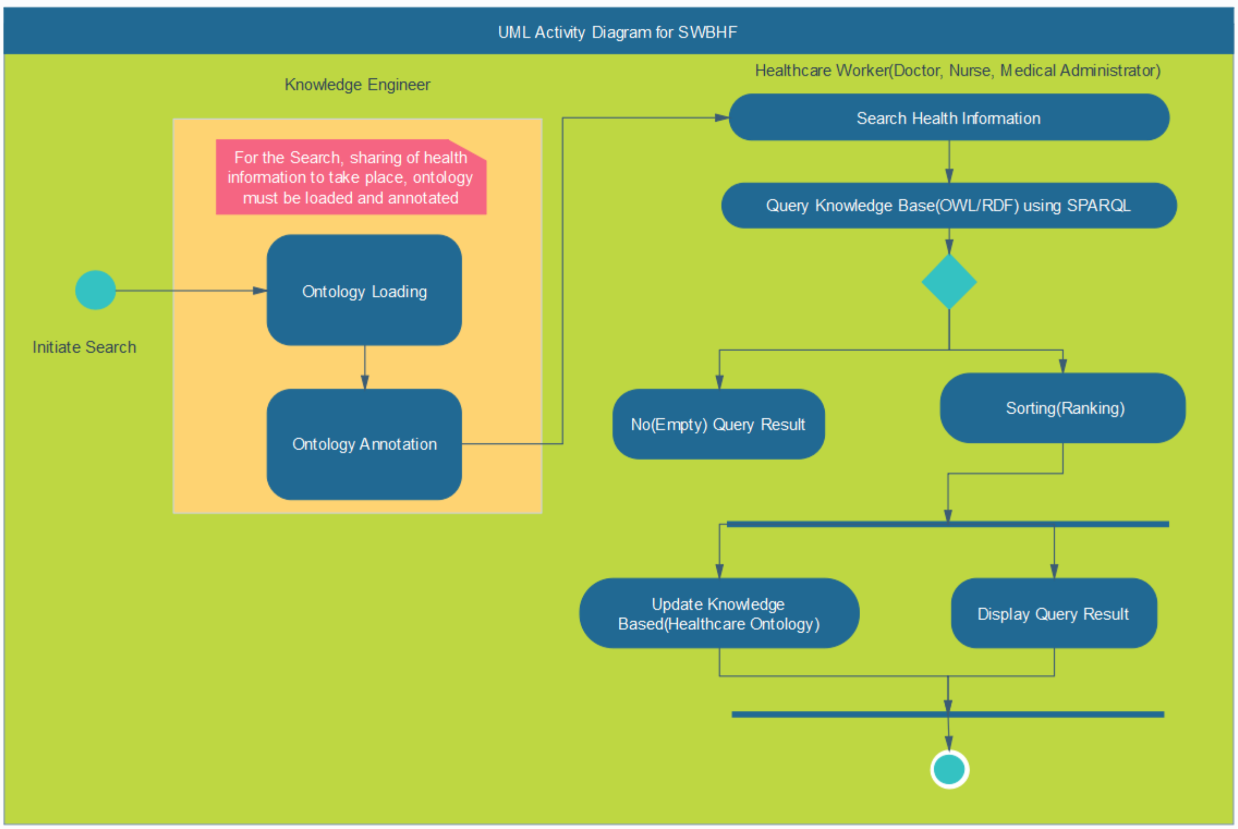

Figure 5.4: Activity Diagram of SWBHF

5.5.4 Component Diagram

The component diagram shows application links among components of the system. A component is an independent, executable unit that provides other components with services or uses the services of other components [Figure 5.5].

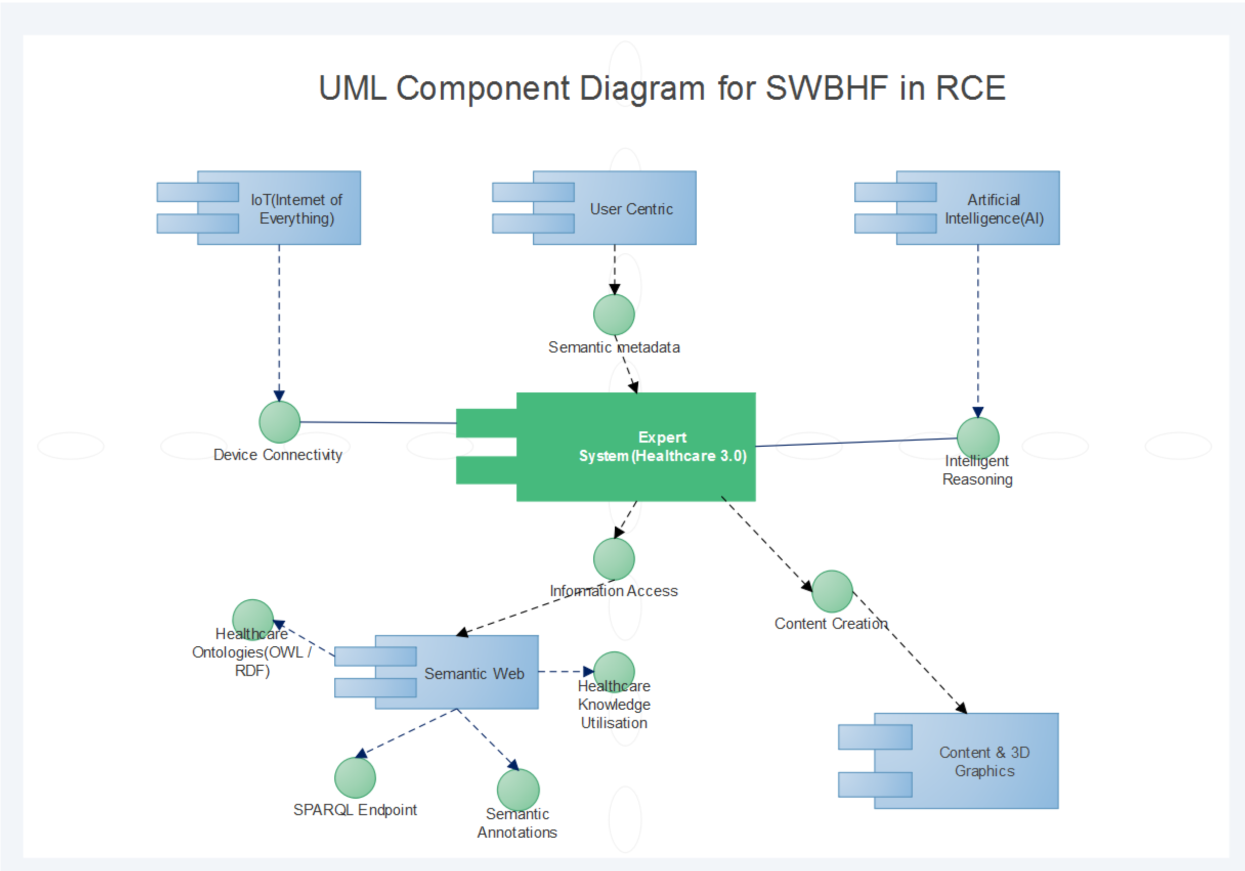

Figure 5.5: UML Component Diagram Depicting the SWBHF in a RCE

5.5.5 Deployment Diagram

The deployment diagram specifies the physical hardware on which the software will execute and specifies how software is deployed on that hardware [Figure 5.6].

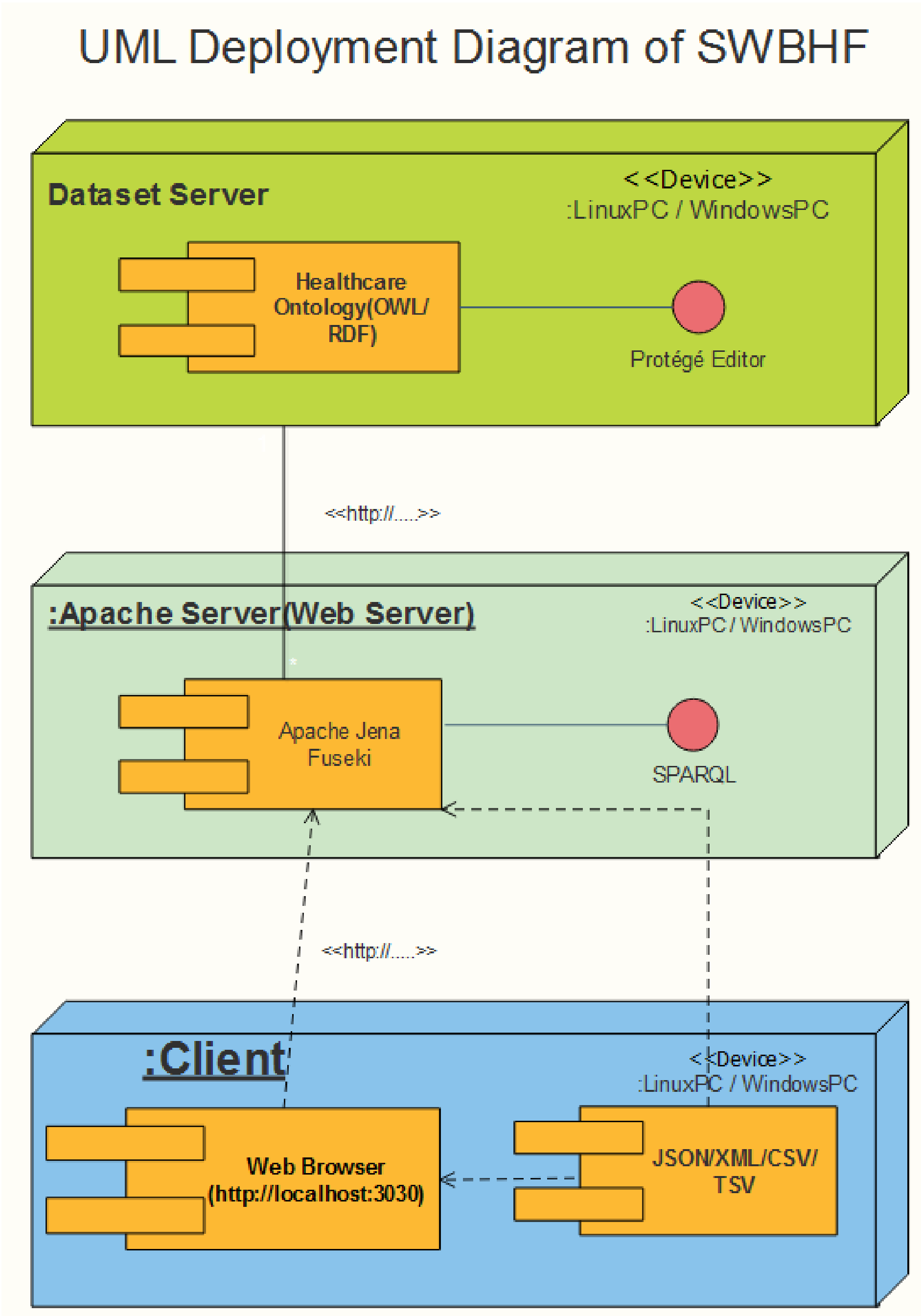

Figure 5.6: Deployment Diagram of SWBHF in a RCE

5.6 Hardware Infrastructure for Resource-Constrained Environment (RCE)

Figure 5.7 illustrates the hardware infrastructure at the selected clinics in Dutywa Health district, with each clinic, having its own decentralized peer-to-peer network thus allowing it to function independently. The main district server that synchronizes data between clinics via a low bandwidth GPRS connection from the normal GSM cellular network is also illustrated. This figure also shows that in these clinics there is also a wireless local area network driven by enhanced connectivity such as 5G that allows healthcare workers (physicians, nurses, junior medical doctors with no field experience and students from medical university school) to be at liberty to access the necessary data since all the data is distributed over the whole network. Through the use of a blockchain technology stack amongst another existing decentralized web stack, the proposed SWBHF framework can be a decentralized, secured and private network that focuses on being humane. It will necessitate better connectivity to users.

