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Ontological Model for Xhosa Beadwork in Marginalised Rural Communities: A Case of the Eastern Cape

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Declaration

I, the undersigned **Loyd Tinarwo** student number **200253948**, do hereby declare that the thesis for **Doctor of Philosophy in Computer Science** is my own original work in design, execution and that it has not been submitted or presented, at any other University for a similar or any other degree award. All reference materials used have been duly acknowledged.

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07/02/2019

Dedication

With genuine gratitude and sincere regard, this work is dedicated to my wife Clarah and my children Irene and Daviro.

Acknowledgements

Foremost, 2 Corinthians 3:5 “Not that we are adequate in ourselves to consider anything as coming from ourselves, but our adequacy is from God.” and Psalm 126:3 “The LORD has done great things for us, and we are glad.”

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Abstract

In South Africa, computational ontologies have gained traction and are increasingly viewed as one of the viable solutions to address the problem of fragmented and unstructured nature of indigenous knowledge (IK) particularly in the marginalized rural communities. The continual existence of IK in tacit form has impeded the use of IK as a potential resource that can catalyze socio-economic and cultural development in South Africa. This study was, therefore, designed to address part of this challenge by developing a Xhosa Beadwork Ontology (XBO) with the goal of structuring the domain knowledge into a reusable body of knowledge. Such a reusable body of knowledge promotes efficient sharing of a common understanding of Xhosa Beadwork in a computational form. The XBO is in OWL 2 DL. The development of the XBO was informed by the NeOn methodology and the iterative-incremental ontology development life cycle within the ambit of Action Research (AR). The XBO was developed around personal ornamentation Xhosa Beadwork consisting of Necklace, Headband, Armlet, Waistband, Bracelet, and Anklet. In this study, the XBO was evaluated focused on ascertaining that the created ontology is a comprehensive representation of the Xhosa Beadwork and is of the required standard. In addition, the XBO was documented into a human understandable and readable resource and was published. The outcome of the study has indicated that the XBO is an adequate, shareable and reusable semantic artifact that can indeed support the formalization and preservation of IK in the domain of Xhosa Beadwork.

Keywords: **Ontology**, **DL**, **Xhosa Beadwork**, **IK**, **NeOn Methodology, OWL 2, AR**

Table of Contents

Table of Figures

Table of Tables

List of Abbreviations

AR	Action Research
ATM	African Traditional Medicine
CQs	Competency Questions
DCMI	DCMI Dublin Core Metadata Initiative
DL	Description Logics
FOL	First Order Logic
HTML	Hyper Text Markup Language
IF	Indigenous Foods
IK	Indigenous Knowledge
LODE	Live OWL Documentation Environment
NCS	Noun Classification System
NIKMAS	National IK Management System
NRS	National Recordal System
ODP	Ontology Design Pattern
OOPS!	OntOlogy Pitfall Scanner
OWA	Open World Assumption
OWL	Web Ontology Language
RDF	Resource Description Framework
RDF(S)	RDF Schema
SAHRA	South African Heritage Resource Agency
SAHRIS	South African Heritage Resource Information System
SKOS	Simple Knowledge Organisation System
SPARQL	Simple Protocol and RDF Query Language
SUMO	Suggested Upper Merged Ontology
SW	Semantic Web
UNA	Unique Name Assumption
URI	Universal Resource Identifier
W3C	World Wide Web Consortium
WWW	World Wide Web
XBO	Xhosa Beadwork Ontology
XBT	Xhosa Beadwork Taxonomy
XML	eXtensible Markup Language

Chapter 1: Introduction

This chapter presents the background of the study and the statement of the problem in Section 1.1. The aim and objectives of the study are detailed in Section 1.2. The rationale of the study is presented in Section 1.3. In Section 1.4 a synopsis of the methodology used by the study is specified. The contributions of the study are presented in Section 1.5 while the outline of this thesis is given in Section 1.6.

1.1 Background of the Study

Semantic Web, also identified as the Web of Data, is an enabling extension of the World Wide Web (WWW) for both human and machine-readable communication and integration of information over the WWW (Berners-Lee et al., 2001; Bizer et al., 2011; Berners-Lee and Fischetti, 2001). Fundamental to the Semantic Web is the concept ontology. The construct ontology in computer science emerged during the 1970s and 1980s (Gruber, 1995; Gruber, 1993). According to Gruber (1995; 1993) and Guarino (1998), the concept of ontology is taken from the discipline of philosophy where it is used as a theory for the description of the nature of being. In the computational setting, Guarino (1995; 1998) asserts the concept ontology as an information object or computational artifact. The most prevalent meaning of the concept ontology is postulated by Gruber (1995; 1993) who delineates the concept as a formalization of a shared conceptualization. In this study, the meaning of the construct of ontology is adopted from Studer et al. (1998) who defines the concept as “a formal, explicit specification of a shared conceptualization”.

Globally Studer et al. (1998) and Guarino (1998) assert that computational ontologies are becoming widespread and are being used in the design of databases, retrieval and extraction of information, management and organization of knowledge, enterprise integration, natural language translation, biomedicine, and electronic commerce as a frame for representing knowledge (Guarino, 1998). Meanwhile, in South Africa, ontologies have gained traction and are increasingly viewed as one of the viable solutions in the collection, dissemination, and management of indigenous knowledge (IK). Fogwill et al. (2011) and Alberts et al. (2012) posit that ontologies have potential use in the management and preservation of IK in South Africa. In this context, they can be utilized to address the problem of fragmented and unstructured IK particularly in the peripheralized rural societies of South Africa. In this study, IK is regarded as the entire traditional knowledge that an indigenous or local community has accumulated over time (Odora Hoppers, 2005). IK has significant value and as such, is increasingly viewed as a potential resource that can catalyze socio-economic and cultural development in South Africa (Cultural Strategy Group, 1998; Jain, 2014; Nfila and Jain, 2013; World Bank, 1998; Njiraine et al., 2010; Department Science Techonlogy, 2006). To date, various key policy instruments and structures have been enacted by the government of South Africa with the goal of recognizing the function of IK in socio-economic development (Department of Arts, 1998). A key policy such as the Indigenous Knowledge System Policy of 2004 is a case in point here. This policy affirms that culture is wealth and is an integral component of livelihoods of the marginalized rural communities. Thus, the general welfare, as well as the survival of these rural communities, is strongly tied to IK.

Despite being positioned as a significant resource with the potential to resolve challenges in agriculture, natural environment, food security, and biodiversity conservation to name a few (Fogwill et al., 2011). This body of knowledge remains relatively untapped especially in the marginalized rural communities of South Africa. The major impediment that has hamstrung marginalized rural communities from benefiting from IK is the fact that its current form of existence is fragmented and tacit (Fogwill et al., 2011; Thinyane, 2009).

As noted by Alberts et al. (2012) and Thinyane (2013; 2009) IK in rural areas is mostly available as tacit knowledge which makes the management and useful dissemination of IK challenging. Tacit knowledge is viewed as knowledge in the mind and largely communicated through oral tradition (Odora Hoppers, 2005; Grenier, 1998; Jain, 2006; Jain, 2014). Various scholars such as , Alberts et al. (2012) and Thinyane (2009) posit that the continued existence of IK in tacit form is accelerating its erosion and thereby compromising its future sustainability as a key resource in the development of marginalized rural communities (Jain, 2014; World Bank, 1998; Cultural Strategy Group, 1998).

The erosion of IK is also compounded by westernization, rapid urbanization and commercialization which are all negatively impacting IK. It is an issue that is well articulated by Costello (1990, p.3) who points out that “with increasing Christianisation and modernization, traditional beadwork is fast dying out and is now found only in remote areas.” Such rapid social change has tended to marginalize the role of IK in development thereby triggering its decline. It is a problem that is further exacerbated by the fact that the proportion of IK bearers (senior citizens) who are the custodians of this wealthy body of knowledge is dwindling (Nfila and Jain, 2013; Jain, 2006; Jain, 2014). The dwindling number of these traditional knowledge holders translates to the loss of this vital resource. It is against such a backdrop that this study developed Xhosa Beadwork Ontology (herein after referred to as XBO) with the goal of structuring the domain knowledge into a reusable body of knowledge (Guarino et al., 2009) that promotes an efficient sharing of a common understanding of Xhosa Beadwork in a computational form (Studer et al., 1998; Borst, 1997; Chandrasekaran et al., 1999). XBO assists with defining consistent terminology that describes the domain of Xhosa Beadwork. This will enable different systems (human or machine) to have a straightforward understanding of the sense of data being communicated. The XBO created an opportunity for data integration, classification and formalization of IK as used in Xhosa Beadwork. The XBO is specified in OWL 2 DL formal language (Hitzler et al., 2009a; Motik et al., 2009).

1.2 Problem Statement

Indigenous Knowledge has emerged as a potential resource that can catalyze socio-economic and cultural development in South Africa. This is evinced by a number of key policy instruments and structures that have been enacted with the goal of recognizing the role of IK in the broader development process. IK is seen as having the capacity to resolve challenges in agriculture, natural environment, food security, and biodiversity conservation to name a few (Fogwill et al., 2011; Alberts et al., 2012). Despite this wider recognition of the role played by IK in the development process, there has been limited success in terms of deriving the actual socio-economic benefits from this body of knowledge. The main challenge that has impeded rural marginalised communities to benefit from IK is the lack of a properly structured IK base that enables the formalization and sharing as well as accessibility of this crucial resource. The absence of a properly structured IK base is viewed by some scholars (Thinyane, 2009; Alberts et al., 2012) as a threat that can lead to the extinction of IK because its current form is tacit and fragmented. It is within such a context that the study developed an ontological model that focused on the codification of IK that underpins the Xhosa Beadwork. The developed ontology has transformed tacit and unstructured IK into a reusable computational artefact that can be easily shared thereby increasing its utilization within the domain of Xhosa Beadwork and the Semantic Web.

1.3 Aim and Objectives of the Study

The overall aim of this study is to develop an ontological model for Xhosa Beadwork. Beadwork is the dominant form of Indigenous Knowledge occurring in the marginalised rural communities of the Eastern Cape Province.

The objectives specific to this study are:

1) Undertake a systematic literature review on the existing ontology development and ontology evaluation methodologies.
2) Develop an ontological model based on Xhosa Beadwork for the formalization and sharing of indigenous knowledge.
3) Undertake an ontology evaluation of the ontological model for Xhosa Beadwork. This was done to ensure that the knowledge represented and the

ontological model are of the required standard for knowledge sharing and reuse within the Semantic Web.

1.4 Rationale of the Study

In South Africa, ontology research is still in its adolescence as evidenced by few ontologies that have been developed to date. Various works of interest and ontologies that have been developed are being implemented to safeguard the future of IK (Fogwill et al., 2011). These include the National Recordal System (NRS) implemented through the government of South Africa using a National IK Management System (NIKMAS) (Fogwill et al., 2011). NIKMAS is a software architecture implemented as a semantic digital IK repository for IK management to support the NRS initiative. According to Fogwill et al. (2011), the IK in NIKMAS is described based much on multimedia and metadata. Although NIKMAS is limited, at present, the significant achievement of the semantic digital IK repository has been the development of ontologies on African Traditional Medicine (ATM) and Indigenous Foods (IF) (Fogwill et al., 2011; Alberts et al., 2012). But there are no ontologies yet in the semantic digital IK repository that represents other forms of IK such as traditional Xhosa Beadwork.

On the other hand, computational ontologies have been developed to represent biodiversity conservation in South Africa. For example, Coetzer et al. (2017) designed an ontology for heterogeneous flower-visiting insect using data from natural history museums in South Africa. Also, on biodiversity protection and management, Gerber et al. (2017) developed a standardized computable taxonomic knowledge base as an OWL ontology using a specific case of Afrotropical bees. However, these ontologies were largely focused on biodiversity conservation.

To support multilingualism, Anderson (2016) produced an African language WordNet lexical ontology based on Sotho and isiZulu Bantu languages. However, according to Anderson (2016, p.22) “African WordNets for Zulu, Xhosa, Northern Sotho, Tswana and Venda have not yet been released”. Chavula and Keet (2014; 2015) designed an ontological framework to systematize inheritance when developing linguistic task ontologies. The work resulted in a linguistic task ontology for Bantu Noun Classification System (NCS) in chiChewa, isiZulu, and isiXhosa. The NCS ontology represented linguistic knowledge to support multilingualism and enhance the production of natural language within the Semantic Web. Similarly, Keet and Khumalo (2014; 2017) have designed an ontology-based grammar engine for isiZulu using basic verbalizations in OWL 2 EL. Though these ontologies show significant research in IK, they are focused on lexical and linguistic knowledge representation.

In the study by Thinyane (2009) 4 ontologies were developed for provisioning e-services to support societal activities within the Dwesa community in the Eastern Cape Province. These include the health ontology that codified traditional health practices and knowledge by encapsulating medical conditions and medicines concepts. Conversely, the commerce ontology defined the knowledge surrounding commerce pertaining to the local economic activities in Dwesa. The commerce ontology defined classes, properties of products, different roles of users and relationships between the different entities in the e-commerce platform. The Xhosa ontology encapsulated stories, riddles, poems and different practices of the Xhosa culture. The agriculture ontology embodied practical knowledge in the area of agriculture based on subsistence farming in Dwesa. These four ontologies were implemented as underlying knowledge in the PIASK framework.

Even so, the study by Thinyane (2009) as well as the NIKMAS (Fogwill et al., 2011) did not give a discursive representation of Xhosa Beadwork. For example, type of beadwork **Item** such as **Necklace**, **Headband**, **Armlet**, **Waistband**, **Bracelet** and **Anklet**, beadwork **Material**, **Tribe**, what type of **Person** or **Sex** or **AgeGroup** wears what kind of beadwork **Item** and the **Occasion** when such a beadwork **Item** is adorned to name a few are not represented. Hence, this study was undertaken with the intent of constructing a comprehensive ontological model that encompasses these facets of traditional Xhosa Beadwork and more. From the literature that has been reviewed in this section, it is evident that little has been done in the area of developing an ontological model to represent tacit knowledge on Xhosa Beadwork. This is the gap existing in the literature that has been identified by this study. Therefore, the study developed an ontological model for IK based on Xhosa Beadwork in the marginalized rural communities of the Eastern Cape Province.

1.5 An Overview of the Research Methodology

This segment discusses an abridged methodology that was followed when conducting the study. A more detailed presentation of the research methodology is given in Chapter 3. In that regard, the study used action research methodology (AR). De Vos et al. (2011) define AR as a kind of study based on discovering a resolution to a local problem emanating within a local environment. This entails having the research process carried out in collaboration with those who experience the problem. The main reason for adopting the AR approach was largely influenced by the overall goal of the study that is: to develop an ontological model for Xhosa Beadwork in the marginalized rural communities of the Eastern Cape Province. Thus, the study was aimed at solving a real-world problem in a real-world setting.

The study concluded that in order to adequately address the design of the ontological model there was a need for some kind of iteration and reflection that comes with the use of AR (Creswell, 2002; De Vos et al., 2011; Suzaan Le Roux, 2013). The study then exploited the reflective, iterative and cyclic nature of AR by following three distinct iterative phases in developing the ontological model. These phases are namely data collection, data analysis, and data representation. Within each phase there was an AR cycle (De Vos et al., 2011; Creswell, 2002; Suzaan Le Roux, 2013) focused on (a) planning, (b) action, (c) observation and (d) reflection, leading to further planning, action, observation and reflection (Suzaan Le Roux, 2013; Brannick and Coghlan, 2007; Creswell, 2002). This is an attribute that was beneficial to the study because it gave the study the chance to investigate the problem thoroughly every time, resulting in better comprehension of the problem (Creswell, 2002). This allowed a comprehensive study of the problem.

Documentation analysis formed the primary source of data in this study and was implemented in conjunction with the focus group method. In the data analysis phase, this study employed domain, taxonomic and componential analyses in the identification, extraction, and organization of the ontology terminology from collected data. The adoption of these methods for ontology data analysis in this study was justified because these methods reduced data to a basic structure of two terms and a relationship (Spradley, 1979). Such a structure corresponded to the triple data model which is a main component in the ontology (Wielemaker et al., 2005; Guarino et al., 2009). The output of the data representation phase is a software artifact and therefore a full development methodology to produce the ontology was followed, as emphasized by Suárez-Figueroa (2010).

The study used the NeOn to develop the XBO (Suárez-Figueroa, 2010; Suárez-Figueroa and Gómez-Pérez, 2009). This is a much recent methodology (Suárez-Figueroa, 2010). Unlike the other methodologies, the objective of NeOn is to develop ontological models that emphasize the reuse of knowledge resources (Suárez-Figueroa, 2010; Suárez-Figueroa and Gómez-Pérez, 2009). NeOn is viewed as a methodology based on a flexible collection of scenarios that can be combined in a myriad of ways (Suárez-Figueroa, 2010). The adoption of NeOn methodology in this study is justified as each of these scenarios can be broken down into various processes and activities using specified comprehensive supporting guidelines. Furthermore, the NeOn methodology was selected for this study because the methodology puts forward a number of flexible activity-based ontology development life cycle models. The other ontology development methodologies such as Methontology, OnToKnowledge and DILIGENT are limited in that they only propose a single standard ontology life cycle. In addition, the choice of NeOn methodology in this study was also based on the fact that it has the methodological support for identifying and defining the ontology life cycle according to the scenario. More so, included in the NeOn methodology is the methodological support for identifying and defining these ontology development life cycles. This rendered the NeOn methodology appropriate for this study. It should be stated that a comprehensive discussion on ontology development methodologies is provided in Section 2.2.

In terms of a life cycle, the study employed the iterative-incremental model within the ambit of the NeOn methodology. The justification, for employing a life cycle that is iterative and incremental was because the ontology development involved a domain that was not well understood comprising tacit knowledge. As such, the ontology requirements were not completely known and they changed during the development of the XBO. Hence, the important aspect about the life cycle was that it is iterative and incremental, which means it allowed the study to continuously improve and expand the XBO through executing manifold iterations including cyclic feedback and adaptation (Suárez-Figueroa, 2010). Consequently, the iterative-incremental model focused on a group of requirements and out those requirements, a subgroup was selected then used in the construction of the XBO. The partial outcome was then studied, including analyzing the risk of progressing to the next iteration. The initial group of requirements was then augmented and adapted with each subsequent iteration. This process continued up until a complete OWL 2 DL XBO was constructed.

1.6 Contributions of the Study

The main conceptual contributions made in this thesis are the following:

1) The study constructed a Xhosa Beadwork Taxonomy (XBT). This is a knowledge organization system that provides categorization and classification

of beadwork knowledge into a logical structure. Such an information architecture by providing controlled taxonomical knowledge on Xhosa Beadwork will facilitate information sharing and promote knowledge management of IK. The taxonomy is presented in Chapter 4.

2) The study developed an ontology for Xhosa Beadwork called Xhosa Beadwork Ontology (XBO). In the context of this study, Xhosa Beadwork was identified as a domain that lacked ontological representation. As result, the XBO was developed as a reusable body of knowledge that will enable formalization and efficient sharing of IK. The XBO is presented in further detail in Chapter 4 and 5.

3) Usage of domain, taxonomic and componential analyses in ontology data analysis were proposed in this study. The study provided the methodological guidance that supports and guides the identification, extraction, and organization of terminology in the development of an ontology. Thus, enriching ontology conceptualization which is a crucial activity in ontology development. These three methods are described as applied in this study in Chapter 3.

These contributions are further discussed in Section 6.2

1.7 Thesis Organization

This study is comprised of 6 chapters as follows:

Chapter 1 Introduction: In this chapter, the background of the study and the problem statement are introduced, as well as detailing the overall aim and objectives of the study. The rationale of the study, the overview of the methodology and the thesis organization are also laid out in this chapter.

Chapter 2 Literature Review: In this chapter, a review of the literature related to the creation of computational ontologies is presented, which is the foundation of the work developed throughout this study. Included in this chapter is the discussion on the existing ontology development and ontology evaluation methodologies as well as a survey of technological support of ontology evaluation.

Chapter 3 Research Methodology: This chapter discusses in detail the methodology which was adopted by this study in developing the XBO. Action Research (AR) is presented as the overarching methodology used by the study. Each stage of AR is discussed and how AR stages were actualized in the development of the Xhosa Beadwork Ontology (XBO).

Chapter 4 Implementation: In this chapter, the development of the OWL 2 DL Xhosa Beadwork Ontology (XBO) is presented. The XBO encompasses the ontological and non-ontological resources that describe Xhosa Beadwork. The development of the XBO pursued the NeOn methodology as discussed in Chapter 3.

Chapter 5 Evaluation and Results: In this chapter, the evaluation of the Xhosa Beadwork Ontology (XBO) is presented. The evaluation is centred on ascertaining the effectiveness of the XBO so as to find out whether the XBO is a comprehensive ontological model for Xhosa Beadwork and is of the required standard.

Chapter 6 Conclusions and Future Work: The conclusion of the study is entailed in this chapter with an overview discussion of the overall study by addressing the research objectives, emphasizing the contributions made, as well as future research emerging from this study. Finally, the bibliographic references used and appendices that provide information relevant to the study are presented.

Chapter 2: Literature Review

In this chapter, a review of the literature related to the creation of computational ontologies is presented, which is the foundation of the work developed throughout this study. In Section 2.1 several definitions of the concept ontology are introduced, from a philosophical viewpoint. Subsequently, different kinds of ontologies are distinguished in Section 2.2. The Web Ontology Language (OWL) is introduced in Section 2.3 whereas the syntax, semantics, and components of OWL 2 DL ontologies are outlined in Section 2.4. In Section 2.5 and Section 2.6, several methodologies for ontology development and ontology evaluation within ontological engineering are presented. This is followed by a discussion of the existing ontology evaluation tools in Section 2.7. This chapter is concluded in Section 2.8.

2.1 Ontologies

The concept ontology has a complicated past both inside and outside computer science. Its conception dates back to the seventeenth century (Guarino et al., 2009). During this period, the use and application of this construct was only confined to the subset of philosophy pertaining to nature and reality. In the philosophical context, Aristotle defined the word ontology as a systematic study of existence or nature of being (Guarino, 1998; Gruber, 1995; Giaretta and Guarino, 1995; Guarino et al., 2009). In this context, the term ontology has an uncountable reading. Nevertheless, in recent years, the term ontology evolved and gained wide recognition of its application in computer science especially with the rise of artificial intelligence. In the computational context, the term ontology became associated with an information object or engineering or computational artifact representing a machine processable abstraction of a domain. Guarino (1995; 1998) views ontologies as a means that can formalize the structure of a system. In this regard, the term ontology has a countable reading and the study follows this reading of the term (Guarino, 1998; Guarino et al., 2009).

There are disparate views within literature trying to establish a comprehensive meaning of an ontology in the field of computer science. The most prevalent definition of an ontology in literature arguably the de facto definition is specified by Gruber (1995, p908) who delineated an ontology as an “explicit specification of a conceptualization.” With this definition, the idea of conceptualization is discussed further by Gruber (1995) and Guarino (1998; 1995) as an abstract simplified view of the domain which we want to represent for a particular purpose including its related concepts. Whereas, explicit is explained by Gruber (1995) and Giaretta and Guarino (1995) as the unambiguous definition of concepts, their types, their constraints and their use in a conceptualization (Guarino, 1998; Guarino et al., 2009).

Another alternative definition is provided by Giaretta and Guarino (1995, p8) who define ontology as “a logical theory which gives an explicit, partial account of a conceptualization.” In this definition, ontology is viewed as providing a partial interpretation of the intended conceptualization. The definition emphasizes the postulation that it is impossible to construct an ontology that totally represents a conceptualization.

Expanding on the work of Gruber (1995), Borst (1997, p12) posits an ontology as “a formal specification of a shared conceptualization.” This definition introduced the notion of a shared view or agreement on the conceptualization. According to Borst (1997) and Guarino et al. (2009), the term shared mean that the ontology should capture a common or collective understanding of the modeled domain. Furthermore, in the definition, Borst (1997) added the word formal to indicate that the ontology needs to be expressed in a format that is machine readable.

Later, Studer et al. (1998, p184) provided a more nuanced understanding of the concept ontology by combining the definition by Gruber (1995) and that of Borst (1997) by positing that an “ontology is a formal, explicit specification of a shared conceptualization." This extends the definition by Borst by adding that the ontology should be explicitly defined. These definitions demonstrate and can be viewed as refinements that occurred to the definition by Gruber. Despite the definition by Gruber (1995) being the most prevalent and most cited in literature, it is argued to be overly broad. More so, as already pointed out, the early definitions of the concept ontology, did not consider the sharing dimension until when the aspect was introduced by Borst (Gruber, 1995; Guarino et al., 2009).

Notwithstanding the contrasting definitions of the concept ontology in literature, the study adopted the meaning of an ontology as espoused by Studer et al. (1998) . This definition was preferred for the purpose of this study because it captured one of the core ideas supporting the study, that is, an ontology should have a formal underpinning. In this study, the ontology constructed is expressed in OWL 2.0 ontology language. Furthermore, as highlighted in the definition the view of shared conceptualization is vital as it suggests that the ontology can be used across diverse systems. As such, the ability to reuse an ontology is possible when the specified conceptualization is generally accepted. Hence, Guarino (1998) states that the advantages of having an ontology are limited without at least a minimal shared commitment on the conceptualization.

The main benefit of computational ontologies is that they make knowledge explicit and accessible. For example, ontologies permit separation of domain knowledge from programming code thereby enabling maintenance, easy extension, sharing and reuse of knowledge in a domain (Guarino, 1998). Since computational ontologies are normally expressed in a decidable ontology language, ontologies offer the advantage that they can be classified and checked for logical consistency automatically, using a reasoner. Ontologies vary from simple hierarchies of classes that rely on strict subsumption to expressive ontologies, with axiomatization expressed in the underlying ontology language as detailed in Section 2.2.

2.2 Ontology Granularity

In literature, the classification of ontologies is not consistent. There are various types of ontologies and these ontologies can be broadly differentiated based on how they depend on a particular task or viewpoint. According to van Heijst, Schreiber and Wielinga (1997b; 1997a) and Guarino (1998) it is possible to differentiate between application, domain, generic and representation ontologies.

Generic (foundational or upper) ontologies define general knowledge. Typically, generic ontologies define concepts, for example, state, time or component separate from a problem or domain (Guarino, 1998; Gómez-Pérez, 1999). These ontologies represent conceptualizations that are general and span across many domains such as, SUMO (Niles and Pease, 2001) and DOLCE (Van Heijst et al., 1997b; Pisanelli et al., 2002; Yu, 2008).

Meanwhile, domain ontologies describe a generic domain like beadwork, or fashion or medicine. They describe vocabulary that is specific to a domain. The domain ontologies are generally considered as ontologies that specialize concepts defined in generic ontologies (Guarino, 1998; Van Heijst et al., 1997b; Gómez-Pérez, 1999). Shared characteristics of domain ontologies are that provide high coverage and granularity with a rich set of annotations but then, domain ontologies are lightweight. For example, there are collections of domain ontologies in literature that are related to the domain of beadwork and these include Xhosa (Culture) Ontology, Agriculture Ontology, eCommerce Ontology, Health Ontology (Thinyane, 2009) for the marginalized rural communities of South Africa, Bantu Noun Class System Ontology (Chavula and Keet, 2015; Chavula and Keet, 2014) and ontologies for the Fashion, Textile, Clothing (Aimé et al., 2016) and Handicraft (Maalej et al., 2014). Furthermore, a domain ontology called Xhosa Beadwork Ontology (XBO) has been developed in the context of this study and is presented in Chapter 4.

On the contrary, task ontologies define a task or activity generic as diagnosing or selling, through specializing the terms introduced in the generic ontology. They have a terminology associated with a task with the same or different domain (Guarino, 1998; Doran, 2009; Gómez-Pérez, 1999). Application ontologies comprise all the vocabulary that is required to model the knowledge desired for a specific application. Typically, application ontologies are a combination of vocabulary taken from domain and generic ontologies. Moreover, application ontologies can contain extensions specific to a method or task. Application ontologies cannot be reused on their own. They can be acquired by choosing theories from the ontology library, which are then modified for a certain application (Van Heijst et al., 1997b).

A representation ontology expounds the knowledge that underpins formalisms in knowledge representation. These ontologies are neutral with respect to entities in the world (Van Heijst et al., 1997b). This means that the representational framework is provided without claims about the world. Domain and generic ontologies are defined as using the vocabulary provided by representation ontologies, for instance, the Frame Ontology was used in Ontolingua (Gruber, 1993; Van Heijst et al., 1997b; Doran, 2009).

Uschold and Gruninger (1996) and McGuinness (2002) propose that ontologies should be classified using formality dimension, ranging from informal to formal. Uschold and Gruninger (1996) provide highly-informal, semi-informal and semi-formal classification. On the contrary, McGuinness (2002) provides an ontological continuum of various types of models that can be classified into informal models, formal models and informal models (Doran, 2009).

2.3 Ontology Languages

In literature, different ontology languages have been recommended for representing ontologies. The formal ontology languages proposed differ with respect to expressivity and decidability. There are languages that have high expressivity, that provide a powerful catalogue of constructs, however, they are undecidable such as FOL. With such languages, computability is of secondary concern. On the other hand, there are those languages that offer a restricted set of constructs and are decidable. These are mainly used in expressing ontologies that are there to establish a common understanding in a domain with the possibility of automatic reasoning.

In order to express ontologies, the World Wide Web Consortium (W3C) developed the Web Ontology Language (OWL) for the Semantic Web. OWL has been established as a de facto standard language designed for the formulation, exchange, and reasoning of knowledge in a domain (Bechhofer et al., 2004; Allemang and Hendler, 2011). In fact, OWL is a computational logic-based language derived from Description Logics (DLs) where DLs are decidable subsets of first FOL (Baader et al., 2003; Baader et al., 2005). Therefore, complete reasoning is possible in OWL language. This is a key advantage of using OWL in processing background (or explicit) knowledge and inferring implicit information. Reasoning services such as ontology satisfiability, instance checking, class satisfiability, subsumption, and classification are supported in OWL. Reasoning is detailed in Section 2.4.5.

Furthermore, OWL provides various W3C standardized syntaxes for ontology serialization. As such ontologies may be serialized in RDF/XML, OWL XML presentation syntax or N3 (Motik et al., 2009). There are other numerous serializations, that can be translated to and from other serializations, for example, the Manchester Syntax (Wang et al., 2006; Vrandečić, 2010; Doran, 2009; Bechhofer et al., 2004). By way of ontology serialization, the sharing of ontology specifications is facilitated through allowing humans and machines to successfully provide the syntax of the specification of the ontology suitable semantics. Throughout this study, the OWL 2 Manchester Syntax (Motik et al., 2009) is used for serializing the axioms and thus the Xhosa Beadwork Ontology. This is the most understandable OWL 2 syntax currently available. OWL 2 Manchester Syntax is readable and concise and unlike the DL syntax Manchester reflects on both the semantics of the axioms and their intention.

OWL has 2 versions. These are OWL 1.0 and OWL 2.0. To start with OWL 1.0 came to be a W3C recommendation in 2004 (Bechhofer et al., 2004). OWL 1.0 is compatible and extends RDF and RDF Schema. OWL 1.0 is available in several profiles with particular properties. The original release of OWL 1.0 comprised 3 sublanguages OWL Lite, OWL DL and OWL Full in the order of increasing expressivity. The first two sublanguages are decidable, where OWL DL is more expressive than OWL Lite (Bechhofer et al., 2004; Doran, 2009).

At the time of writing, the current version of OWL was OWL 2.0 and became a standard in 2009 (Allemang and Hendler, 2011). OWL 2.0 is the new extended version of OWL 1.0 (Motik et al., 2009; Hitzler et al., 2009a) and is more expressive than OWL 1.0. By and large, different sublanguages can be distinguished under OWL 2 based on expressivity and scalability. These sublanguages (or profiles) are

OWL 2 DL, OWL 2 Full, OWL 2 QL, OWL 2 EL and OWL 2 RL (Motik et al., 2009; Hitzler et al., 2009a; Sengupta and Hitzler, 2014; Grau et al., 2008).

OWL 2 DL has high expressivity while retaining guaranteed computational decidability on reasoning. According to Krotzsch et al. (2014), OWL 2 DL is based on DLs SRIOQ (D). OWL 2 DL can be seen as a restricted version of OWL 2 Full with the restrictions designed to allow eased ontology modeling. Since OWL 2 Full is undecidable, OWL 2 DL makes writing a reasoning mechanism with guaranteed decidability. As a result of such a design, there are numerous reasoners that cover OWL 2 DL language unlike OWL 2 Full (Hitzler et al., 2009a).

The most expressive OWL 2 profile is OWL 2 Full. OWL 2 Full can be seen as an extension of RDFS. As such, the RDF based semantics for OWL 2 Full use the RDFS semantics and general triple data model syntax and it is reflective. In fact, the OWL 2 Full sublanguage is comprised of all of OWL 2 DL and RDF(S) constructs with no restrictions. However, with OWL 2 Full no assurance is there that the reasoning on an ontology would terminate (Sengupta and Hitzler, 2014; Allemang and Hendler, 2011).

In general OWL 2.0, is a very expressive language but difficult to implement and work with. In addition to OWL 2 DL and OWL 2 Full profiles, OWL 2 has 3 more sublanguages, namely, OWL 2 EL, OWL 2 QL and OWL 2 RL (Sengupta and Hitzler, 2014). With regards to OWL 2 EL, it is useful for applications that have a huge number of classes and property hierarchies that do not need complex OWL constructs. The computational complexity of OWL 2 EL is polynomial. Meanwhile, OWL 2 QL was designed to support conjunctive queries in relational database applications. The complexity of inferencing in OWL 2 QL is also polynomial. Lastly, OWL 2 RL has been developed for applications that are implemented based on rule-based engines. In addition, OWL 2 RL offers interoperability with other rule-based knowledge representation languages. The reasoning performance in this sublanguage for rule-based systems is polynomial (Hitzler et al., 2009a).