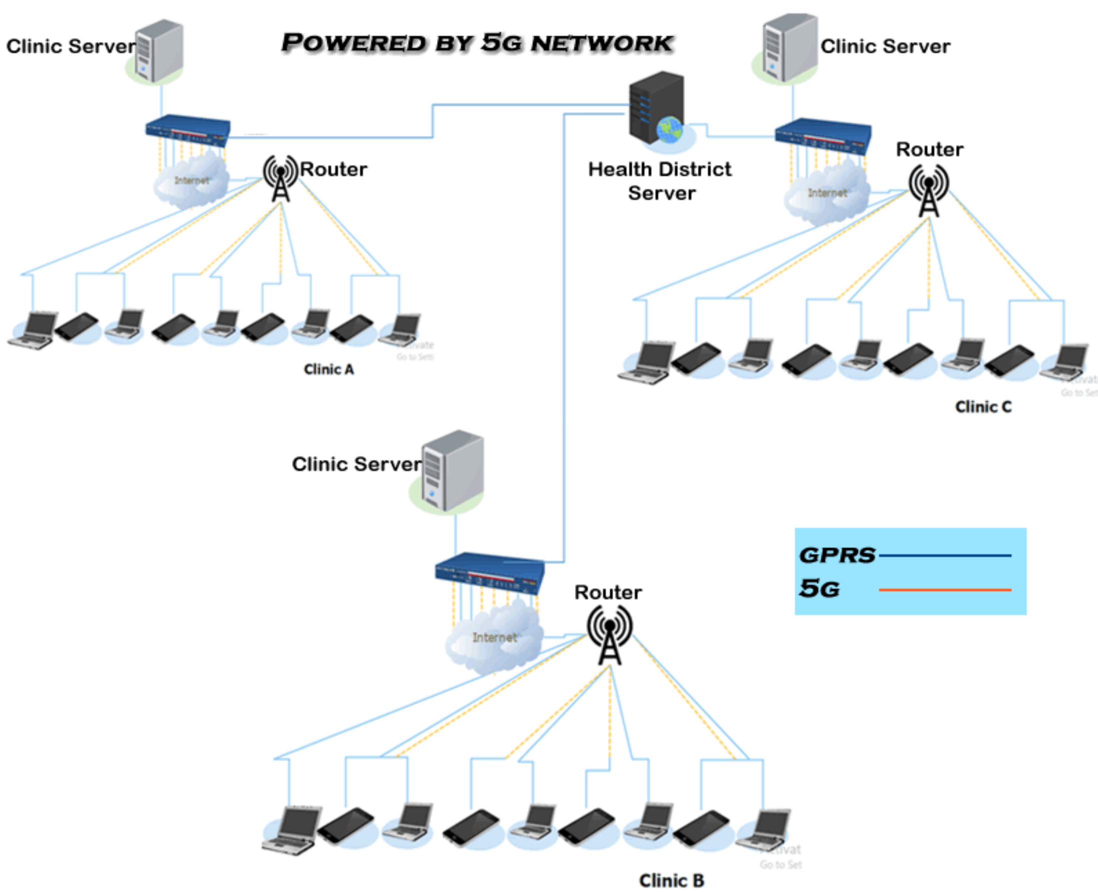

Figure 5.7: Propose Hardware Infrastructure Healthcare in RCE

5.7 Chapter Summary

This chapter discussed the different components of the prototype design of Semantic Web-Based Healthcare Framework for Digital Healthcare in a Resource-constrained Environments (SWBHF). The hardware infrastructure for resource-constrained environments was also discussed. The use of UML was to graphically represent functionalities of the system through the use of use cases, sequence and activity diagrams. A use case model portrayed the proposed functionality of a new system between a user (healthcare workers) and the system. The sequence and activity diagrams illustrate how sequentially information is extracted in the knowledge based for evidence-based medicine or clinical decision support, mitigating the information overloading challenges of healthcare workers in the resource-constrained environment in developing countries.

Chapter 6 Model Prototyping and Evaluation

6.1 Introduction

Chapter 5 was around the model design and development of the SWBHF, the discussion that supports healthcare workers in a resource-constrained environment. The model design was represented using a UML diagram approach to show the system's architectural blueprints, which include activities, actors, business processes and reusable software components. This chapter discusses the implementation of the prototype using Free and Open Source Software tools. This Open Source choice will mitigate the costs of healthcare in the resource-constrained environments as well as the development cost. Existing healthcare / medical ontologies available are reused e.g., Human Disease Ontology, Diabetes Ontology, HIV Ontology, Symptom Ontology, Infectious Disease Ontology, Drug Interaction Knowledge Base Ontology, Breast Cancer Ontology, etc... instead of building each of them from the beginning. Finally, this chapter discusses the evaluation of the prototyping system.

6.2 Software Platform for Prototyping SWBHF

To keep the vision of the Semantic Web, which is to efficiently enable machines to interpret information, allowing them to perform the most complex tasks, which include finding, searching, combining, and acting upon information on the web. Several software platforms and application interfaces (APIs) have been developed to permit the editing and use of RDF(S) and OWL ontologies.

The prototype version of the SWBHF to support healthcare providers in resource-constrained environments has been made possible with the support of several tools contributing to the achievement of the goal.

There is plethora of Semantic Web software tools proposed both by private and open source institutions when coming to developing Semantic Web applications. For the current dissertation project, the utilized software tools deal with the triple store server, the provision of a SPARQL endpoint and the editing of the ontology. This section gives an overview of the chosen software products and their use for the project purposes. Furthermore, they are all open source software and might facilitate the reusability and repeatability of this study.

6.2.1 Apache Jena

Apache Jena is a free and open source Java framework (collection of tools and Java libraries) for simplifying the development of the Semantic Web and Linked Data applications. It supports-:

1) RDF – Resource Description Framework:
    a) RDF API – Interacts with the core API to create and read RDF graphs. It serializes triples by using popular formats such as RDF/CML or Turtle
    b) ARQ (SPARQL) – Query your RDF data using ARQ, is a SPARQL 1.1 compliant engine. The ARQ supports remote federated queries and free text search
2) Triple Store:
    a) TDB – Data is persisted by using TDB, a native high-performance triple store. TDB supports the full range of Jena APIs
    b) Fuseki – Exposes triples as SPARQL end-points accessible over HTTP. Fuseki provides REST-style interaction with RDF data
3) OWL – Web Ontology Language:
    a) Ontology API – It work with models, RDFS and the OWL to add extra semantics to RDF data.
    b) Inference API – Provides reason over data to expand and check the content of the triple store.

6.2.2 Framework Architecture with Fuseki Server

Jena Fuseki Apache is a SPARQL server. It can operate as a utility for the operating system, as a Java web application (WAR file) and as a standalone server. This provides security and a server control and management user interface. It offers query and upgrade protocols for SPARQL 1.1 as well as protocol for the SPARQL Graph Store. To provide a robust, transactional, persistent storage layer. Fuseki is tightly integrated with TDB and incorporates Jena text query and Jena spatial query. It can be used to provide other RDF database and storage systems with the protocol engine.

It is worth noting that Fuseki is among the best available triple stores that supports most of the Semantic Web technologies and only works well with the Java programming language. It can be installed on all types of computers e.g., servers and / or client computers running on any type of operating system e.g., Linux, Windows, Unix, etc. There exist some special versions of triplestores that are produced for ubiquitous devices (low-power devices with less powerful CPU and smaller memory size), e.g., Androjena, μJena are examples of such triplestores.

Fuseki [Figure 6.1] provides REST-style interaction with RDF data. It is a SPARQL server that provides REST-style SPARQL HTTP Update, SPARQL Query, and SPARQL Update using the SPARQL protocol over HTTP.

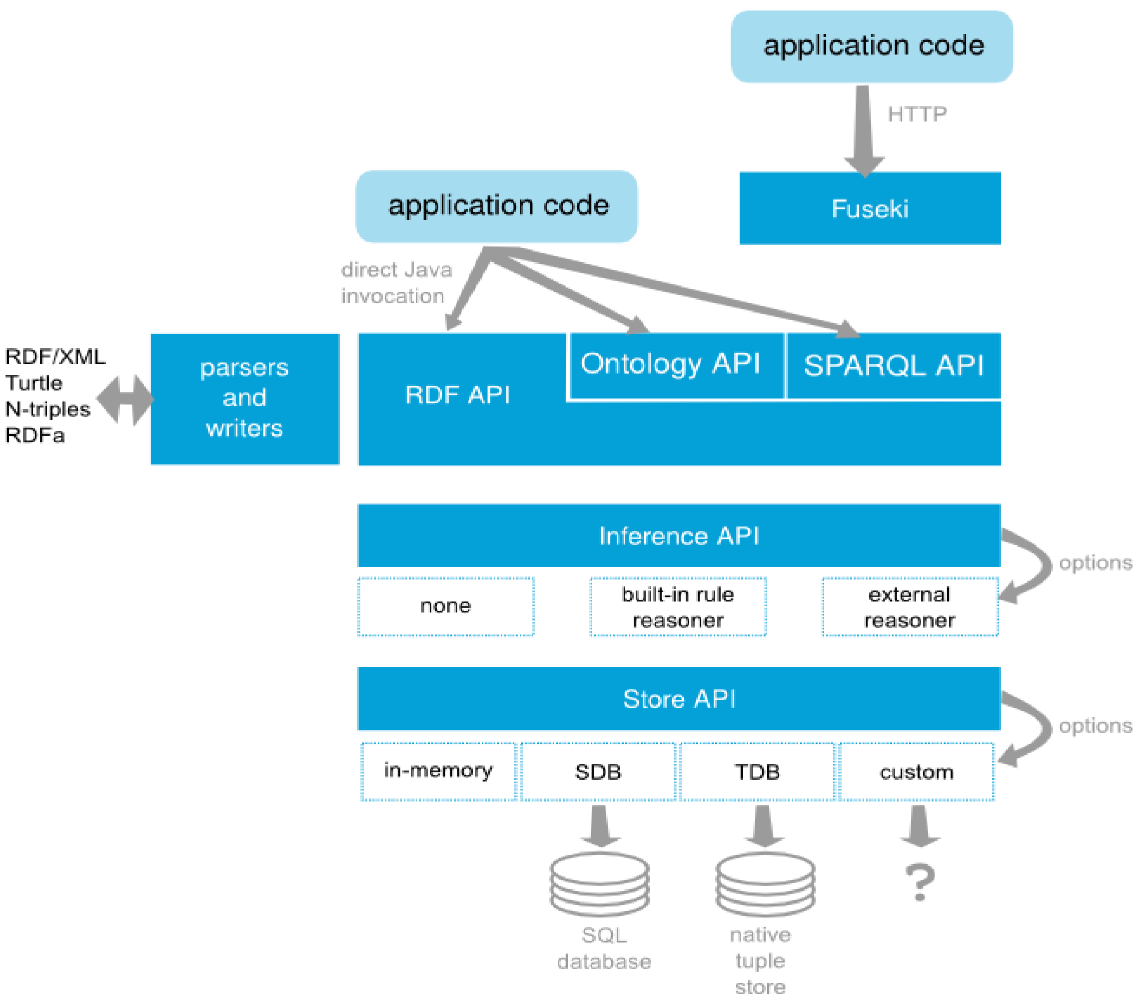

Figure 6.1: Framework Architecture with Fuseki Server

6.2.3 Setup of Apache Jena Fuseki server

To setup Jena Fuseki, the following software must be downloaded [Figure 6.2].

- To download Apache Jena Fuseki Server, follow this link: https://jena.apache.org/download/index.cgi . Jena requires Java8 from Jena version 3.0.0 onwards. Therefore, to download java8 follow this link: https://www.oracle.com/technetwork/java/javase/downloads/jdk8-downloads-2133151.html
- First of all, install first Java8 and Java Runtime Environment
- Unzip apache-jena-fuseki-3.10.0.zip on the root folder. In my case it is C:

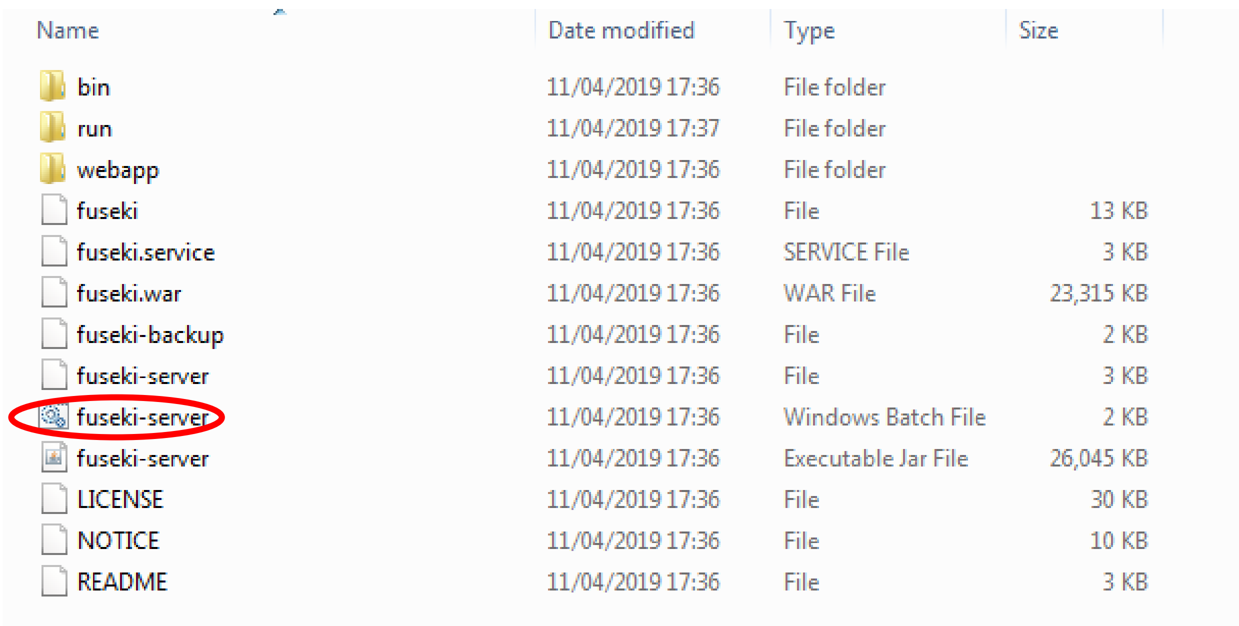

Figure 6.2: Screenshot after unzipping Apache-Jena-Fuseki-3.10.0.zip:

Double click on Fuseki server Windows Batch to start it as a windows service (Figure 6.3) and run Apache Fuseki Server in the browser by entering: localhost: 3030 (See Figure 6.3)

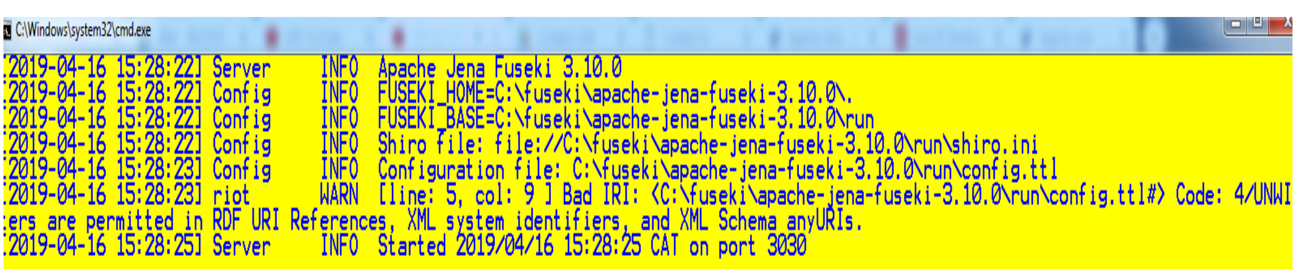

Figure 6.3: Screenshot after double-clicking fuseki-server (Windows Batch File)

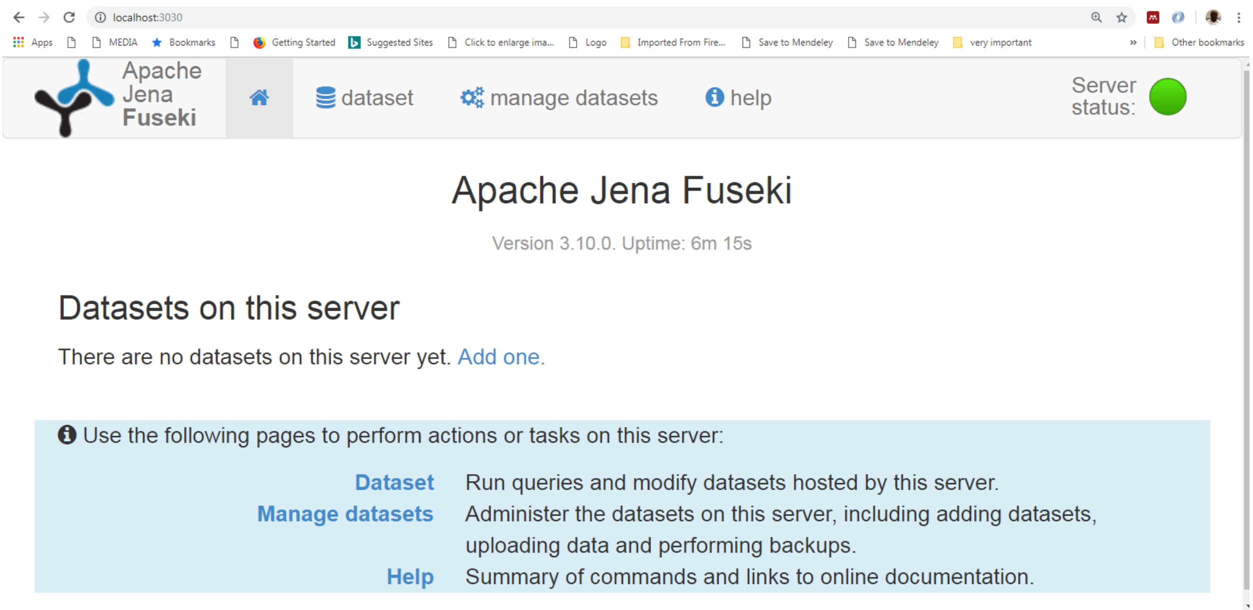

Figure 6.4: Apache Fuseki Server Running on Port 3030 on http:// protocol

6.2.4 Managing Datasets and Running of the SPARQL Query

For the prototyping simulation, the following ontologies on this ontology repository were selected: https://bioportal.bioontology.org/ontologies :

- Cardiovascular Disease Ontology (CVDO)
- Human Disease Ontology (DOID)
- HL7 FHIR and SSN ontology-based Type 1 Diabetes Mellitus Ontology (FASTO)
- Symptom Ontology (SYMP)
- The Drug Ontology (DRON)
- HIV ontology (HIV)
- Ontology for General Medical Science (OGMS)

Step 1: is the dataset creation like CVDO, DOID, FASTO, SYMP, DRON, HIV, and OGMS as shown in Figure 6.5.

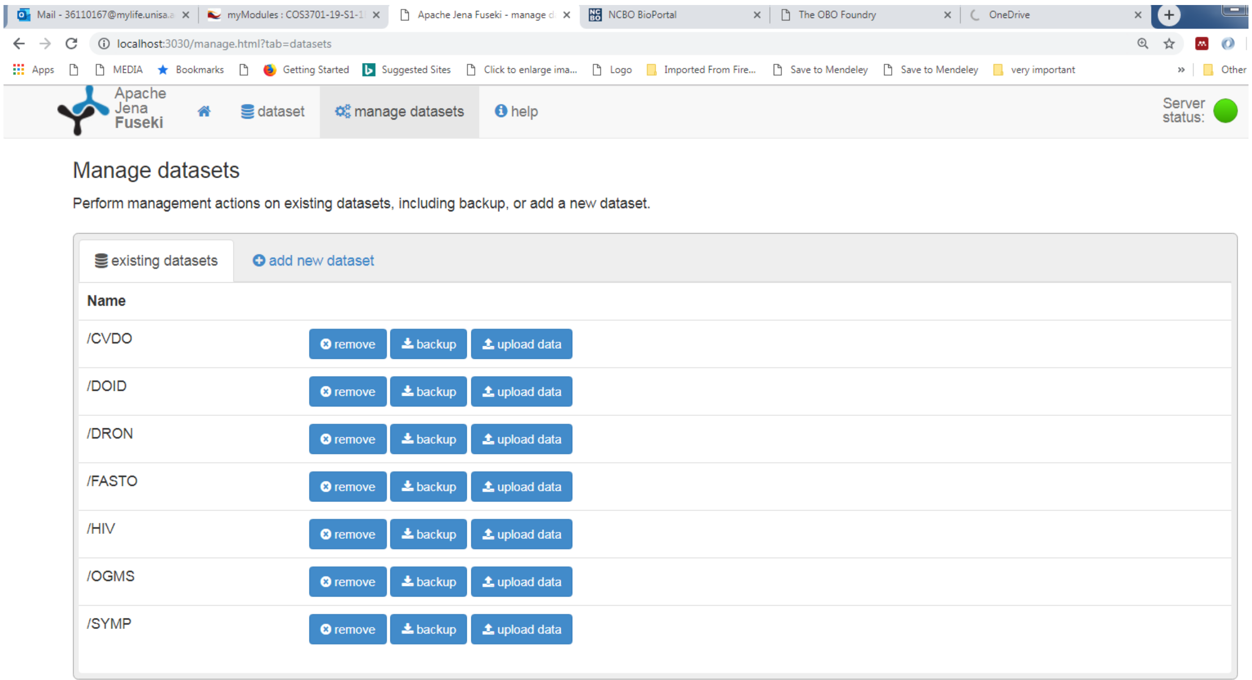

Figure 6.5: Dataset creation

Step 2: is the uploading of ontology to their respective datasets as shown in Figure 5.5

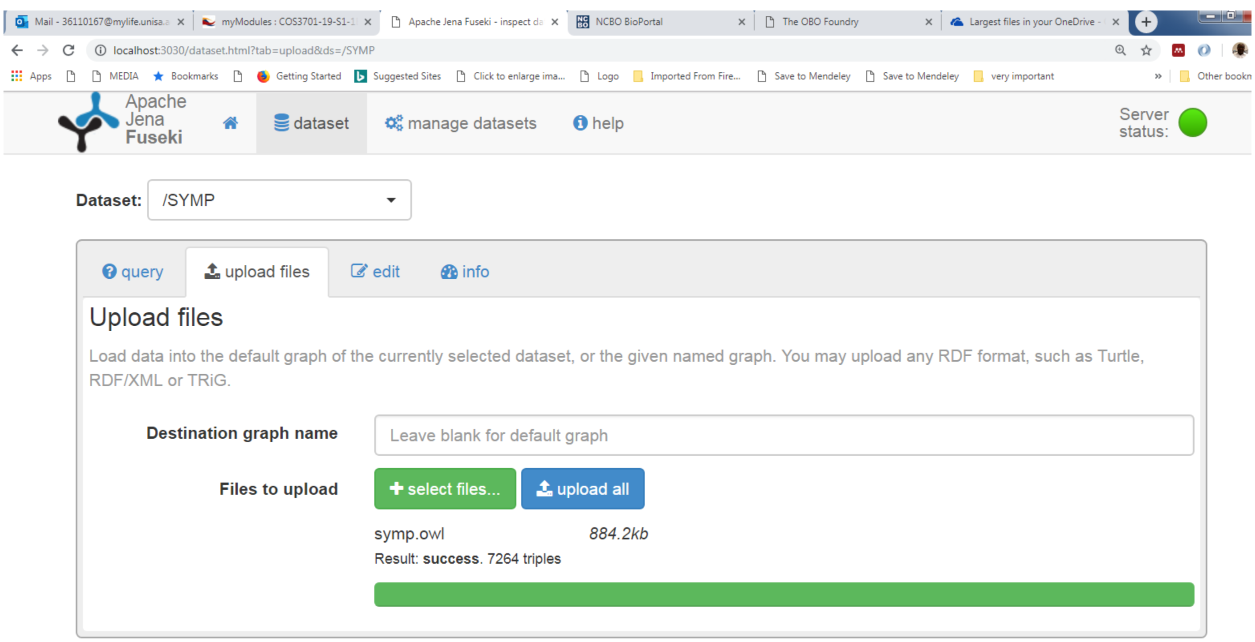

Figure 6.6: Uploading of Ontology

Step 3: is running SPARQL in Apache Jena Fuseki to extract knowledge as shown in Figure 6.7

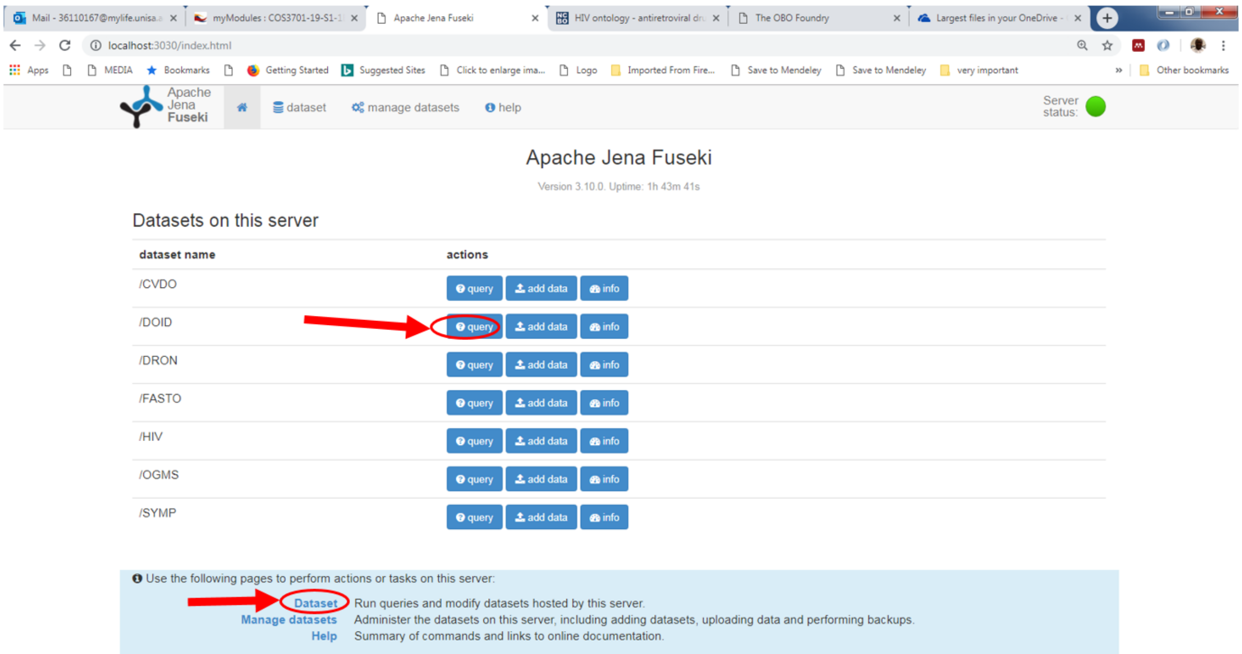

Figure 6.7: Uploading of ontology and running query

Step 3.1 is the query: as shown in Figure 6.8. This SPARQL query extracts the class of diseases, their labels and disease description without duplicates from the Human Disease Ontology knowledge base.