These sublanguages are created to be easy profiles of OWL 2 with robust scalability given existing technology. The OWL 2 sublanguages presented in this section were identified as having considerable use. In this study, the OWL 2 DL profile is used. This profile belongs to the current standard for expressing ontologies and is the most expressive sublanguage with balanced expressivity and guaranteed decidability on reasoning.

Tool support is essential in order to express ontologies using OWL 2.0. There are 2 kinds of tools that deal with the 2 main stages in the ontology development lifecycle. These are semantic editors which are used to create ontological models and semantic reasoners which are used to inferring implicit knowledge (Hitzler et al., 2009a). For instance, semantic reasoners are used to determining the logical consequence of an ontological model. An example of a common modelling system is Protégé. This is a free open source software with an open plugin structure that allows integration with other components for ontology modelling. Other examples of editors are TopBraid Composer, SWOOP and NeOn Toolkit (Hitzler et al., 2009a; Lombard, 2014).

There are several semantic reasoners for performing reasoning in OWL 2 DL such as FaCT++, HermiT, Pellet, and RacerPro (Hitzler et al., 2009a; Sirin et al., 2007; Vrandečić, 2010; Abburu, 2012). In addition, there are reasoning systems intended for the sublanguages of OWL 2.0. For example, Classifier for EL (CEL) supports OWL EL, QuOnto supports OWL QL and ORACLE 11g supports OWL RL (Hitzler et al., 2009a; Motik et al., 2009; Doran, 2009; Dentler et al., 2011). More detail on reasoning is provided in Section 2.4.5.

2.4 OWL 2 DL Ontologies: Building Blocks

Here an introduction is given on components that are used to build ontologies in OWL 2 DL. Detailed literature on DLs is given by Baader et al., (2003; 2005) and for an extensive description of OWL 2 the reader is referred to Hitzler et al. (2009b),Motik et al. (2009) and Grau et al. (2008).

2.4.1 Basic Components

In an OWL 2 DL ontology, there are three kinds of basic components: individuals, properties and classes (or concepts) where properties are further subdivided into object properties and datatype properties (Baader et al., 2005; Krotzsch et al., 2014; Horridge et al., 2004). To start with, individuals represent the concrete and countable objects in the domain of discourse. Individuals could be referred to as instances of classes (Horridge et al., 2004). However, it is important to note that OWL does not use the Unique Name Assumption (UNA) (Horridge et al., 2004). This means that two different names could refer to the same instance. As such it must be clearly stated whether the instances are different or otherwise.

Concepts and properties have a set-theoretic interpretation. An OWL class is interpreted as a set that contains individuals (Hitzler et al., 2009a). The word concept is used sometimes in place of class (Baader et al., 2003; Baader et al., 2005). In that sense, classes are a concrete representation of concepts (Krotzsch et al., 2014). The set is an extension of the class and the instances therein are its individuals. The set is then described using mathematical descriptions that define the membership of the class. For example, possible classes of a beadwork ontology are **Person**, **Bracelet** and **Necklace.** The class **Necklace**, for instance, would contain all the instances of beadwork items that are necklaces in the domain of Xhosa Beadwork.

OWL properties denote binary relationships that connect two concepts or an object to a property. There are 2 main kinds of properties, namely object and datatype properties. An object property is interpreted as a relationship between two individuals. On the other hand, a datatype property is regarded as a set of pairs of instances and data values (Hitzler et al., 2009a). Properties such as **hasColour** or **isWornBy**, that link classes (or instances), are represented as object properties in OWL 2. Properties such as **itemUse** and **commonName**, which associate concepts to data values, are represented as datatype properties.

A distinctive feature of classes, properties, and instances is that they have a unique Uniform Resource Identifier (URI), comprising a namespace and a local name. The local name should be unique in the namespace, and the namespace is abbreviated by a prefix. For example, in the URI **http://www.semanticweb.org/XBO#Bracelet**, the namespace ends with # and Bracelet is the local name. Given the prefix **xbo**, the URI reduces to **xbo: Bracelet**. On one hand, OWL has a predefined universal concept denoted as ⊤ representing class **owl:Thing.** This has all individuals as an extension. On the other hand, there is bottom concept denoted as ⊥ representing class **owl:Nothing.** This class is also predefined and is a void set (Baader et al., 2003).

2.4.2 Concept Constructors

OWL 2 ontologies may contain more anonymous classes, properties, and individuals in order to express more complex knowledge. Concepts are then developed from several types of constructors. In that regard, OWL provides logical class constructors, namely: (class) intersection, union, and complement borrowed from set theory. These constructors are used to join atomic classes to build complex classes (Hitzler et al., 2009a). These classes are important in defining the explicit meaning of ontology elements. These complex classes consist of other classes using different constructors, in deep nesting (Baader et al., 2003).

The constructors in OWL 2 DL are presented in Appendix A. The concept conjunction is used to represent instances that are in both classes in the conjunction expression (Baader et al., 2003; Hitzler et al., 2009a). For example, the intersection of concepts, which may be denoted as **Female ⊓ Parent** can be used in a beadwork ontology to limit the set of instances to those that belong to both **Female** and **Parent**. An inference that could be drawn from this is a set of all instances that belong in both class **Female** and **Parent**. The concept conjunction (or intersection) is based on the formulae stated in Appendix A

Concept disjunction (also called union) is a dual of intersection (Krotzsch et al., 2014). According to Hitzler et al. (2009b), the concept disjunction of 2 classes has every instance which is contained in one of the classes. For example, disjunction could be characterized as **Mother ⊔ Father** to represent a new complex concept of individuals that are at least one of the constituent classes (Hitzler et al., 2009a; Krotzsch et al., 2014). The concept of disjunction is also based on the formulae stated in Appendix A.

In addition, the existential and the universal restrictions provide an additional type of logic-based class constructor used in creating new complex classes. They utilize constructors involving properties. The existential quantification describes a set of all instances that are associated through a property to another instance which is an instance of a specific class (Hitzler et al., 2009a). The existential quantification would allow one to describe, for example, the concept of instances that have a female gender as ∃**hasSex. Female**. On the other hand, the universal quantification is employed to describe a set of instances for which all the related instances must be instances of a certain class (Hitzler et al., 2009a; Baader et al., 2003). This can be represented using the following concept expression, ∀**hasTribe. Thembu**, which describes the concept of individuals all of whose tribe is **Thembu**. Both these constructors are useful in the beadwork ontology in capturing incomplete knowledge and in defining relationships between classes that depend on relationships other than **EquivalentTo** and **DisjointWith**.

2.4.3 Axioms

An axiom is a unit of knowledge in an ontology that defines formal relationships involving entities (Vrandečić, 2010; Hitzler et al., 2009a). The statements about how concepts are connected in a domain are expressed using axioms in OWL 2 DL ontologies. It should be noted that the corresponding formulae for all the axioms described in this section are specified in Appendix A.

Axioms can be of type subsumption, equivalence, and disjointness. These are expressed as **rdfs: subClassOf**, **owl: equivalentClass** and **owl: disjointWith** in OWL 2. For example, say that class **TabNecklace** is a subclass of the class **Necklace** can be expressed using a subsumption axiom

$$\textbf{TabNecklace} \sqsubseteq \textbf{Necklace}.$$

This axiom means that class **TabNecklace** is a subset of class **Necklace.** That is, every instance of **TabNecklace** is also an instance of **Necklace**.

Furthermore, concept equivalence asserts that two concepts have the same instances. The fact that class **Person** is equivalent to class **Human** can be expressed as in the class equivalence axiom

$$\textbf{Person} \equiv \textbf{Human.}$$

Such an axiom denotes that classes **Person** and **Human** have the same extension. Though synonyms are an apparent example of equivalent classes, in reality, one usually uses concept equivalence to provide a name to complex expressions as introduced in Section 2.4.4.

Furthermore, class expressions can be joined with equivalence and inclusion axioms to portray more compound situations like the disjointness, which states that 2 concepts have no common instances (Krotzsch et al., 2014). The fact that the class **Bracelet** is disjoint from class **Necklace** is expressed through a disjointness axiom **Bracelet** $\sqcap$ **Necklace** $\sqsubseteq \bot$. Such a disjointness axiom says that the intersection of classes **Bracelet** and **Necklace** is void set. That is, these 2 classes do not have common instances. In fact, both equivalence and disjointness axioms can be redacted to subsumption (Baader et al., 2003).

The usage of subsumption and equivalence in specifying defined concepts in ontology is explained in Section 2.4.4. Regarding the object and datatype properties, axioms could be stated to specify domain and range restrictions, including some additional characteristics. For instance, the domain and range restrictions on a property entail that all pairs of instances connected by the property are from the specified domain and range, despite that it is not explicitly stated. In addition, characteristics such as transitive, symmetric, functional or inverse functional may further be specified on object properties. According to Bechhofer et al. (2004), datatype properties can further be asserted only as functional.

2.4.4 Concept Definitions

In an OWL representation, classes, properties, and instances require additional detailed information so as to enable inference. To achieve the specification of the ontological resources, axiomatization should be asserted that link them to other resources in order to explicitly define the intended meaning. The typical form of a declaration in an ontology is a definition. A definition is an equality expression with a left-hand side atomic concept and arbitrary class on the right-hand side (Baader et al., 2003; Krotzsch et al., 2014).

For example, by the axiom

CharmNecklace ≡ Necklace ⊓ ∃hasDecoration. Charm

CharmNecklace is associated with the description on the right-hand side

This a declaration that is normally interpreted as equivalence, which is the same as giving both sufficient and necessary conditions in classifying an instance as a **CharmNecklace**. According to Baader et al. (2003), such a definition is stronger than those that impose only necessary conditions to the class. This kind of declaration is considered a feature of OWL 2 DL ontologies. The OWL 2 DL ontology developed in this study was constituted of definitions of such form.

Another type of a concept prevalent in an ontology is called a primitive concept, whose meaning cannot be defined in an exhaustive way. These concepts are considered incomplete definitions (Baader et al., 2003; Horridge et al., 2004). Primitive concepts are introduced by specifying the necessary conditions in order for a given entity to be considered as belonging to the class that the concept represents.

In the context of this study, a subsumption axiom (or inclusion axiom) with an arbitrary class on the right-hand side and a named class on the left-hand side is called a primitive definition. For example, **Bracelet ⊑ Item** asserts that each individual of **Bracelet** is also an individual of beadwork **Item**. An inclusion of this nature is called a specialization (Baader et al., 2003). However, the definition only asserts necessary and not sufficient conditions for the instances that belong to the named class. This is vital in circumstances where certain concepts cannot be defined completely. In this case, necessary conditions are stated for concept membership using an inclusion.

In OWL 2 DL ontologies, the primitive concepts and defined concepts that involve an appropriate restriction on the classes on their right-hand side are the way by which relationships between classes are asserted for example **hasDecoration**. As argued by Stevens et al. (2007) the exact nature of the relation should be stated before a new relation is defined in an ontology, and including the choice of the type of class on the restriction should be unequivocal (Baader et al., 2003). Again, the corresponding formulae of the formal concept definitions described in this section are presented in Appendix A.

2.4.5 Reasoning

As mentioned in Section 2.3, OWL 2 DL naturally supports reasoning with background knowledge whereas implied knowledge is inferred because it is underpinned by a DL, a fragment of FOL. This means that an ontology relying on DLs is able to do specific types of inferencing. An OWL 2 ontology not only does it have terminologies and assertions (or classes, object properties, datatype properties, and individuals) but also provides mechanisms that reason about them. This process is known as reasoning (Baader et al., 2003). This is done by using a semantic reasoner which is a software created for the purpose of examining knowledge in the ontology and drawing inferences using well-defined semantics of OWL 2 (Sirin et al., 2007). As such from the axiomatizations in an ontology logical consequence can be computed.

Most OWL reasoners support reasoning such as determining whether a description is satisfiable in an ontology or whether one description is more specialized than the other. Additional services offered by a semantic reasoner are finding the set of statements in an ontology that are satisfiable (Baader et al., 2003; Sirin et al., 2007). These satisfiability and consistency checkings are valuable in determining if an OWL ontology is meaningful.

In order to comprehend the foremost features of inference, the model-theoretic behind OWL 2 DL ontologies should be considered. The reasoning is specified through the idea of interpretation (Baader et al., 2003). According to Baader et al. (2003), an interpretation is made up of a set and an interpretation function. The interpretation function allocates each concept a subset of the domain of interpretation, to each role a relation, and to each individual a part of the domain of interpretation.

Axioms, act as restrictions on interpretations. If the interpretation satisfies all axioms in an ontology, that is called a model of the interpretation (Baader et al., 2003; Beißwanger, 2013). As a consequence, a concept in an ontology is satisfiable if there is a model of the ontology in which a set contains instances in that interpretation. In this case, a concept that has such a characteristic is satisfiable or unsatisfiable otherwise.

For example, concept **Waistband** is subsumed by another concept **Item** in an ontology, if in each model of the ontology the set **Waistband** is a subset of the set **Item**. Subsumption checking is also used in organizing terminology of an OWL 2 DL ontology in a taxonomy according to their generality. In addition, there are other relationships between concepts such as equivalence and disjointness as previously given in Section 2.4.4 (Baader et al., 2003).

There is a broad array of technological support in semantic reasoning (Dentler et al., 2011; Abburu, 2012). Several different reasoning tools have been proposed for OWL 2 DL like Pellet (Sirin et al., 2007). FaCT++ (Tsarkov and Horrocks, 2006), HermiT (Glimm et al., 2010), RacerPro (Haarslev et al., 2012). Ontological reasoning is important for various reasons. The use of a reasoner such as Pellet during development and maintenance of an OWL 2 DL ontology enhances the construction of accurate ontologies (Horridge et al., 2004; Sirin et al., 2007). Also, the automatic classification of ontologies after modifying them reduces the error-prone manual maintenance work involved (Horridge et al., 2004; Sirin et al., 2007; Abburu, 2012).

Nonetheless, when automatic reasoning is employed, there is need to be aware of the fact that OWL 2 DL ontologies are based on the open world assumption (OWA) and not the unique name assumption (UNA). According to the OWA, missing information shows a lack of information and not negative information (Horridge et al., 2004; Hitzler et al., 2009a; Rector et al., 2004). Though OWA is useful in ontology modelling, to avoid unnecessary side effects of OWA reasoning, the ontological meaning should be clearly stated through axioms such as disjointness axioms, formal definitions or equivalence axioms, subclass axioms with disjunction, the complementation of existential restrictions with universal restrictions and vice versa, as required (Horridge et al., 2004; Krotzsch et al., 2014).

The equivalence axiom and the subclass axiom with the disjunction are called covering axioms while a universal restriction that complements an existential restriction is called a closure axiom (Horridge et al., 2004). Covering and the closure axioms are used to avoid trivial satisfiability. In other words, they are used to close down descriptions of entities, so that it is possible in an OWL DL ontology to state that there are these entities and there are no others. For the formulae, the reader is referred to Appendix A.

2.4.6 Annotations

OWL 2 does allow classes, properties, instances, and the ontology to have metadata using annotation properties. An annotation link an entity via an annotation property with an annotation value (Hitzler et al., 2009a). These annotations are designed to add extra information about the entities in an ontology. However, in OWL DL the usage of annotations is constrained. They cannot be used in property axioms or hierarchies and no domain or range allowed to be set on them (Horridge et al., 2004).

In OWL, there are predefined annotation properties such as **rdfs:label** and **rdfs:comment** that can be used to annotate classes, properties, and individuals. There are a number of other annotation properties in OWL that can be utilized to annotate an ontology. These are called ontology annotations they add metadata to the ontology (Horridge et al., 2004) for example **owl:priorVersion**. Furthermore, SKOS (Simple Knowledge Organisation System) is a formal language that can be employed to annotate classes, properties, and individuals to support semantic interoperability. SKOS has rich support for labelling and reporting metadata such as **skos:prefLabel**. Annotation properties like **skos:broader** and **skos:narrower** are also specified in the SKOS vocabulary for defining linguistic relationships and **skos:altLabel** for showing different synonyms and translations (Allemang and Hendler, 2011; Miles and Bechhofer, 2009; Miles et al., 2005).

However, also custom properties may be defined in an OWL DL ontology. Annotations are there to provide semantic interoperability or semantic integration with intent to share the meaning of the ontology within the Semantic Web (Hitzler et al., 2009a; Allemang and Hendler, 2011; Beißwanger, 2013).

2.5 Ontology Development Methodologies

This section provides a description of 5 main ontology development methodologies within the ontology engineering field. These are methodology by Gruninger and Fox (1995), Methontology (Fernández-López et al., 1997), OnToKnowledge (Sure et al., 2004), DILIGENT (Pinto et al., 2004) and NeOn (Suárez-Figueroa, 2010) methodologies. Each of these main ontology development methodologies is briefly explained below, considering how such methodologies undertake data analysis (terminology extraction in the universe of discourse) and ontology evaluation.

2.5.1 Methodology by Gruninger and Fox

Gruninger and Fox (1995) proposed a methodology that is based on the development of FOL knowledge-based systems. The methodology is based on the TOVE within the domain of enterprise modelling. The goal of this methodology is the development of a next-generation common sense enterprise model that has the ability to respond to queries with what is explicitly defined in the model and with what is inferred by the enterprise model (Gruninger and Fox, 1995; Fernández-López and Gómez-Pérez, 2002b; Fernández-López, 1999).

In this methodology, the enterprise model is not developed directly. An initial informal specification description made and then the description is formalized. The procedure for engineering such an enterprise model is as follows: (i) capturing of the motivating scenario, (ii) enumeration of informal competency questions (CQs) (iii) specification of the terminology in the ontology in first-order logic language, (iv) formulation of the formal CQs by means of the terminology of the ontology, (v) specification and definition of axioms in first-order logic language and (iv) lastly the definition of the completeness theorems in order to establish and characterise the completeness of the ontology (Gruninger and Fox, 1995; Fernández-López and Gómez-Pérez, 2002b; Fernández-López, 1999).

Complex enterprise models have been developed following the methodology by Gruninger and Fox (Fernández-López and Gómez-Pérez, 2002b; Yu, 2008; Fernández-López, 1999). This methodology was used to construct the TOVE ontologies. The TOVE ontologies included ontologies such as enterprise design, project, scheduling, and service ontologies. Furthermore, ontologies built using this methodology were used in applications such as enterprise design workbench and integrated supply chain management project agents (Gruninger and Fox, 1995; Grüninger and Fox, 1995).

These ontologies comprise of a FOL integrated model. Hence, this method is formal and uses classic logic which is robust. As such the methodology can be utilized in transforming an informal scenario into a computable model. By the way in which the development established and undertaken, including provision for extending an already built ontology. But the most important strength of the methodology by Gruninger and Fox (1995), is the identification and introduction of the CQs method in knowledge-based development (Grüninger and Fox, 1995; Suárez-Figueroa, 2010; Fernández-López et al., 1997; Fernández-López, 1999).

Conversely, the major limitation of this methodology is that; there is no clear separation into phases involved in the development of the enterprise models. There are no detailed approaches given by this methodology. For example, neither a procedure for formulating the CQs is given nor specific activities are described. With regard to formalization, the methodology is based on logic implemented in Prolog and no other formalization language is proposed. In addition, there is no recommended approach for selecting the ontology life cycle in the methodology.

Accordingly, it is not possible to ascertain if the ontology development is through evolving prototyping or incremental life cycle development (Yu, 2008; Villalón and Pérez, 2016; Suárez-Figueroa, 2010).

With respect to data analysis (for terminology extraction), the methodology by Gruninger and Fox (1995)proposes the specification of the relevant terminology in the domain of discourse through the CQs method. In this case, the terminology is extracted through identification vocabulary in the domain. Although terminology specification is mentioned, there are neither techniques nor precise methodological detail on how to identify, organize and structure concepts, relations, attributes and instances in the domain of discourse.

2.5.2 Methontology

Methontology is a methodology designed to support knowledge level ontology development from scratch (Fernández-López et al., 1997; Fernández-López, 1999). The Methontology framework relies on software engineering development processes and knowledge engineering methodologies (Fernández-López, 1999; Suárez-Figueroa, 2010; Yu, 2008).

This methodology was proposed for ontology development by the Foundation for Intelligent Physical Agents (FIPA), which promotes interoperability across applications that are agent-based (Corcho et al., 2005; Fernández-López and Gómez-Pérez, 2002b). A scalable workbench for ontological engineering called WEBODE and ODE tool were developed to provide technological support to the

Methontology framework (Fernández-López, 1999; Fernández-López and Gómez-Pérez, 2002b). This methodology allows the use of other modelling suites when developing ontologies, for example, Protégé-OWL.

Methontology recommends an evolving prototyping ontology development life cycle in order to enable flexible modification of the ontology in each iteration. The ontology life cycle proposed and the main activities identified in the methodology are management, development-oriented, and support activities. The management activities are planning, control and quality assurance while development-oriented has the specification, conceptualization, formalization and implementation activities. Support activities consist of activities, executed simultaneously with the development-oriented activities. Knowledge acquisition, evaluation, integration, documentation, and configuration management comprise the development-oriented activities (Fernández-López and Gómez-Pérez, 2002b; Fernández-López et al., 1997; Yu, 2008).

Ontologies and applications have been developed using this methodology in different domains. Methontology has been employed in developing ontologies such as chemicals ontology, monatomic ions ontology, reference ontology, silicate ontology, and environmental pollutants ontologies. In addition, the applications using the ontologies that were developed with this methodology are, Chemical OntoAgent, Ontogeneration and the OntoRoadMap web application. Both Chemical OntoAgent and Ontogeneration applications use the chemicals ontology as the basis of their knowledge while the OntoRoadMap make use of the reference ontology (Fernández-López et al., 1997; Fernández-López, 1999; Corcho et al., 2003).

A sizable part of this methodology is very detailed. For example, Methontology has stages, activities undertaken in every stage and how the stages are linked. The Methontology framework also provides a recommended life cycle based on evolving prototyping. In addition, the methodology is flexible with regard to knowledge formalization.

The methodology proposed ontology evaluation based on a frame of reference in each phase and between phases of the ontology development life cycle and reuse of other ontologies that are already available. Methontology identified and classified various types of anomalies in ontologies for evaluation. The anomalies that are encountered then divided into inconsistency, incompleteness, and redundancy errors (Gómez-Pérez et al., 1995; Gangemi et al., 2006; Fernández-López et al., 1997).

Regardless, Methontology is not without shortcomings. Methontology have a prescribed order in which the proposed tasks are undertaken. Besides, in the evolving prototype-based life cycle, the proposed process groups such as software life cycle model process and pre-development processes are missing. Also, the recommended techniques for control activity are unspecified. Methontology does not regard the concept of reuse (Suárez-Figueroa and Gómez-Pérez, 2009; Suárez-Figueroa, 2010).

The methodology uses a middle-out strategy as an approach for enumerating relevant concepts within a domain (Fernández-López and Gómez-Pérez, 2002b). Though the task of extracting terminology in the universe of discourse is alluded to in the methodology what is lacking are precise guidelines on how to undertake such a task. The data analysis task or terminology extraction in Methontology needs to be clarified in order to guide the identification and organization of the concepts, attributes, relations or instances for ontology representation.

2.5.3 OnToKnowledge (OTK)

The OnToKnowledge is a methodology based on developing ontologies oriented on the future use of the ontologies in knowledge management in large and distributed organizations (Sure et al., 2004; Suárez-Figueroa, 2010; Yu, 2008). This application-driven development of ontologies in OnToKnowledge is achieved through knowledge meta-processes and knowledge processes (Sure et al., 2004; Tempich, 2006). The knowledge meta-processes proposed in the methodology are five phases. These are feasibility study, kickoff, refinement, evaluation and application, and evolution while the knowledge processes are knowledge creation or import, capture, access and use (Sure et al., 2004).

The methodology is an iterative-oriented development methodology. It has an evaluation phase which proves the adequacy. During the evaluation phase 2 main steps are done: (i) the target ontology is checked against CQs (ii) the ontology is checked in the target application environment with view on feedback for more refinement of the ontology. The recommended ontology development life cycle in OnToKnowledge is an evolutionary prototyping life cycle model (Fernández-López and Gómez-Pérez, 2002b; Yu, 2008).

OnToKnowledge makes use of OntoEdit in the formalization process. However, other modelling technologies can also be used. In addition, OnToKnowledge suggests the use of intermediate representations of the knowledge model. In this respect, this methodology follows the basic notion of Methontology. Another important characteristic of OnToKnowledge is ontology learning when developing the ontology. The CQs method as introduced by Grüninger and Fox (1995) for ontology specification is part of OnToKnowledge.

Although OnToKnowledge incorporates the CQs method, there are no guidelines provided for carrying out the ontology specification. The methodology does not provide guidelines for identifying resources reuse. Also, OnToKnowledge does not regard collaborative ontology development. The ontologies developed depend on the application (Suárez-Figueroa, 2010).

With respect to data analysis for the purpose of terminology extraction, the methodology proposes the identification of relevant concepts in the kickoff stage and refinement stage. Approaches like middle-out and bottom-up are proposed intended for identifying the relevant concepts, relations and attributes within the corpora (Sure et al., 2004). However, no guidelines are given as to how to identify and extract these concepts, relations, and attributes from the data collected in the universe of discourse. Furthermore, how to organize and structure them for the ontological model is not espoused. Consequently, neither descriptive nor prescriptive methods are presented by the methodology regarding data analysis for ontology development. Furthermore, the evaluation phase is still open to be investigated in more detail in OnToKnowledge (Yu, 2008; Villalón and Pérez, 2016).

2.5.4 DILIGENT

DILIGENT is an ontology engineering methodology focussed on the evolution of ontologies and not the initial design, with the perspective that knowledge is tangible and not constant (Pinto et al., 2004). The DILIGENT methodology is a distributed, loosely controlled, evolving and user-centric methodology with a methodological approach based on the argumentation framework (Villalón and Pérez, 2016; Suárez-Figueroa, 2010).

DILIGENT recognizes methodologies like OnToKnowledge (Sure et al., 2004) and Methontology (Fernández-López et al., 1997) as established and valuable for the initial design of the ontology. But then it expands these methodologies with a focus on the user-based ontology development. In contrast to such methodologies, the strength of DILIGENT is distributed and collaborative ontology development centred on augmentation framework with user-centric perspective. This methodology has been employed in developing ontologies in the biology and legal domains (Pinto et al., 2004; Suárez-Figueroa, 2010).

To build the ontology DILIGENT recommends an ontology life cycle dependent on the evolutionary prototyping life cycle model. In that regard, the methodology is comprised of 5 main activities. These activities include build, local adaptation, analysis, revision, and local update. At the start of the process, domain experts, users, knowledge and ontology experts build a preliminary ontology. When the ontology is made available, users are allowed to use the ontology and locally adapt the shared ontology to their own use cases. In their own environment, users are permitted to modify the shared ontology. Nevertheless, they are not endorsed to directly modify the shared ontology except through the use of the control board (Pinto et al., 2004).

As an argumentation framework DILIGENT facilitates discussions regarding the design rationale of modifications introduced in the different phases of the ontology life cycle. The arguments to the shared ontology are collected and balanced by the control board in order to reach consensus on how the shared ontology should change going forward. The argumentation model may also be utilized by the control board in understanding why specific changes were done, for example during the analysis and revision phases. The control board regularly amend the shared ontology, so as not to diverge from the scope of the shared ontology. Though the users actively participate in the construction of the ontology, through making suggestions and adapting the ontology, it creates numerous versions of the model which need to be combined (Pinto et al., 2004; Villalón and Pérez, 2016).

In addition, the methodology has no guidelines on when to create different versions of the ontology nor how to manage the various ontology versions. Another shortcoming of this methodology is that it can be cumbersome to develop an ontology using DILIGENT, especially reaching consensus through the control board. Furthermore, when developing the preliminary ontology, there is no ontology requirements specification suggested. Lastly, the methodology also has no methodological guidance provided on reuse of ontological and non-ontological resources.

Under ontological data analysis, DILIGENT utilizes the rhetorical structure theory. The rhetorical structure theory is used to analyze dialogue in real-time instead of written text. This creates a tangledness posing classification problems. Furthermore, the discussions are manually processed requiring one to have the full grasp of the natural language.

The lack of appropriate evaluation measures in DILIGENT will make it harder to achieve agreement on contradicting arguments. However, the evaluation process can be improved with methodological evaluation criteria and tool support. DILIGENT does not have ontology evaluation (Villalón and Pérez, 2016; Suárez-Figueroa, 2010).

Additionally, in the building phase or the analysis phase, this methodology does not have precise detail on strategies and methodological guidelines on how to analyze, organize and structure the data obtained in the domain during ontology conceptualization. As a result, terminology extraction techniques that support ontology data analysis for ontology construction in DILIGENT framework need to be improved. As such DILIGENT framework should give more detail and priority to how to analyse, organise and structure the data in the universe of discourse.

2.5.5 NeOn Methodology

NeOn is a context-based methodology for developing ontologies and networks of ontologies (Suárez-Figueroa, 2010; Suárez-Figueroa and Gómez-Pérez, 2009). According to Suárez-Figueroa (2010), NeOn methodology is informed by methodologies such as Methontology (Fernández-López et al., 1997), OnToKnowledge (Sure et al., 2004), DILIGENT (Pinto et al., 2004) and Gruninger and Fox methodology (Gruninger and Fox, 1995).

The main objective of NeOn is to accelerate ontology and ontology network development through reuse. This methodology is based on a list of activities and processes, a collection of 9 scenarios common in the development of ontologies and ontology networks. In addition, the methodology has life cycle models for ontology development and an established collection of guidelines on developing ontologies and ontology networks.

Each scenario in NeOn is composed of different tasks and processes (Suárez-Figueroa, 2010; Suárez-Figueroa and Gómez-Pérez, 2009). Methodology guidelines are given in each task or process. This is achieved through 9 adaptable scenarios identified by the methodology. For a detailed discussion on the scenarios, the reader is referred to Suárez-Figueroa (2010). According to Suárez-Figueroa (2010), these scenarios are shared in most ontology network developments. The list of the scenarios is not limited to 9, they can be combined in a myriad of ways during ontology development.

NeOn proposed ontology evaluation as an activity that should be done through the entire development of the ontology or ontology network. Though this methodology includes the ontology evaluation activity there are no precise guidelines on this activity. As an extension, a collection of suitable evaluation techniques and methods are suggested in Sabou and Fernandez (2012). These authors discuss ontology (network) evaluation based upon the choice of existing techniques and the evaluation goals selected.

One of the advantages of NeOn is the 9 scenarios proposed which can be adapted and modified in numerous ways. This is in contrast to the inflexible scenario presented in Methontology (Fernández-López et al., 1997), OnToKnowledge (Sure et al., 2004), DILIGENT (Pinto et al., 2004) and Gruninger and Fox methodology (Gruninger and Fox, 1995). Furthermore, NeOn includes the development of both single and several ontologies through collaborative and reuse centred ontology development.

Although NeOn toolkit has been built to provide explicit support, this methodology allows the use of other various technological support and modelling platforms such as Protégé-OWL. In comparison to Methontology (Fernández-López et al., 1997), DILIGENT (Pinto et al., 2004) and OnToKnowledge (Sure et al., 2004), NeOn methodology is not application independent and has more methodological detail.

With regards to ontology data analysis, the identification of terminology in the domain of interest is CQs-based. The methodology proposes extraction of terminology such as names, adjectives, and verbs from these CQs. However, the methodology does not provide precise methodological detail to aid the identification, extraction, and organization of concepts, relation and attributes in the universe of discourse. As a consequence, terminology extraction in NeOn should be clarified in order to provide the necessary input to ontology conceptualization of ontology development. Even the automatic tools for extracting the terminology, according to Suárez-Figueroa (2010) are not useful in most of the cases when building ontologies with NeOn.

2.6 Ontology Evaluation Frameworks and Methodologies

In this section, methodologies for evaluating ontologies are presented. These methodologies are different from ontology development methodologies because they outline the methods and techniques appropriate for ontology evaluation. According to Suárez-Figueroa (2010) evaluation of an ontology can be seen as a task purposed for examining the technical adequacy of an ontological model against a frame of reference such as an ontology standard or a gold standard ontology. This judgment is done in all phases of the ontology development life cycle (Gómez-Pérez et al., 1995; Gómez-Pérez, 1995). As such ontology evaluation is important in that modelling weakness are revealed as soon as possible. The weaknesses such as wrong, incomplete, or misused definitions and functionalities and strengths of the candidate ontology are easily identified in order to be effectively deployed in practical applications (Gómez-Pérez et al., 1995). An extensive discussion on the evaluation approaches is presented in Sabou and Fernandez (2012), Brank et al. (2005), Gómez-Pérez (2001), Hartmann et al. (2005), Suárez-Figueroa (2010) and Villalón and Pérez (2016). In the following sections, core ontology evaluation methodologies are discussed.

2.6.1 OntoMetric

OntoMetric is a criteria-based methodology. The OntoMetric method was proposed by Lozano-Tello and Gómez-Pérez (2004). This method depends on a collection of processes that assist in selecting the most suitable ontology for reuse. This method can be used in selecting the most suitable ontology and in determining the suitability of the ontology selected.