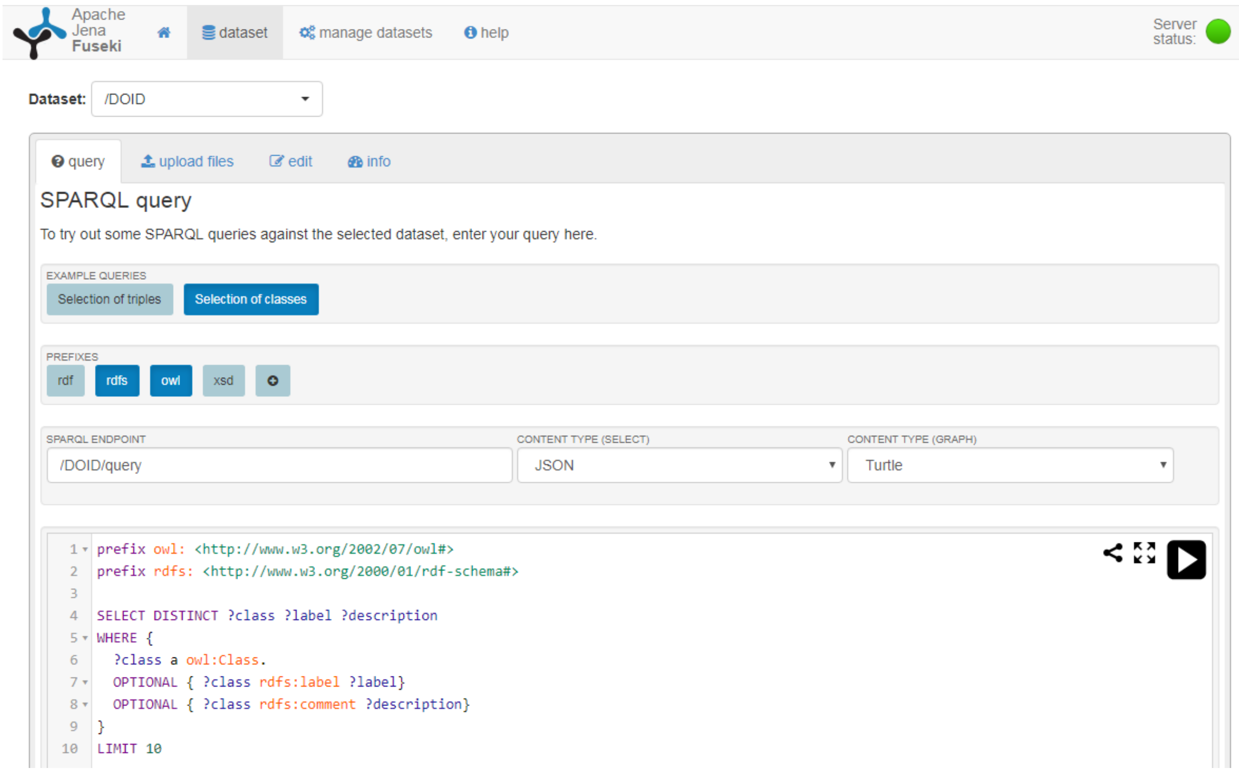

Figure 6.8: Query Execution

Step 3.2: is the results of the query as shown in Figure 6.9. The Figure shows a view of the results of the query, which are a selection of triples (S-P-O)-Triplestores.

	subject	predicate	object
1	<http://purl.obolibrary.org/obo/doid.owl>	<http://www.w3.org/1999/02/22-rdf-syntax-ns#type>	owl:Ontology
2	<http://purl.obolibrary.org/obo/doid.owl>	owl:versionIRI	<http://purl.obolibrary.org/obo/doid/releases/2018-12-17/doid.owl>
3	<http://purl.obolibrary.org/obo/doid.owl>	owl:imports	<http://purl.obolibrary.org/obo/doid/obo/ext.owl>
4	<http://purl.obolibrary.org/obo/doid.owl>	<http://purl.org/dc/elements/1.1/description>	"The Disease Ontology has been developed as a standardized ontology for human disease with the purpose of providing the biomedical community with consistent, reusable and sustainable descriptions of human disease terms, phenotype characteristics and related medical vocabulary disease concepts."
5	<http://purl.obolibrary.org/obo/doid.owl>	<http://purl.org/dc/elements/1.1/title>	"Human Disease Ontology"
6	<http://purl.obolibrary.org/obo/doid.owl>	<http://purl.org/dc/terms/license>	<https://creativecommons.org/publicdomain/zero/1.0/>
7	<http://purl.obolibrary.org/obo/doid.owl>	<http://www.geneontology.org/formats/oboInOwl#date>	"12:17:2018 15:51"
8	<http://purl.obolibrary.org/obo/doid.owl>	<http://www.geneontology.org/formats/oboInOwl#default-namespace>	"disease_ontology"
9	<http://purl.obolibrary.org/obo/doid.owl>	<http://www.geneontology.org/formats/oboInOwl#hasOBOFormatVersion>	"1.2"
10	<http://purl.obolibrary.org/obo/doid.owl>	<http://www.geneontology.org/formats/oboInOwl#saved-by>	"lschriml"

Showing 1 to 10 of 10 entries

Figure 6.9: Query Result after Execution

Figure 6.19 is a view of the query results on the selection of classes. To get more information about a particular disease, the class link is clicked on.

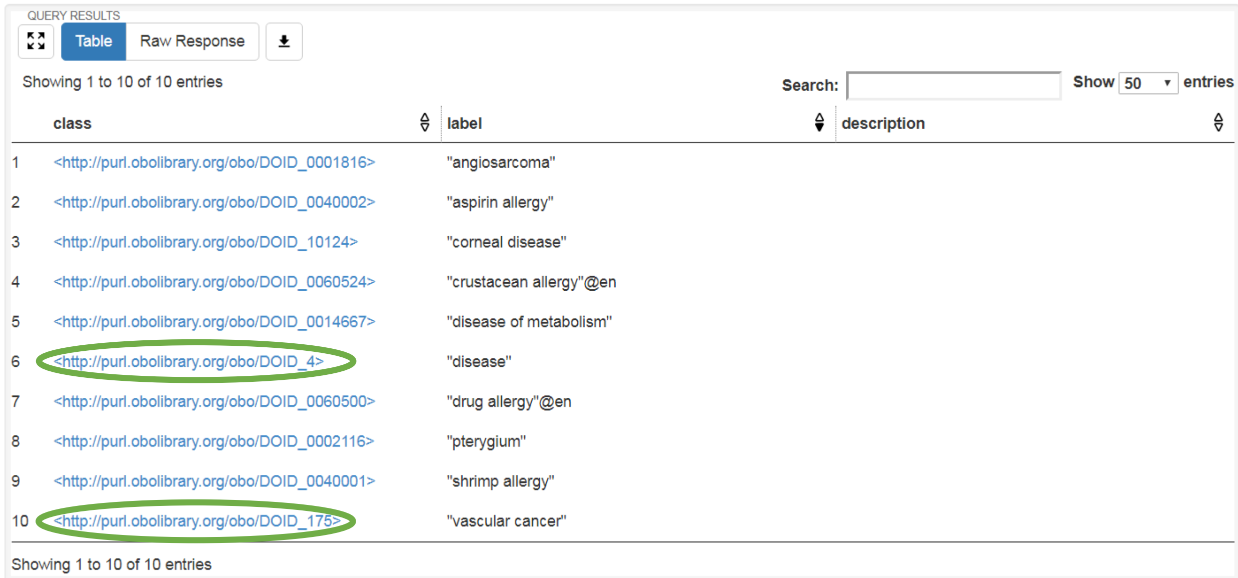

Figure 6.10: Selection of Classes

6.3 Protégé

Protégé is a free, open source ontology editor, a knowledge management system and a framework for building intelligent systems that was developed at Stanford Medical Informatics. It is the most widely used domain and platform independent technology for developing and managing terminologies, ontologies, and knowledge bases in a broad range of application domains as diverse as biomedicine, e-commerce, and organizational modelling, etc.

Protégé provides a graphical user interface to define ontologies. It also includes deductive classifiers to validate the narrative that models are consistence and to infer new information based on the analysis of an ontology. Additionally, Protégé has a library of various tabs for the access, graphical visualization, and query of ontologies. Protégé can be currently used to load, edit and save ontologies in different formats including XML, RDF, UML, and OWL.

The use of Protégé has been very important in this project to simplify the editing of the ontology.

6.3.1 Setup of Protégé and uploading of ontology

To set up Protégé, it can be downloaded from https://protege.stanford.edu/ . The simulation for this research is done on a Windows platform. After successful completion of the download, the folder is unzipped as shown in Figure 6.11

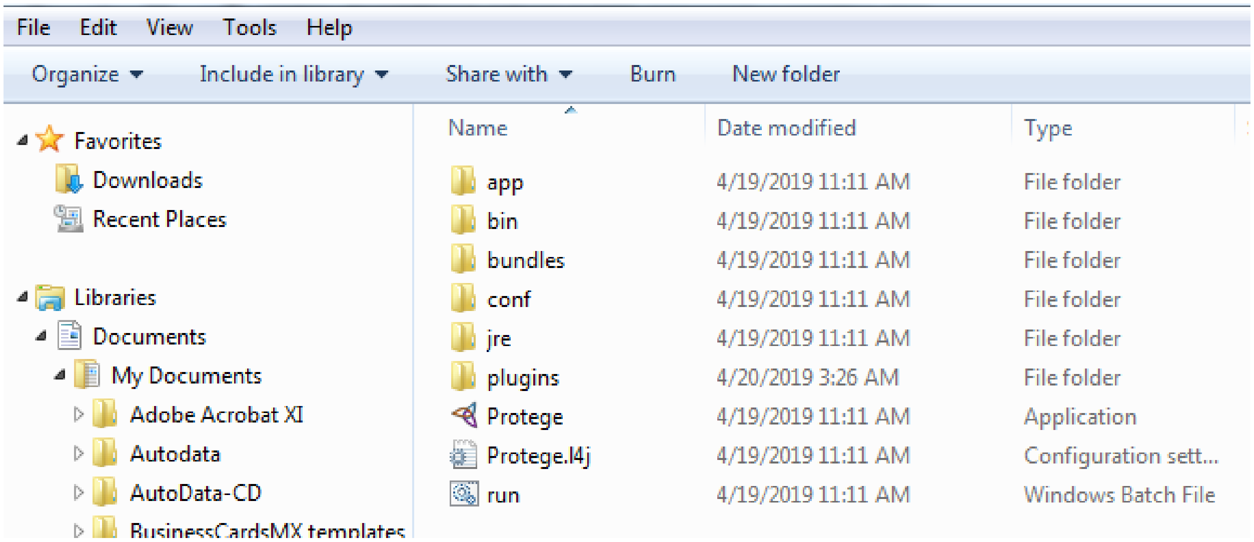

Figure 6.11: Protégé after Unzipping Protege-5.5.0-beta-8-win

Protégé is downloaded by double-clicking on Protege.exe or alternatively double-clicking on run.bat which starts up Protégé as shown in Figure 6.11.

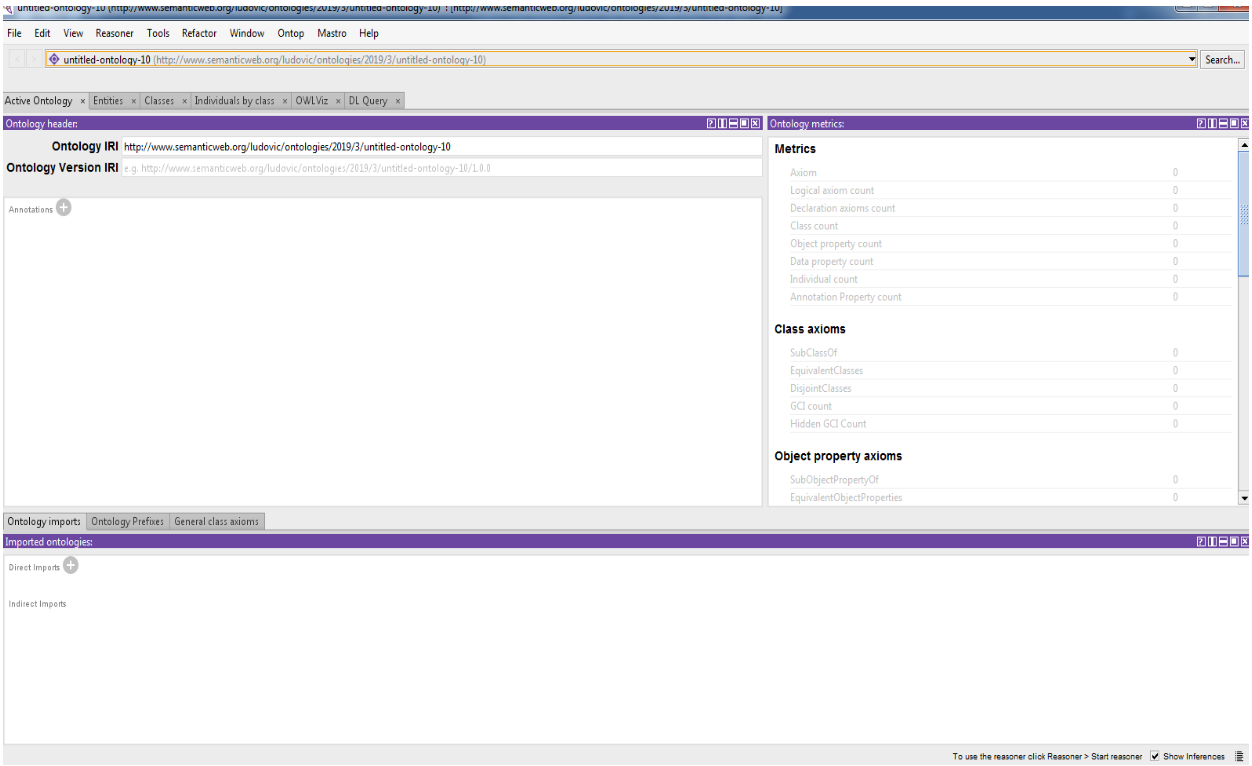

Figure 6.12: Launching of Protégé on Windows Platform

The next step is uploading the ontology. In this simulation, the Human Disease Ontology was chosen and imported into protégé as shown in Figure 6.13.