Further, this method is built upon the Analytic Hierarchy Process (AHP) (Lozano-Tello and Gómez-Pérez, 2004).This method adapts ontology reuse processes and employs multi-criteria decision method. The decision method uses dimensions. These are the important features to be considered prior to selecting an ontology. The dimensions stipulate the features such as content, the implemented ontology language, methodology used during ontology development, ontology modelling environment used and the cost of utilizing the ontological model in the system (Yu, 2008).

Separately these dimensions have a group of factors that are then used in establishing ontology suitability. The ultimate outcome of the method is a valuation of the appropriateness of the ontologies evaluated. The OntoMetric result will then assist one in reaching a decision on which ontology is the most suitable for the application in question.

The main component in OntoMetric is the hierarchical tree of characteristics. The tree comprises 160 features that are used to describe the domain of the ontology.

This framework has the outline for characterizing the information of an ontology, choosing and comparing the ontologies. As such the method uses the MTC to get a quantitative measure representing the appropriateness of each ontology. In addition, the hierarchical tree can be contextualized depending on the particularities of the application that will reuse the ontology (Hartmann et al., 2005; Yu, 2008).

The process model of this methodology is comprised of 5 steps, which are: (i) analysis of the aims of the project, (ii) obtaining the MTC, (iii) examining each feature against each other, (iv) assigning a linguistic score on each characteristic and (iv) selection of the most appropriate ontology (Duque-Ramos et al., 2011; Villalón and Pérez, 2016). The OntoMetric method offers a valuable schema to undertake complex decision making in selecting ontologies. This method assists in justifying the decision as to which ontology is the most suitable (Hartmann et al., 2005; Yu, 2008).

However, there are some limitations with this methodology (Duque-Ramos et al., 2011). Implementing OntoMetric require substantial effort. More so, determination of the customized hierarchical tree depends on manual specification, which can be subjective. OntoMetric has no methodological guidelines on the process of evaluating ontology content. In fact, when developing a new ontology OntoMetric has no support on determining an appropriate method to employ when evaluating such an ontology. Moreover, the methodology lacks guidance on how undertake the evaluation of the ontology during development. Instead this methodology useful in determining the most appropriate ontology from a pool of ontologies (Villalón and Pérez, 2016; Yu, 2008).

2.6.2 OntoClean

OntoClean method was developed by Guarino and Welty (2002) in order to confirm whether the ontology is adequate and consistent based on taxonomical relationships. According to Guarino and Welty (2002), this will expose inappropriate and inconsistent modelling issues. OntoClean relies on ontological ideas from analytic metaphysics (Guarino and Welty, 2002; Villalón and Pérez, 2016; Gangemi et al., 2001; Yu, 2008). These are rigidity, unity, identity, and dependence. Through using the concept taxonomic structure, they can denote the behaviour of those taxonomical concepts.

Based on these notions a group of metaproperties is defined, which are then utilized to represent pertinent features of the intended meaning of the knowledge in the ontology. By imposing various restrictions on an ontology, the metaproperties assist in the evaluation of the hierarchical structure of the ontology (Yu, 2008).

This methodology is a layered framework consisting of 4 layers. The layers are structured in such a way that a layer above is based on the layer below. Each layer has a function, for example, the bottom layer deals with formal ontological properties, and meta-properties. The function of the second layer is checking property types for characterizing meta-properties and constraint checking. This followed by the third layer that is based on ontology modelling principles and the top layer is the upper-level ontology (Villalón and Pérez, 2016; Yu, 2008).

In this method, first the ontology classes are given meta-properties. The assigned meta-properties cascade to subclasses. These features are then used to identify problematic areas in the ontology that need to be re-examined. Every class in the ontology is recommended to be labelled with meta-properties when using this method. A downside is that this requires manual intervention in annotating the concepts with the appropriate meta-properties. The manual assignment of meta-properties is time-consuming (Hartmann et al., 2005; Villalón and Pérez, 2016).

Also, another limitation of OntoClean is that the evaluation is more structural, anchored only on subsumption evaluation of the ontology. More so, OntoClean does not permit inferring the usability dimension of the ontology and does not evaluate structural issues between descriptions of properties. However, OntoClean can be employed as an additional method to support ontology evaluation, especially in those domains that require formal correctness (Yu, 2008; Villalón and Pérez, 2016).

2.6.3 OntoQA

According to Tartir et al. (2010), the OntoQA approach is a metric-based method for evaluating ontologies. This approach analyses the ontology schemas (TBox) including the instances (ABox) so as to describe the schemas using metrics. The metrics proposed in OntoQA can be separated into 2 related dimensions of 5 metrics for the schema and 9 metrics for the knowledgebase. The first dimension is for the evaluation of the design of the ontology. In this dimension, the metrics show among other things the depth, and schema design inheritance (Tartir et al., 2010).

In the second dimension, the instance data and the effective usage of the knowledge in the schema are evaluated. The knowledgebase metrics include knowledgebase description metrics and the metrics that describe every class in the schema and how these classes are used in the knowledgebase, for example, class importance and connectivity (Tartir et al., 2010; Villalón and Pérez, 2016). OntoQA works on ontologies that are populated, in order to have a better evaluation measure of the adequacy of the ontology by using the knowledge in the KB (Villalón and Pérez, 2016).

2.6.4 O^2 and oQual Integrated Framework

Gangemi et al. (2006) propose an integrated single framework for ontology evaluation using a model. The model is formal and based on a multi-layered approach consisting of three integrated components. The first component is an ontology called O^2 that describes an ontology as a semiotic object. The purpose of O^2 is intended to give meta-theoretical basis to the evaluation and annotation of ontologies. The O^2 ontology has a second component which also has an ontology for evaluation and validation of ontologies called oQual. The ontology evaluation is performed as diagnostic activity in oQual ontology. Such a set up permits the ontology entities to be picked up using O^2 ontology and be given quality values when possible. The third component of this formal model is qood. This part of the oQual ontology that performs the task of describing the evaluation criteria required.

In addition, the O^2 is based on the information description design pattern based on DOLCE. The intuition in this method is formalized through using description situation design pattern to create O^2 (Gangemi et al., 2006). Similarly, oQual ontology uses the description situation design which is then combined with the information description design pattern used for O^2.

Based on O^2 and oQual the formal model evaluates ontologies based on structural, functional and usability profiling evaluation dimensions. The structural dimension has 32 characteristics that are used to evaluate ontology syntax and semantics. The functional dimension is made up 5 of measures that check the relationship of the ontology and the intended meaning of the ontology. Lastly, the usability profiling dimension is focused on the annotations context of the considered ontology (Villalón and Pérez, 2016).

2.6.5 Evaluation Framework by Vrandecic

Vrandečić (2010) designed a framework for evaluating ontologies through an ontology. The framework was designed mainly for evaluating the quality of an ontology placed on the Web. Further, the framework is based on O^2 and oQual (Gangemi et al., 2006) as described in Section 2.6.4.

Using this framework, a conceptualization and constraints are specified based on the development of models that are consistent with the ontology. Also, the Vrandečić (2010) evaluation framework indicates different formats that an ontology document may assume such as info set in XML or as a graph in RDF.

The Vrandečić (2010) framework classifies ontology evaluation approaches into two dimensions. The first dimension, considers the quality criterion used such as accuracy and completeness. On the other hand, the second dimension is based on the ontology feature that is considered by an approach such as syntax or structure of an ontology.

The Vrandečić (2010) framework identified 6 aspects based on automatic, domain and task-independent evaluation of ontologies including methods of evaluation that are aligned to each identified aspect. For example, the vocabulary aspect has 10 methods while the syntax aspect has 1 method (Vrandečić, 2010). In contrast to other methods and frameworks of evaluation, this framework provides an explicit division of evaluation aspects clearly indicating what is being evaluated. However, the framework is based on assessing a single ontology (Beißwanger, 2013; Vrandečić, 2010; Villalón and Pérez, 2016).

2.6.6 OQuaRE

OQuaRE is an evaluation framework for ontologies developed based upon Software product Quality Requirements and Evaluation (SQuaRE) standard (Duque-Ramos et al., 2013). The main goal of this framework is the provision of standard quality evaluation, applicable to various situations for identifying anomalies and strengths of ontologies. To do so the OQuaRE quality model recommends evaluation of ontology quality through reuse and adaptation of the SQuaRE standard (Duque-Ramos et al., 2011).

In order to assess the quality of an ontology, this method uses quality model and quality metrics. The quality model is comprised of features for quality evaluation such as reliability and maintainability. The quality features are further divided into sub-features such as formalization and tangledness (Duque-Ramos et al., 2013; Duque-Ramos et al., 2011).

In OQuaRE a specific feature is examined depending on the evaluation of its quality sub-features. The metrics for the sub-features are topology-based, such as the average number of relations and properties that a class has (Villalón and Pérez, 2016; Duque-Ramos et al., 2013; Duque-Ramos et al., 2011). In summary, this approach provides a platform that defines aspects that are needed for the evaluation of an ontology such as process, metrics, and support of evaluation. Nonetheless, only the model and metrics for ontology quality are included in OQuaRE while aspects such as requirements and reports for evaluation are not presented (Villalón and Pérez, 2016).

2.7 Ontology Evaluation Tools

Previously, in Section 2.6 various methodologies used in evaluating ontologies were presented and this part focusses on technological support for ontology evaluation. More precisely, the review is based on tools that examine ontology content such as properties, classes, and data about data. The purpose of the technological support is to ease ontology evaluation and give support to the methodologies and frameworks proposed for ontology evaluation.

2.7.1 ODEClean

According to Fernández-López and Gómez-Pérez (2002a), ODEClean is a plugin that was developed to provide support to OntoClean in WebODE. The WebODE was based on Methontology. As an ontology editor, WebODE permitted collaborative development of ontologies by providing technological support to Methontology (Guarino and Welty, 2002; Fernández-López and Gómez-Pérez, 2002a).

The key functions that ODEClean provided allowed for the establishment of the mode of the evaluation, assignment of the meta-properties to entities and evaluation based on taxonomical restrictions. In addition, the ODEClean plug-in allowed automatic evaluation of ontologies. By using a form-based web UI or through a graphical UI in OntoDesigner the user could visualize the ontological model in ODEClean (Fernández-López and Gómez-Pérez, 2002a).

In regard to evaluation, the plug-in utilizes the top-level of universals ontology with axiomatizations in Prolog. This happens each time that ODEClean is evaluating an ontology. The main strength of the plug-in is that during ontology evaluation knowledge that would be used is expressed declaratively over an ontology within the plug-in (Villalón and Pérez, 2016). However, the plug-in is outdated and does not support ontologies that are formalized in OWL 2. In this study, though ODEClean is described because it represents seminal development of automatic evaluation of ontologies in ontology engineering.

2.7.2 ODEval

The ODEval evaluation tool was developed by Corcho et al. (2004). ODEval is a tool that evaluates ontologies like RDF(S), DAML+OIL, and OWL based on knowledge representation with the objective to detect taxonomical errors proposed by Gómez-Pérez (1995; 2001). According to Corcho et al. (2004), these taxonomical errors include circularity errors, partition errors, semantic errors, incomplete concept classification, grammatical, and identical formal definition of class instances.

In order to detect the possible taxonomical anomalies in ontologies, ODEval utilizes a collection of algorithms that are based on graph theory. ODEval considers an ontology as a directed graph. The information that is contained in a graph is different based on language and the kind of problem that has to be detected. This tool is capable of detecting possible taxonomical anomalies in respect of the considered language (Hartmann et al., 2005; Corcho et al., 2004).

Of the anomalies that arise when modelling taxonomical knowledge, ODEval is only focused on automatically detecting errors such as inconsistencies and redundancy grammatical errors. Consequently, anomalies such as semantic errors, incomplete concept classification, grammatical and identical formal definition of classes cannot be detected by this tool. No architectural description has been found on ODEval. In addition, ODEval is no longer maintained (Hartmann et al., 2005; Villalón and Pérez, 2016).

2.7.3 AEON

AEON (Automatic Evaluation of ONtologies) is an ontology evaluation tool based on the OntoClean methodology (Völker et al., 2005; Völker et al., 2008). AEON uses appropriate OntoClean meta-properties to automatically tag entities. In addition, the tool is able to perform constraint checking on ontologies. The tagging component in AEON acquires positive and negative evidence on a characteristic such as rigidity of concepts in an RDFS or OWL ontology by matching the lexical and syntactic patterns on the Web. The AEON implementation relies on extensive usage of the Web.

The AEON architecture is comprised of a component for evaluation, classifier, pattern library as well as a search engine wrapper. Each meta-property has a set of abstract patterns contained in an XML file. The pattern library is initialized through this XML file. Each of these patterns has a specification of the kind of evidence such as negative evidence for rigidity. Based on a group of instantiated patterns in the pattern library the search engine wrapper then utilizes Google™ API so as to get web pages from the Web (Völker et al., 2005; Villalón and Pérez, 2016).

For all the patterns that are in the pattern library, the evidence of those patterns is calculated for concepts with meta-properties. The evidence values that are obtained from all patterns based on a concept are then used by the classifier to decide if a meta-property is related to the concept. An example of such a classifier was developed by Volker et al. (2005; 2008), for each meta-property.

To tag concepts using AEON based on OntoClean is cumbersome in time and knowledge. In addition, the terminology used in OntoClean on meta-properties is rigid unlike in natural language, which is not as strict and formal. Despite that OntoClean documentation is detailed, but its usage on the other hand is uncommon because of the high cost associated with its usage (Völker et al., 2005; Völker et al., 2008). For example, experts in ontology engineering are needed to perform tagging as recommended in OntoClean(Poveda Villalón, 2016).

2.7.4 MoKi

MoKi is implemented based on the Semantic MediaWiki (Pammer, 2010; Villalón and Pérez, 2016). Semantic MediaWiki is a plugin to MediaWiki which allows storing data as RDF and thus enriching textual and multimedia content of MediaWiki pages by structured knowledge. MoKi is itself a plugin to MediaWiki and it requires the plugins Semantic MediaWiki and Semantic Forms to be installed in order to run correctly. MoKi is implemented to a large part in PHP but MoKi uses JavaScript and Java as well (Pammer, 2010).

Ontology evaluation in MoKi is done through the MokiValidation plug-in (Pammer, 2010). The MokiValidation plugin, has 4 modules for ontology validation, pertaining to the questionnaire for the ontology, the quality indicator, checklist of the model including the assertional effects functionality. The objective of the 4 modules is to give information on how the ontologies can be enhanced for the better and not rate the quality of the ontology. In that regard, the ontology questionnaire module is for displaying and supporting the review of inferences for the purpose of evaluating the ontology. On the other hand, the module for assertional effects module presents information after the modification of the KB. Ontology evaluation in MoKi is supported by the ontology questionnaire and assertional effects modules using the formal interpretation of the ontology and the reasoning mechanism. The model checklist module is concerned with displaying those elements that are not aligned with ontology modelling standards whereas the quality indication module is about the visualization of the extent an element is in compliance with the required ontology modelling guidelines (Villalón and Pérez, 2016).

In MoKi, when evaluating an ontology anomalies such as entities lacking a verbal definition are detected. In addition, MoKi has a user based auto-fill form in order to support formal modelling (Villalón and Pérez, 2016; Pammer, 2010). Nevertheless, MoKi does not support OWL 2 Full. In fact, formal modelling of complex classes is not yet supported by MoKi. More so, the evaluation in MoKi is supported by checklists which only list the ontology elements with potential modelling mistakes and thus should be reviewed (Villalón and Pérez, 2016).

2.7.5 XD Analyzer

XD Analyzer is one component of XD (eXtreme Design) Tools. The XD Analyzer is a plug-in based ontology evaluation tool that was developed in order to give technological support to the XD methodology (Suárez-Figueroa, 2010; Villalón and Pérez, 2016; Blomqvist et al., 2010; Presutti et al., 2012). The main goal of the XD Analyzer is the provision of ontological modelling advice information about the extent to which the ontology modelling rules have been complied with as recommended in the XD methodology. The XD Analyzer is an extensible plugin-based architecture that has the option of extending the rules in respect to ontology modelling principles. The tool was designed using the ontology modelling standards in XD as the basis. One of the functionalities of this plug-in is to give technological support based on ODPs (Blomqvist et al., 2010; Villalón and Pérez, 2016; Presutti et al., 2012).

After evaluating the ontology, the tool presents the feedback information as an error, warning or suggestion. The warning information shows ontology elements that are not complying to the recommended ontology modelling principles while suggestion information display information that can enhance the model through additional axiomatization. There are different kinds of evaluations that can be performed by this evaluation tool, some of them are: (i) Domain or range intersection (error), (ii) Missing type (error), (iii) Missing comment (warning), (iv) Missing label (warning), (v) Missing inverse (warning), (vi) Unused imported ontology (warning), (vii) Isolated entity (warning), (viii) Architectural import notice (suggestion) and (ix) Missing domains or ranges (suggestion). This evaluation represented by the evaluation tool works in OWL-based ontologies. Nevertheless, there is no description on the architectural design of the XD Analyzer in the literature yet (Villalón and Pérez, 2016; Blomqvist et al., 2010).

2.7.6 OntoCheck

According to Schober et al. (2012), OntoCheck is a java based plug-in designed using the Protégé OWL API for use within the Protégé-OWL modelling system. The functionalities provided by OntoCheck for ontology evaluation are checking the cardinalities, completeness of metadata, examining the regular expressions for lexical patterns in names, testing for typographic naming conventions, comparing values between specified entities and quantifying ontology measures.

To evaluate an ontology using OntoCheck, the plug-in provides ontology editing functionalities in Protégé-OWL in form of check, compare and count subpanels. In order to evaluate the completeness of the metadata in the ontology, the OntoCheck uses the check subpanel. This subpanel permits one to indicate the annotations which need to be examined. In addition, the check subpanel has the functionality to perform syntactic naming convention or naming patterns verification within the ontology (Villalón and Pérez, 2016; Schober et al., 2012).

The compare subpanel permits the comparison of values of annotations including metadata specified in a class as well as those that are specified among classes within the ontology. Finally, the purpose of the count subpanel is to detect and quantify measures such as progress monitoring, evaluation and complexity analysis of the ontology including a measure for isolated entities. Specifically, the count subpanel presents information such as the percentage of nodes that have metadata, child, parent and direct superclasses, including statistics on the usage of those classes. OWL ontologies can be evaluated using the OntoCheck plug-in. As a result, this plug-in enables curation and detection of labelling anomalies in OWL-based ontologies. However, OntoCheck was developed as a plug-in targeted for the Protégé-OWL version 4.1 and OntoCheck is outdated (Villalón and Pérez, 2016; Schober et al., 2012).

2.7.7 OntOlogy Pitfall Scanner! (OOPS!)

The OntOlogy Pitfall Scanner! (OOPS!) was developed by Poveda (2016; 2016; 2014) as a web-based service intended for ontology evaluation during the ontology validation. This tool is based on a semi-automatic evaluation of ontologies in OWL utilizing a broad pitfall catalogue. Various evaluation dimensions are represented in pitfall catalogue covering ontology modelling issues such as internal structure, documentation, and publication of ontologies on the Web. OOPS! uses various methods for detecting and diagnosing anomalies in OWL ontologies. These include the characteristic search, pattern matching, and linguistic analysis methods.

OOPS! architecture has 3 layers based on presentation, business, and persistence. The purpose of the presentation layer is to permit human and machine interaction with OOPS!. For instance, OOPS! has a web UI for human interaction and a web REST service for machine interaction. On the web UI the ontology is loaded through a URI or OWL code. Upon completion of ontology diagnosis, the evaluation outcome is presented based on title and code of the anomaly, the number representing the extent of occurrence of the anomaly in the ontology, and how serious the anomaly is. In addition, the outcome also shows the description of the anomaly as well as the entities in the ontology that are affected that particular anomaly (Villalón and Pérez, 2016).

The second layer is the business layer, which is responsible for generating the ontology evaluation outcome. This layer uses the ontology to be analyzed as input. The RDF parser is used to load the ontology into OOPS!, the ontology is then scanned for anomalies by the Pitfall Scanner. The Suggestions module produces modelling advice based on the anomalies detected in the ontology. On the other hand, the objective of the persistence layer is to maintain a log of the number of anomalies detected in each ontology that has been evaluated (Villalón and Pérez, 2016).

According to Poveda (2014; 2016), OOPS! can be used independently of the ontology modelling system. More so, OOPS! has a broader anomaly catalogue including a web-based UI and a RESTful service for both humans and machines. In addition, OOPS! is not limited to an ontology modelling system and is not plug-in based. As a result, OOPS! was employed in this study in evaluating the Xhosa Beadwork Ontology (XBO) as presented in Chapter 3 and 5. In that regard, the study was able to achieve the third objective of the study.

Even though the pitfall catalogue is extensive, OOPS! is a standalone application requiring human intervention when repairing the ontology (Villalón and Pérez, 2016; Beißwanger, 2013). Unfortunately, OOPS! does not have methodological guidance on repairing the anomalies detected in the ontology. In order to address that, the study revised and repaired the XBO by undertaking manual correction of the anomalies detected guided by the iterative-incremental ontology life cycle within the ambit of NeOn and ontology modelling standards (NISO, 2005; ISO, 1990; ISO, 2000).

2.8 Conclusion

This chapter has explored the literature relevant to this study. Therefore, the chapter presented literature on ontologies, mainstream ontology development methodologies and ontology evaluation methodologies as well as ontology evaluation tools existing in ontology engineering. The investigation found that the most comprehensive ontology development methodology is NeOn. In light of the literature review, an inherent shortcoming of ontology development methodologies found was the lack of detailed methodological guidance on ontology data analysis as to how to conduct a comprehensive ontology terminology identification, extraction, and organization. In regard to ontology evaluation methodologies, the study found that some of the methodologies provided an extensive range of evaluation aspects, others were criteria-based or metric-based but had no detailed methodological guidance prescribed for undertaking ontology evaluation. In addition, most of the ontology evaluation tools, the number of anomalies detected was small and focussed on few ontology evaluation aspects. In any case, the study found that OntOlogy Pitfall Scanner! had automatic technological support with a broad pitfall catalogue including providing guidance on repairing them. In the next chapter, a discussion on the research methodology pursued in this study is presented.

Chapter 3: Research Methodology

This chapter discusses in detail the methodology which was adopted by this study in developing the Xhosa Beadwork Ontology (XBO). In Section 3.1 Action Research (AR) is presented as the overarching methodology used by the study. Each stage of AR is discussed and how AR stages were actualized in the development of the XBO. In Section 3.2 data collection is presented whereas data analysis is discussed in Section 3.3. This is pursued on by the discussion of the ontology development methodology NeOn together with the iterative-incremental ontology life cycle which are detailed under data representation in Section 3.4. Lastly, Section 3.5 concludes the chapter.

3.1 Action Research

Scientific research is undertaken to generate and contribute knowledge to the existing scientific body of knowledge (Creswell, 2013; Creswell, 2002). Scientific knowledge is produced when a scientific approach is followed which includes a systematic research methodology. Such a systematic research methodology will guarantee a better process of research and an outcome that is both precise and reliable (Babbie, 2015). There are numerous methodologies that can be used when undertaking research. For instance, an extensive discussion on such methodologies is given by Babbie and Mouton (2005) and Creswell (2013; 2002). To this end, the overall aim in this chapter is to detail the methodology that was employed when developing the ontology for Xhosa Beadwork. The study adopted the action research (AR) methodology. Hereinafter action research is referred to as AR.

Although the exact origins of AR are imprecise and open to discussion AR has been a distinctive form of inquiry since the 1940s (Babbie and Mouton, 2005; Davison et al., 2004; Susman and Evered, 1978). De Vos et al. (2011) define AR as the study that is based on discovering a resolution to a problem emanating from a local environment within a mutually acceptable ethical framework. It is a definition that resonates with Baskerville (1999), Kemmis and McTaggart (2005; 2013), Zuber-Skerritt (2002; 2001), Susman and Evered (1978), who state that AR is a procedure designed to deal with a concrete problem located in an immediate problematic situation through involvement while concurrently expanding the body of scientific knowledge. It is a notion that is supported by Babbie (2015) who stated that research (understanding) and action (solution) to a concrete problem occur simultaneously (Suárez-Figueroa and Gómez-Pérez, 2009; Creswell, 2002).

There are a couple of reasons why AR methodology was favoured in this study. Firstly, the overall aim of this study is the development of an ontological model for Xhosa Beadwork. The study was of the view that this goal of developing an ontology could only be attained by employing AR methodology. The main strength of the AR methodology lies in its iterative and collaborative nature, with emphasis on both solving a practical problem and generation of scientific knowledge (Davison et al., 2004; Baskerville, 1999). Indeed, AR was viewed as the methodology appropriate for this study because it is carried out in collaboration with those who experience the problem. This is a distinctive feature of AR that ensured the meaningful participation of all relevant stakeholders especially experts on Xhosa Beadwork throughout the process of developing the ontology (Babbie and Mouton, 2005).

The meaningful and collective participation of experts on Xhosa Beadwork yielded detailed, accurate and rich information for the ontology. Davison et al. (2004) and Baskerville (1999) contend that the active involvement of those affected by the problem is essential, as it allows a comprehensive study of the problem and production of research that is both scientifically and socially meaningful (Babbie and Mouton, 2005). Thus, the AR methodology enabled the collection of authentic data at the same time enhancing the procedure of ontology data analysis. This resulted in the development of a detailed and comprehensive Xhosa Beadwork Ontology (XBO).

The use of AR enabled this study to interlace quantitative and qualitative approaches within the study (Creswell, 2002; De Vos et al., 2011). For instance, documentation analysis and focus groups were employed so as to collect rich and in-depth data on Xhosa Beadwork through descriptive questioning. This data was then subjected to qualitative analysis methods such as domain, taxonomic and componential analysis to generate output such as taxonomies or conceptual models at the knowledge level. On the contrary, quantitative methods use of structural and contrast questioning on the data collected and within the focus groups was quite useful when addressing gaps emanating from the qualitative approach as is outlined in Section 3.3. The qualitative and quantitative data was then transformed into a computational artifact using the NeOn methodology following using an iterative and incremental ontology development life cycle.

Utilizing such multiple methods ingrained in AR allowed methodological and descriptive triangulation. This was important to this study because it enabled the collection of well-rounded information and in-depth understanding of Xhosa Beadwork (De Vos et al., 2011; Creswell, 2013). Triangulation in this study not only enhanced the quality of data collection but also data analysis and ultimately data representation (Leech and Onwuegbuzie, 2007; Onwuegbuzie et al., 2012). This immensely benefited and ensured an accurate and authentic development of the XBO.

Another important reason why the study adopted AR is because AR is spiral and cyclic in nature (Creswell, 2002; De Vos et al., 2011; Suzaan Le Roux, 2013). Using this methodology, the study was able to divide the ontology development into three distinct iterative phases when developing the XBO. These distinct phases are data the collection, analysis and representation of data. The spiral and cyclical processes of AR guided these phases when modelling the ontology. For instance, an AR cycle comprising (a) planning, (b) action, (c) observation and (d) reflection, (Suzaan Le Roux, 2013; Brannick and Coghlan, 2007; Creswell, 2002) was iteratively applied to each phase of data collection, data analysis, and data representation. This attribute of AR was quite beneficial to this study because it gave the study a chance to analyze the Xhosa Beadwork at great depth each time, subsequently culminating in a profound understanding of the situation (Creswell, 2002). In other words, each iteration of the AR process improved the framework that was used to develop the XBO. In general, the collective, reflective and cyclical nature of AR systematically promoted convergence that improved the validity and reliability (Onwuegbuzie and Leech, 2006; Onwuegbuzie et al., 2012) of the developed XBO.

3.1.2 Action Research Model

The diagrammatical model depicted below in Figure 3.1 shows the nature of AR selected for this study. It is an adapted and customized version of the AR described by Susman and Evered (1978) and Altrichter et al. (2002). As represented in Figure 3.1 the structural cycle of the AR followed in this study is made up of 4 stages viz, plan, act, observe and reflect (Zuber-Skerritt, 2001; Tacchi et al., 2003). In keeping with Hearn and Foth (2005), AR is operationalized by these 4 stages and each of these stages is reviewed in the following.

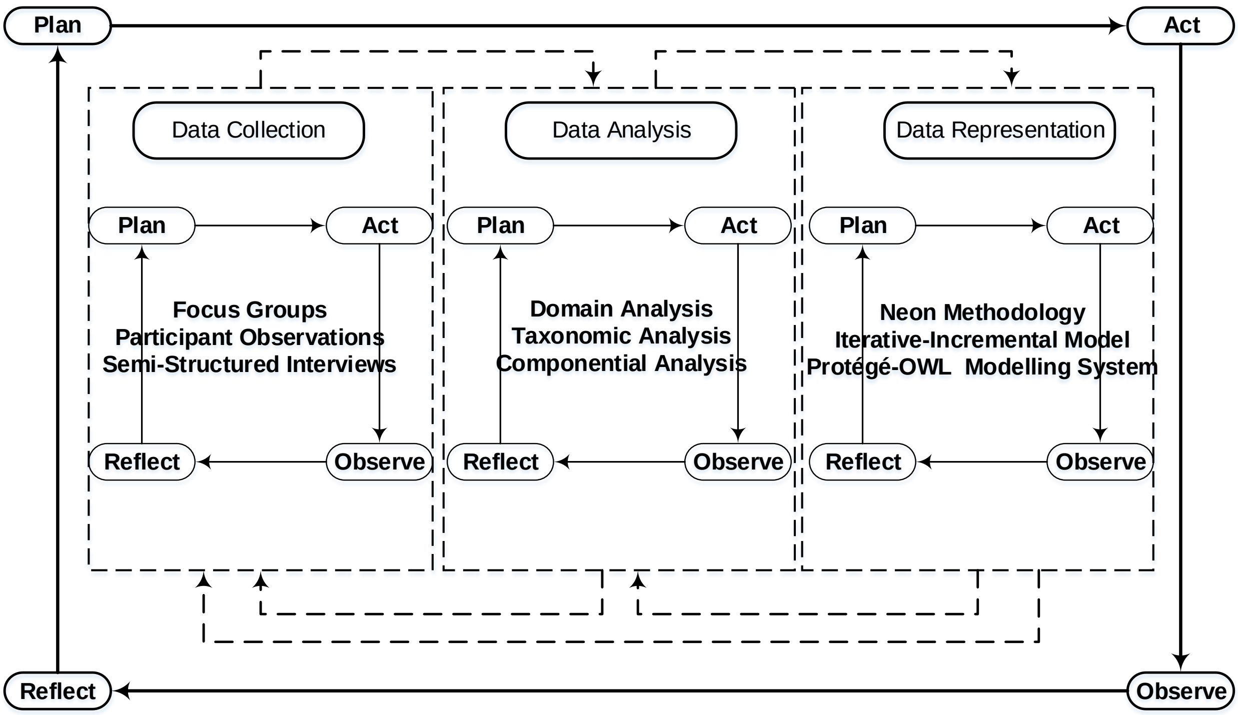


Figure 3.1: AR Model as Used in this Study Source: (Tinarwo, 2019:72)

Stage 1: Plan

The planning stage is the genesis of the AR project and involves problem identification (Hearn and Foth, 2005; Kemmis and McTaggart, 2005). In this study, the first cycle of AR was an exploratory or preliminary fact-finding stage which culminated in the development of the research proposal that was successfully defended to the UFH Department Committee. The actual problem that this study addresses was also identified in this stage. Here the problem under investigation was systematically analyzed, research questions were formulated and a plan for action on how to address the problem was outlined. In addition, for the planning stage, a literature review was conducted and presented in Chapter 2. This aided in determining and selecting the ontology modelling environment, ontology language and technological support for ontology evaluation. The planning stage also involved defining more CQs which were later used for pre-domain analysis (terminology identification and extraction) under data analysis and the CQs provided the scope within which the XBO was developed. This was then followed by an extensive collection of data and data analysis in the subsequent AR cycles as presented respectively in Section 3.2 and Section 3.3.

Stage 2: Action

The focal aim of the action stage is plan implementation (Baskerville, 1999). In the case of this study, the action was a technological intervention through developing an ontology. One of the main activities during the action stage was the development of the Xhosa Beadwork Ontology (XBO). This entailed undertaking systematic data collection, data analysis, and data representation. Furthermore, development of the ontology was guided by an ontology development methodology called NeOn, which used an iterative and incremental ontology life cycle model. Section 3.4 on data representation unpacks in detail the activities of each stage of the iterative and incremental ontology life cycle and NeOn as employed in this study. The action stage was iterative.

Stage 3: Observation

This stage comprises the observation of the outcomes of the action developed in the previous stage (Tacchi et al., 2003). The ontology developed in the action stage was evaluated with the appropriate methods and techniques (Baskerville, 1999). The aspect of evaluation is discussed in detail in Chapter 5. Also contained within this observation stage is the compilation of the outcome of the action stage. Each iteration (AR cycle) yielded more information which was subjected to further analysis leading to the identification of gaps. These were then addressed by collecting more data. For example, documentation analysis was used which involved consulting relevant primary and secondary sources of information on Xhosa Beadwork such as the national heritage Broster Beadwork Collection (SAHRA, 2019b) and South African Heritage Resource Information System (SAHRIS) (SAHRA, 2019a). Thus, more data collection was undertaken with each iteration in this observation stage. This was possible because the observation stage, as well as the action stage, was guided by the NeOn methodology and the iterative-incremental ontology cycle model.

Stage 4: Reflect

This is an evaluation stage of AR (Davison et al., 2004) where the study engaged in critical reflection, of the whole development of the ontology. This involved understanding the issues and processes related to the problem and the interpretation of various forms of information emanating from the study (Tacchi et al., 2003). This stage also included the documentation and publication of the XBO. The XBO was documented utilizing the Live OWL Documentation Environment (LODE) whereas the XBO publication was done by sharing it on the GitHub repository. The decisions for the next AR cycle were also made at this stage as a basis for further planning, subsequent action, observation and reflection through a succession of AR cycles, as shown in Figure 3.1. Each AR cycle subsequently provided further improvement in gathering, analyzing, and representing data in the development of the XBO.