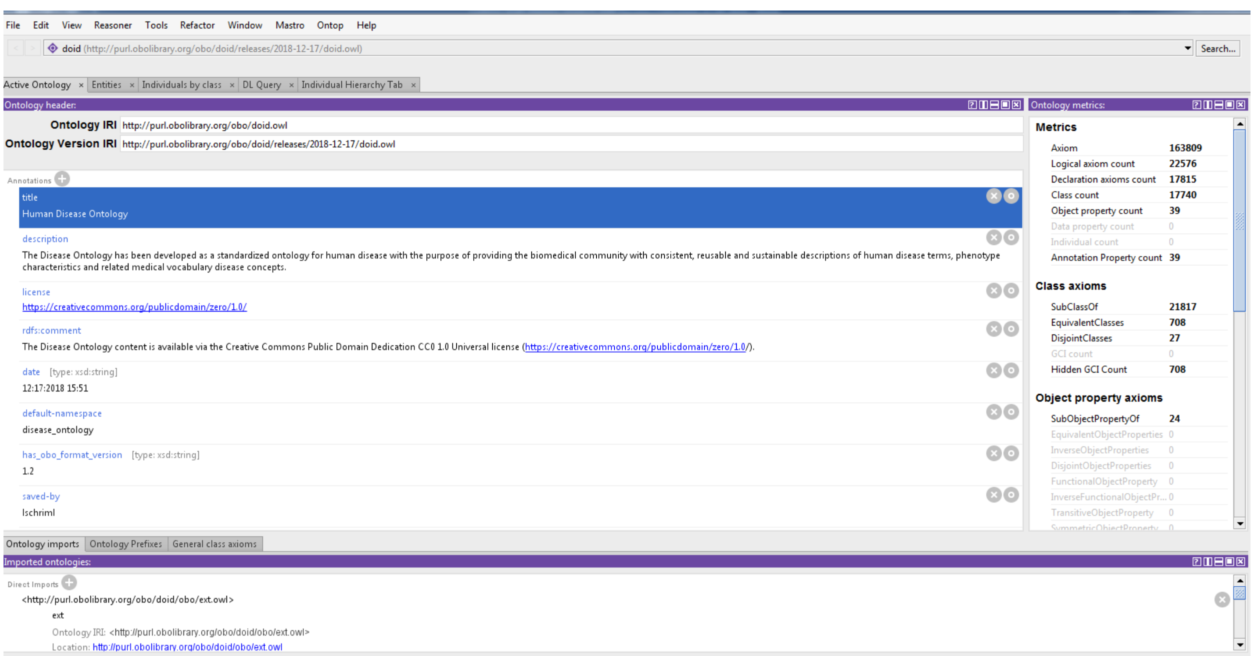

Figure 6.13: Human Disease Ontology loaded in Protégé on Windows Platform

After successful import, the user sees the tab showing Active Ontology, Entities, Individuals by class, etc. as shown in Figure 6.14. By selecting the Entities Tab, the following Protégé User Interface appears, and it is where the knowledge engineer / ontology developer / ontology editor spends most of their time.

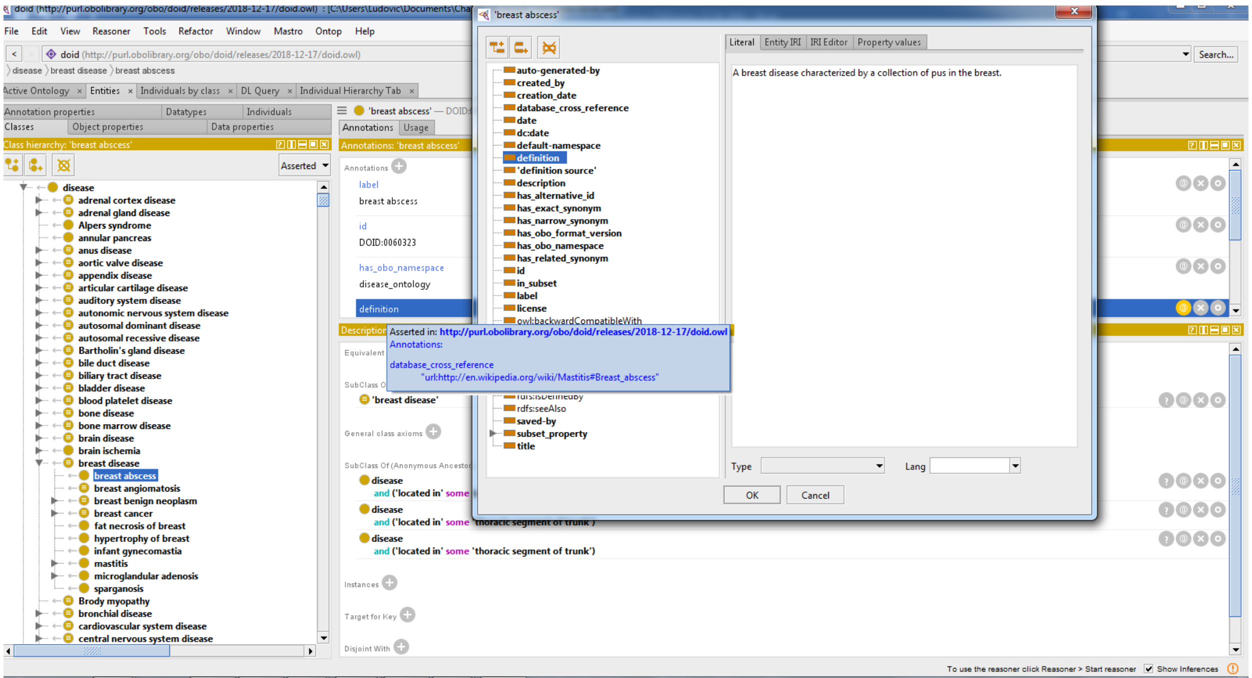

Figure 6.14: Breast Disease Ontology After Selecting Entity Tab

At the top of the screen are various tabs. Each tab provides a different perspective on the ontology. For example, the classes tab allows the viewing and editing of the classes in the ontology, and similarly the properties tab focuses on the properties in the ontology. For reasoning and inconsistency checking, Protégé comes with several reasoners, and more can be installed via the plugins mechanism. A reasoner is selected from the Reasoner menu (HermiT, Pellet or Fact++ will work). Once a reasoner is highlighted, then "Start reasoner" is selected from the menu.

The DL query tab shown in Figure 6.15 provides an interface for querying and searching an ontology. The ontology must be classified by a reasoner before it can be queried in the DL query tab.

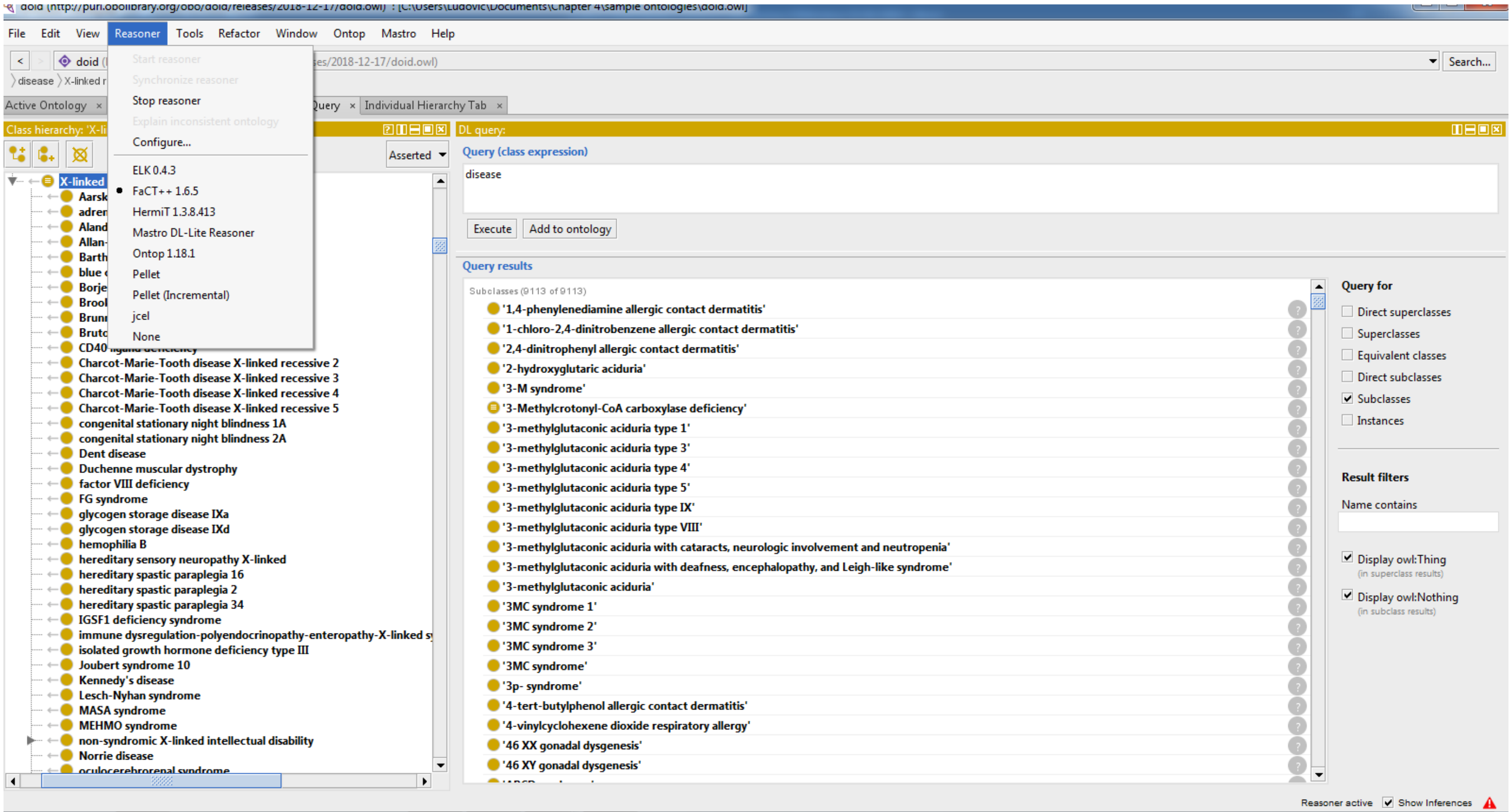

Figure 6.15: Extraction of Classes Using the Description Logic (DL) Tab

6.3.2 Running of the SPARQL Query under Protégé

In using the Protégé tool, one clicks on the Windows menu to go to the Tab submenu in order to check SPARQL Query as shown in Figure 5.15. opens the panel.

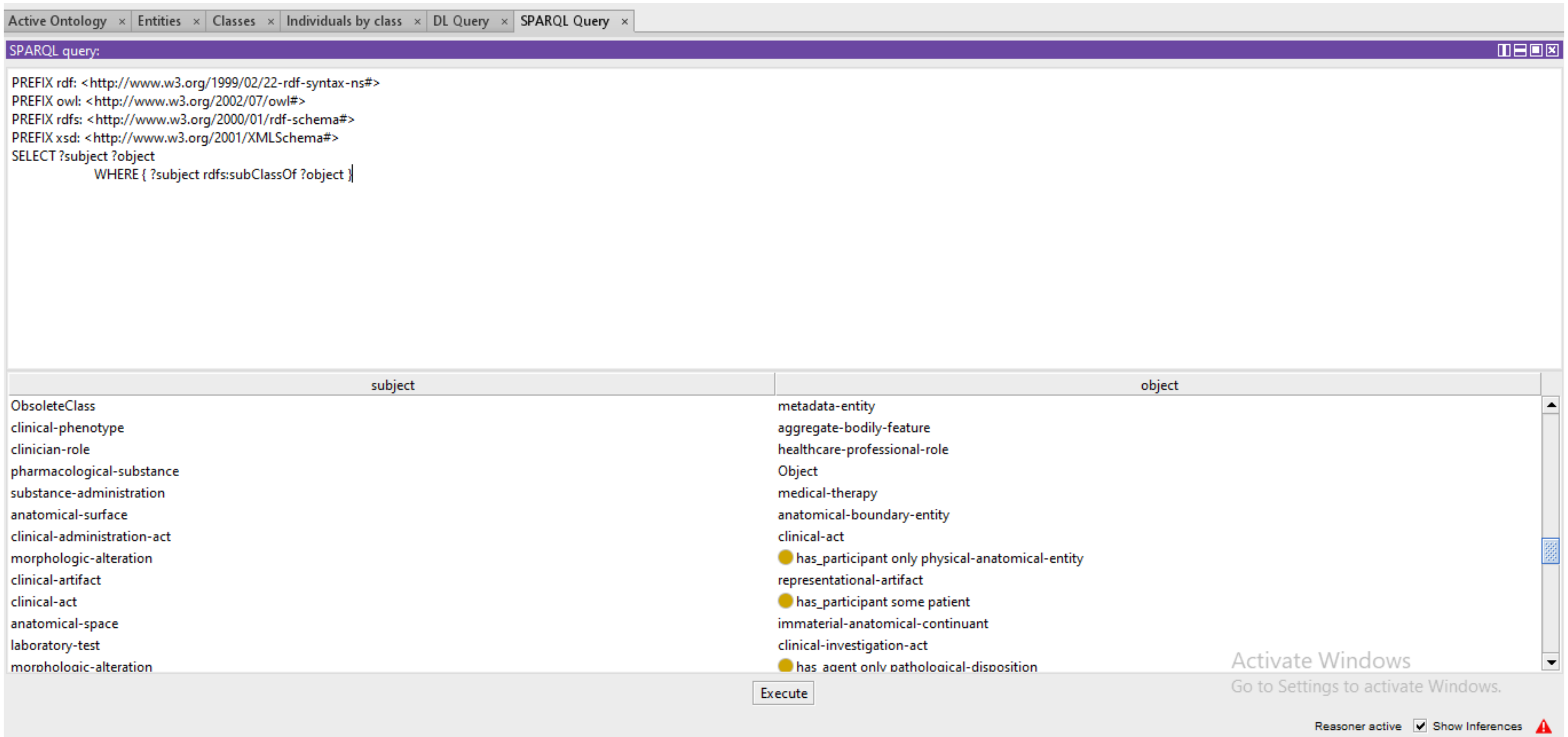

Figure 6.16: SPARQL Query under Protégé

6.3.3 Class hierarchy

With OntoGraf functionality from the Protégé-OWL ontology tool, the class hierarchy of ontology can easily be visualized. In the Figure 5.16 a class hierarchy of a part of disease ontology (‘anus disease’) is visualized.

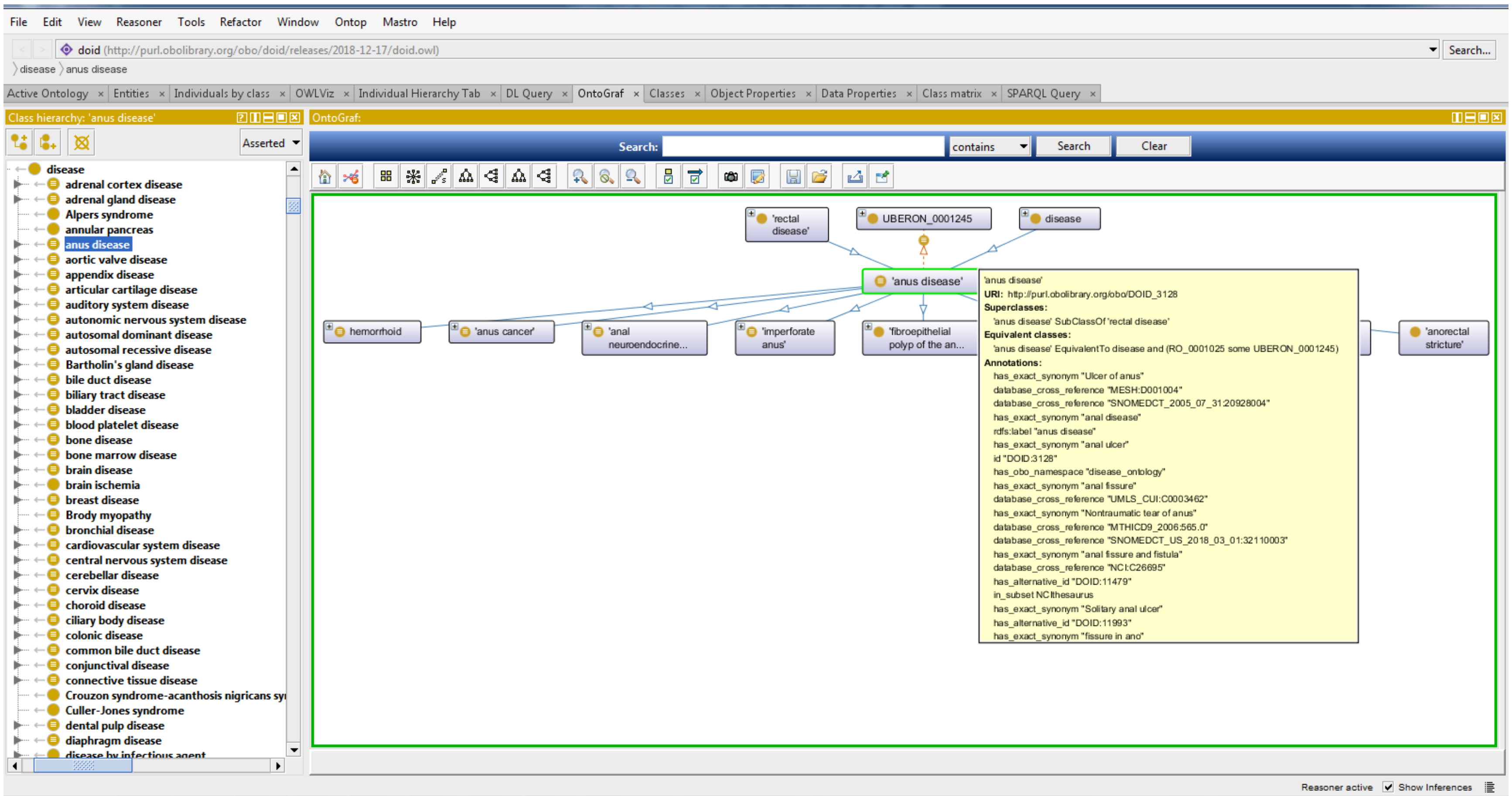

Figure 6.17: Class Hierarchy and OntoGraf Visualization of Part of the Disease Ontology ‘Anus Disease’ in Protégé

6.4 Evaluation

An evaluation of this SWBHF model was conducted on the basis of the cost of deploying the framework on BioMedLib, which is one of the dedicated Medical Specialty Search Engine currently in use besides Health on Net, e-medicine, MedScape, PubMed, and many others. Furthermore, expert and end-users evaluation is conducted and presented in this section.

6.4.1 Comparative Analysis of Cost of Deployment of SPARQL Endpoint and Dedicated Medical Search Tool (BioMedLib)

To illustrate the cost estimation, the case of SPARQL Endpoint using Apache Jena Fuseki was examined and a dedicated medical search tool (BioMedLib Search Engine) used.

Table 6.1 shows the specifications of the system where SWBHF application, based on the model that was developed in this research was run on.

Since Apache Jena Fuseki is open source the only cost involved for deploying it is Internet connection and configuration of the system for secure connection as well as the purchase of the proposed hardware infrastructure (see figure 5.7) and maintenance. Once all these requirements are taken care of, healthcare workers can take advantage of the services that comes with this healthcare engine to improve knowledge sharing, searching and efficiency in resource-constrained healthcare environments.

Table 6.1: Apache Jena Fuseki instance type used for our Semantic Web-based Healthcare Framework

Endpoint	CPU	RAM	HARD DISK	Operating System (Linux)	Platform	Programming Language	Cost of Deployment
Apache Jena Fuseki Server	2.6 GHZ CORE i5 Processor	16 GIG	1000 GB (1TB)	CentOS (Open Source)	32/64 bits	Java8 (Including JVM) (Open Source)	• Purchase the Propose Hardware Infrastructure Healthcare(See Figure 5.7) • Cost of data and configuration of the System for

							secure connection

The BioMedLib™ Search Engine uses semantic technology features. It takes a query and finds the best responses from millions of biomedical articles in the National Library of Medicine's MEDLINE® database (BioMedLib, 2019). BioMedLib saves time by sorting the articles so that the most relevant ones show at the top of the list. Therefore, the user does not have to spend a significant amount of time screening long lists of articles.

In terms of costing, BioMedLib access is provided to the public free of charge. However, it does cost a significant amount of money to run and maintain BioMedLib software and hardware. It is on these terms that BioMedLib offers some web services in order to minimize the maintenance costs. One of the web services offered is the monthly fee premium service where visitors can subscribe for faster access and it is ad free. The payment plan for BioMedLib Search Engine premium service is as follows:

✓ Full access to Premium BioMedLib Search Engine; 25 million publications

✓ Downloads of fulltext PDFs of publications (availability varies)

►Purchase one year discounted at $48.86

► Purchase six months discounted at $27.92

►Purchase one month for $6.98.

A straightforward, reasonably priced monthly subscription that covers Java SE licencing and support for desktop, server, and cloud deployments is called Java SE Universal Subscription. Directly from Oracle, the subscription gives users access to performance, stability, and security upgrades for Java SE that have been verified and tested. Among other advantages, it offers access to My Oracle Support (MOS) for 24 hours a day, support for 27 languages, and Java SE 8 Desktop administration, monitoring, and deployment features. Sales of the Java SE Universal Subscription are made depending on employee metrics. The monthly cost per employee begins at $15. Publicly available tier prices start at just $5.25 a month, and they can go considerably cheaper for clients who employ more than 50,000 people.

6.4.2 Expert and end-users evaluation

The Eastern Cape Health Department authorities as well as other groups (doctor, nurse, and junior and intern doctor) were asked to provide expert review. It was crucial to get the opinions of professionals in the semantic web and healthcare domains regarding the SWBHF's adaptability and applicability—including its hardware and network infrastructure—in the environment of limited resources. The IT manager of Dutywa Health District, a doctor with experience with healthcare information systems, a junior physician, an intern physician, and a nurse comprised the panel of five healthcare providers designated by the Eastern Cape Health Department.

Invited to a panel presentation and discussion, the team convened at Dutywa Community Health Centre (CHC) and welcomed the researcher. The SWBHF was deemed appropriate, relevant, and helpful for the province by the expert group.

The evaluation criteria and metrics employed for the ontologies shown in Table 6.2 were chosen following a review of pertinent ontology evaluation literature; the criteria were adapted from the application-based evaluation methodology put forward by Brank et al. (2005).

Table 6.2 Measure description

Measure	Definition
Accuracy	Whether the SWBHF captures and represents correctly aspects of the real world
Clarity	The effectiveness of the SWBHF in communicating the defined terms and their intended meaning
Completeness/Competency	Whether the SWBHF covers all essential and relevant concepts in the domain of interest.
Conciseness	Whether the SWBHF includes any irrelevant or redundant axioms
Interoperability	Whether the SWBHF interacts or reuses axioms from other data models.
Ease of Use	Whether it is easy to operate the SWBHF and there is appropriate guidance
Learnability	How easy it is to find the information needed to use,

	and whether there is any relevant documentation
Indexing and Linking	Whether the defined classes can act as indices to retrieve the requested information
Inferencing	Whether the SWBHF can make implicit knowledge explicit through reasoning
Consistent Research and Query	Whether the SWBHF can achieve better querying and searching methods

Table 6.3: Summary of the evaluation of the SWBHF ('1'denotes that the SWBHF doesn't exhibit good performance with respect to the corresponding criterion, '2' denotes that the SWBHF performs well, and '3' that the SWBHF has excellent performance)

Table 6.3 Evaluation summary

Measure	**Expert view**
Accuracy	3
clarity	3
Completeness/competency	2
Conciseness	2
Interoperability	2
Ease of use	3
Learnability	3
Indexing and linking	3
Inferencing	2
Consistent research and query	3

6.5 Chapter Summary

In summary, it can be said that the proposed Semantic Web-Based Healthcare Framework (SWBHF) for digital Healthcare shows incredible cost savings for healthcare centres in resource-constrained environments. This implies that healthcare providers in the clinics in resource-constrained environments can make use of this technology instead of paying a subscription fee to use a dedicated medical search engine.

Chapter 7: Discussion, Analysis, Summary and Conclusion

7.1 Introduction

This chapter addresses the research objectives 1,2 and 3. The aim of research objective 1 was to investigate the state of art of the semantic web technologies in healthcare and the aim of research 2 was to identify the challenges that hinder SWBHF implementation in a resource -constrained environment in South Africa. The aim of research objective 3 was to model a SWBHF. Moreover, this chapter provides the research contribution and limitations.

The research objectives to be addressed in this chapter are as follow:

- To investigate the state of the art of semantic web technologies practice in healthcare.
- To identify the challenges that hinder the implementation of SWBHF in a resource-constrained environment in South Africa.
- To model the Semantic Web-Based Healthcare system based on our designed Framework by means of a prototype development

7.2 The state of the art of semantic web technologies practice in healthcare.

To address this research objective, literature review data, interview, and questionnaire data were used.

From the interview and questionnaire conducted in this study, respondents claim that e-health is not implemented in the area yet. Furthermore, respondents said that doctors use hard copies to share information. When asked which internet medical information sources in regard to patient care preferred, 89% of respondents strongly agreed to be using Google while 78% of respondents strongly agreed to be using medical representative websites, and 78% of the respondents agreed to be using social media [Table 7.1]. It can be deduced that semantic web ontologies technologies systems are not fully in use yet.

This study also used the literature to gauge the state of art of the semantic web technologies.

The quick development of digital healthcare technologies has made healthcare one of the fastest-growing and largest sectors today. Connecting and exchanging vast amounts of healthcare data is essential to improving healthcare services. Haque, Arifuzzaman, Siddik, Kalam, Shahjahan, Saleena, & Hossain (2022*)* claim that semantic web is used generally in *E-healthcare service, Diseases, Information management, and Frontier technology.*

E-Healthcare Service: E-service in healthcare, or e-healthcare service, is the use of different technologies to deliver healthcare support. As they remained at home, a

Through e-healthcare services, a person can get all the information they need about medicine and healthcare, including advice, prescription, and illness rationale. It bears resemblance to a doorstep delivery service. Web 3.0, often known as the Semantic Web, is essential in this regard. Semantic Web technologies, such as morphological variation, semantic reasoning, and semantic interoperability, can be used to develop a range of frameworks that enhance e-healthcare services. Researchers employed Semantic Web services to convert relational databases into RDF and OWL-based ontologies. The process involves extracting instances from relational databases and expressing them as RDF datasets (Mohammed & Benlamri, 2014; Philipp, 2015; Arch-Int, Arch-Int, Sonsilphong, & Wanchai, 2017). Several RDF datasets were generated using Apache JENA 4.0 in earlier research, and numerous healthcare ontologies were constructed and represented using protege versions. The Apache Jena framework was utilised for OWL reasoning on the RDF datasets, and the EYE engine was employed for reasoning (Schweitzer, Gorfer, & Hörbst, 2017; Meddaoui, 2021).

This theme area, "Diseases," tries to highlight and analyse how Semantic Web technologies have helped to achieve information interoperability in the healthcare industry. sector and support early illness identification and care, including diabetes, long-term ailments, heart disease, dementia, and so forth. SW offers a framework for integrating medical knowledge and data for efficient clinical service and diagnosis. They assist in patient selection, identify medication effects, and conduct result analysis by using electronic health data from several sources. Pharmaco-epidemiologists were given access to queryMed packages, which connect medical and pharmacological information with electronic health records. This software looks for individuals with critical limb ischemia (CLI) who are taking medicine or not at all, and provides recommendations for their medical care. Additionally, SW highlights the investigation of phenotypes and how they impact individual genomes (Rivault, Dameron, & Le Meur, 2019). The Linked Clinical Data (LCD) project at the Mayo Clinic makes it simpler to express and extract phenotypes from electronic medical records and makes SW easier to use. Additionally, it highlights the application of semantic reasoning in the detection of cardiovascular disorders. Medical professionals frequently employ ontology-based tools to create mappings between medical terminology, such as the Concept Unique Identifier (CUI) from the Unified Medical Language System, the Drug Indication Database (DID), and the Drug Interaction Knowledge Base (DIKB) (Rivault et al., 2019).

Information Management.

In the medical and healthcare sectors, maintaining patient records and test results are important responsibilities. Applying the SW-based strategy here can have a big impact on this data organisation. This method of collecting fresh and important medical data was mainly made possible by setting up a computer network (Yu & Jonnalagadda, 2006; Haque et al., 2022). Healthcare professionals were able to exchange useful information on mapping-related information in the dataset through a medical discussion forum built on the SW. Utilising the fuzzy cognitive system in the SW made maintenance easier and allowed for the sharing and reuse of database knowledge (Papageorgiou, De Roo, Huszka, & Colaert, 2011).