3.2 Data Collection Phase

Few knowledge-intensive systems such as computational ontologies are ever developed without recourse to the domain expert (Shadbolt and Smart, 2015). In the literature, there are various data collection methods (Burge, 2001; Shadbolt et al., 1999; Babbie, 2015; De Vos et al., 2011). The study used documentation analysis and focus groups (Shadbolt and Smart, 2015; Burge, 2001; Hoffman et al., 1995) for data collection. This allowed gathering manifold, context-rich data which not only aided the grounding and development of the XBO but also ensured reliability and validity of the acquired data (Leech and Onwuegbuzie, 2007; Shadbolt et al., 1999).

The documentation analysis in this study involved studying written material that contained information relevant to Xhosa Beadwork and the development of the XBO thereof. The study consulted both the primary and secondary sources of information on Xhosa Beadwork in the development of the XBO. The documentation used included the national heritage Broster Beadwork Collection (SAHRA, 2019b). This is an extensive collection that comprises the Thembu, Pondo, Xesibe, Bomvana and Xhosa Beadwork. SAHRIS (SAHRA, 2019a) was also used. SAHRIS is a national repository of heritage information including beadwork from across South Africa. In addition, documentation in form books was also used in this study such as “The Arts and Crafts of the Xhosa in the Ciskei: Past and Present” (Gitywa, 1971), “Not Only for its Beauty: Beadwork and its Cultural Significance among the Xhosa-speaking Peoples” (Costello, 1990), ”The Red Blanket Valley” (Broster, 1967) and “The Thembu: Their Beadwork, Songs and Dances” (Broster, 1976) were also used. It should be mentioned that the heritage inventory system SAHRIS also provided the study with visual data that assisted in the visualization of beadwork in image form.

Alongside documentation analysis, the study employed the focus group method. The advantage of the focus group method to this study was that it gave a comprehensive perspective on the problem under investigation. In this study, focus groups were used as both a data elicitation method and data triangulation method. As a triangulation method, the study was able to discover aspects of Xhosa Beadwork that were previously unnoticed**.** For example, the study was able to confirm and disconfirm the data represented in the XBO. In general, the use of multimethod approach in this study enhanced the soundness and consistency of the study which ultimately led to the development of a more comprehensive XBO.

According to Babbie and Mouton (2005), the focus groups method is valuable in scenarios where multiple perspectives to a specific issue are needed. In this scenario, the advantage is that this method allowed gathering of rich data over a shorter period of time. They were quite useful also in this study in that issues that were not likely to emerge in documentation analysis emerged in focus groups. The use of focus groups in this study also allowed data comparisons (Babbie, 2015; De Vos et al., 2011) and such a process generated valuable insights that further enriched the development of the XBO. The synergy of the group uncovered important constructs which may have been lost with documentation analysis. For example, contrast data on Xhosa Beadwork came to the fore because of different expertise that existed amongst the group members instead of one area of expertise. Such group dynamics were the catalytic factor in bringing such information to the fore (Babbie, 2015). In general focus groups were important because they represented a confluence of knowledge. As a result, they were compatible with this study for an ontology is by definition a shared conceptualization representing collective knowledge arrived at through collective agreement.

Both methods were informed by descriptive, structural and contrast questions as previously highlighted in Section 3.1. These types of questions were crucial in this study because they enabled the collection of data that was compatible with the domain, taxonomic and componential methods of data analysis (Roulston, 2010; Spradley, 1979). Thus, descriptive questions were used to generate data that was later subjected to domain analysis. The same applies to the structural questions which were used to generate structural data that was later subjected to taxonomic analysis. On the contrary, contrast questions were used to generate contrast data that was analyzed through componential analysis (Roulston, 2010; Spradley, 1979). Once data was collected it was analyzed. From this analysis, terminology was identified, extracted and organized. In order to undertake data analysis domain, taxonomic and componential analyses were used by the study. A detailed discussion of how data analysis was conducted in this study is provided in Section 3.3.

3.2.1 Sampling Technique, Sample and Sample Size

Babbie and Mouton (2005) delineate sampling as a procedure in which a preestablished amount of observations are selected from a larger population. The study used two non-probability sampling methods namely, purposive and snowball sampling (De Vos et al., 2011; Creswell, 2002). The justification for using purposive sampling in this study is that not everyone in the rural landscape of the Eastern Cape is an expert in Xhosa Beadwork. The study was interested in involving people with the expertise in beadwork who possessed a rich history, cultural and social-economic knowledge about Xhosa Beadwork. These individuals were able to provide relevant data that was key to the development of the XBO.

In this study, the sample size was determined on the basis of theoretical saturation (Leech and Onwuegbuzie, 2007; Onwuegbuzie and Leech, 2006). Theoretical saturation is defined by Leech and Onwuegbuzie (2007) as a point in the collection of data when more data being collected is not providing additional understanding to the study anymore . Likewise, De Vos et al. (2011) and Babbie and Mouton (2005) speak of theoretical saturation as a point during data gathering phase where there are no new categories of data nor any new inputs into existing categories of data being found (De Vos et al., 2011; Onwuegbuzie and Leech, 2006). Therefore, the size of the sample utilized by the study was determined once the process of data collection was no longer generating any new information that was relevant and useful to the development of the XBO.

To achieve the point of data saturation the study only concentrated on the beadwork of a single ethnic group in the Eastern Cape. This is chiefly because Xhosa Beadwork is very broad and diverse. For instance, Xhosa Beadwork is a shared resource over various traditional communities comprising “Mfengu, Bomvana, Thembu, Bhaca, Mpondomise, Xesibe, Mpondo, Hlubi and Xhosa proper” (Costello, 1990:1). The latter can be further split into the Gcaleka and Ngqika tribes. In addition, the beadwork of these various ethnic groups is also reported to be different. To this end, the study selected Thembu beadwork as the basis for the development of the XBO.

3.3 Data Analysis Phase

Data analysis is viewed by Creswell (2013; 2002) as a procedure of understanding the collected data. Whereas, De Vos et al. (2011) on the other hand outlines data analysis as a procedure that entails the reduction of the data volume, scrutinization, detection of important patterns, and structuration of the data in order to communicate the core of what is revealed by the data. In the context of this study, domain taxonomic and componential analyses were employed to analyze the data gathered on Xhosa Beadwork (Leech and Onwuegbuzie, 2007; Onwuegbuzie et al., 2012; Spradley, 1979). In this regard, the study divided the process of data analysis into three sequential stages comprised of domain, taxonomic and componential analyses. As delineated by Spradley (1979), each successive method of analysis depended on the previous method. These methods are described in the following subsections with an outline of how each method was used in the study. The three-stage sequence is intended to set up a general yet an explicit picture of where and how each method of data analysis unfolded and proceeded within the study.

3.3.1 Domain Analysis Method

The domain analysis method formed the initial stage of analysis of data in this study. This method of data analysis is defined by Spradley (1979) as probing for the broader categories of knowledge. These, he termed them domains. Spradley (1979) goes on to say that a category that contains another category is referred to as a domain. He views a category as an array or collection of distinct things treated as if they were equivalent. A domain is made up of 4 elements (Spradley, 1979). The first element in the structure of a domain is a cover term (broader or top term). A cover term is referred to by Spradley (1979) as a name that corresponds to a category of knowledge. While according to NISO (2005) a cover term is defined as single or many terms used in representing concepts. Secondly, a domain should have more than two narrower terms (Spradley, 1979; Casagrande and Hale, 1967; NISO, 2005). These become the terms that belong to the category denoted by the broader term. Thirdly every domain has a boundary. Thus, some terms are internal or external to the domain. Lastly, all domains have one semantic relationship. According to Spradley (1979), a semantic relationship is viewed as the linkage that exists between 2 categories. In a simple definition a semantic relationship will link only two terms but in a domain, a semantic relationship will link a broad term to all the narrow terms in its set (Spradley, 1979).

Semantic relationships are the foundation of the domain analysis method. In order to identify domains or terms Spradley (1979) including Casagrande and Hale (1967) maintain that one needs to reduce given data or knowledge to a basic structure of two terms and a relationship. Such a description corresponds to a semantic data triple in the Semantic Web. This mechanism for describing resources as a semantic triple data model is the main constituent of this study (Wielemaker et al., 2005). For example, domain analysis and the resource description framework (RDF) standard including the ontology modelling system Protégé-OWL, are all based on the semantic triple data model (Wielemaker et al., 2005). Such synergy allowed the output of domain analysis to be compatible with OWL 2 and Protégé-OWL. The study used Protégé-OWL to develop the XBO.

Furthermore, there are a number of interesting facts about these semantic relationships that were important to this study. These are that (a) the number of semantic relationships is quite small, (b) certain semantic relationships appear to be universal (Spradley, 1979) and (c) the semantic relationships can be reduced to 3 general types namely taxonomy or inclusion, attribution and queuing or sequencing (Spradley, 1979). In this study, inclusion was used in Section 3.3.1.1 and Section 3.3.2.1. For example, the **is a kind of** semantic relationship as in a **TabNecklace is a kind of Necklace**. On the other hand, attribution was used in Section 3.3.3.1 where semantic relationships such as **has a** or **is an attribute of** were used. For example, the **has a** semantic relationship was used as in **StrandWaistband has a**

Strand or Charm is an attribute of CharmNecklace. Besides that, the semantic relationships are a part of the RDF standard which is a major component of the Semantic Web (Wielemaker et al., 2005). These remarkable facts made domain analysis a useful method in analyzing data that informed the development of the XBO in this study.

Since Xhosa Beadwork has a huge collection of top concepts and an even bigger collection of subconcepts, it becomes problematic to search and figure out from the collected data whether a term is contained in one or the other term. In that regard, the study used semantic relationships as a tool in facilitating the discovery of domains (or classes or concepts) as suggested by Spradley (1979). In other words, the semantic relationships were crucial to this study because they provided vital clues to analyzing concepts and the structure of concepts in Xhosa beadwork. Casagrande and Hale (1967) recognized thirteen kinds of semantic relationships while later in 1979 Spradley (1979) identified 9 more. Combined, these 22 semantic relationships represent the core tools of undertaking domain analysis.

To kick start domain analysis, the study did a preliminary domain search using what this study calls a pre-domain analysis method. The first step in the pre-domain analysis was selecting a sample of verbatim from the data collected in Section 3.2. The second step involved reading through the data identifying terms that named things. This was achieved by identifying nouns that labelled objects for example **Necklace**, **Waistband**, **Anklet**, and **Armlet**. The next step was checking whether the terms found so far were broad terms. In that regard, the study used the plural form in identifying broad terms that contained many other terms in them. As it turns out, the study identified terms such as bracelets, tribes, and sizes in plural form.

It should be mentioned that the method of identification and extraction of terms as suggested in Methodology 101 by Noy and McGuinness (2001) and that use of terms from CQs as proposed by Suárez-Figueroa (2010) in NeOn methodology were considered and utilized in the study under pre-domain analysis. The purpose of this method was to gain a preliminary overview of the Xhosa Beadwork domain and provide initial terminology to kick start thorough terminology identification and extraction using the domain, taxonomic and componential analyses. In the next section, this output of pre-domain analysis was used as input in undertaking a systematic domain analysis, leading to the identification of broad terms that revealed the holistic organization of knowledge in the domain of Xhosa Beadwork.

3.3.1.1 Domain Analysis Procedure

Domain analysis is different from the pre-domain analysis in that it uses the semantic relationships rather than using broad terms (i.e. nouns) to identify and extract terminology. To identify the broad categories of Xhosa Beadwork the study followed a set of interrelated steps as given by Spradley (1979).

Step 1: Select a single semantic relationship. In order to enable identification of the main terms, the study used the universal semantic relationship of inclusion. The relation had the form of **X is a kind of Y**. This relation enabled the study to be focused on nouns or names of things in the data collected.

Step 2: Prepare a domain analysis worksheet. The study used an excel worksheet instead of directly underlining or highlighting terms in the documentation. This had a distinct advantage in that it helped in visualizing the broad term, semantic relationship and included terms (or subterms) for each category (or class). The broad term and the included terms were written as they were identified in the data.

Step 3: Choose a sample of statements. In this step, sample data was selected from the documentation given in Section 3.2 such as that by Broster (1976; 1967) and Costello (1990).

Step 4: Probe probable broad and narrow terms that fit the semantic relationship. At this stage, the data was searched through reading and looking for terms that suited the semantic relationship identified in Step 1. For example, included terms like **Headband**, **Necklace**, **Armlet**, **Bracelet**, **Waistband**, and **Anklet** emerged as kinds of the broad term **Item**.

Step 5: Frame structural-based questions in each category. The study formulated the structural-based questions with a view to confirm or disconfirm the broad and included terms found in Step 4. Each structural question made use of the semantic relationship and terms on either side of the relation (broad term or included term). For example, structural question such as “Are there different kinds of X” was used. By repeatedly using this question the study was able to extract included terms such as **TabNecklace**, **StrandNecklace**, **CharmNecklace** for the broad term **Necklace**.

Step 6: Develop a list of all categories. In this stage, a list of all the terminology enumerated was made. The list enabled a more intensive study using the taxonomic analysis as detailed in Section 3.3.2. The objective of domain analysis was the identification of the main terms and to have a surface view of Xhosa Beadwork. It should be pointed out that this was not done once but it was repeated as new data was collected. As consequence steps 1 through 5 were repeated in order to expand the terminology as shown in Figure 3.2.

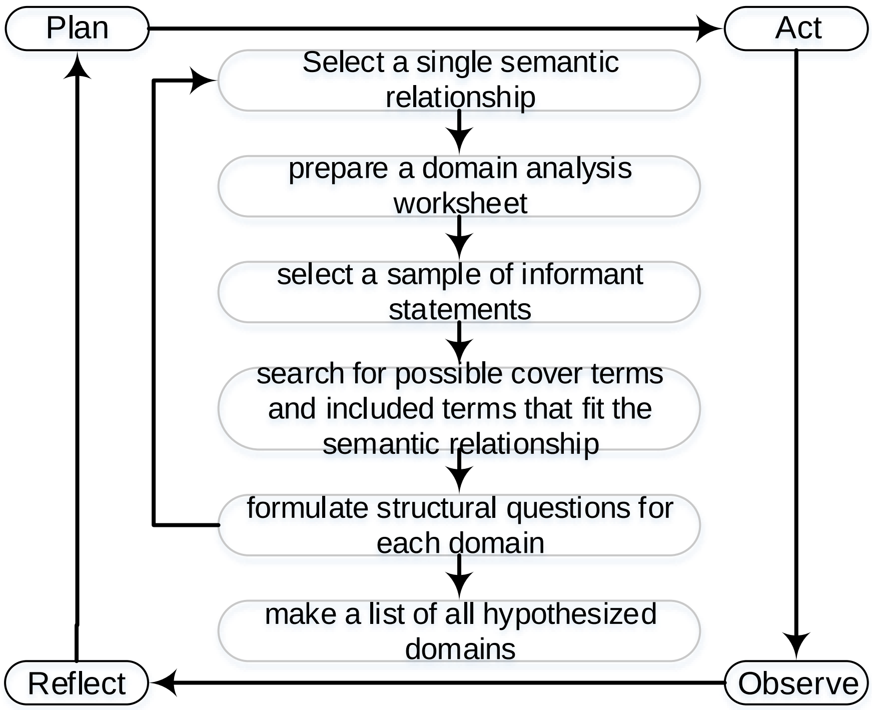


Figure 3.2: Domain Analysis Procedure Source: (Spradley, 1979:112 - 117)

In this study, the purpose of using domain analysis was to identify and extract the main classes of knowledge in the domain of Xhosa Beadwork. These are the classes that included other classes. The semantic relationship that was used here was an inclusion of the form **X** is a type of **Y** as in **Thembu** is a type of **Tribe**. The terminology that was identified and extracted using the domain analysis method included broad classes such as, **Necklace**, **Bracelet**, **Anklet**, **Tribe**, **Waistband**, **Headband**, and **Person**. In addition, what should be also registered is that underpinning the domain analysis method was the NeOn methodology, the iterative and incremental ontology life cycle within the iterative and cyclic AR as previously shown in Figure 3.1. In order to undertake further intensive interrogation of the classes identified by domain analysis, the study made use of the taxonomic analysis method (Spradley, 1979; Leech and Onwuegbuzie, 2007; Onwuegbuzie et al., 2012) in Section 3.3.2.

3.3.2 Taxonomic Analysis Method

In this study taxonomic analysis was the second stage of data analysis after domain analysis. Once the main classes (or domains) of Xhosa Beadwork had been identified, the taxonomic analysis was conducted by choosing a single class (or domain) such **Necklace** and put it into a taxonomy (Leech and Onwuegbuzie, 2007; Spradley, 1979). The taxonomic analysis was selected for this study because it produced a taxonomy. According to Guarino et al. (2009), this hierarchical structure is considered as the mainstay of an ontological model. The term taxonomy according to Hedden (2010) has Greek origins, meaning arrangement science. The same view is maintained by Spradley (1979) and later Leech and Onwuegbuzie (2007) who refer to a taxonomy to mean a classification scheme that catalogues the categories on knowledge into a hierarchical representation to enable understanding of the relationships among the categories (NISO, 2005).

Spradley (1979), states that the purpose of taxonomic analysis is to discover and reveal the internal structure of domains (or classes). To achieve that, this method organizes a collection of categories based on one semantic relationship (Spradley, 1979; Leech and Onwuegbuzie, 2007). Emerging from the previous statement is the fact that taxonomic analysis, as is, domain analysis uses semantic relationships to organize knowledge. However, in contrast to domain analysis, taxonomic analysis displays relationships of all the terms belonging to a category. In addition, this method revealed the hierarchical structure of narrow terms and the way these terms were related to broad terms.

3.3.2.1 Taxonomic Analysis Procedure

In this study, taxonomic analysis was accomplished by following 8 specific steps espoused by Spradley (1979) as can be seen in Figure 3.3.

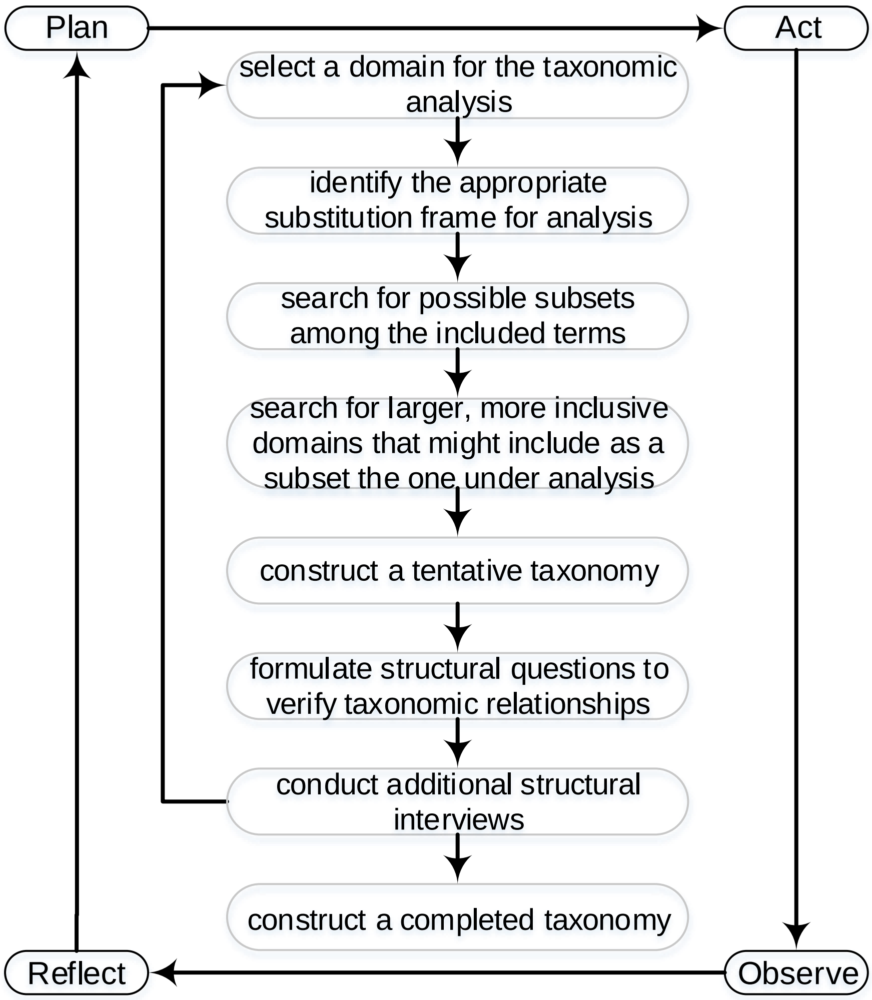


Figure 3.3: Taxonomic Analysis Procedure Source: (Spradley, 1979:144 - 150)

The steps were followed as highlighted in Figure 3.3. **Step 1:** Selection of a category for taxonomic analysis. The step involved selecting the category which had the most information for example **Necklace.**

Step 2: Identification of a suitable substitution frame. At this point the study identified the primary relationship of form **X is a type of Y**. Where **X** and **Y** represented a term. The substitution frame was then based on this relationship and became the main tool for the analysis that followed. It was used to discover how the included terms of the broad term such as **Necklace** were organized.

Step 3: Search for probable subterms among the narrow terms. Here the search began with the substitution frame **X is a kind of Y.** The included terms under **Necklace** were then checked to see if any conformed to the relationship represented in the substitution frame. For example, a **ChokerNecklace** is a kind of **Necklace.** This search of the data revealed terms such as **ChokerNecklace, TabNecklace**, **and StrandNecklace** as subsets of the broad term **Necklace**.

Step 4: Search for broad, inclusive categories that may contain as a subset the one being analyzed. This step involved searching inclusive broader terms within the data. For example, the term **Item** was identified as an inclusive broad term under which a term like **Necklace** belonged.

Step 5: Develop a preliminary taxonomy. After searching for broader inclusive terms, a tentative taxonomy was then constructed using Protégé-OWL 5.5.0. The taxonomy was represented in a hierarchical form in Section 4.4.

Step 6: Formulation of structural-based questions so as to confirm taxonomical relationships and allow the elicitation of more terms. Here structural-based questions were formulated such as “What are all the different kinds of Necklaces?” using the same semantic relationship identified in Step 1.

Step 7: Undertake supplementary structural interviews. The preliminary taxonomy was then checked by a beadwork expert. This stage also included more interrogation of the data collected that led to the identification and extraction of new terms. As a result, in this step the study looped back to Step 1.

Step 8: Develop a completed taxonomy. After repeating Step 1 through 8 and there was no new input into the existing categories of data found so far. The study then constructed a completed taxonomy in Section 4.4. All in all, the taxonomic analysis procedure enabled the study to identify, extract and depict the terminology as a hierarchical structure in Protégé-OWL 5.5.0. The taxonomic analysis was guided by the overarching AR methodology, NeOn methodology, the iterative and incremental life cycle.

3.3.3 Componential Analysis Method

Componential analysis was the third stage of data analysis in this study. It was combined in sequence with domain and taxonomic analyses. According to Spradley (1979) and Onwuegbuzie et al. (2012), componential analysis is viewed as a methodical probe for attributes associated with terms (or concepts). An attribute is defined by Spradley (1979) as information frequently associated with a concept such as **Colour** or **Size.** When the attributes of terms are contrasted the focus of analysis shifts from their similarities to their differences (or contrast principle). These differences are regarded as attributes of a concept. Unlike in the case of domain or taxonomic analysis, componential analysis cannot be handled by a single semantic relationship but by multiple semantic relationships (Spradley, 1979). The componential analysis method was used in this study because these terms or concepts in Xhosa Beadwork had acquired meaning that could not be revealed by domain or taxonomic analysis (or similarity principle) but only by componential analysis based on the contrast principle.

As a result, componential analysis led to the discovery of attributes and specific ways to represent these attributes by using multiple semantic relationships between a term and other terms in the taxonomy. Here, tables (or matrices) were used to determine the differences among the terms (Onwuegbuzie et al., 2012). The table (or matrix) was two dimensional having a contrast set and a dimension of contrast. The contrast set contained terms that went together by reason of a single semantic relationship whereas the dimension of contrast was designed as a set of attributes for any term in the contrast set (Spradley, 1979; Leech and Onwuegbuzie, 2007; Onwuegbuzie et al., 2012).

3.3.3.1 Componential Analysis Procedure

The entire procedure of componential analysis included the process of searching, sorting, and grouping of attributes (or contrasts). The study followed a series of 8 steps put forward by Spradley (1979) as depicted in Figure 3.4.

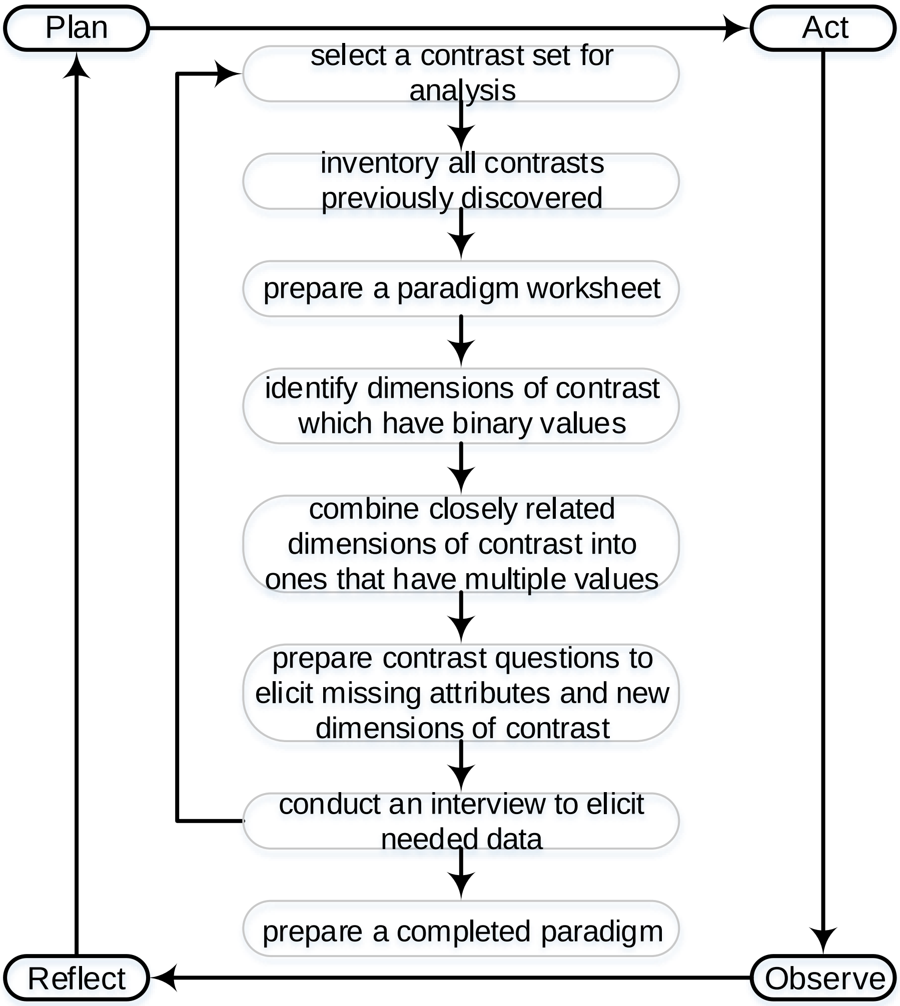


Figure 3. 4: Componential Analysis Procedure Source: (Spradley, 1979:178 - 182)

These 8 steps are discussed in the following.

Step 1: Selection of a contrast set. This stage involved selecting a contrast set to be analyzed one at a time. For example, in order to fully understand the term **Headband**, the term was contrasted with all the other terms in its contrast set such as **Necklace**, **Armlet**, **Bracelet**, **Waistband**, and **Anklet**.

Step 2: List all contrasts discovered earlier. During this stage, all the contrasts (or attributes) that were found in data were compiled into a list. Any statement about a term in the contrast set was inventoried and written down in an excel worksheet.

Step 3: Prepare a paradigm worksheet. This stage involved the creation of a two-dimensional table in an excel worksheet with the left-hand column labelled contrast set and the top row marked dimension of contrast. The worksheet was made of large enough columns to enter the attribute data. Such a table was important in this study because it was compatible with the Matrix Plugin (Horridge et al., 2004) in Protégé-OWL that was used in the development of the XBO in Chapter 4. The plugin allowed attributes to be added in XBO in the similar way as in a normal table. This reduced the ontology modelling time.

Step 4: Identification of dimensions of contrast with binary values. After creating the paradigm worksheet in excel the study identified the attributes that had binary values. In addition, as the attributes were generated in this stage, they were entered in the table created in Step 3.

Step 5: Integration of related dimensions of contrast into those with many values. The study began with attributes with binary values because of their simplicity. Many binary attributes were entered in the paradigm worksheet. In this stage, those attributes that were closely related such as **Small**, **Medium** and **Large** were combined into a more general attribute with multiple values for example attribute **Size**.

Step 6: Preparation of contrast-based questions to get missing attributes and more dimensions of contrast. One of the advantages of the worksheet in this study was it revealed the missing information and attributes that needed more analysis. In this stage more, contrast questions were formulated. These were prepared using the paradigm worksheet as the guide.

Step 7: Undertake an interview to acquire required data. Here, previous data was revisited and more data was collected in order to fill in the missing information revealed in Step 6.

Step 8: Prepare a completed paradigm. In this stage, each attribute table for each contrast set was then completed. For example, **Decoration**, **Size**, **Colou**r, **Position**, **Side**, **Tribe**, **BodyType**, and **Sex** were identified, extracted and classified as attributes. Again, it should be noted that componential analysis was guided by AR and NeOn methodology.

As can be seen, from the whole data analysis phase, the case of domain and taxonomic analyses led to further descriptive and structural questions respectively, while componential analysis led to further contrast questions. In the event that there were significant gaps in the analysis of the gathered data, the study collected or revisited documentation, interview or observational data to address these descriptive, structural and contrast questions. This enabled the study to fill in the missing information. Such an undertaking was made possible because AR underpinned data analysis through a series of planning, action, observation and reflection cycles (Susman and Evered, 1978; Altrichter et al., 2002)

The adoption of domain, taxonomic and componential analyses in this study was justified, because first and foremost, all three methods of data analysis were used on all the data sources selected to inform this study. Secondly, this allowed multiple methodological and theoretical perspectives in examining and interpreting the data collected. In other words, the flaws of one method were compensated for by the strengths of the next method. To elaborate, domain analysis was used to identify domains within the Xhosa Beadwork (Spradley, 1979). Domain analysis is a surface analysis method as a consequence it only allowed a holistic study of Xhosa Beadwork. Upon identifying the main classes, there was still a need for further analysis. To solve that, the study used taxonomic analysis. In turn, taxonomic analysis permitted an exhaustive analysis of the internal structure of the main classes (super-concepts) found previously by domain analysis (Spradley, 1979) in order to discover their corresponding subconcepts (subclasses).

However, both domain and taxonomic analysis focused chiefly on similarities of terms but not on differences of terms. As such, the study utilized componential analysis to enable the systematic organization and search for the attributes associated with terms (or concepts) in a category. Domain and taxonomic analysis could not handle this extra information because the process involved other multiple semantic relationships such as **hasSex and hasSize**. Therefore, componential analysis was used to handle and represent these other semantic relationships based on the contrast principle.

The selection of domain, taxonomic and componential analyses in this study are for the reason that they all support the triple data model. The triple data model as stated before, is the cornerstone of the RDF standard and the Semantic Web (Wielemaker et al., 2005). The study is situated within the Semantic Web. Wherein, ontological models are considered the mainstay of the Semantic Web (Yadav et al., 2016). As such, the output of the data analysis phase was compatible with the development of the XBO.

However, in order to achieve research relevance and scientific rigor, the study also employed descriptive triangulation (Onwuegbuzie and Leech, 2006; Onwuegbuzie et al., 2012). The study presented the findings and interpretations of the data analysis phase to Xhosa Beadwork experts. This enabled them to assess the data analysis output for completeness and accuracy (Leech and Onwuegbuzie, 2007; Onwuegbuzie and Leech, 2006; Onwuegbuzie et al., 2012). Using descriptive triangulation as an additional structure to methodological triangulation assisted the study to address gaps within the output of the data analysis phase and the study. This ensured correct data analysis output that later supported the data representation phase of the XBO.

3.4 Data Representation

The output of this phase is a software artefact and therefore a full development methodology to produce the ontology must be followed, as emphasized by Suárez-Figueroa (2010). The AR methodology mentioned before in Section 3.1 does not substitute the requirement for an ontology development methodology to construct the ontological model for Xhosa Beadwork. In order to develop the ontology, ontology engineering methodologies that have established and comprehensive methodological support are often used. In that regard, the study used the iterative-incremental ontological life cycle within the NeOn methodology

The NeOn methodology was developed by Suárez-Figueroa (2010). Unlike the other ontology development methodologies, the objective of NeOn is to develop ontological models that emphasize the reuse of knowledge resources (Suárez-Figueroa, 2010; Suárez-Figueroa and Gómez-Pérez, 2009). The NeOn is viewed as a methodology based on a flexible collection of scenarios that can be combined in a myriad of ways (Suárez-Figueroa, 2010). The study used the NeOn (Suárez-Figueroa, 2010; Suárez-Figueroa and Gómez-Pérez, 2009) to develop the XBO. The adoption of NeOn methodology in this study is justified because a scenario could be broken down into various processes and activities with comprehensive supporting guidelines given. A comprehensive discussion on ontology development methodologies is provided in Chapter 2.