Frontier Technology

Here is a critical examination of the works that focus mostly on the ways in which cutting-edge technologies, such as artificial intelligence (AI) and computer vision, can be used in the medical sector as science and technology in the International Journal of Clinical Practice continue to improve. Semantically Web-enabled intelligent systems can assist medical personnel with diagnosis and treatment by using a knowledge base and reasoning engine to address problems.

For example, Haque et al. (2022), Chondrogiannis et al. (2022)., Haque and Bhushan (2021), and Haque et al. (20210) developed a decentralised, quick, and safe application utilising blockchain technology to enable users and health insurance companies to come to a consensus while the healthcare insurance policies in each contract are being implemented. The formal expression of contract terms and the data of insured users were preserved through the application of Semantic Web technology and health standards. In order to provide digital healthcare, question-answering (QA) systems—such as chatbots and forums—are becoming more and more common. Such systems require thorough analysis of both user queries and records in order to extract the necessary data. The underlying technology, natural language processing (NLP), improves the precision and dependability of electronic health records by transforming unstructured text into standardised data. An NLP-based Semantic Web application has been implemented to allow users to ask inquiries about health-related data (Abacha & Zweigenbaum, 2015; Haque et al., 2022).

Despite the general recognition of the benefits of semantic web technologies in the health area, the assessment highlights several issues and difficulties with the current state of affairs. Mappings from proprietary formats to ontology ideas are challenging and time-consuming, which is one of the disadvantages. Another difficulty is maintaining datasets and ontologies. It is crucial to develop the tools necessary to automate these procedures. Additionally, the creation of applications, use cases, and functional interfaces as proof-of-concept will boost the trust in the Semantic Web's applicability in the medical field. Ultimately, new knowledge can be extracted by data mining techniques; however, a variety of factors, including data quality, are critical to the finding of high-quality knowledge.

7.3 The challenges that hinder the implementation of SWBHF in a resource-constrained environment in South Africa

To identify the challenges, variables such as too much information to scan, lack of familiarity, lack of time, too slow connection, software problems, data security concerns etc were measured. The results [Table 7.1] reveal that too much information to scan, lack of training or skills about the internet, lack of familiarity or experience, and no internet access proved to be the barriers factors. 89% of the participants strongly agreed that too much information to scan is a barrier. 78% of the respondents agreed that lack of training or skills about the internet is seen as a barrier. Furthermore, 78% of respondents agreed that lack of familiarity or experience is considered as a barrier, meanwhile, 56% of respondents strongly agreed that the language barrier is a challenge.

Table 7.1 Variables

Variables	**Frequency (%)**				
	1	**2**	**3**	**4**	**5**
• Too much information to scan	0%	0%	0%	11 %	89 %
• Lack of time	0%	11 %	56 %	33 %	0%
• Language barrier	0%	0%	11 %	33 %	56 %
• Low relevance for clinical practice	30 %	20 %	40 %	5%	5%
• Lack of training or skills about the Internet	0%	0%	11 %	78 %	11 %
• Unreliability of the information	0%	0%	33 %	56 %	11 %
• Lack of familiarity or experience	0%	0%	11 %	78 %	11 %
• Too slow connection	0%	0%	78 %	22 %	0%
• Too complicated to use	0%	0%	33 %	11 %	56 %
• Software problems	0%	11 %	89 %	0%	0%

• Data security concerns	89 %	11 %	0%	0%	0%
• No Internet access	0%	0%	33 %	56 %	11 %
• Costs	78 %	0%	22 %	0%	0%
• Other(s)__________________________________	-	-	-	-	-

7.4 Achievement of objective

This research achieved the following objectives:

Issues affecting the access to quality healthcare services in resource-constrained environments were identified. A case study conducted in selected community healthcare centres of Dutywa Health District on issues hindering the provision of quality healthcare was useful in assessing these issues in addition to the review of the relevant literature.

- Existing frameworks that can be adapted / customized to meet the healthcare quality needs of community healthcare centres in resource-constrained environments were identified from a review of the relevant literature on related work on SWBHF and healthcare.
- This review of literature coupled with the DSR method were useful in selecting an advantageous framework and customizing it to this research. The literature on the state of the art in the utilization of the Semantic Web in the healthcare domain and related work on the Semantic Web in the healthcare was also reviewed to assist in the identification of framework components that relate to SWBHF so that the study could design and deploy a customized SWBHF for digital healthcare in community healthcare centres.
- A Semantic Web-based for digital healthcare framework was developed. This framework was custom-made for community healthcare centres and deployed on computer systems for evaluation purposes. This was achieved by designing a

Semantic Web-based for digital healthcare framework for community healthcare centres by combining the capabilities of both the related work on Semantic Web in healthcare and evidence-based healthcare (healthcare knowledge management).

- Keeping in mind the financial constraints and the needs of community healthcare centres, this work evaluated BioMedLib Search engine against Apache Jena Fuseki so that the most suitable one could be selected for community health centres. Model design and development was performed to define the framework components, use case diagrams, sequence diagrams, activity diagrams, component and deployment diagrams for the prototype that satisfied specified requirements. An experimental set-up of Semantic web-based for digital healthcare for community health centres was implemented and evaluated against existing Medical Specialty Search Engine to validate the relevance of the proposed framework.

7.5 Research Contribution

This research covered various Semantic Web-Based Healthcare Framework, medical ontology and rural healthcare solutions. The SWBHF for digital healthcare proposed in the research will enhance clinical decision support, healthcare knowledge management and evidence-based medicine in the resource-constrained environments. The framework would also address the challenge of applying healthcare knowledge into existing healthcare provider environments to improve decision making, the quality of patient care services, the quality, efficiency and efficacy of healthcare delivery system specifically in rural, remote and marginalized areas. The reduction of healthcare costs is projected in the long run and medical errors to be reduced as well.

The proposed framework is an attempt to also assist healthcare software engineers, and application developers, amongst other technical experts involved in healthcare development, to implement custom-made health systems for resource-constrained environments in developing countries.

Apache Jena Fuseki and Protégé that are Free and Open Source Software (FOSS) were used in this work and were compared with the BioMedLib Search engine pricing model. It was noticed that the price of the Apache Jena Fuseki and Protégé instant type deployment and configuration is cheaper than the equivalent BioMedLib Search engine in the proposed architecture. This means that the pricing model in this study will have huge cost savings for the targeted community healthcare centres in the Dutywa Health District.

In addition to the prior point, this work has made the following contributions:

- A well-articulated problem statement was presented in Section 1.3. The problem formulation was presented clearly and concisely.
- A sound solution was proposed which was determined via a state of the art of Semantic Web in healthcare and life sciences, healthcare KM and evidence-based medicine that resulted in the deployment of Apache Jena Fuseki Server and Protégé.
- The use of DSR is relatively new in the world of computing. Therefore, this research work contributes to this important paradigm's general understanding. Recognizing DSR as a concept and not as a technique is important for the IS research community in general. This is because DSR offers a new research methodology, but it does not provide for that reason clear and practical methods and techniques. Building on this argument, this research provides a working example in which the author illustrates how it is essential to recognize DSR as a paradigm and also clarifies the need within this paradigm to use a compatible methodology.
- A thorough solution validation was conducted through a detailed literature review in addition to the analysis of a case study. The suggested solution to the research problem is well justified and validated. However, it is not without some limitations. These limitations are discussed in the next section.

7.6 Limitations and Future Work

Deploying Apache Jena Fuseki Server and Protégé confirmed the suitability of the proposed framework for selected clinics. However, the prototype is a look and feel of how our application would look like; therefore, another primary goal of future work is to observe the usability of the proposed approach in a real-life environment.

The usability here speaks to the ordinary end-users (e.g., nurses, doctors, healthcare workers, software developers, etc.) who are not necessarily familiar with domain specific semantic data, ontologies, or SQL-like query languages (SPARQL) and are incapable of answering complex semantic queries over structured repositories through the study's proposed front-end interface only accepting hard code SQL-like. To address this usability challenge, it would be useful to develop an ideal system that would allow end-users to benefit from the expressive power of Semantic Web capability while at the same time hiding their complexity behind an intuitive and easy-to-use interface.

Throughout the study, some limitations were picked out.

- The loading of ontologies of size greater than 750MB was impossible in both Apache Jena Fuseki Server and Protégé.
- More research needs to be undertaken to improve the loading of bigger capacities of ontologies on Semantic Web platforms to enable the storage and query of large ontologies.
- The study used only two Semantic Web platforms, namely, Apache Jena Fuseki Server and Protégé in our prototype.

Further research could focus on building a custom-made application using an ecosystem of Eclipse, Java Development Platform and Semantic Web Framework with Jena API to store and query ontologies.

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Appendix A: Approval Letter of Eastern Cape Department of Health

Eastern Cape Department of Health

Enquir1es:	Madoda Xokwe	Tel No:	040 608 0856
Date:	19 April 2017	Fax No:	043 642 1409
e-mail address:	madoda.xokwe@echealth.gov.za		

Dear Mr. L. Tonguo

Re: Designing a Semantic Web-Based Framework to Support Health Providers in a Resource Constrained Environment (EC_2017RP46_623)

The Department of Health would like to inform you that your application for conducting a research on the abovementioned topic has been approved based on the following conditions:

1. During your study, you will follow the submitted protocol with ethical approval and can only deviate from it after having a written approval from the Department of Health in writing.
2. You are advised to ensure, observe and respect the rights and culture of your research participants and maintain confidentiality of their identities and shall remove or not collect any information which can be used to link the participants.
3. The Department of Health expects you to provide a progress on your study every 3 months (from date you received this letter) in writing.
4. At the end of your study, you will be expected to send a full written report with your findings and implementable recommendations to the Epidemiological Research & Surveillance Management. You may be invited to the department to come and present your research findings with your implementable recommendations.
5. Your results on the Eastern Cape will not be presented any w here unless you have shared them with the Department of Health as indicated above.

Your compliance in this regard will be highly appreciated.

SECRETARIAT: EASTERN CAPE HEALTH RESEARCH COMMITTEE

PGDP EASTERN CAPE 2004 - 2014

Ikamva eliqaqambileyo!

Appendix B: Ethical Clearance

UNISA university of south africa

CAES GENERAL RESEARCH ETHICS REVIEW COMMITTEE

National Health Research Ethics Council Registration no: REC-170616-051

Date: 07/04/2017

Ref #: **2017/CAES/083**
Name of applicant: **Mr L Tonguo**
Student #: **36110167**

Dear Mr Tonguo,

Decision: Ethics Approval

Proposal: Designing a semantic web-based framework to support health providers in a resource constrained environment

Supervisor: Prof A Coleman

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Approval is granted for the project, *subject to submission of the relevant permission letters.*

Please note that the approval is valid for a one year period only. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 30 April 2018

Please note the points below for further action:

1. Permission from the hospitals is outstanding. This must be obtained and submitted to the Committee before data gathering may commence.
2. The proposal is written in the past tense. The researchers are requested to confirm with the committee if any of the research has already been done? Retrospective clearance may not be given.

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

3. The consent form is outstanding. Unisa has a standard consent form that must be used to obtain consent from participants. The researcher may not use any other consent form, and is requested to submit the corrected draft consent form to the Committee for record purposes.
4. The risk section at the end of the application form was removed. All research has a form of risk associated with it and Ethics committees in Unisa comply by completing a risk register for each project. This is required to allow the researcher the opportunity to consider the risks involved to the participants and to the researcher himself. The Risk Section must be completed and submitted to the Committee for record purposes.
5. The researcher indicates that feedback will not be given to participants and this is not acceptable The Unisa Research Ethics policy stipulates that participants must receive feedback on the outcome of the research, should they wish to do so. The feedback must be given in a format that is suitable to the level of education of the various participants. The researcher must clarify how feedback will be provided to the participants in this project.
6. The Committee is concerned that the questionnaire does not address all the objectives and it may improve the results of the study if this aspect is improved. However, the final decision remains with the supervisor and no feedback on this point is required.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 06 April 2017.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*

Note:

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The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

pp: Acting ED

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

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Appendix C: Editor’s Declaration

KMN EVENTS & LANGUAGE SERVICES

PO Box 8679 15B Alkalien Ave
Centurion Zwartkop x8
0046

Cell: 0730494110 Tel.: 0466038544
Email address: ndlodlo@gmail.com

EDITOR’S DECLARATION

I, Dr Nomusa Dlodlo, confirm that I edited Ludovic Tunguo’s Masters thesis entitled:

TOWARDS A SEMANTIC WEB-BASED HEALTHCARE FRAMEWORK FOR DIGITAL HEALTHCARE IN A RESOURCE-CONSTRAINED ENVIRONMENT

During the editing process, the following changes were recommended:

1. Structural – some sentences and paragraphs were moved around to promote coherence;
2. Grammatical – some sentences were rephrased to promote clarity;
3. Spelling and tenses – a few spelling mistakes were noted and corrected and the same applies to tenses;

It is up to the candidate to accept and effect these changes as s/he remains the author of this document.

.... 4/12/2019 ....

Editor's Signature Date

Appendix D: Interviews and Questionnaires

UNISA university of south africa

INTERVIEW QUESTIONS FOR DOCTORS

The aims of this study is to investigate the level of usage of E health tools in clinics/hospitals in Dutywa Health District in the Eastern Cape Province in South Africa. And based on the findings, design a semantic web based framework that provide support healthcare workers in resource constrained environment

- Your participation in this research project is voluntary and you may withdraw at any time if so desired
- Your interview will take 5-10 minutes
- Your response remains confidential

1. What type of services do your hospital provide to the citizens of Eastern Cape?
2. How many doctors do you have in this hospital?
3. How do the doctors share information regarding patients, medication and referrals?
4. Is there any e-health system that is used in your hospital?
5. If yes, what type of e-health system and what is it use for.
6. Does the e-Health system share information with any other e-Health Systems?
7. Are the e-Health systems useful in meeting healthcare needs at the hospital?
8. What are the processes involved when patients first arrive in the hospital before they are referred to medical practitioners and how long do these processes take?
9. How do other healthcare professionals eg nurses, ward attendants and pharmacists share information and exchange ideas?
10. Is there anything else you would like to recommend?