Furthermore, Suárez-Figueroa (2010), asserts that there is no single universal ontology life cycle that can be applied to all ontology development projects. As such the selection of an ontology life cycle is dependent on numerous features and these features are not standard as they vary from ontology to ontology. This claim is considered the premise of the NeOn methodology. The selection of NeOn methodology for this study is justified because the methodology puts forward a number of flexible activity-based ontology life cycles. The other ontology development methodologies such as Methontology, OnToKnowledge and DILIGENT are limited in that they only propose a single standard ontology life cycle. In addition, the choice of NeOn methodology, in this study, was also based on the fact that it has the methodological support for identifying and defining the ontology life cycle according to the scenario.

3.4.1 Iterative and Incremental Ontology Life Cycle

The life of a software artefact such as an ontology can be modelled through following an ontology development life cycle model (Suárez-Figueroa, 2010). According to Suárez-Figueroa (2010), the ontology development life cycle is viewed as a model to define in what way is an ontology developed and maintained from concept to disposal. In fact, an ontology development life cycle describes different ways of organizing the processes and activities into stages that govern ontology development and maintenance. Various ontology development life cycle models can be discerned in literature namely, waterfall, iterative, incremental, spiral, conical-spiral, cyclic and evolutionary prototyping life cycle model among others(Suárez-Figueroa, 2010). This study used the iterative-incremental model by Suárez-Figueroa (2010). The iterative-incremental life cycle model guided the entire life of the ontology from concept to disposal, established and determined the order and transition between the different stages of the XBO development.

The iterative-incremental model is made up of two terms: iterative and incremental. The foremost characteristic of the first term iterative is that it splits requirements of the ontology into small segments. The ontology is then developed, using ontology requirements from each and every segment (Suárez-Figueroa, 2010). For example, the initial iteration can be based on concepts, while the following iteration would be focused on properties to improve the ontology etcetera. The main feature of the second term, incremental, is anchored on dividing requirements into separate segments. Then each segment of the ontology is developed in a separate cycle (Suárez-Figueroa, 2010). The iterative-incremental was employed in this study because it allowed the development of the XBO to grow in layers centred on different topics. For example, in the XBO, the **Necklace** was represented first, then the **Headband**, followed by the representation of knowledge on **Bracelet** and so on. By combining the two terms (or models), the iterative-incremental model can be defined as a model whose main feature is incremental construction of the ontology ordered by a collection of iterations undertaken within a fixed period (Suárez-Figueroa, 2010). The iterative-incremental model adopted for this study is indicated in Figure 3.5.

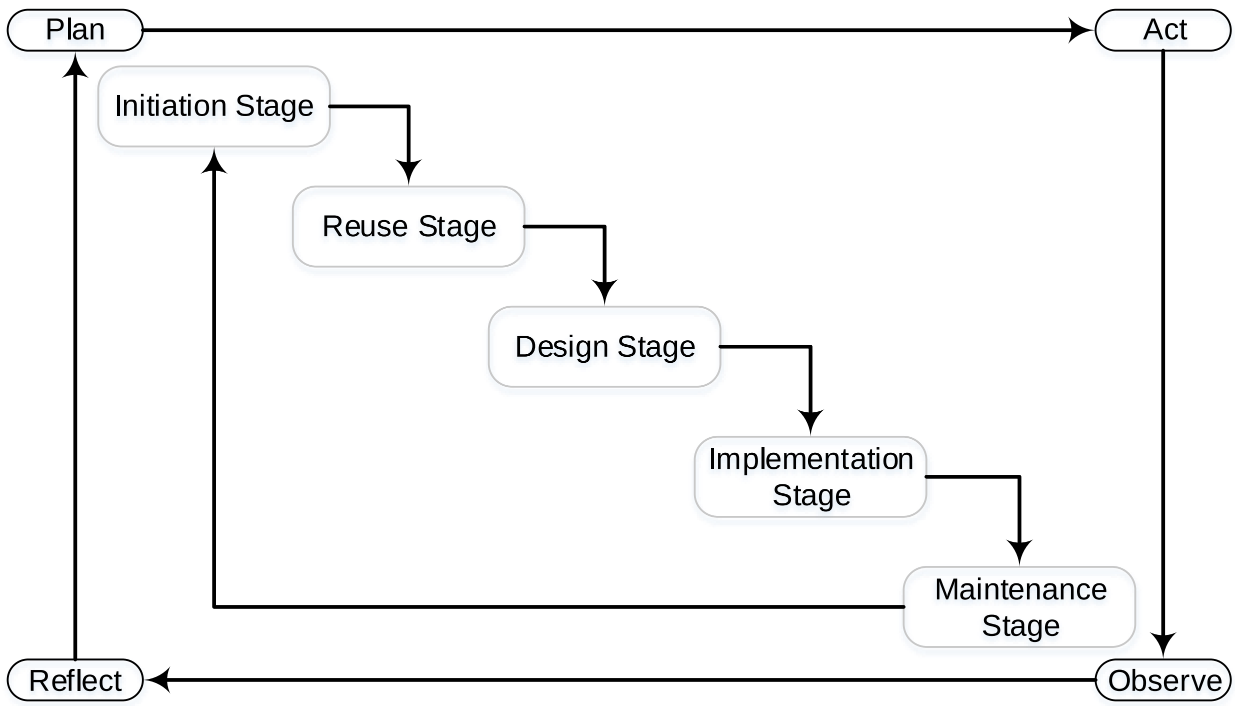


Figure 3.5: Iterative-incremental Ontology Life Cycle Model Source: (Suárez-Figueroa, 2010:108 - 109)

As shown in Figure 3.5, the life cycle was comprised of the following five stages: initiation, reuse, design, implementation and maintenance. The subsequent sections describe the main purposes and outcomes of each stage of the iterative-incremental model as applied in this study.

Initiation Stage

In this phase, the main outcomes consisted of ontology requirements specification and the overall plan for the development of the whole ontology. According to Suárez-Figueroa (2010) specification of the ontology requirements should fulfil the intent of the ontology in accordance with the domain knowledge. To achieve this, the study used CQs to provide the scope of the ontology. The activities undertaken under the initiation stage included activities such as analyzing the environment in which the ontology was developed. A variety of sources of data were used in this study, these included beadwork documentation (Costello, 1990; Broster, 1976; Broster, 1967) and SAHRIS (SAHRA, 2019a). These were acquired during the data collection phase as detailed in Section 3.2. During the knowledge acquisition, ontological and non-ontological concepts and their instances were acquired. This stage was requisite to identifying and establishing the resources for the development, and the scheduling of the whole Xhosa Beadwork Ontology (XBO). The study used Protégé-OWL as the ontology modelling environment.

Reuse Stage

This is the stage where the reuse of non-ontological and ontological resources was undertaken (Suárez-Figueroa, 2010). As result, the main purpose was to acquire relevant ontological and non-ontological resources for reuse in the XBO. The output of the reuse stage could be a formal or informal model that can utilized in the design stage. On the other hand, the model can be already declared in an ontology language that can be made use of in the implementation stage. The study had both formal and informal models that were used in the modelling and implementation stage of the XBO respectively. In this stage, non-ontological resource reuse involved retrieving and transforming available non-ontological resources from SAHRIS(SAHRA, 2019a) into the development of the ontology. Whereas ontological resource reuse comprised the use of available ontological resources such as SKOS and Dublin Core, modules, statements, and ontology design patterns (ODPs) such as naming pattern (this included term normalization and naming convention), value partition pattern (Section 4.5.5), closure pattern (Section 4.5.6) and covering pattern (Section 4.5.6) in the development of XBO.

Design Stage

As stated by Suárez-Figueroa (2010), the outcome of this stage is both a formal and informal model that should fulfil the ontology requirements specified in the initiation stage. The design stage included undertaking activities such as organizing and structuring data obtained, into meaningful informal and formal models at the knowledge level. This was undertaken in accordance with the ontology specification.

In this study, the classes (i.e. **Necklace**, **Anklet**, **Bracelet**), properties (i.e. **hasColour**, **hasTribe**), attributes (i.e. **Size**, **Rank**) and instances were identified and extracted by applying domain analysis on descriptive data, taxonomic analysis on structural data and componential analysis on contrast data. These were then organized using a combination of top-down method, bottom-up method, domain, taxonomic and componential analyses into a formal model that took the form of a non-computable taxonomy within Protégé-OWL environment. The taxonomy is presented in detail in Section 4.4.

Implementation Stage

In this stage, a formalised ontological model was formalised in OWL 2 DL within the Protégé-OWL 5.5.0 modelling system. The implementation stage comprised of converting the model from a conceptual model to a computable formal model. Hence, the primary activity of the implementation stage was generating a full-fledged computable model for Xhosa Beadwork in OWL 2 DL (Hitzler et al., 2009a; Grau et al., 2008). It is important also to point out that development and implementation were performed in parallel in Protégé-OWL.

Maintenance Stage

At the core of this stage, the study undertook activities such as ontology evaluation, ontology publication, documentation and enrichment of the XBO. Gomez-Perez Gómez-Pérez et al. (1995) delineates ontology evaluation as an examination of the technical adequacy of an ontology in tandem with a frame of reference. In that regard, the evaluation was focused on ascertaining the effectiveness of the XBO in order to confirm that the ontology comprehensive represented Xhosa Beadwork.

The study implemented a three-pronged (semi) automatic approach comprised of primary and secondary evaluation. In the first step, the logical consistency of the domain ontology was evaluated. The second step was a three-stepped approach based on evaluating the functional, structural and usability profiling dimensions of the XBO. The secondary evaluation of the ontology was implemented using the OOPS! (OntOlogy Pitfall Scanner). The third step involved the comparison-based evaluation. Here, the XBO was evaluated against gold standard ontologies. Within this step, the structural, functional and usability profiling dimensions of XBO were compared to those of the gold standard ontologies. This was accomplished according to the procedure established in the second step. Embedded in this evaluation was the corrective development of the XBO based on the evaluation outcome that emerged under each evaluation dimension. In this sense, the XBO was enhanced under the ontology repair phase as triggered by the outcome of the diagnosis phase. Further detailed discussions on XBO evaluation are in Chapter 5.

The ontology was extended with new conceptual structures such as concepts, properties and axioms. The maintenance stage also involved enriching the ontology and the information inside the XBO with metadata. The ontology element metadata was added using SKOS and the ontology metadata was implemented using Dublin Core (DC). In addition, at this stage, the implementation code of the XBO was generated in OWL 2DL. In addition, the XBO was converted into an HTML readable document, using Live OWL Documentation Environment (LODE) web service.

Finally, the maintenance stage included the ontology publication and as a result, XBO was uploaded on GitHub repository using OnToology.

The development of this ontology involved a domain that was not well understood and made up of tacit knowledge. More so, the ontology requirements were not completely known and changed during the development of the ontology. Hence, the important aspect about the ontology life cycle used by the study is that it was iterative and incremental. As a result, it allowed the study to continuously improve and expand the XBO through executing manifold iterations including cyclic feedback and adaptation (Suárez-Figueroa, 2010). As such, the iterative-incremental model focused on a set of requirements and out these requirements, a subgroup was selected then used in the construction of the XBO. The partial outcome was then studied, including analysing the risk of progressing to the next iteration. The initial group of requirements was then augmented and adapted with each subsequent iteration. This process continued till the whole ontology on Xhosa Beadwork was developed.

In this study, the iterative-incremental model also allowed the identification and alleviation of possible risks as soon as possible. Since, each iteration was modified with respect to the experience of the preceding iteration. However, the number of iterations, in the model needed to be limited because of the specificity of the time constraint on the duration of the study. In order to limit the number of iterations, a more complete and detailed specification of ontology requirements was performed, as suggested by Suárez-Figueroa (2010). In this case, a lesser number of iterations and fewer revisions were needed.

Equally important is the issue of how the stages within the different iterations were guided or controlled. In this study, every iteration was regulated in one of two ways. In the first place, no backtracking was permitted amid stages in an iteration, since the enhancement was performed in the ensuing iteration. In the second place, ontology requirements review and the overall plan were performed in the initiation stage of each iteration, including a comprehensive plan of each iteration.

3.5 Conclusion

The chapter has explained AR as the underpinning methodology utilized in this study. The reasons for selecting AR were portrayed. There are specific phases pursued when undertaking AR and those phases have been presented. The three distinct phases that were followed in this study, to be specific, gathering of data, analysis of data, and representation of data in the development of the XBO have been presented. These phases were guided by AR with each phase as an AR cycle concentrated on planning, action, observation and reflection. In addition, the study proposed adapted domain, taxonomic and componential analyses as methods appropriate in doing ontology data analysis. The chapter described these methods as applied in this study. These proposed methods for ontology data analysis are pragmatic. They are adaptable and are given specific methodological guidance which is a necessity for ontology data analysis. In addition, this chapter has demonstrated that domain, taxonomic and componential analyses are appropriate in the identification, extraction and organization of ontology terminology. As presented in this chapter, these methods were effective in the identification, extraction and organization of terminology for the XBO. The study used the NeOn methodology in developing the XBO. As such, the chapter has gone further to indicate how the NeOn methodology together with the iterative-incremental ontology life cycle was applied in the development of XBO. In the subsequent chapter, a detailed discussion on XBO development is presented.

Chapter 4: Implementation

In this chapter, the development of the OWL 2 DL Xhosa Beadwork Ontology (XBO) is presented. The XBO encompasses the ontological and non-ontological resources that describe Xhosa Beadwork. The development of the XBO pursued the NeOn methodology as discussed in Chapter 3. In this chapter, the development of the XBO is elaborated upon by highlighting the ontology development methodology in Section 4.1. In Section 4.2 the coverage of the XBO, the language the XBO is formalised in and the purpose of the XBO are described. The ontology requirements are presented in Section 4.3 while the development of the Xhosa Beadwork Taxonomy (XBT) is outlined in Section 4.4. XBO development is provided to in Section 4.5 and last of all, in Section 4.5 the conclusion of the chapter is presented.

4.1 Ontology Development Methodology

In order to ensure that the requirements are fulfilled and to guarantee the effectiveness of the XBO, a methodology was used. A methodology offers a well-organized approach to develop the XBO using an approach that has been tested in knowledge-based modelling throughout the world. In this study, as was stated in Chapter 3, NeOn was chosen as the methodology to develop the XBO (Suárez-Figueroa, 2010; Corcho et al., 2003; Fernández-López and Gómez-Pérez, 2002b; Fernández-López et al., 1997). The reason being that NeOn methodology matches the requirements of this study better than the other methodologies such as

Methontology (Fernández-López et al., 1997), DILIGENT (Pinto et al., 2004), OnToKnowledge (Sure et al., 2002) et cetera.

NeOn provided a setting that facilitated the development of the XBO through collaboration, in this case, the ontology expert and the Xhosa Beadwork experts. Furthermore, it allowed the likelihood of remodelling knowledge resources and the capability of including upper ontologies like DC and SKOS (Miles and Bechhofer, 2009; Dublin Core Metadata Initiative, 2006). Finally, NeOn methodology allowed the evolution and development of XBO to be iterative and incremental minimising development time. The main strengths of the NeOn methodology have been fully detailed in Chapter 3.

4.2 XBO Scope, Purpose, Implementation Language

4.2.1 Scope

The domain was examined in order to determine the scope of the XBO. The scope of the XBO is Xhosa Beadwork of the Thembu tribe. According to Costello (1990) and Broster (1976), Xhosa Beadwork is used for two things: a) personal ornamentation and b) decoration of garments and objects. In this study, the former is viewed as the primary function while the latter is considered the secondary function of beadwork. The XBO is anchored on the primary function of Xhosa Beadwork namely, **Headband**, **Necklace**, **Armlet**, **Bracelet**, **Waistband**, and **Anklet**. These are the subsets that were studied in this study and are represented in the XBO. The granularity level is associated with the CQs and terminology discovered, extracted and organised through the domain, taxonomic and componential analyses on the data collected as presented in Chapter 3.

4.2.3 Purpose

The primary objective of XBO is the preservation, promotion, development, and management of beadwork knowledge with special attention on Xhosa Beadwork. The main problem addressed by the XBO is the erosion of IK in the beadwork domain. Indeed, a large amount of beadwork knowledge is being eroded. This confirmed by Costello (1990, p.3) who argues that "…traditional beadwork is fast dying out and is now found only in remote areas". This is not some isolated phenomena but a scourge prevalent and affecting IK across South Africa (Fogwill et al., 2011; Alberts et al., 2012). Given this problem description, the ontological representation by the XBO will provide a platform that will correct the affectations or anomalies of IK erosion on Xhosa Beadwork.

In view of the heterogeneity of Xhosa Beadwork and beadwork in South Africa, the goal of the XBO also consists of enhancing the understanding of Xhosa Beadwork including standardising the knowledge of Xhosa Beadwork. Besides standardising Xhosa Beadwork, the XBO is an enabling platform for sharing information within the beadwork domain interoperating with other existing IK management systems.

The XBO should be capable of representing and connecting IK in Xhosa Beadwork. In order to overcome this challenge, the XBO would be communicated in an interoperable setting while at the same time, providing semantic relations to other ontologies or systems (Fogwill et al., 2011; Kathryn et al., 2016; Alberts et al., 2012). As a consequence, the XBO is developed for a setting where the semantic model can be extended continuously as required. For example, applications could be added that are capable of utilizing classified or generated knowledge.

In addition, XBO could be used by several public and private organisations within and without South Africa. For instance, the XBO can be used by the Indigenous Knowledge System Documentation Centres (IKSDC) established across South Africa including various governmental and non-governmental institutions such the UNESCO.

4.2.4 Implementation Language

In this section, the language used on XBO is discussed. The ontology language was selected in line with the coverage of the XBO. The main characteristics needed by the XBO were identified and these pertain to the ontological size required to formalise Xhosa Beadwork, annotations and metadata information to support ontological annotations, the degree of expressivity of the ontological terminology for comprehensive ontology development and DLs that support reasoning in XBO.

OWL 2.0 is the language that was chosen to describe the XBO. Although OWL1.0 and OWL 2.0 are comparable, OWL 2.0 is the new extended version of OWL 1.0 (Motik et al., 2009) and is more expressive than OWL 1.0. In this study, OWL 2 DL profile is used because as a sublanguage of OWL 2.0 it is the current standard. In addition, of the sublanguages of OWL 2.0, OWL 2 DL is the most expressive OWL 2 sublanguage with balanced expressivity and guaranteed decidability on reasoning (Hitzler et al., 2009b). OWL 2.0 was selected because it has high expressivity and supported DL as alluded to in Section 2.3. Other ontology modelling languages were not considered because their expressivity is below that of OWL 2.0.

4.3 Ontology Requirements - Competency Questions (CQs)

Whenever one is commencing study on a domain, one must start by becoming conversant with the domain by investigating documentation relevant to the domain of study (Hoffman et al., 1995). This entailed specific documentation analysis as espoused in Chapter 3. The documentation analysis was undertaken in order to commence the collection of data and formulation of CQs. Through this process, the study obtained the initial set of requirements for the XBO in form of CQs.

Most of the methodologies for developing ontologies (Uschold and Gruninger, 1996; Fernández-López et al., 1997; Noy and McGuinness, 2001; Suárez-Figueroa, 2010) recommend CQs as a method for establishing ontology requirements. The CQs technique was proposed by Grüninger and Fox (1995), who defined CQs as those questions that are in natural language intended for the ontology answer, as soon as the model is formalised. To identify the functional and non-functional requirements of the XBO, the study used the CQs method.

The primary objective of the CQs was to align the determined scope of the ontology to the knowledge in the XBO (Sure et al., 2002; Uschold, 1996; Uschold and Gruninger, 1996). Apart from establishing XBO requirements, CQs are important to this study in that they were used in conjunction with pre-domain, domain, taxonomic and componential analyses in the extraction of the preliminary concepts, properties and relations in the discourse.

The approach the study followed for identifying the CQs was a bottom-up approach (Suárez-Figueroa, 2010; Suárez-Figueroa and Gómez-Pérez, 2009). Using the bottom-up approach simple CQs were created first and followed by complex CQs which were derived from simple CQs through composition. A total of 74 CQs were enumerated, which are described and presented in detail in Appendix C. These are the CQs that were utilised to control the development of the overall XBO. It is also worth to mention that these CQs are not exhaustive. Examples of some of the CQs are shown in Figure 4.1.

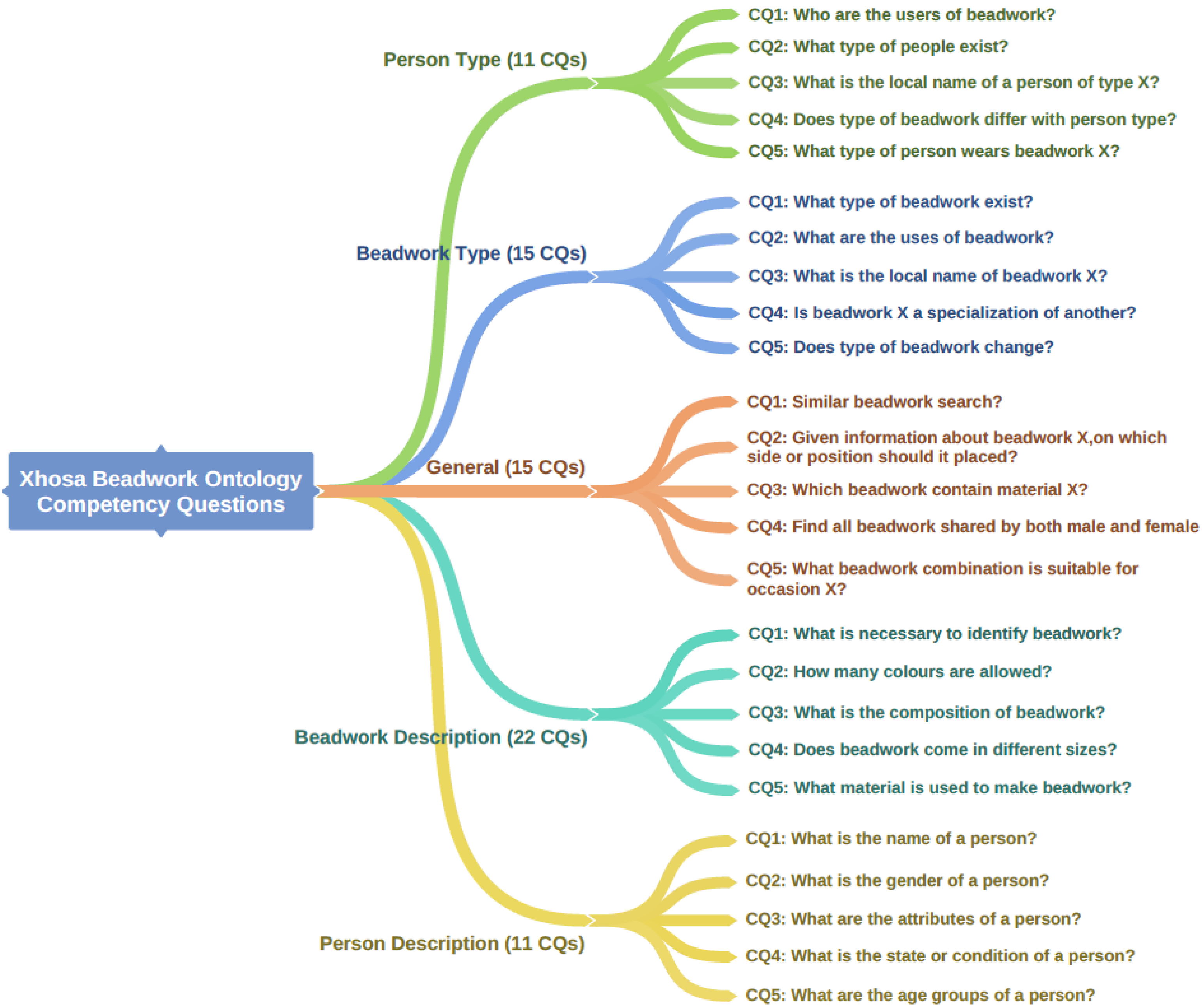


Figure 4.1: CQs Groups and a Selection of corresponding CQs View in Coogle a Mind Map Tool

The 74 CQs were then divided into 5 categories each including a different set of CQs. These are Person Type (11 CQs), Person Description (11 CQs), Beadwork

Type (15 CQs), Beadwork Description (22 CQs) and General (15 CQs). General CQs were based on combining simple CQs into complex CQs. The CQs categories and some of the corresponding CQs are shown in Figure 4.1. These CQs were put in MS Word and then rewritten in Coogle as shown in Figure 4.1.

The criteria for identifying and grouping the CQs depended on the uses that were identified, users and purposes of Xhosa Beadwork as gathered from the domain expert and existing documentation on Xhosa Beadwork. To group the CQs into 5 categories, we used a hybrid approach (Suárez-Figueroa, 2010). The approach combined domain, taxonomic and componential analyses on the existing documentation and the use of categories, like **Size**, **Colour**, **Tribe** and **Sex** to name a few. According to Suárez-Figueroa (2010), grouping the requirements was valuable for controlling the ontology development by using different modules with different characteristics of the XBO. The CQs were grouped so that each group of CQs included CQs that were relevant to a specific module of the XBO.

4.4 Xhosa Beadwork Taxonomy

Before describing the process of the development of the taxonomy the study deems as necessary to briefly revisit data analysis that was presented in Chapter 3. This is viewed as crucial because the outcome of the data analysis was used in the development of the taxonomy and the XBO in Section 4.5. The extraction of the terminology relevant to taxonomy was done by undertaking pre-domain analysis followed by comprehensive domain, taxonomic and componential analyses. As a result, the terminology (i.e. names, adjectives, verbs, and objects) in the domain of

Xhosa Beadwork was extracted, including terminology from the CQs and answers of the CQs. In turn, this terminology was represented in the taxonomy as a hierarchy and in XBO as concepts, instances, attributes, and properties.

The existing taxonomy covers the concepts based on descriptions and definitions linked to the primary function of Xhosa Beadwork. These categories are **Necklace**, **Headband**, **Armlet**, **Waistband**, **Bracelet**, and **Anklet**. As mentioned before, these categories were included using an iterative and incremental approach. The concepts and attributes related to the concept **Person** were added in the taxonomy so as to a give better sense to the knowledge contained in the XBO.

In this study, one of the important features of the taxonomy was that it enabled the creation of disjoint classes for the purpose of separating and limiting the instantiation of concepts. For each concept defined, a group was created with the view to separate definitions in XBO. Therefore, disjoint classes provided knowledge separation and at the same time the capacity to eliminate unsatisfiabilities in the XBO.

Since the taxonomic structure developed is quite big, the core classes, ordered by categories are presented in Table 4.1. A detailed and complete taxonomy is presented in Appendix B. In Table 4.1 the parent class, description of the class and subclasses are presented with the aim of making the concept more comprehensible.

Table 4.1: A part of the Taxonomy with the Description of Classes and Child Classes as Defined in the XBO

Class:	**DomainEntity**
SubClassOf:	**owl: Thing**
Description:	The class **DomainEntity** is a subclass of **owl: Thing**. The whole Xhosa Beadwork Ontology (XBO) is placed underneath **DomainEntity**. The class **DomainEntity** is used for housekeeping to manage routine tasks in order for efficient ontology modelling and functioning. For instance, class **DomainEntity** is a common super class in case of a property having multiple classes as domain or range. In this regard, the property is inherited or propagated to all other classes.
Subclasses:	**BeadworkEntity**, **PersonEntity** and **ValuePartition**.
Class:	**BeadworkEntity**
SubClassOf:	**DomainEntity**
Description:	This class is a subclass of **DomainEntity**. **BeadworkEntity** comprise concepts that represent objects or items of beadwork and the associated description of the beadwork **Item.**
Subclasses:	**Item**
Class:	**Item**
SubClassOf:	**BeadworkEntity**
Description:	This class is a subclass of **BeadworkEntity**. The term **Item** is used for concepts that represent a tangible or physical visible beadwork

	Item. This can be a collection or a single **Item** of beadwork.
Subclasses:	**Headband**, **Necklace**, **Armlet**, **Bracelet**, **Waistband** and **Anklet**.
Class:	**Headband**
SubClassOf:	**Item**
Description:	**Headband** is a subclass of **Item**. Class **Headband** designates a beadwork **Item** or article in form of a band or narrow strip worn on or around the forehead.
Subclasses:	**FlexibleHeadband** and **InflexibleHeadband**
Class:	**Necklace**
SubClassOf:	**Item**
Description:	**Necklace** is a subclass of **Item**. **Necklace** is a beadwork **Item** in form of a band or string that is worn around the **Neck.**
Subclasses:	**StrandNecklace, TabNecklace, TasselNecklace, CharmNecklace, ChokerNecklace** and **CollarNecklace**
Class:	**Armlet**
SubClassOf:	**Item**
Description:	**Armlet** is a subclass of **Item.** The **Armlet** is used to represent a beadwork **Item** in form of a band or ring or string or strip worn around the **Upper Arm** or high on the **Arm**.
Subclasses:	**FlexibleArmlet** and **InflexibleArmlet**
Class:	**Bracelet**
SubClassOf:	**Item**
Description:	This is a subclass of **Item.** The class **Bracelet** represent an **Item** of beadwork in form of a loop or band encircling or worn around the

	Wrist.
Subclasses:	**InflexibleBracelet** and **FlexibleBracelet.**
Class:	**Item**
SubClassOf:	**Waistband**
Description:	**Waistband** is a subclass of **Item**. Class **Waistband** represents an **Item** of beadwork designating a strip or band encircling and fitting around the **Waist**.
Subclasses:	**StrandWaistband**
Class:	**Anklet**
SubClassOf:	**Item**
Description:	**Anklet** is a subclass of **Item.** Class **Anklet** is used for concepts that represent an **Item** beadwork in form of a string or band or strip or ring worn around the **Ankle**.
Subclasses:	**FlexibleAnklet** and **InflexibleAnklet**
Class:	**ValuePartition**
SubClassOf:	**Item**
Description:	This class is a subclass of **DomainEntity.** The concepts in **ValuePartition** denote the information about a beadwork **Item** or **Person**. These concepts define the characteristics (or features or qualities or attributes) of an **Item** beadwork or **Person**.
Subclasses:	**Colour**, **Decoration**, **BodyType**, **Sex**, **Material**, **Age**, **Rank**, **Position**, **BodyRegion**, **Use**, **Quantity**, **Side**, **Size** and **Tribe**.
Class:	**Material**
SubClassOf:	**ValuePartition**

Description:	**Material** is a specialization of **ValuePartition.** Class **Material** is comprised of concepts that represent discrete pieces of materials used in the production of an **Item** of beadwork.
Subclasses:	**Natural** and **Synthetic**.
Class:	**Colour**
SubClassOf:	**ValuePartition**
Description:	**Colour** is a subclass of **ValuePartition**. The concepts of class **Colour** designate the hue quality of a beadwork **Item**.
Subclasses:	**Primary, Secondary** and **Tertiary.**
Class:	**Tribe**
SubClassOf:	**ValuePartition**
Description:	Class **Tribe** is a subclass of **ValuePartition** representing concepts of social divisions in a traditional society. The social divisions consist of families or communities linked by social, or blood, with a common dialect and culture.
Subclasses:	**Pondo**, **Bhaca**, **Xhosa**, **Thembu**, **Fengu**, and **Bomvana**.
Class:	**Quantity**
SubClassOf:	**ValuePartition**
Description:	This class is a subclass of **ValuePartition**. Class **Quantity** represents terms that denotes the numeric value of **Quantity** such as the specification of how many or the total number there is of an **Item** of beadwork.
Subclasses:	**Single, Double** and **Multi.**
Class:	**Side**

SubClassOf:	**ValuePartition**
Description:	Class **Side** is a subclass of **ValuePartition**. Class **Side** is comprised of terms that represent an aspect to the **Right** or **Left** with reference to the trunk of the human body.
Subclasses:	**LeftSide** and **RightSide**
Class:	**BodyRegion**
SubClassOf:	**ValuePartition**
Description:	Class **BodyRegion** is a subclass of **ValuePartition**. The class **BodyRegion** comprise concepts that denote the anatomical areas or regions of the human body where a beadwork **Item** should be worn or placed.
Subclasses:	**Ankle**, **Arm**, **Head**, **Neck**, **Shin**, **Waist** and **Wrist**.
Class:	**BodyType**
SubClassOf:	**ValuePartition**
Description:	Class **BodyType** is a subclass of **ValuePartition.** Class **BodyType** is used for concepts that represent the general physical capability of the body of a beadwork **Item** in bending or stretching usually without breaking.
Subclasses:	**Flexible** and **Inflexible.**
Class:	**Position**
SubClassOf:	**ValuePartition**
Description:	The class **Position** is a specialization of **ValuePartition**. The concepts that make up class **Position** are those that represent a point or position where an **Item** of beadwork is located or placed.

	This is the point or **Position** that is occupied or should be occupied by a beadwork **Item**.
Subclasses:	**Upper**, **Middle** and **Lower**.
Class:	**Decoration**
SubClassOf:	**ValuePartition**
Description:	This is a subclass of **ValuePartition**. **Decoration** is comprised of concepts that denote a decorative element or design or motif that serves as an ornament or **Decoration**, added to an **Item** of beadwork to enhance the appearance of or distinguish the beadwork **Item**.
Subclasses:	**Tab**, **Streamer**, **Tassel**, **Fringe**, **Charm** and **Strand**.
Class:	**Size**
SubClassOf:	**ValuePartition**
Description:	This class is a specialization of **ValuePartition.** Class **Size** is made up of concepts that represent the relative proportions of an **Item** of beadwork or physical magnitude or the overall dimensions according to which an **Item** of beadwork is made.
Subclasses:	**Small**, **Medium** and **Large**.
Class:	**Use**
SubClassOf:	**ValuePartition**
Description:	This is a specialization of **ValuePartition.** Concepts contained in **Use** are those that represent the category of **Use** for which the beadwork **Item** is intended or is considered suitable.
Subclasses:	**Ritual** and **Ceremony**.

Class:	**Rank**
SubClassOf:	**ValuePartition**
Description:	Class **Rank** is a subclass of **ValuePartition.** Class **Rank** is made up of concepts that conceptualize position of a **Person** with respect to another **Person** or other **Person**s.
Subclasses:	**Royal**, **Noble** and **Common.**
Class:	**Sex**
SubClassOf:	**ValuePartition**
Description:	Class **Sex** is the subclass of **ValuePartition.** Class **Sex** consists of concepts that represent the total assemblage of reproductive characteristics or functions differentiating the **Male** from the **Female** organism.
Subclasses:	**Male** and **Female**
Class:	**Age**
SubClassOf:	**ValuePartition**
Description:	This is a subclass of **ValuePartition.** Class **Age** comprise concepts that represent one of the stages of a **Person** from the beginning to any given time.
Subclasses:	**Adulthood, Adolescence, Childhood** and **Infanthood.**
Class:	**Adolescence**
SubClassOf:	**Age**
Description:	This is a subclass of **Age**. **Adolescence** represents **Age** or phase of growth and development of a human being between **Childhood** and **Adulthood**.

Subclasses:	**EarlyAdolescence**, **MiddleAdolescence** and **LateAdolescence**
Class:	**Adulthood**
SubClassOf:	**Age**
Description:	This is a subclass of **Age**. Class **Adulthood** is a period or phase of growth and development in the lifespan of a human being in which the legal age of majority or the age of maturity has been attained as specified by law.
Subclasses:	**EarlyAdulthood, MiddleAdulthood** and **LateAdulthood.**
Class:	**Childhood**
SubClassOf:	**Age**
Description:	Class **Childhood** is a subclass of **Age**. **Childhood** comprise a stage of growth of a human being between birth and puberty or phase below the age of puberty.
Subclasses:	**EarlyChildhood, MiddleChildhood** and **LateChildhood.**
Class:	**Infanthood**
SubClassOf:	**Age**
Description:	This is a subclass of **Age**. Class **Infanthood** comprises concepts that designate a period or phase of growth and development of a human being from the period of birth up to or below the age of **Childhood**.
Subclasses:	**EarlyInfanthood** and **Toddlerhood.**
Class:	**PersonEntity**
SubClassOf:	**DomainEntity**
Description:	This class is a subclass of **DomainEntity**. Class **PersonEntity**

	comprise concepts that represent a **Person** or **Person**s as recognized by culture or the law of a country.
Subclasses:	**Person**
Class:	**Person**
SubClassOf:	**PersonEntity**
Description:	**Person** is a subclass of **PersonEntity**. Class **Person** contains concepts that denote a human being, regarded as an individual in the physical commonsense intuition as recognized by culture or country.
Subclasses:	**Man** and **Woman**.

The study employed domain, taxonomic and componential analyses for the identification, extraction, and organisation of the vocabulary according to the discussion in Section 3.3. Within that context, the study used the top-down method in conjunction with the bottom-up method in constructing the XBT. For example, the broad terms were defined first, with the narrow terms identified next, and then the narrow terms were grouped to come up with possible intermediate-level terms (Hedden, 2010). Indeed international standards for controlled vocabulary construction such as ISO 704, ISO 1087 and NISO Z39.19 (NISO, 2005; ISO, 1990) informed the construction of the taxonomy. These standards were used in this study because they provided recommended strategies used worldwide in the description, definition, and development of taxonomies. In addition, they provide a shared framework of knowledge and describe how that knowledge should be implemented. As a result, the study developed a more informative taxonomy that will enable interoperability, adoption, and adaptation inside and outside the domain of Xhosa Beadwork.

After identifying and describing the classes and subclasses as presented in Table 4.1 the taxonomy was created in Protégé-OWL 5.5.0. A snapshot of the taxonomy is presented in Figure 4.2.

Figure 4.2: Asserted Class Hierarchy Displaying Some Classes as Implemented in the final XBO

Lastly, as a note, the taxonomy developed in this study shown in Figure 4.2 was then expanded and enhanced during the entire development of the XBO. This included enhancing the taxonomy with object properties, attributes, data properties, instances, annotation properties including enhancing the ontological expressivity with restrictions and axioms as detailed next in Section 4.5.

4.5 Data Representation

This section gives the description of the development of the XBO including the ontological elements used. Furthermore, this description gives an understanding of how the ontological elements are interconnected with the purpose of supporting the objective of the XBO. As a result, work accomplished by the following sections is centred on enhancing the taxonomy developed in Section 4.4 toward a complete ontological definition and representation of the Xhosa Beadwork Ontology (XBO).

4.5.1 XBO: General Description

The core hierarchical tree developed in this study to support XBO is shown in Figure 4.3. The XBO is in OWL 2 DL. The OWL 2 DL language offers the XBO the expressivity needed to model the domain of Xhosa Beadwork. Selection of this language has been discussed in depth in Chapter 3.

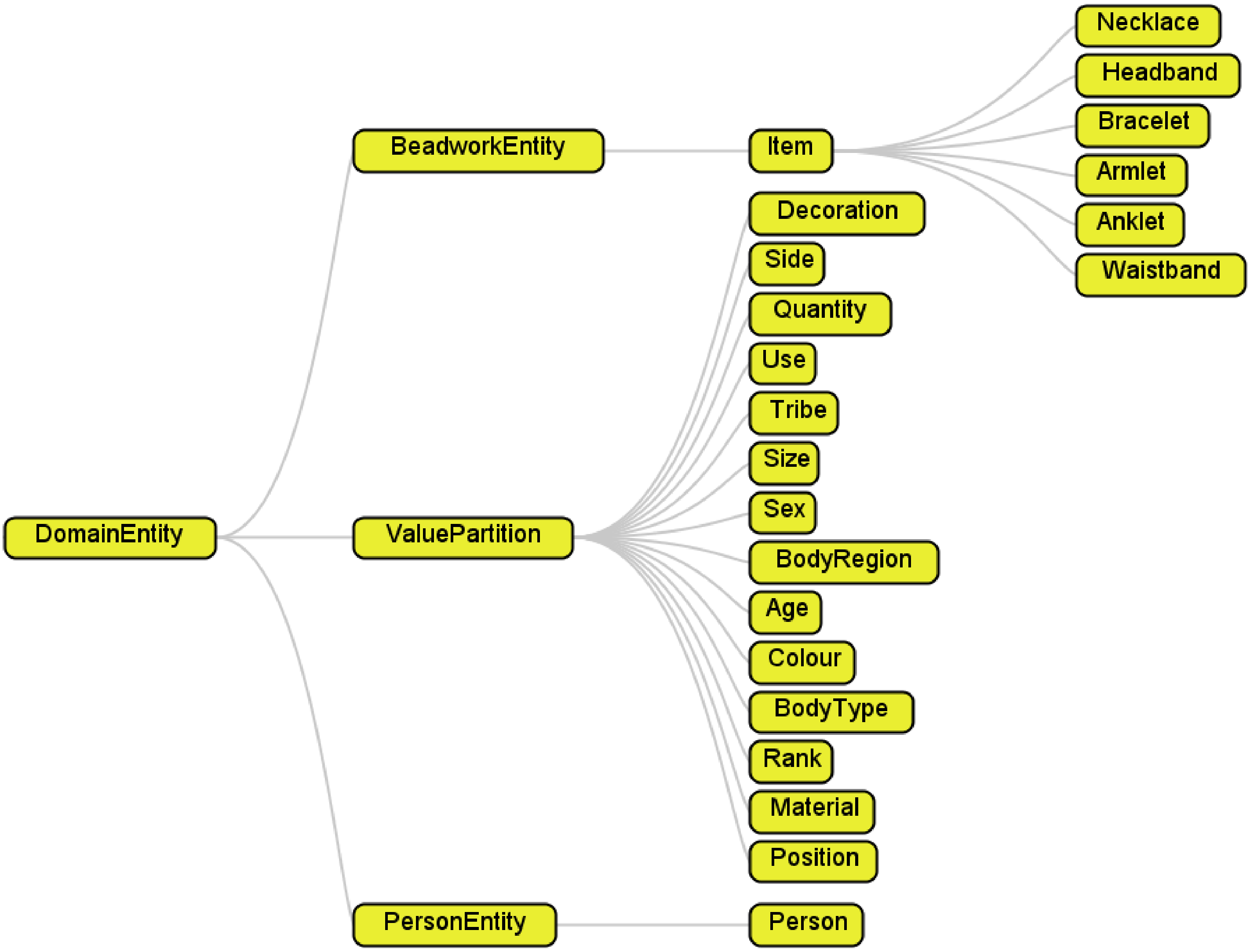


Figure 4.3: Tree Visualisation using PG ETI SOVA Plugin 1.0.0 Displaying the Core Classes in XBO

In Figure 4.3 the **XBO** is separated into **BeadworkEntity** module and **PersonEntity** module. The **BeadworkEntity** is divided into **Item**. The **Item** module is implemented in the XBO by semantic linkage of the descriptors contained in the **ValuePartition** module to a specific type of an **Item**. The **Item** module is comprised of **Necklace**,

Armlet, **Headband**, **Anklet**, **Bracelet**, and **Waistband** while **ValuePartition** module is composed of 14 main classes as descriptors. According to Welty and Guarino (2001), these descriptors are also known as features, qualities, attributes or modifiers (Guarino, 1995; Guarino et al., 2009; Noy and McGuinness, 2001). The **ValuePartition** module is focused on defining each attribute of an **Item** of beadwork. These attributes as defined in **ValuePartition** are **Material**, **Size**, **Colour**, **Side**, **Position**, **Quantity**, **BodyType**, **Age**, **Sex**, **Rank, Use, BodyRegion, Decoration**, and **Tribe**. As shown in Figure 4.3 the **Item** module is aligned to the attributes as defined in **ValuePartition**.

On the other hand, the **PersonEntity** module is partitioned into **Person**. This part of the XBO is focused on representing the type of **Person** according to **ValuePartition**. The **Person** module comprises of information associated with the type of a **Person** such as a **Man** or a **Woman**. The **ValuePartition** module contains feature information such as **Age**, **Sex and Tribe** to define a **PersonEntity**. With such knowledge represented in the XBO, one can ask what type of **Person** can wear what type of beadwork **Item** and the XBO can provide such knowledge.

Then, the entire XBO is placed underneath class **DomainEntity**. **DomainEntity** is a house-keeping class within the XBO. This creates the opportunity of having probe classes, outside the ontology in order to use them to evaluate the XBO. **DomainEntity**, in turn, is contained in the class **owl: Thing.** OWL 2 has the class **owl: Thing** as a universal class of all entities. This was beneficial when there was a need, for example, to express the universal use of property in the XBO.

It is worth to note that the **ValuePartition** module is implemented following the value partitioning ontology design pattern. Such an ontology design pattern will permit the XBO to be extended since the XBO was created with the idea of continuously expanding scenario. In Section 4.5.6, the implementation of value partitioning in XBO is discussed in depth. The core OWL utilised in the description of XBO is introduced next. The machinery used in XBO from OWL provided the terminology for representing instances, classes, and properties in the domain of Xhosa Beadwork.

4.5.2 XBO: Entities Enrichment Mechanism

In XBO, classes support domain definition through concrete representation referring to concepts that are utilised in the beadwork domain. Beyond the taxonomy constructed in Section 4.4, there was a need to augment the class definitions in the taxonomy so as to strengthen knowledge represented in the XBO. The enhancement of the XBO was provided along the following: (i) differentiating concepts definition through disjointness in order to create consistent knowledge inside the XBO; (ii) declaring defined classes (iii) creating the object properties and defining data properties, (iv) defining attributes or modifiers necessary to understand the classes using value partition approach (v) including annotation properties in the XBO in order to enhance the vocabulary where necessary.

4.5.3 XBO: Disjointed Classes

The XBO class hierarchy is made up of several classes such as **Armlet, Anklet**, **Bracelet**, **Headband**, **Necklace**, and **Waistband.** By default, OWL assumes that these classes overlap unless somehow stated that they are not. This is achieved when classes are axiomatised as disjoint. Classes are disjoint when they do not share any instance. The study indicated that these classes have no common members using **owl: DisjointWith** to create the disjoint axiom. In that regard, the normalisation ontology design pattern was used in conjunction with **owl: DisjointWith** to implement the disjoint mechanism in the XBO. In this pattern, a set of primitive classes including their sibling classes declared as pairwise disjoint was used.

For example, the subclasses **Headband**, **Necklace**, **Bracelet**, **Armlet**, **Waistband** and **Anklet** of class **Item** are defined as disjoint. The disjoint axiom separates different beadwork items between them in order to clearly identify corresponding beadwork items specific to each class. In other words, there can be no **Item** that can be both a **Headband** and **Waistband.** This is a case in point of explicit knowledge defined in the XBO.

Using the same procedure, several classes were specified as disjoint in XBO. The disjoint classes are dependent on the level at which they are at in the XBO. The disjoint mechanism has been applied at each taxonomical level throughout the XBO between sub-concepts that take part in each class from the top taxonomical level. This was accomplished by studying classes that formed part of the same taxonomical level to determine if it was required to separate or not. If not the then an instance of a concept would simultaneously be an instance of another concept.

Disjoint axiomatization is an important mechanism in this ontology because it was utilized to describe knowledge in the domain and it enabled inference on the XBO. One of the important advantages of having the XBO was to have explicit knowledge made available and disjointness makes the beadwork domain knowledge explicit for both humans and computers. This mechanism was applied in XBO in order to avoid the semantic inconsistency where an individual is realised into two incompatible concepts.

For example, in Figure 4.4 the disjoint axiom declares that class **Armlet** is disjoint with **Anklet**, **Bracelet**, **Headband**, **Necklace**, and **Waistband**, meaning no beadwork **Item** can simultaneously be **Armlet** and **Necklace**.

Class: Armlet
    DisjointWith: Anklet, Bracelet, Headband, Necklace, Waistband

Figure 4.4: Disjoint Axiom on Class Armlet and the Class Description View Showing the DisjointWith on Class Armlet

This is useful for clarifying modelling assumptions such as asking whether any **Armlet** can be both a **Bracelet** and **Necklace**. Furthermore, disjointness was used in this study because it does enable a lot of inference to take place on the XBO.

Disjointness had a significant function in causing entailments. In other words, not making class disjoint that is considered as being disjoint in the XBO will then lead to not getting the expected entailments.

4.5.4 XBO: Defined Classes

The classes created up until now in the XBO have been described using just the necessary conditions. Such classes are called primitive classes. Necessary conditions are important in that they provide the background knowledge upon which the definitions are declared. However, primitive classes are limited (Baader et al., 2003; Krotzsch et al., 2014; Horrocks and Patel-Schneider, 2004). With necessary conditions alone, primitive classes do not support dual deduction. They only have implication in a single direction. This is so because a primitive class includes only necessary conditions to determine membership. As such the membership of any or random individual in the XBO cannot be determined. As a consequence, definitions are needed in the XBO. For example, definitions can use primitive classes as the basis for creating polyhierarchy in the XBO.

All the classes that contain at least a single set of necessary and sufficient conditions are simply called definitions (Baader et al., 2003). In contrast to primitive classes, defined classes have a dual implication. The equivalence axiom was used as the basic form of declaration to create definitions in the XBO. Some of the equivalent classes in the XBO were defined following the equivalence axiom of the form shown in Figure 4.5.

Class: CharmNecklace
EquivalentTo: Necklace and (hasDecoration some CharmDecoration)

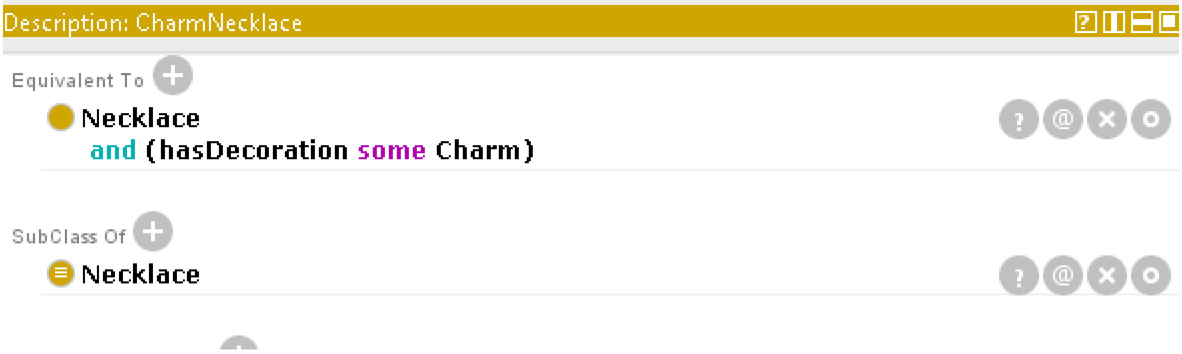


Figure 4.5: Equivalence Axiom on **Class CharmNecklace** and the Class Description View Showing **Class CharmNecklace** as a Defined Class

The equivalence axiom in Figure 4.5 defines the class **CharmNecklace** as an intersection of the classes **Necklace** and **hasDecoration** some **CharmDecoration**; thus, the instances of **CharmNecklace** are exactly those instances that are both an instance of **Necklace** and an instance of **hasDecoration some CharmDecoration**. Such a definition has dual implication and this is important in XBO. In Figure 4.5 the first direction implies that each instance of **Necklace** and **hasDecoration some CharmDecoration** is an instance of **CharmNecklace**. If any random instance satisfies the two conditions; it is then categorized as a **CharmNecklace** instance. In the second direction, the implication is that each **CharmNecklace** is an instance of **Necklace** and instance of **hasDecoration some CharmDecoration**; thus, a **CharmNecklace** is classified as an instance of **Necklace** and of **hasDecoration some CharmDecoration**.

Such a declaration in Figure 4.5 is seen as a logical equivalence, meaning the provision of sufficient and necessary conditions for classification in XBO. This form of definition was employed in this study because it is much stronger than the primitive classes which typically impose only necessary conditions. All of the defined or equivalent classes in the XBO were defined as shown in Figure 4.5. With definitions the complete definition of the class is known, relevant and unambiguous. Furthermore, these definitions are important in XBO because defined classes do enable automatic classification of individuals to determine class membership.

As shown in Figure 4.5 the XBO is made up of 73 defined classes. These were created using the logical equivalence axiom. These definitions or equivalent classes that are represented in the XBO have been obtained taking into account the expertise of the domain expert and the documentation prevalent in the domain of Xhosa Beadwork.

4.5.5 XBO: Attributes and Value Partitioning

The classes defined thus far alone cannot provide enough information for the XBO to be able to answer the CQs in Section 4.3. To overcome this weakness, the study took a step further and described the internal structure of the concepts in the XBO. Objects in the ontology were described using attributes (Horridge et al., 2004). Other words for attribute include quality, feature, property, characteristic, and modifier (Welty and Guarino, 2001). An attribute can be independent or dependent and, in this study, an attribute is defined as a characteristic of some entity (Noy and

McGuinness, 2001; Guarino, 1997; Guarino et al., 2009; Welty and Guarino, 2001). The relationship between entities in the XBO is determined by looking at the type of object and type of the attribute.

Some attributes have been defined in the XBO with the objective of specifying information on concepts. Attributes describe concepts that do not have enough strength to be an entity on their own, however, they are essential for one to comprehend the meaning of an entity. For example, attributes are vital in identifying or specifying the type of **Item** such as **Necklace**, **Bracelet**, **Armlet**, **Anklet**, **Waistband**, and **Headband** in the ontology. These attributes are also important in the XBO because they permit a filter to be created over the entities and can be used in queries so as to extract relevant information.

In this study, an attribute was regarded as a class and each attribute in the XBO is implemented as a class. Of the classes in the XBO 14 of them are defined as attributes. These classes are **Sex**, **Age**, **Colour**, **Decoration**, **BodyType**, **Material**, **Position**, **BodyRegion**, **Use**, **Rank**, **Quantity**, **Side**, **Size**, and **Tribe**. For each attribute, the class which the attribute described was determined and was attached to that particular class. According to Noy and McGuinness (2001), these attributes are attached to general classes that can have that attribute. For example, attributes **Size** and **Colour** are attached to the class **Item** because class **Item** is a general class whose individuals can have attributes **Size** and **Colour**. The classes belonging to class **ValuePartition** as represented in XBO are shown in Figure.4.6.

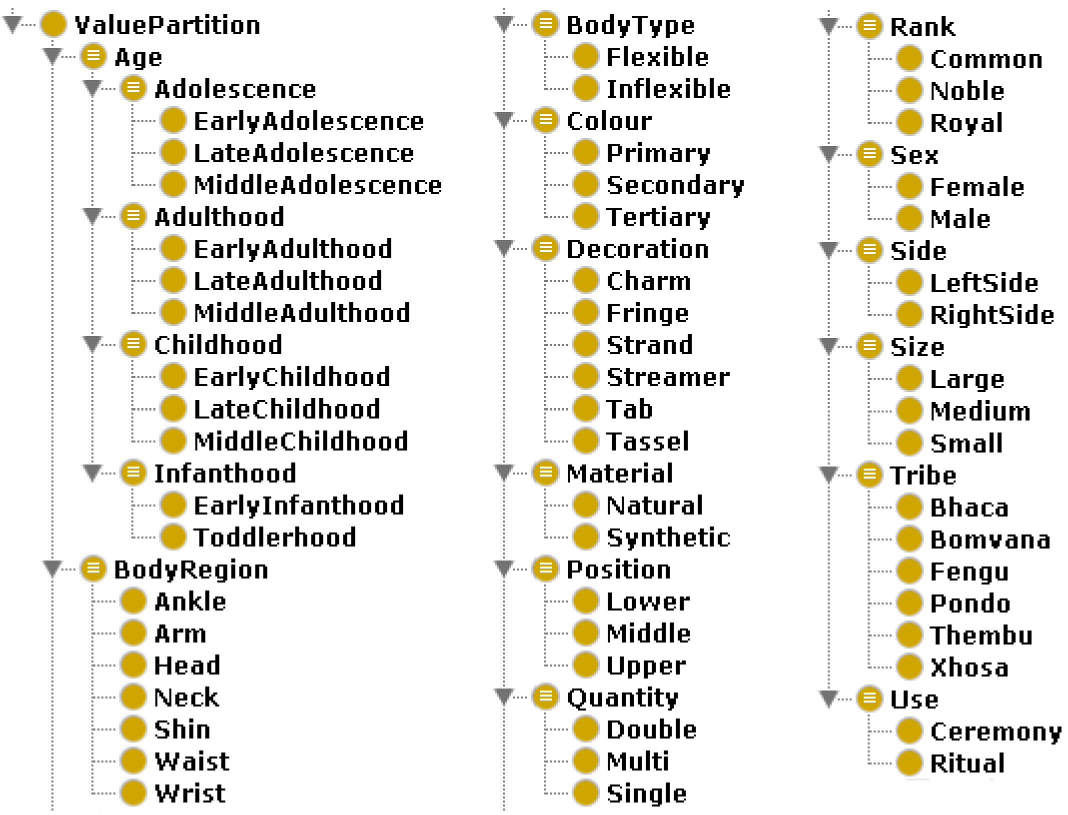


Figure 4.6: Asserted Class Hierarchy Displaying Classes comprising Class **ValuePartition**

There are different ontology design patterns to represent specified attributes such as those in Figure 4.6. They can be represented as enumerations of individuals or disjoint subclasses that partition the parent class denoting the characteristic (Rector, 2004). In this study, the latter approach was used in XBO. In that approach, a feature is regarded as a concept signifying a continuous space that is divided by values in a set of values. Values are subclasses partitioning a feature.

For example, in Figure 4.7 to model the various descriptive attributes in the XBO, the class representing the attribute was divided by a set of subclasses. These subclasses are pairwise disjoint and the covering axiom ensures coverage of the class representing the attribute by the subclasses. Thus, the disjunction of the child classes is equivalent to the parent class. This ontology design pattern is shown in Figure 4.7 as implemented in XBO and attribute **Size** is used as an example.

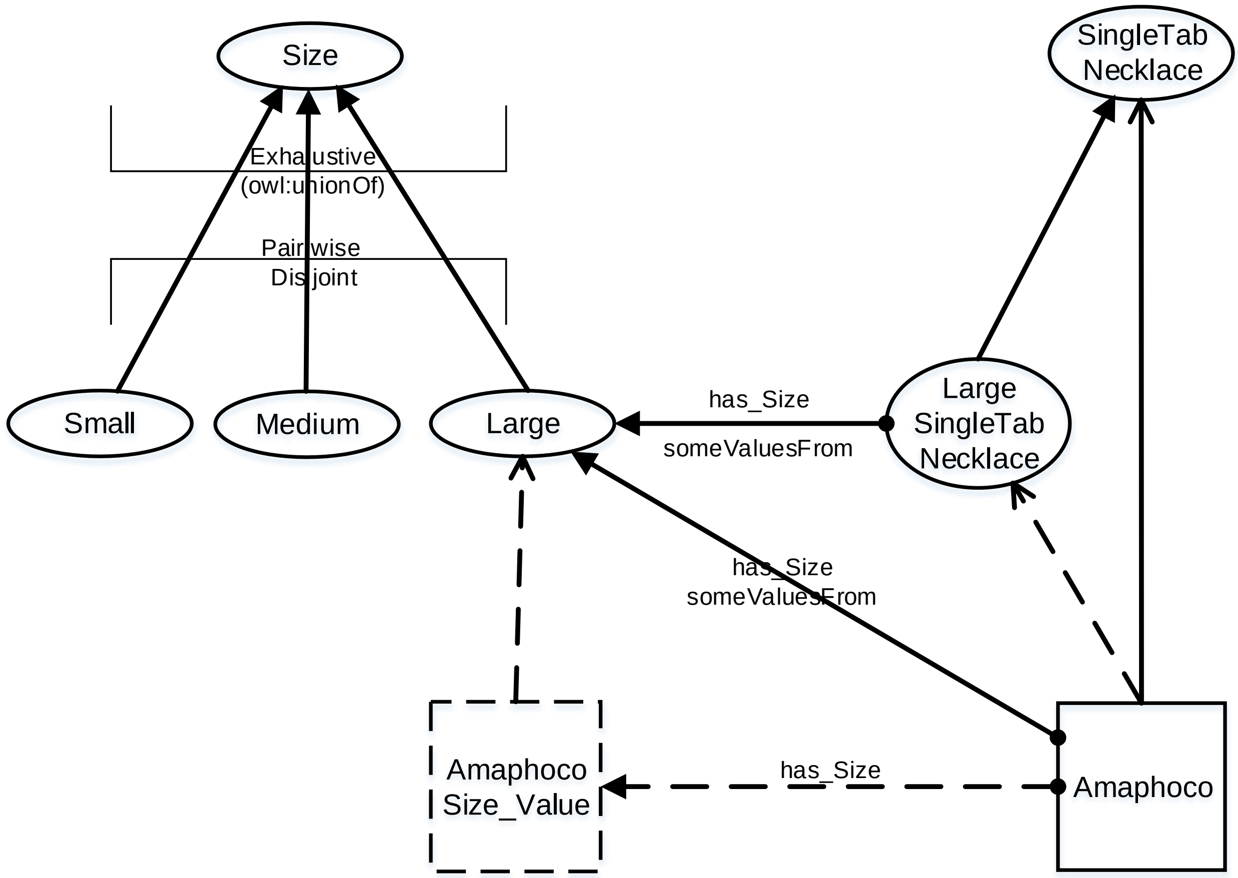


Figure 4.7: Value Partitioning: Values as Subclasses Partitioning Attribute **Size**

In Figure 4.7 a beadwork **Item** of type **SingleTabNecklace** is described by an attribute **Size** whose feature space is constrained to take on values **Small**, **Medium** and **Large**. Herein a feature space is defined as an array of values that an attribute can have (Welty and Guarino, 2001). In Figure 4.7 the subclasses **Small**, **Medium** and **Large** are the values partitioning the attribute class **Size**.

The classes **Small**, **Medium** and **Large** are axiomatised as disjoint, and they are subclasses of **Size**. Disjointness is important in ensuring that an individual of **Size** cannot be an individual of **Small** and an individual of **Large** at the same time. In addition, there is a covering axiom on class **Size** using the equivalence axiom with disjunction as declared in XBO. This is shown in Figure 4.8.

```
Class: Size
      EquivalentTo: (Small or Medium or Large)
```

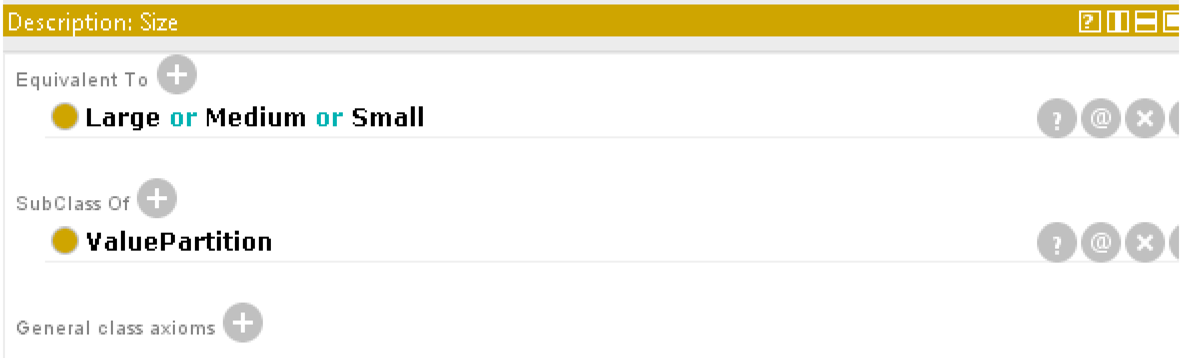


Figure 4.8 : Class Description Displaying the Subclasses Partitioning Attribute Class **Size**

In Figure 4.8 any instance of **Size** must be either **Small** or **Medium** or **Large** and there is no other kind of **Size**. The use of the equivalence axiom with the disjunction serve to cover the kinds of children class **Size** can have. Covering axioms are discussed in Section 4.5.7.

In Figure 4.7 **Amaphoco** is an individual. The class **LargeSingleTabNecklace** is the class of all those single tab necklaces that have a size in the **Large** partition. To say that the size of **Amaphoco** is large is to say that the individual size value of the instance **Amaphoco** is within the partition **Large** of attribute **Size**. There is a specific size value for the instance **Amaphoco**, but all that is stated (or known) about it is that somewhere in the **Large** partition of class **Size**.

To this effect, the individual size value for the instance **Amaphoco** is not explicitly created in the XBO. Instead, an existential restriction is used in which the existence of the individual size value for the instance **Amaphoco** is implied (or anonymous). So, **Amaphoco** is not only an individual of type **SingleTabNecklace** but also of type **(hasSize some Large)**. In Figure 4.7 this is shown by the box in dotted lines representing inferable information.

Such an ontology design pattern was used in the XBO because it is extensible. Since the XBO is based on NeOn and an iterative-incremental ontology development cycle subpartitioning or alternative partitioning of the feature space was implemented in the XBO to allow easy expansion of the ontology. For example, the **Large** partition in Figure 4.7 might be subdivided into **ExtraLarge** and **ExtraExtraLarge** or **ExtraExtraExtraLarge**, simply by subdividing the **Large** partition. Using this ontology design pattern alternative partitions can be created on the same feature. This allows easy modification and extension of the XBO**.**

4.5.6 XBO: Closing Down Descriptions using Covering and Closure Axioms

OWL has an open world assumption (Horridge et al., 2004; Wang et al., 2006). For example, in the XBO there are 6 subclasses namely, **Necklace**, **Bracelet**, **Armlet**,

Anklet, **Waistband**, and **Headband** of type **Item**. Unless the XBO and the automated reasoner are told that there can be no other subclasses of type **Item**, it is assumed that there can be. There is a need to constrain or close down the descriptions in the XBO in order to prevent unintended models in the XBO. This was done by describing the children of a particular class such class **Item** that there are these 6 subclasses the class **Item** can have and there are no others.

To close down on classes in the XBO covering and closure axioms were used. The covering axiom used in the XBO is made up of logical equivalence with disjunction. As an example, a covering axiom of such a form is depicted in Figure 4.9 on class **Item**.

```
Class: Item
EquivalentTo:
      (Anklet or Armlet or Bracelet or Headband or Necklace or Waistband)
```

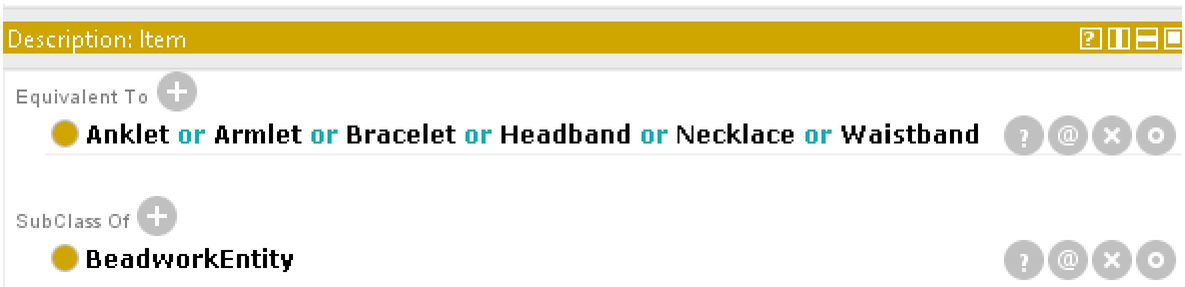


Figure 4.9 : Covering Axiom on Class **Item** and a Class Description View on of Class **Item** with a Covering Axiom

Figure 4.9 shows that being a member of the class **(Anklet or Armlet or Bracelet or Headband or Necklace or Waistband)** is sufficient to recognise an individual as a member of **Item**. As stated, before in Section 4.5.4 logical equivalence has a double implication. It works the other way around too. By saying an individual is of the class **Item** is enough to know that it is one of class **(Anklet or Armlet or Bracelet or Headband or Necklace or Waistband)**. Thus, class **Item** is covered by **(Anklet or Armlet or Bracelet or Headband or Necklace or Waistband)**.