THE END

Thank you for your participation

Open Rubric

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QUESTIONNAIRE FOR MEDICAL DOCTORS

All information will be treated as confidential. The completion of this questionnaire is voluntary and your participation will be highly appreciated.

Aim: The purpose of this questionnaire is to collect information about:

- The use of the internet to search for health information.
  - Internet Medical Information Sources used in regard to patient care, health information and general practice.
  - Barriers and obstacles to internet use for information seeking in clinical practice
  - Facilitating factors to internet use for information seeking in clinical practice
  - Computer literacy and internet usage competency of the respondents

Section A: Socio-demographic characteristics of the respondents

1. Age

   a. 25-30 ☐ b. 30-35 ☐ ☐ c. 35-40 c. 40 ☐ and Above

2. Gender

   a. Male ☐ b. ☐ Female

3. Healthcare professional status

   a. Physician ☐
   b. Nurse ☐
   c. Junior Medical Doctor ☐
   d. In-Service trainee student Medical Doctor ☐

4. Department

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a. Medicine ☐
b. Family medicine ☐
c. Surgery ☐
d. Obstetrics and Gynecology ☐
e. Pediatrics ☐
f. Radiology ☐
g. Community Medicine/Community Health

h. Other ______________________________ ☐

5. Practice location
   a. Rural ☐
   b. Semi-rural ☐
   c. Remote area ☐
   d. Marginalized area ☐

Section B: Internet Medical Information Sources used in regard to patient care, health information and general practices preference on a scale 1 "Least Preferred" to 5 "Most Preferred".

Least Preferred (1)/Less Preferred (2)/Neutral (3)/Preferred (4)/Most Preferred (5)

Internet medical Information Sources	1	2	3	4	5

A. Discussion Forum	☐	☐	☐	☐	☐
B. Social Media	☐	☐	☐	☐	☐
C. PubMed/MEDLINE|PubMed Central (PMC)	☐	☐	☐	☐	☐
D. Scopus	☐	☐	☐	☐	☐
E. African Index Medicus (AIM)	☐	☐	☐	☐	☐
F. Web of Knowledge	☐	☐	☐	☐	☐
G. Google	☐	☐	☐	☐	☐
H. Yahoo	☐	☐	☐	☐	☐
I. Google Scholar	☐	☐	☐	☐	☐
J. Professional Association Websites	☐	☐	☐	☐	☐
K. Medical representative Websites	☐	☐	☐	☐	☐
L. Other(s)____	☐	☐	☐	☐	☐

Section C: Barriers and Obstacles to internet use for information seeking in clinical practice. *Disagree Strongly (1)/Disagree (2)/Neutral (3)/Agree (4)/Agree Strongly (5)*

Barriers and Obstacles	**1**	**2**	**3**	**4**	**5**
A. Too much information to scan	☐	☐	☐	☐	☐
B. Lack of time	☐	☐	☐	☐	☐
C. Language barrier	☐	☐	☐	☐	☐
D. Low relevance for clinical practice	☐	☐	☐	☐	☐
E. Lack of training or skills about the Internet	☐	☐	☐	☐	☐
F. Unreliability of the information	☐	☐	☐	☐	☐
G. Lack of familiarity or experience	☐	☐	☐	☐	☐
H. Too slow connection	☐	☐	☐	☐	☐

	1	2	3	4	5
I. Too complicated to use	☐	☐	☐	☐	☐
J. Software problems	☐	☐	☐	☐	☐
K. Data security concerns	☐	☐	☐	☐	☐
L. No Internet access	☐	☐	☐	☐	☐
M. Costs	☐	☐	☐	☐	☐
N. Other(s)____	☐	☐	☐	☐	☐

Section D: Facilitating factors to internet use for information seeking in clinical practice. *Disagree Strongly (1)/Disagree (2)/Neutral (3)/Agree (4)/Agree Strongly (5)*

Facilitating Factors	**1**	**2**	**3**	**4**	**5**
A. Website with evidence-based summaries	☐	☐	☐	☐	☐
B. Website with selected documents or useful links for clinical practice	☐	☐	☐	☐	☐
C. More relevant information for clinical practice	☐	☐	☐	☐	☐
D. More available time	☐	☐	☐	☐	☐
E. Simplification of information seeking	☐	☐	☐	☐	☐
F. More reliable information	☐	☐	☐	☐	☐
G. Faster Internet connection	☐	☐	☐	☐	☐
H. Internet training	☐	☐	☐	☐	☐
I. Internet access during consultation time	☐	☐	☐	☐	☐
J. Technical assistance	☐	☐	☐	☐	☐

K. Reduced costs	☐	☐	☐	☐	☐
L. Other(s)____	☐	☐	☐	☐	☐

Section E: Computer literacy and internet usage competency of the respondents

Computer literacy and internet usage competency	1(Yes)	2(No)	3(No Response)
A. Are you computer literate?	☐	☐	
B. Do you own a personal computer?	☐	☐	
C. Ever used the Internet?	☐	☐	
D. Used the Internet during the last week preceding the survey?	☐	☐	☐
E. Do you have personal access to the Internet?	☐	☐	

F. Internet access points used the last time.

Office / Consultation Room ☐

Home ☐

Library ☐

Cyber café ☐

No Response ☐

G. Main reason for using the Internet the last time.

E-mail ☐

Research ☐

Health information ☐

Patient care ☐

Others ☐

No response ☐

H. Mode of usage

assisted ☐

Not Assisted ☐

No response ☐

Thank you

APPENDIX E Group interview findings

Interviews were part of data collection process and conducted with health workers in need of health information through sharing and searching to address medical decision making and information overloading. The respondents included doctors, nurses, junior/intern medical doctors from the selected community health centres(CHC). The aims of these interviews were envisioned to investigate the level of usage of EHealth tools in clinics/hospitals in Dutywa Health District in the Eastern Cape Province of South Africa.

The responses are summarised in table. The table consists of the summary of responses from the group interviews in the three hospitals.

Question No	Interview questions	Summarised responses
1.	What type of services do your hospital / Community Health Centre(CHC) provide to the citizens of Eastern Cape?	The respondents (doctors) from selected CHC gave the same services which are: • Pharmaceutical & outreach services • Consultation • Radiology • Dentistry • HIV/AIDS & TB care • Maternity • Child health • Vision care • Emergency care unit • Health promotion & laboratory services
2.	How many doctors do you have in this hospital?	**Respondent 1** from iDutywa Nqabara CHC: Two doctors and 6 intern-doctors. **Respondent 2** from Willowvale CHC: One sessional doctor and 2 intern-doctors. **Respondent 3** Xhora CHC: One sessional doctor
3.	How do the doctors share information regarding patients, medication and referrals?	**Respondent 1** from iDutywa Nqabara CHC: Patient's file(Hardcopy)

		Respondent 2 from Willowvale CHC: Written information in patient's file and referral is made using Phone. **Respondent 3** Xhora CHC: Same as respondent 1 and 2
4.	Is there any e-health system that is used in your hospital?	No
5.	If yes, what type of e-health system and what is it use for.	N/A
6.	Does the e-Health system share information with any other e-Health Systems?	N/A
7.	Are the e-Health systems useful in meeting healthcare needs at the hospital?	N/A
8.	What are the processes involved when patients first arrive in the hospital before they are referred to medical practitioners and how long do these processes take?	**Respondent 1, 2 and 3** gave a standard process on arrival enumerated as follows: • Admission • Observation • And history talking The process take a minimum of one hour.
9.	How do other healthcare professionals e.g. nurses, ward attendants and pharmacists share information and exchange ideas?	**Respondent 1, 2 and 3** said the sharing of health related information is done at three level as follows: • During in-services training • During meetings • Via telephonically communication
10.	Is there anything else you would like to recommend?	

Summary of responses from the group interviews in the three hospitals

APPENDIX F Questionnaire Findings

Self-administered questionnaires (cf. Appendix D) distributed by hand to nurses, junior medical doctors / intern doctors and doctors accompanied by a letter of approval to conduct the research and a consent form with an explanation of the research and a research proposal were attached to the questionnaires.

The purpose of this questionnaire is to collect information about:

- The use of the internet to search for health information.
- Internet Medical Information Sources used in regard to patient care, health information and general practice.
- Barriers and obstacles to internet use for information seeking in clinical practice
- Computer literacy and internet usage competency of the respondents

Socio-demographic data for the 9 participants in the study

	Variables	Count	Frequency(%)
1.	Age(Years)		
	25-30	0	0
	30-35	3/9	33%
	35-40	2/9	22%
	40 and Above	4/9	44%
2.	Gender		
	Male	2/9	22%
	Female	7/9	77%
3.	Healthcare professional status		
	Physician	1/9	11%
	Nurse	6/9	67%
	Junior Medical Doctor	1/9	11%
	In-Service trainee student Medical Doctor	1/9	11%
4.	Department		

	Medicine	1/9	11%
	Family medicine	2/9	22%
	Surgery	0/9	0%
	Obstetrics and Gynecology	0/9	0%
	Paediatrics	1/9	11%
	Radiology	0/9	0%
	Community Medicine/Community Health	5/9	56%
	Other…………………	-	-
5.	Practice location		
	Rural	9/9	100%
	Semi-rural	0	0%
	Remote area	0	0%
	Marginalized area	0	0%
		0	0%

Internet medical Information Sources for the 9 participants in the study

Least Preferred (1)/Less Preferred (2)/Neutral (3)/Preferred (4)/Most Preferred (5)

variables	**Frequency (%)**				
	1	**2**	**3**	**4**	**5**
• Discussion Forum	0%	0%	67%	33%	0%
• Social Media	0%	0%	22%	78%	0%
• PubMed/MEDLINE|PubMed Central (PMC)	0%	0%	89%	11%	0%
• Scopus	0%	0%	78%	11%	11%
• African Index Medicus (AIM)	0%	0%	89%	11%	0%
• Web of Knowledge	89%	0%	11%	0%	0%
• Google	0%	0%	0%	11%	89%
• Yahoo	0%	11%	56%	33%	0%

• Google Scholar	0%	0%	89%	11%	0%
• Professional Association Websites	0%	11%	56%	33%	0%
• Medical representative Websites	0%	0%	11%	11%	78%
• Other(s)________________________________	-	-	-	-	-

Barriers and Obstacles to internet use for information seeking in clinical practice for the 9 participants in the study.

Variables	**Frequency (%)**				
	1	**2**	**3**	**4**	**5**
• Too much information to scan	0%	0%	0%	11%	89%
• Lack of time	0%	11%	56%	33%	0%
• Language barrier	0%	0%	11%	33%	56%
• Low relevance for clinical practice	30%	20%	40%	5%	5%
• Lack of training or skills about the Internet	0%	0%	11%	78%	11%
• Unreliability of the information	0%	0%	33%	56%	11%
• Lack of familiarity or experience	0%	0%	11%	78%	11%
• Too slow connection	0%	0%	78%	22%	0%
• Too complicated to use	0%	0%	33%	11%	56%
• Software problems	0%	11%	89%	0%	0%
• Data security concerns	89%	11%	0%	0%	0%
• No Internet access	0%	0%	33%	56%	11%
• Costs	78%	0%	22%	0%	0%
• Other(s)__________________________________	-	-	-	-	-

Computer literacy and internet usage competency of the respondents

Variables	**Frequency (%)**

	1(Yes)	2(No)	3(No Response)
• Are you computer literate?	33%	67%	0%
• Do you own a personal computer?	56%	44%	0%
• Ever used the Internet?	60%	40%	0%
• Used the Internet during the last week preceding the survey?	70%	30%	0%
• Do you have personal access to the Internet?	78%	22%	0%

• **Internet access points used the last time.**	Count	Frequency
Office / Consultation Room	2/9	22%
Home	7/9	78%
Library	0/9	0%
Cyber café	0/9	0%
No Response	0/9	0%
• **Main reason for using the Internet the last time.**		
E-mail	1/9	11%
Research	0/9	0%
Health information	2/9	22%
Patient care	2/9	22%
Others	4/9	44%
No response	0/9	0%
• **Mode of usage**	Count	Frequency
assisted	3/9	33%
Not Assisted	4/9	44%
No response	2/9	23%

Appendix G: EXPERT REVIEW LETTER FROM DUTYWA HEALTH DISTRICT EXPERT

Province of the
EASTERN CAPE
HEALTH

Office of the Sub – District Manager: Mbhashe Sub- District • 307 Charlotte Street • Dutywa •
Private Bag X1232 • Dutywa •5000 • REPUBLIC OF SOUTH AFRICA Tel.: +27 (0)47 489 1223• Fax: +27 (0)47 489 1224• Cell 0605446364 Email danjiswa.nyengule@echealth.gov.za • Enquiries Mrs D Nyengule Date: 19 April 2021

TO WHOM IT MAY CONCERN

This serves to confirm that the study has been conducted by Mr L. Tongou at Mbhashe Sub District in Dutywa CHC. The proposed Semantic Web-Based Healthcare Framework is suitable for Dutywa Health Centre to assist healthcare workers in dealing with information overloading when looking for health information.

If the system is approved and adopted by Department of Health, it can increase clinical decision support and can be used in a variety of health facilities where services are provided and especially if there are sufficient resources.

Compiled by

D. Nyengule
Mbhashe Sub District Manager

19/04/2021

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