The other classes in the XBO were closed down using the closure axiom. The closure axiom implemented by this study comprised logical equivalence and conjunction with universal quantification implied as shown in Figure 4.10 on class **Necklace**.

```
Class: Necklace
        EquivalentTo: Item and (wornAt some Neck)
```

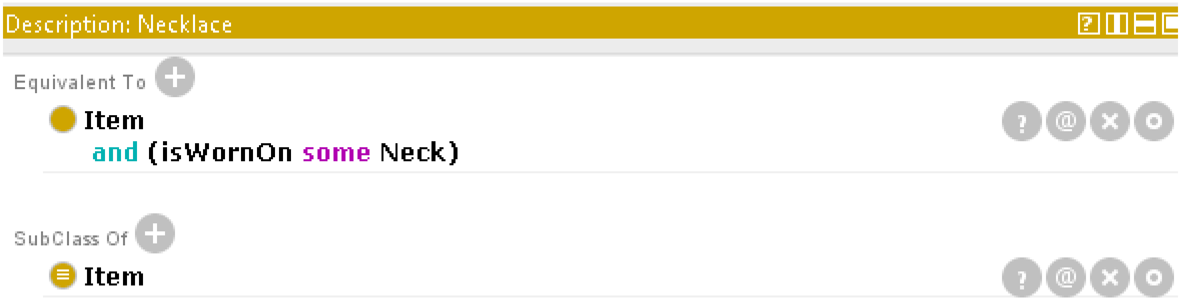


Figure 4.10: Closure Axiom for Class **Necklace** and Class Description View Displaying a Closure Axiom on Class **Necklace**

In the instance of Figure 4.10, the closure axiom is saying that a **Necklace** must be an **Item** that is worn at the **Neck** and that any **Item** worn at the **Neck** is recognised as a **Necklace**. Here using the universal quantification to close the description is implied in the axiom. As such an **Item** worn around the **Wrist** would not fit the description in Figure 4.10. Therefore, the description of class **Necklace** is closed down by the intersection of classes **Item and (wornAt some Neck)**.

Both the covering axiom and the closure axiom patterns shown in Figure 4.9 and Figure 4.10 were used where relevant in the XBO. In the XBO whether a class is covered or closed the reasoning outcome is the same. Through a covering or closure axiom, the XBO has an adequate and relevant definition of a concept. Of which without such axiomatization, unintended models would have been inferred. However, by having covering and closure axioms in the XBO unintended models are avoided.

4.5.7 XBO: Object Properties Definition

Up to this point the study has created primitive classes and defined classes including implementing subclass, disjoint, covering and closing axiomatization. However, more often than not, an ontological model is required to indicate how an individual connects to another individual and this is done through object properties. Object properties are also known as relationships. Typically, an object property is for specifying how an object is linked to another object in the ontology (Noy et al., 2003; Noy et al., 2001; Horridge et al., 2004). These object properties were central in describing the semantics of Xhosa Beadwork in the XBO.

Object properties are vital to the XBO for permitting either addition of data to a concept or linking various concepts or both. Xhosa Beadwork is a complex domain with a variety of concepts that follow diverse functions and comprise different features so it is essential to define various types of object properties. As a result, as shown in Table 4.2, a total of 20 object properties were identified as the main description pairs for the concepts defined in the XBO.

In XBO, object properties are used to query information, produce and discover new knowledge in order to improve the domain. For this reason, object properties are a central mechanism for modelling the domain of Xhosa Beadwork. The object properties defined in the XBO have been extracted under data analysis and thorough study of relationships provided by other ontologies like Servive (Vogiatzis et al., 2012), Falcon (Cho, 2016), and VetiVoc (Aimé et al., 2016) that support some of the concepts defined in the XBO. The name and corresponding description of each object property in the XBO are presented in Table 4.2.

Table 4.2 : Object Properties Definitions, their Names and associated Descriptions

Object Property	**Description**
isWornOn	Associates an **Item** with a particular place, location or region of the human body occupied by an **Item** as represented in **BodyRegion.**
hasColour	Relates an **Item** to the presence of **Colour** in the makeup or content of an **Item**.

hasDecoration	The **hasDecoration** property relates a specific elaborate design motif or feature or theme of **Decoration** to an **Item**.
hasBodyType	The **hasBodyType** relates **Item** to the type of body that the **Item** is equipped with as determined in the entity **ItemBody**.
hasMaterial	This relationship associates an **Item** to a type of underlying physical **Material** used to make or is incorporated in the **Item**.
hasPosition	Associates the **Item** with the recommended **Position** that denotes a point within some **BodyRegion** where the **Item** is intended to occupy or be placed or worn.
hasQuantity	Associates an **Item** with a unit of measure in **Quantity,** where **Quantity** is proportion or how much there is of an **Item**, **Colour** or **Material.** For example, this allows specifying that a certain **Quantity** is valid only for a certain **Item**.
hasSide	Relates an **Item** to the **Side** on which to put the **Item** relative to a centre or reference location such as the trunk of the human body.
hasSize	The **hasSize** associates **Item** to **Size,** where **Size** is the physical magnitude or dimensions used to represent an **Item**.

hasTribe	Associates an **Item** or **Person** to a **Tribe** representing a group or social division of people an **Item** or **Person** belongs to such as **Thembu**, **Pondo** or **Bomvana**.
hasUse	Relates an **Item** or **Person** to the appropriate or recommended category of **Use** for which the **Item** is intended.
hasRank	Relates a **Person** or **Item** to the appropriate type of rank or status held by a **Person** according to social classifications or structure defined in **Rank**.
hasSex	Links a **Person** or **Item** to the property values defining or describing **Sex**. A **Person** is linked to an instance of **Sex**. Each **Person** has single relationship to a **Sex** object.
hasAgeGroup	Relates a **Person** or **Item** and the required groups of **Age** associated with the use of the **Item**. This allows specifying that a certain **Person** or **Item** is valid only for a certain **Age** group.
isWornBy	Relates the **Item** to the recommended **Age** group or type of a **Person** whom the **Item** is considered suitable or allowed to adorn that Item**.**

Since object properties in Table 4.2 are responsible for linking concepts among them. The association is semantic, in that the concepts are connected using a particular transformation function with a particular collection of object property characteristics such as functional or transitive etcetera. In that regard, OWL permits object properties to be enhanced by the use of property characteristics. The various characteristics assigned to object properties in the XBO are shown in Table 4.3. Furthermore, in Table 4.3 an object property is presented with the property characteristic, domain, range and the name as applied in the XBO.

Table 4.3 : Object Properties and their Domains, Ranges and Characteristics

Object Property	**Domain**	**Range**	**Characteristic**
isWornOn	**Item**	**BodyRegion**	
hasColour	**Item**	**Colour**	**Functional**
hasDecoration	**Item**	**Decoration**	
hasBodyType	**Item**	**BodyType**	**Functional**
hasMaterial	**Item**	**Material**	
hasPosition	**Item**	**Position**	
hasQuantity	**Item**	**Quantity**	
hasSide	**Item**	**Side**	
hasSize	**Item**	**Size**	**Functional**
hasTribe	**DomainEntity**	**Tribe**	
hasUse	**Item**	**Use**	
hasRank	**DomainEntity**	**Rank**	
hasSex	**DomainEntity**	**Sex**	**Functional**
hasAgeGroup	**DomainEntity**	**Age**	
isWornBy	**Item**	**Person**	

In Figure 4.11 is the object property hierarchy is presented as declared in the XBO and displaying the **hasSex** object property as represented in the XBO. Such modelling of object properties with annotations, characteristics and description like on **hasSex** object property has been applied to all the XBO object properties.

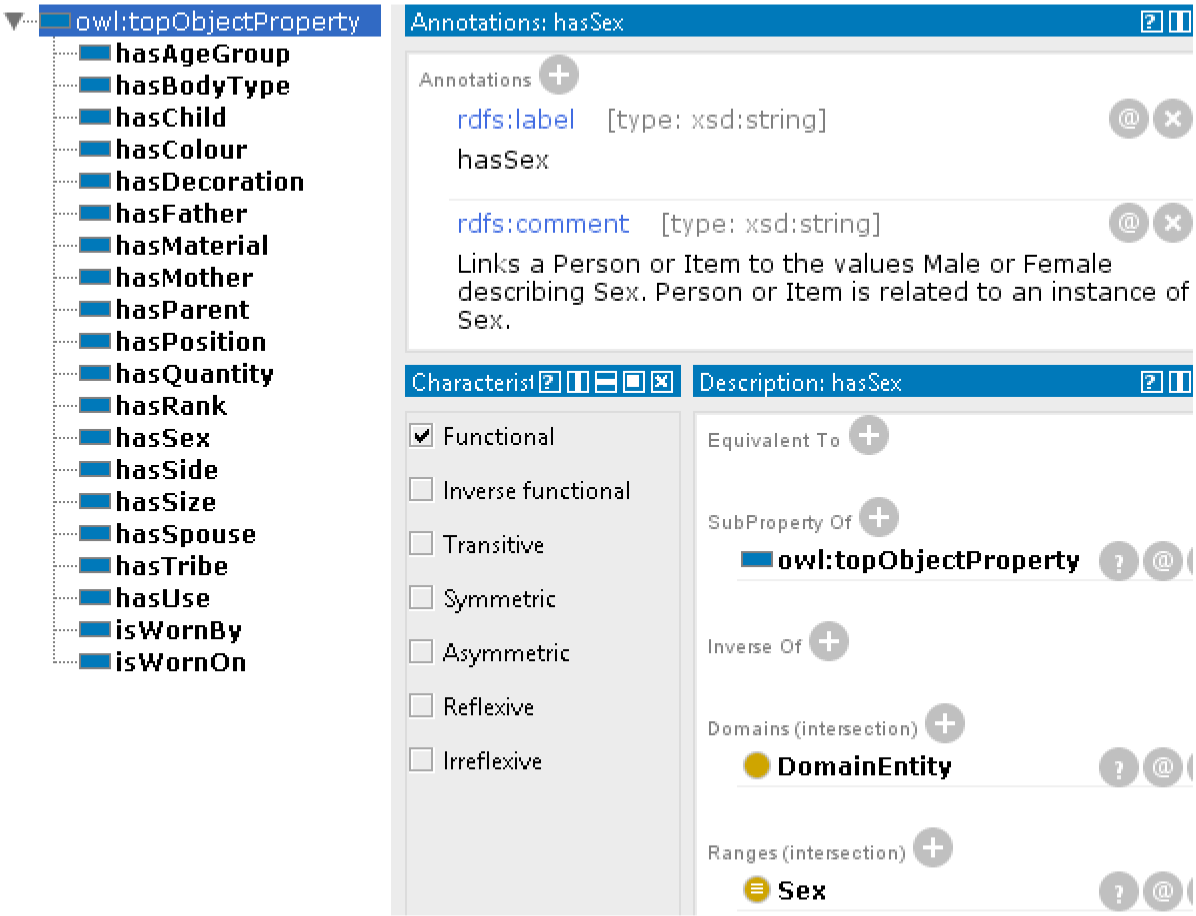


Figure 4.11: Object Property Hierarchy of the final XBO and Displaying Annotations, Characteristics and Description of **hasSex** Object Property

4.5.8 XBO: Data Properties Definition

XBO data properties are used to give a comprehensive definition of values for entity provenance. Data properties can be utilised in a query in order to obtain information regarding an **Item**, find an **Item** and more. XBO data properties are presented in Table 4.4 showing data property name, domain, type and range.

Table 4.4 : Data Properties Definitions with Domains, Data Types and Ranges

Data Property	Domain	Type	Range
placementRegion	**BodyRegion**	Datatype	xsd:string
itemColour	**Colour**	Datatype	xsd:string
itemDecoration	**Decoration**	Datatype	xsd:string
bodyType	**BodyType**	Datatype	xsd:string
materialType	**Material**	Datatype	xsd:string
placementPosition	**Position**	Datatype	xsd:string
itemQuantity	**Quantity**	Datatype	xsd:integer
placementSide	**Side**	Datatype	xsd:string
itemSize	**Size**	Datatype	xsd:double
ethnicTribe	**Tribe**	Datatype	xsd:string
itemUse	**Use**	Datatype	xsd:string
sexType	**Sex**	Datatype	xsd:string
ageGroup	**Age**	Datatype	xsd:integer
personType	**Person**	Datatype	xsd:string
socialRank	**SocialStatus**	Datatype	xsd:string
commonName	**Item**	Datatype	xsd:string
localName	**Item**	Datatype	xsd:string

There are 17 data properties created in the XBO. As depicted in Table 4.4 the data types used in the XBO are **xsd: string**, **xsd: integer** and **xsd: double**. The **xsd: string** is used to relate a resource or attribute or concept to a character string uniquely associated with an **Item** of beadwork. While on the other hand **xsd: integer** and **xsd: double** relates a resource to an integer, double or range of integers indicative of **Size**, **Quantity** or **Age** range appropriate for a beadwork **Item**. Also vital is to emphasize that information on object properties in Table 4.3 and data properties in Table 4.4 are presented in Appendix B. Figure 4.12 shows a snapshot from Protégé-OWL 5.5.0 of the data properties as asserted in XBO.

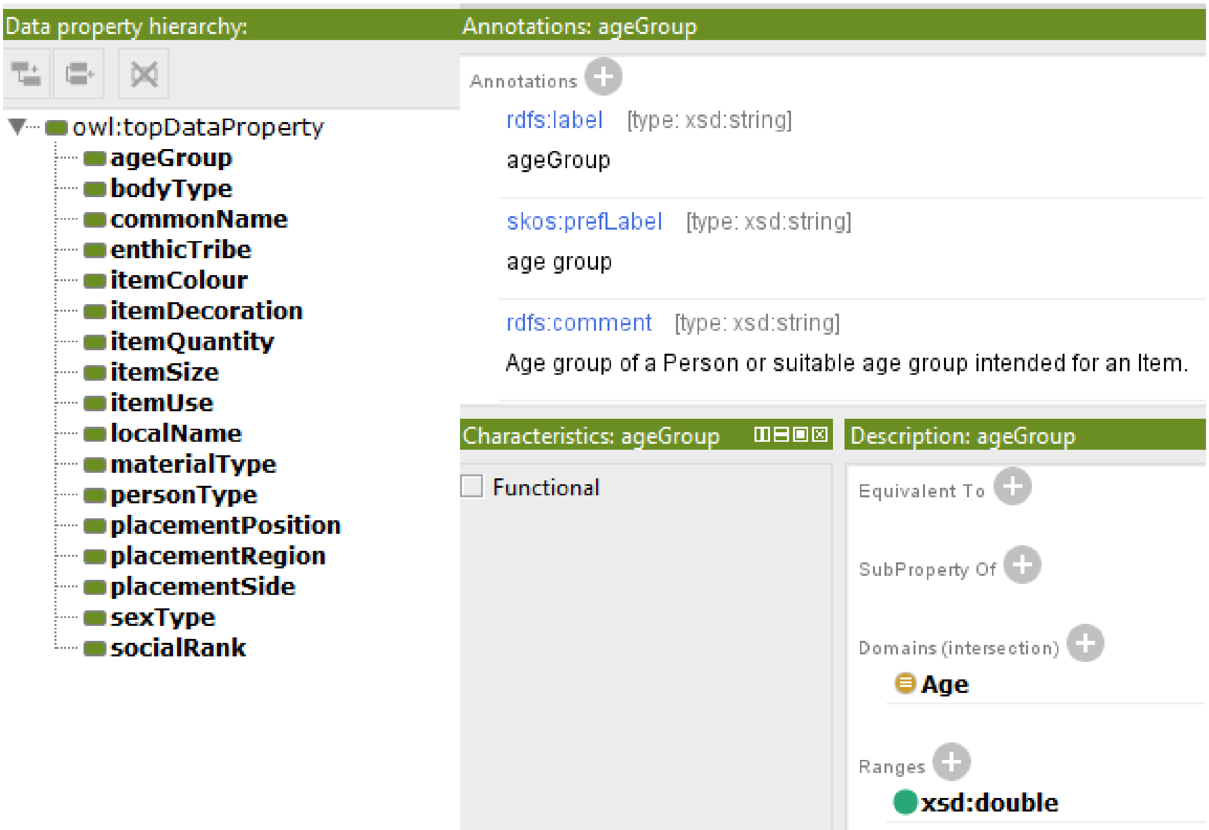


Figure 4.12: A snapshot of the Data Property Hierarchy and Displaying the Annotations, Characteristics and Description of Data Property **ageGroup**

In addition to using the predefined set of datatypes that are specified in the XML schema, the use of these built-in datatypes was further specialised in XBO. In the XBO restrictions on the possible values of a given type were specified for example specifying a range of values as shown in Figure 4.13. In that regard, by using the datatype property like **ageGroup** defined classes that specify a range of required values of **Age** for a given age group such as class **Adulthood** were created.

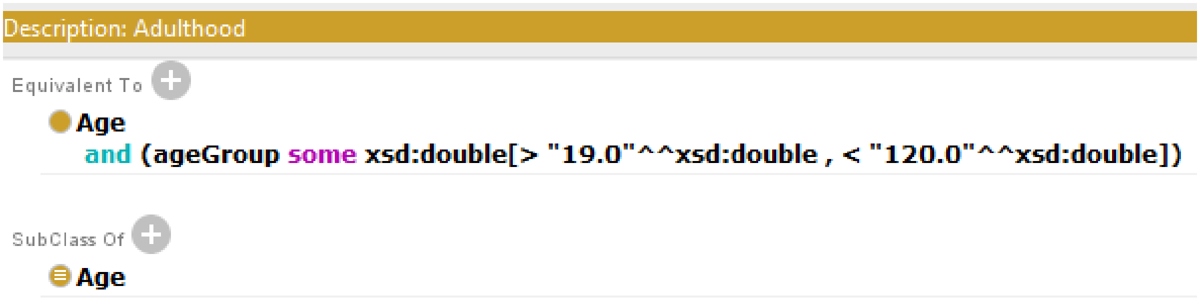


Figure 4.13: Using Datatype Restrictions to Define Ranges and Creating a Defined Class **Adulthood**

4.5.9 XBO: Annotation Properties

At this stage, the ontology is devoid of human-readable information to help people better understanding the XBO. To overcome that problem, the study used annotation properties. Annotations are the apparatus used to augment the understanding of the XBO. These properties permit meta-data information about ontological concepts to be added in the XBO. The importance of annotations properties in the ontology is in that they make the ontology more readable, accessible and interoperable within the Semantic Web (Hitzler et al., 2009a). XBO annotations were implemented with the intent of enhancing the understanding of the ontology and ontology elements through the use of descriptions in the ontology. In addition, labelling and commenting were added for the XBO to be understood in crawling contexts. Lastly, XBO annotations standardized the ontology to facilitate knowledge sharing.

These features were added based on defining the descriptions, labels and comments that improve each ontological resource in the XBO with meta-data information. In this aspect, to enrich what is contained in the XBO concepts and predicates from DC, SKOS and IANA Language Subtag Registry were also used.

4.5.9.1 XBO: Labels

Labels allow the addition of meaningful, human-readable information to individuals, classes, data and object properties of the ontology. Labels are viewed as meta-data within an ontology with the ability to connect the ontological model inside the Semantic Web through automatic understanding (Horridge et al., 2004). In XBO labels are utilised to describe a name for an ontology element with the purpose to give various tools the opportunity to read and understand the XBO.

In Figure 4.14 labelling in XBO has been implemented on classes, object and data properties. Annotations for individuals are also included in this ontological representation. To start with, SKOS was used as a formal language in XBO to support labelling. SKOS is a W3C recommendation that gives ontologies a standard approach to describe knowledge using the RDF (Miles et al., 2005; Miles and Bechhofer, 2009). Encoding information in RDF allows interoperability. As such using SKOS in this study was vital in allowing the XBO to be used in multiple distributed, decentralised and different metadata applications.

To that end, SKOS provided 4 standard properties in the XBO. These are **skos: prefLabel** and **skos: altLabel** and were utilized in the ontology to attach to concepts preferred and alternative lexical label respectively. In the direction of semantic relationships, the XBO used the **skos: broader** and **skos: narrower** from SKOS. In order to state a broad concept **skos: broader** was utilized whereas to declare a narrow concept **skos: narrower** was employed. Figure 4.14 exemplify a set of XBO classes organised within the hierarchy using the **skos: broader** and showing different translations using the **skos: altLabel**.

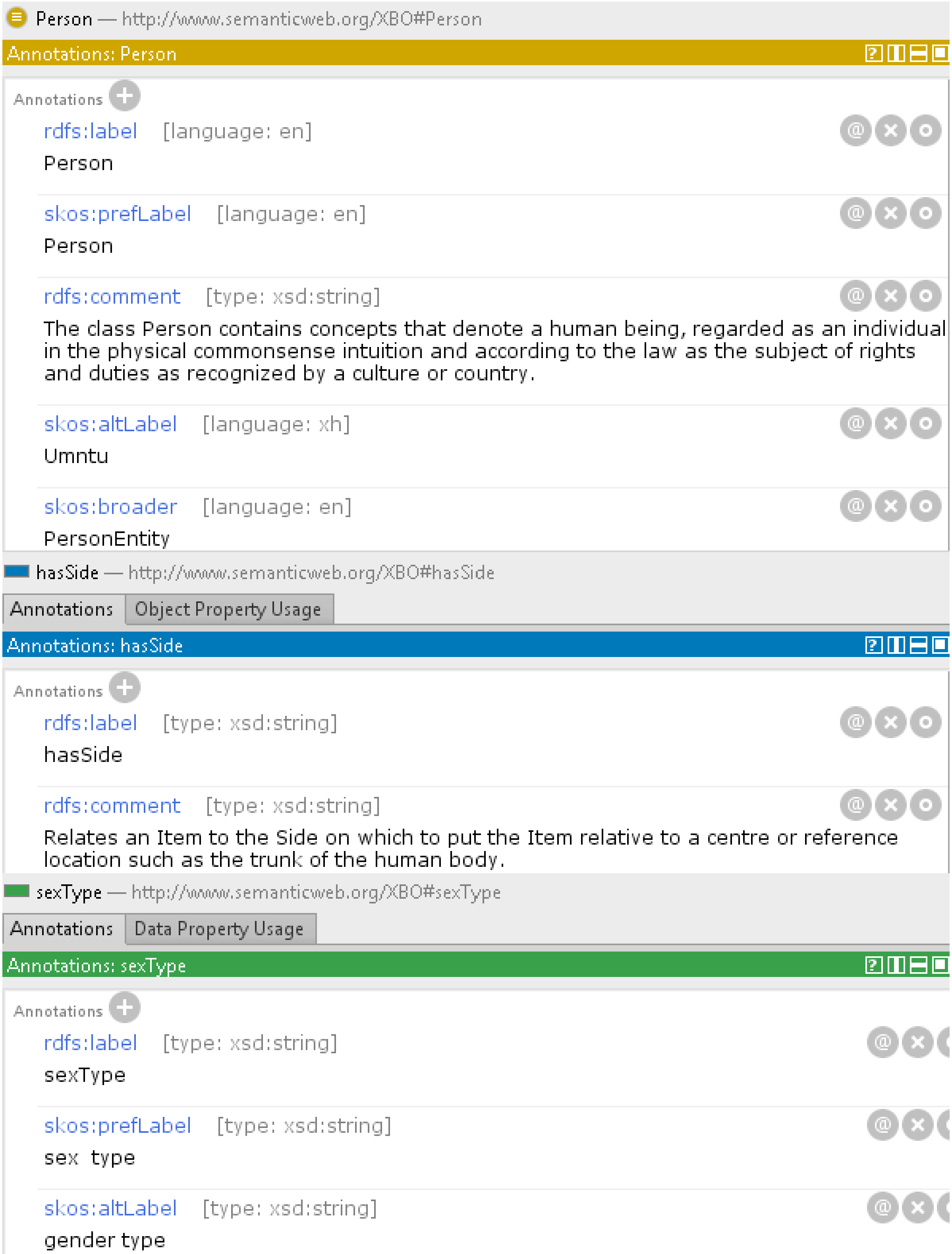


Figure 4.14: An Annotations View Displaying the SKOS and RDFS Label Annotations for Classes, Object and Data Properties

Furthermore, as shown in Figure 4.15 the XBO uses the standard IANA Language Subtag Registry to enhance multilingualism. The IANA Language Subtag Registry defines codes for use in forming subtags for the identification of languages (Phillips and Davis, 2009). This allowed the creation of subtags for each desired custom language in the XBO. The XBO implemented the **[xh]** subtag for the Xhosa language alongside the **[en]** subtag for the English language. For example, in Figure 4.15, there is only one ontological concept denoting **Sex**, but there are labels and comments using subtags **[xh]** and **[en]** that allow the concept **Sex** to be presented in both English language and Xhosa language in the ontology.

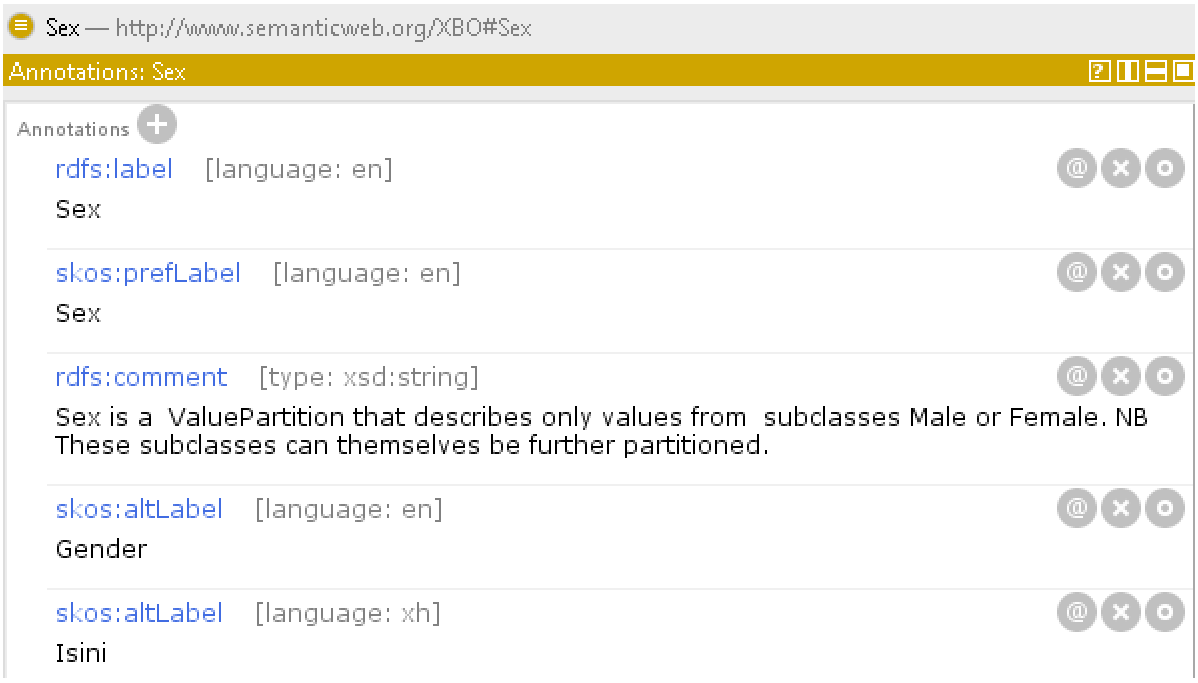


Figure 4.15 : An Annotations View Displaying the Language Subtags **[xh]** for Xhosa and **[en]** for English on Class **Sex**

4.5.9.2 XBO: Comments

The use of comments in an ontology promotes a better understanding of the elements in contained therein through using of natural language. Therefore, commenting provided additional information that supported the comprehension of resources defined in XBO. The comments were defined as a string. XBO comments as shown in Figure 4.16 were added on classes, individuals, data and object properties. Some instances have been defined in the XBO and corresponding comments on these instances are included in the XBO as well.

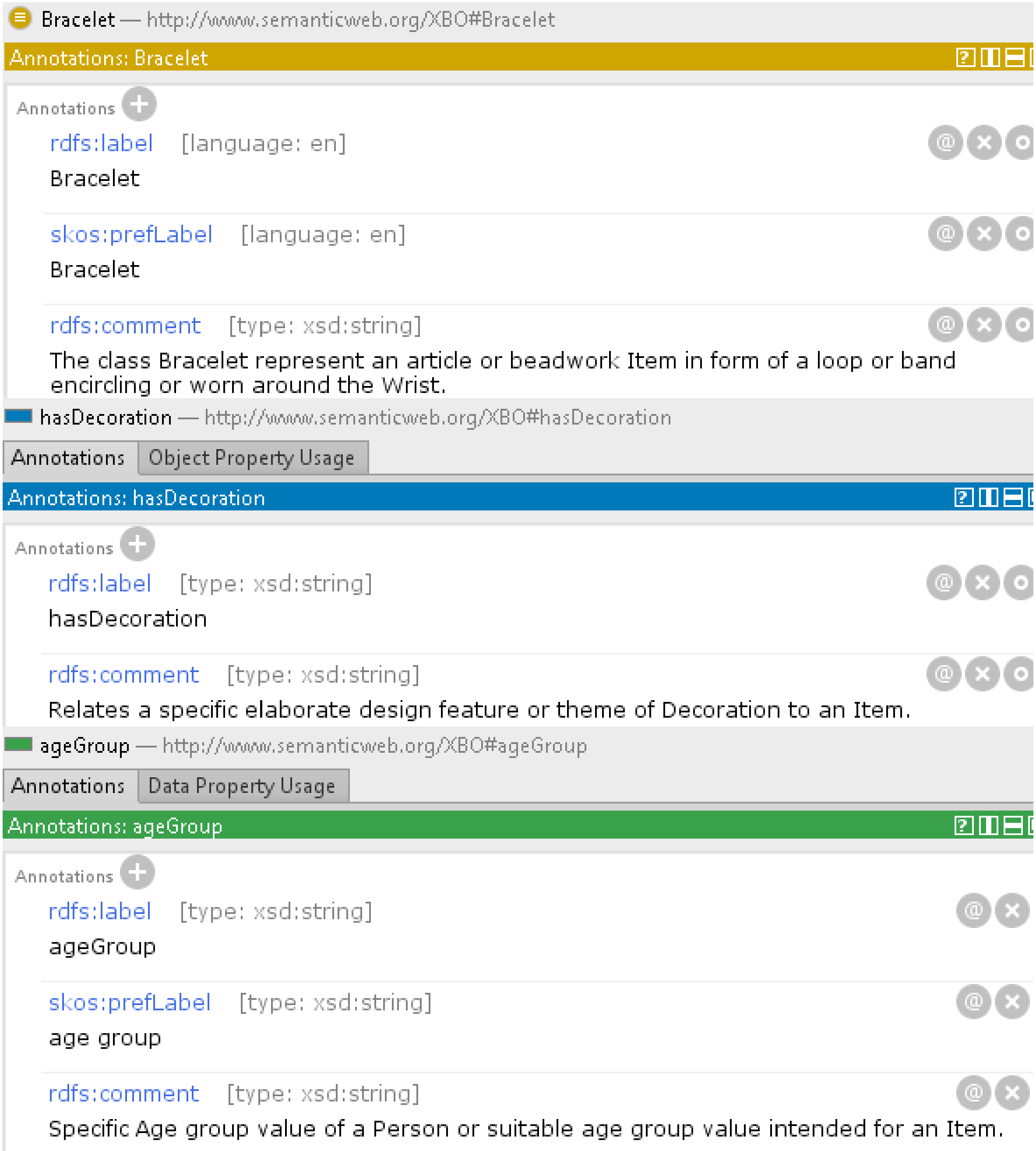


Figure 4.16 : An Annotations View Displaying the Comments Annotations on Classes, Object and Data Properties

The XBO is also standardized by the reuse of some upper-level metadata belonging to Dublin Core (DC) as shown in Figure 4.17. The DC specification is a collection annotation focussed on the discovery of resource and description of documents. These are significant for interoperability and resource description of the XBO. In this aspect, the following DC properties were used **dcterms: creator, dcterms: title** and **dcterms: date** to describe the XBO. This study used DC because it is not a huge ontology. This actually made DC a straightforward ontology to use. In view of the fact that DC terminology is weakly constrained, it allowed the study to redefine the terms internally in XBO without importing the whole model. As such, the study was able to make DC properties annotation properties, without violating compatibility with OWL 2.

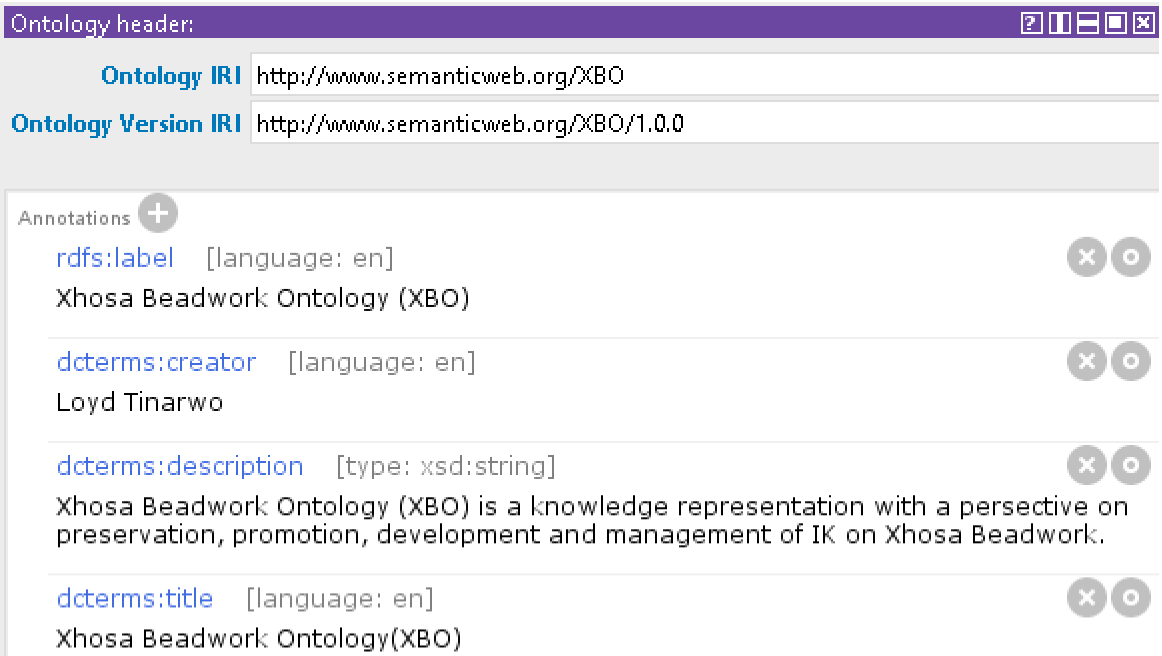


Figure 4.17: Ontology Annotations View Displaying the DC Annotations on the XBO

4.6 Conclusion

The chapter has discussed XBO development. An ontology development methodology called NeOn and the iterative-incremental ontology development cycle within the ambit of AR was applied as described in Section 3.4. NeOn methodology and the iterative-incremental development ontology cycle provided a structured approach to reach a coherent and comprehensive XBO. The scope, purpose, implementation, and requirements of the ontology have been highlighted in this chapter. Moreover, the chapter described the classes, properties and restriction definitions as implemented in the XBO. Due to the use of NeOn methodology and the iterative-incremental ontology development life cycle, the Xhosa Beadwork Taxonomy and Xhosa Beadwork Ontology were enhanced as necessary throughout the entire study. The enhancement corresponded to the incorporation of object properties, axioms, restrictions, data and annotation properties as needed in the XBO. The XBT organised taxonomical knowledge without losing specific knowledge of Xhosa Beadwork. This chapter described the ontological model that was developed hence addressing objective two of the study as stated in Section 1.2. Lastly, the XBO successfully demonstrated the practical relevance of ontologies in the codification IK in the domain of Xhosa Beadwork in the specific context of personal ornamentation beadwork. In the next chapter, the evaluation of XBO and the evaluation outcome are discussed.

Chapter 5: Evaluation and Results

In this chapter, the evaluation of the Xhosa Beadwork Ontology (XBO) is presented. The evaluation is centred on ascertaining the effectiveness of the XBO so as to find out whether the XBO is a comprehensive ontological model for Xhosa Beadwork and is of the required standard. The overarching evaluation approach applied to the ontology is portrayed in Section 5.1. Section 5.1.2.1 is devoted to logical consistency evaluation while structural evaluation is presented in Section 5.1.3.1. The evaluation of the functional dimension and the usability profiling dimension of the XBO are provided in Section 5.1.3.2 and Section 5.1.3.3 separately. Meanwhile, the comparison-based evaluation is the subject of Section 5.1.4, and the ontology documentation and publication are outlined in Section 5.3. Section 5.4 presents the conclusion of this chapter.

5.1 Implemented Evaluation Procedure

The study implemented a three-pronged (semi) automatic approach comprising of primary and secondary evaluation. In the first step, the logical consistency of the domain ontology is evaluated as shown in Figure 5.1. Logical consistency evaluation is confined to primary evaluation. The Pellet reasoning mechanism was utilised to evaluate the logical consistency of the XBO within Protégé-OWL modelling system (Sirin et al., 2007). According to Beißwanger (2013), this step is important because checking the logical consistency of OWL ontologies has become a standard approach in the Semantic Web.

In Figure 5.1 the diagrammatic representation of the evaluation procedure used in this study is depicted.

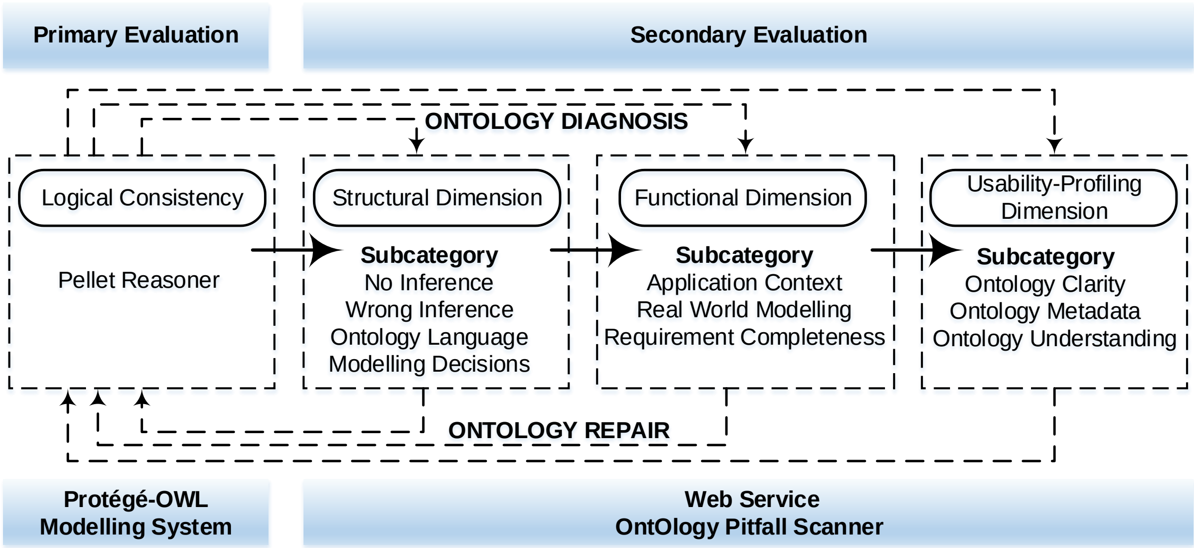


Figure 5.1: The Evaluation Procedure on XBO Source: (Tinarwo 2019:159)

The second step is a three-stepped approach based on checking the structural, functional and usability-profiling dimensions of the XBO. As shown in Figure 5.1, the second step is under secondary evaluation. The secondary evaluation of the ontology is implemented using the OOPS! (**O**nt**O**logy **P**itfall **S**canner) web service system. In addition, the second method is premised on ontology standard and guideline compliance (Beißwanger, 2013; Villalón and Pérez, 2016). In this second step, firstly, the structural dimension of the XBO was evaluated, followed by functional dimension evaluation and finally, the usability profiling dimension. The third step involves the comparison-based evaluation. Here the XBO was evaluated against gold standard ontologies. Within this step, the structural, functional and usability profiling dimensions of XBO are compared to those of the gold standard ontologies. This was accomplished according to the procedure established in the second step. In fact, the third step utilized the second step under secondary evaluation.

Within each dimension of the secondary evaluation, there are evaluation subcategories. In Figure 5.1, the structural dimension is comprised of evaluation of four subcategories. These are no inference, wrong inference, ontology language, and modelling decisions subcategories. The functional dimension consists of the application context, common-sense and requirement completeness subcategories (Poveda Villalón, 2016). Conversely, the usability-profiling dimension is made up of ontology clarity, ontology metadata, and ontology understanding subcategories.

Both primary and secondary evaluations are divided into diagnosis phase and repair phase. The diagnosis phase comprised of automatic diagnosis of anomalies in the XBO using Pellet and OOPS!. On the other hand, the repair phase was concerned with the manual repair of defects detected in the XBO. The repair phase is triggered by the diagnosis phase and it is where the anomalies detected in each dimension were fixed through human intervention. In addition, the set of results obtained from the diagnosis phase are divided and organised according to the evaluation categories namely, logical consistency, structural, functional and usability-profiling dimensions. Once each dimension of the XBO had gone through the diagnosis phase, it was followed by the repair phase. The diagnosis phase and repair phase were consecutively executed and then cyclically repeated guided by the iterative-incremental ontology development life cycle.

5.1.2 Primary Evaluation of XBO in Protégé-OWL

5.1.2.1 Logical Consistency

The primary evaluation of the XBO followed the approach presented in Figure 5.1. The logical consistency on XBO was accomplished by utilising an OWL reasoner inside the Protégé-OWL system. The study used an open-source Java based OWL reasoner called Pellet (Sirin et al., 2007). In this study, a reasoner is seen as a mechanism that understands knowledge implemented in the ontology (Sirin et al., 2007). Such a reasoning mechanism enabled the study to acquire new knowledge within the XBO. This OWL reasoner was also quite instrumental in permitting querying of the ontological knowledge in the XBO through navigating the entities by means of relationships between them.

Pellet enabled the study to check whether any of the explicit statements that have been made in the XBO were inconsistent, whether the classes had any individual and the computation of subsumption relationships in order to create a full classification of the XBO.

The process of checking the logical consistency of the XBO started with loading the ontology into Protégé-OWL. Then Pellet was invoked via the GUI of Protégé-OWL. Upon completing the reasoning process, Pellet constructed the inferred class hierarchy. As such the Pellet reasoner enabled the study to construct the inferred class hierarchy. For example, inconsistent or unsatisfiable classes were shown as subclasses of **owl: Nothing** in Protégé-OWL. This classification generated by Pellet was further subjected to analysis with the goal of identifying unsatisfiable classes. In the event that Pellet detected inconsistencies in the diagnosis phase, the ontology was revised under the repair phase. Upon completion of the repair phase, the Pellet reasoner would be rerun. This process was undertaken several times until results generated by Pellet showed no further inconsistencies. Only then was the ontology development continued. Consequently, the process was iterative and incremental.

Pellet was run on XBO and the current state of the ontology was found to be consistent as shown in Figure 5.2. The relationships and restrictions including the rules defined in the domain ontology allowed for the creation of a satisfiable state. In the regard, all the classes were classified and related according to logics in the XBO. The consistent state was achieved when the hierarchical decision tree classified all classes corresponding to its branch avoiding unsatisfiable classes. In other words, there were no classes found in the XBO classified under the class **owl: Nothing** as shown in Figure 5.2.

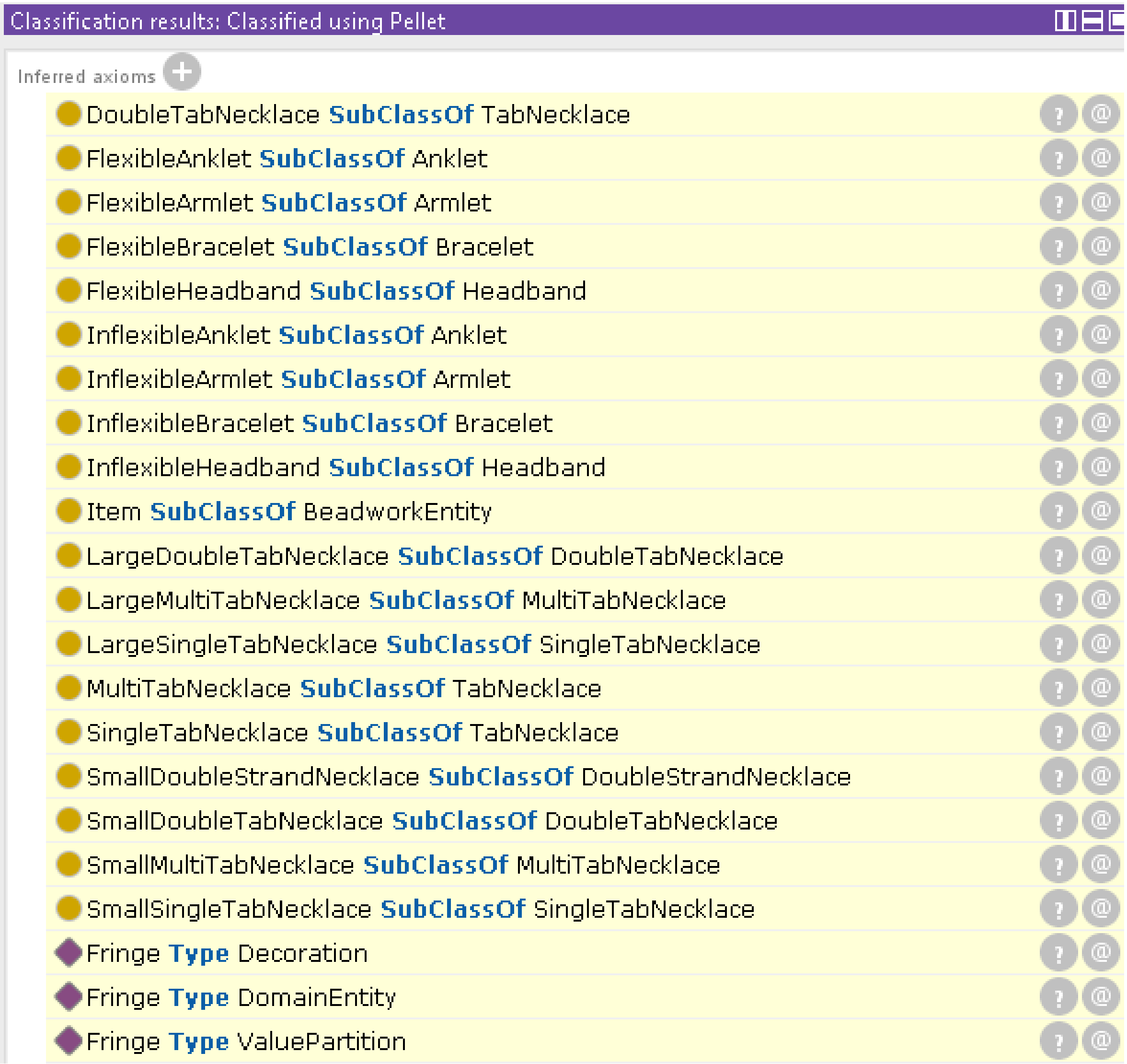


Figure 5.2: XBO Logical Consistency Check using Pellet

It is also important to state that the logical consistency evaluation was run throughout the development of the XBO. For example, during the implementation stage of the XBO in Chapter 4, the ontology was repeatedly classified and checked for logical consistency using Pellet. Unsatisfiable classes were corrected before the development of the XBO was continued.

As a result, the inclusion of logical consistency in the development of the XBO was crucial in discovering logical inconsistencies in the XBO. Such a measure allowed the study to get rid of inconsistencies and avoid their propagation in the XBO through corrective development under the repair phase. Although the XBO was checked for logical consistency by running Pellet the study deemed as necessary to subject the XBO to further evaluation. Since the logical consistency evaluation alone cannot entirely guarantee that the knowledge represented in the ontology is adequate. In order to further evaluate the XBO, an evaluation of the domain ontology was done using the secondary evaluation procedure as detailed next in Section 5.1.3.

5.1.3 Secondary Evaluation of XBO using OOPS!

As mentioned before, the secondary evaluation was focused on the structural, functional and user-profiling evaluation of the XBO using the evaluation approach highlighted in Section 5.2. The secondary evaluation was undertaken using OOPS! software. OOPS! is a web-based service whose main purpose is to scan for modelling anomalies (or pitfalls) in OWL ontologies. In this study, the ontology was uploaded via URL and RDF coding and OOPS! then scanned the ontology according to the dimension activated and informed about the entities the XBO that had anomalies (Poveda-Villalón et al., 2014; Villalón and Pérez, 2016).

As stated in Chapter 2 and 3 OOPS! : i) was run independent of modelling platform without being configured or installed; ii) functioned with the main web browsers; iii) had a large error catalogue than most of the recent and available tools such as XD Analyser and MoKi (Poveda-Villalón et al., 2014; Poveda-Villalón et al., 2012), and

iv) had a RESTful service for applications and a web-based interface. In addition, the system is not implemented as a plugin, as such, OOPS! use is not limited only to Protégé-OWL (Villalón and Pérez, 2016; Beißwanger, 2013).

To evaluate an ontology, OOPS! has a web UI consisting of a view where the URL or the ontology document can be input. When the ontology was entered, the diagnosis phase was initiated and the model was scanned for defects. When the diagnosis phase was finished, the evaluation outcome was displayed on OOPS! web UI listing all anomalies detected by OOPS!.

Based on the outcome of the diagnosis phase, corrective development was implemented on XBO and the correction is summarized under each evaluation category. As alluded to in Section 5.1, the structural dimension was the first category evaluated, followed by the functional dimension in the second and lastly the usability profiling dimension. A detailed discussion and explanation of the diagnosis phase and the repair phase for each evaluation category are presented in the following subsections.

5.1.3.1 XBO: Structural Dimension

The structural dimension is based on checking out the syntax and formal semantics of each of the ontological resources of the XBO. This dimension was the initial dimension to be evaluated according to the secondary evaluation procedure depicted in Figure 5.1. The structural dimension evaluation included (i) checking modelling decisions in order to see if the language primitives were correctly implemented in the ontology, (ii) examining the ontology for no inference in order to see whether expected information is not being inferred, (iii) wrong inference comprised of checking the ontology for inference of incorrect knowledge and (iv) ontology language involved evaluating the adherence of the ontology to the ontology language and syntax specification. Figure 5.3 shows the pitfalls under structural dimension in conjunction with their corresponding evaluation subcategories.

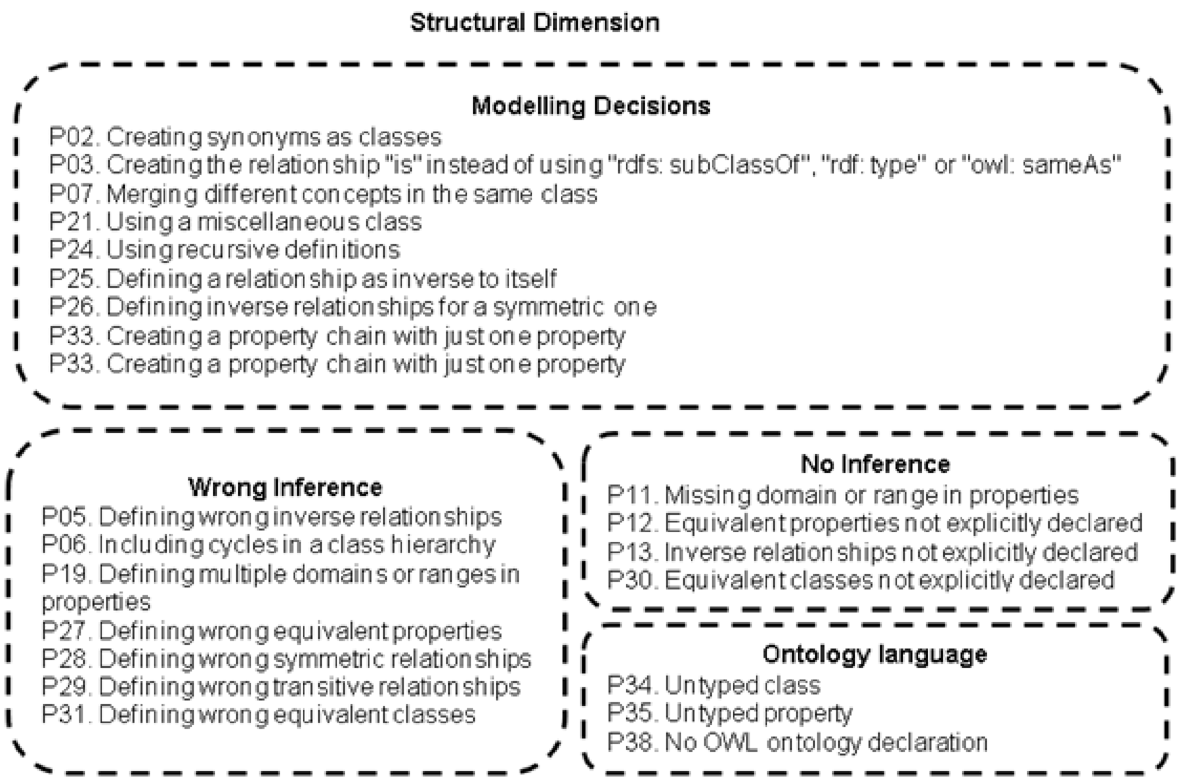
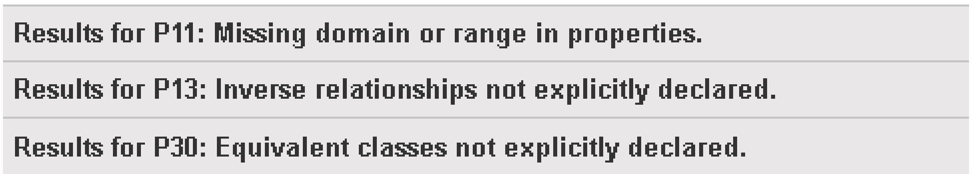


Figure 5.3: Pitfall Catalogue Checked under the Structural Dimension

The OOPS! online evaluation system was used to evaluate the structural dimension of the XBO. A total of 23 pitfalls were evaluated under the structural dimension. First, the ontology was entered using RDF coding on OOPS! website. The structural dimension was selected and the scanning procedure was activated. Then ontology was checked for structural anomalies under the subcategories of the structural dimension. Once the diagnosis was done, OOPS! generated a web page showing all the anomalies found in the ontology under structural dimension according to the evaluation subcategories. Figure 5.4 shows the web page generated by OOPS! listing which elements of the XBO were affected.


Results for P11: Missing domain or range in properties.

Results for P13: Inverse relationships not explicitly declared.

Results for P30: Equivalent classes not explicitly declared.

Figure 5.4: Structural Dimension Evaluation Results: Webpage Generated by OOPS!

In this context, OOPS! identified 19 object properties of XBO that were lacking domain and range as a case of P11. Object properties such as **hasQuantity** and **isWornBy** missed both domain and range. The explanation that can be given on the occurrence of P11 in XBO is due to conflicting ontology development philosophies regarding the declaration of domain and range on object properties. In literature, there are two dissenting views, on one hand, Horridge et al. (2004) school of thought disregard declaration of domain and ranges on object properties. On the other hand, Villalón and Pérez (2016) positively acknowledges and recommends a complete declaration of domain and ranges in OOPS!. The declaration of domain and ranges of object properties in XBO was informed by Horridge et al. (2004) which explains why P11 was detected in XBO. In fact, this led to a high occurrence of pitfall P11 in the XBO. Furthermore, OOPS! found 20 object properties in XBO, where inverse relationships were not explicitly defined as a case of **P13** (inverse relationships not explicitly declared). In addition, it identified classes **Side** and **Position** as cases of **P30** (equivalent classes not explicitly declared).

After diagnosis, the domain ontology was repaired based on the evaluation outcome generated by OOPS! as shown in Figure 5.4. To solve **P11** the domain and range were defined providing the object properties with complete definitions. For each object property in the XBO that did not have a domain defined, a general class whose instances could be used as a subject of the object property was declared as a domain of the property. For example, class **Item** was set as the domain of object property **hasQuantity**. In order to repair the range for each object property in the XBO that did not have a range defined, the general class in the XBO whose instances could be used as an object of the property was implemented as the range of the object property. In this instance, class **Quantity**, for example, was set as the range of the object property **hasQuantity.**

The inverse relationships in XBO that were a case **P13** (inverse relationships not explicitly declared) were fixed. For example, **isTribeOf** was defined as the inverse of the **hasTribe** object property. As a consequence, the XBO could now assert that any resource in the XBO that is the subject or object (respectively) can be inferred to also have that class. All the missing domain or range anomalies on the object properties in the XBO were repaired. This included fixing the anomalies on object properties where the inverse relationships were not asserted. However, the definition of the inverse relationships was done on all other object properties apart from symmetric object properties and object properties that were created for an n-ary relationship.

To resolve P30 (equivalent classes not explicitly declared), classes **Side** and **Position** were reviewed and it turned out that both were not equivalent. While class **Side** is needed for the representation of an aspect to the right or left with reference to the trunk of the human body, the class **Position** is required because it introduces the point or position that should be occupied by a beadwork item. Both classes are required in XBO and are not stated as equivalent. However, classes **Side** and **Position** were provided with explicit definitions to avoid misinterpretation. During the repairing phase, Pellet was repeatedly run. Upon completion, Pellet classified XBO as consistent. Furthermore, after repairing the XBO OOPS! was rerun and there were no anomalies found under the structural dimension.

On the overall, the structural dimension evaluation revealed a 14% occurrence of anomalies in XBO. The ontology did not adhere to the structural dimension category on P11, P13, and P30. These 3 pitfalls are contained in no inference evaluation subcategory. As already mentioned, these anomalies were fixed during the ontology repair phase and were successfully implemented in the XBO. However, a larger percentage of 86% of the XBO conformed to the structural dimension recommendations. The modelling decision, wrong inference, and ontology language subcategories complied with structural dimension. In addition, the pitfall scanning tool OOPS! was capable of detecting various types of modelling errors during the diagnosis phase (P11, P13, and P30). This indicates that OOPS! was effective in detecting structural anomalies and assisted in revising the development of the XBO as explained under the repair phase.

5.1.3.2 XBO: Functional Dimension

The main goal of the functional dimension was evaluating the use context of the XBO (Gangemi et al., 2006). The functional dimension is associated with the use of the ontology and of its function in a context. Thus, the evaluation was focused on the conceptualisation specified by the XBO. The subcategories that were evaluated within this dimension are: (i) checking the real world modelling or common-sense dimension; (ii) validating the requirement completeness of the ontology (iii) and checking the application context of the ontology whether the ontology is adequate for an application context (Villalón and Pérez, 2016). The functional dimension of the XBO was evaluated second according to the secondary evaluation procedure described in Section 5.1. The evaluation subcategories checked under the functional dimension are depicted together with their corresponding pitfall catalogues in Figure 5.5.

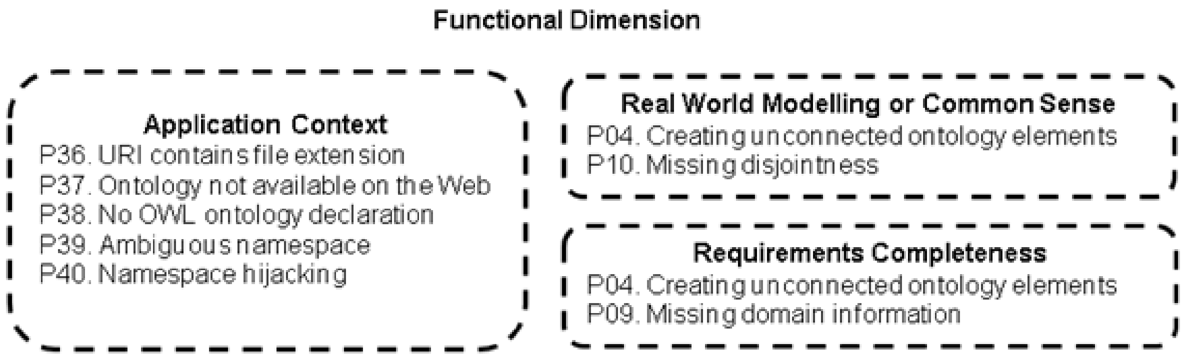


Figure 5.5: Evaluation Subcategories with Corresponding Pitfalls Checked under Functional Dimension

As depicted in Figure 5.5, the functional dimension comprised of checking 9 pitfalls under three evaluation subcategories. Again, OOPS! web service was used to evaluate the functional dimension of the XBO. The ontology was loaded into OOPS! using the URI method on OOPS! website. The functional dimension was chosen including all three subcategories and then the diagnosis on the XBO was activated. On finishing the diagnosis, OOPS! generated a webpage with the outcome of functional anomalies detected in each evaluation subcategory including the element affected. Figure 5.6 shows the results of functional dimension evaluation on XBO as generated by OOPS!.


Results for P36: URI contains file extension.
Results for P37: Ontology not available on the Web.

Figure 5.6: Functional Dimension Evaluation Results: Webpage Generated by OOPS!

In evaluating the functional dimension of the XBO, OOPS! identified the ontology as a case of P36 and P37. Both P36 and P37 are under the application context evaluation subcategory of the functional dimension. Pitfall P36 occurred because a file extension was included in the URI assigned to the ontology. In fact, XBO contained the file extension**. owl** in the ontology declaration header. On the other hand, the evaluation result on P37 revealed that the ontology source code or its documentation was not on the Web when OOPS! scanned for the XBO URI.

The ontology was then subsequently revised in order to fix P36 and P37 under the ontology repair phase. In terms of solving P36, the ontology URI was renamed excluding the file extension**. owl**. To fix pitfall P37 the XBO was uploaded on GitHub repository and was published using GitHub and OnToology. This is detailed further under ontology documentation and publication in Section 5.3. After each anomaly was repaired Pellet and OOPS! were rerun each time and the XBO was found consistent and without anomalies under the functional dimension.

In summary, the functional dimension evaluation revealed that XBO did not have anomalies detected under the real-world modelling or commonsense and requirement completeness evaluation subcategories. However, OOPS! detected P36 and P37 both under the application context evaluation subcategory. This constituted a 22% occurrence of the pitfalls in XBO under functional dimension. As stated, before in this section P36 and P37 were successfully repaired during the ontology repair phase. On the overall, the evaluation revealed that 78% of the pitfall catalogue under functional dimension has been implemented as recommended in the XBO.

5.1.3.3 XBO: Usability - Profiling Dimension

Usability-profiling category was used to evaluate the XBO from the communication context point of view (Villalón and Pérez, 2016; Poveda Villalón, 2016; Gangemi et al., 2006). The usability profiling dimension is based on the profile of the ontology, which addresses the communication context of the ontology. As such the following aspects were evaluated under the subcategories of this dimension: (i) evaluation of information that can help one understand the ontology content (ontology understanding); (ii) examining ontology clarity as to whether the properties of the elements of the ontology are identifiable and understandable (ontology clarity); (iii) and checking the information that can assist understanding the ontology context besides the conceptualisation defined (ontology metadata) (Villalón and Pérez, 2016). The evaluation subcategories under the usability profiling dimension are presented in Figure 5.7 including the relevant pitfalls under each evaluation subcategory.

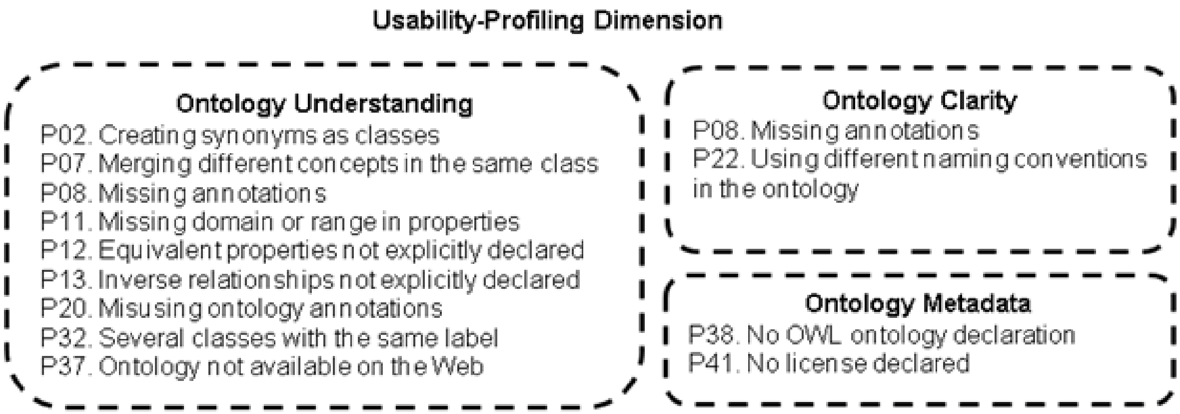


Figure 5.7: Pitfalls Checked under the Usability Profiling Dimension

Usability-profiling dimension was the third dimension of the XBO to be evaluated using the evaluation process highlighted in Section 5.1. In total 13 pitfalls were checked under usability profiling dimension and the pitfalls were computed with the help of the OOPS! web service. In this case, the XBO was loaded into OOPS! through RDF coding on OOPS! website. The usability-profiling dimension was selected and then the diagnosis phase was initiated on the ontology. In turn, XBO was scanned for anomalies under all the evaluation subcategories of the usability profiling dimension. Once the diagnosis phase was completed, OOPS! software generated a web page showing the evaluation results on each of the evaluation subcategories under usability profiling dimension. The results are shown in Figure 5.8 alongside the description of the pitfall and components of the XBO that were affected.

Results for P08: Missing annotations.
Results for P41: No license declared.
Results for P37: Ontology not available on the Web.

Figure 5.8: Results of the Usability Profiling Evaluation on XBO Web Page Generated using OOPS!

OOPS! identified 3 types of anomalies in this dimension. These are P08 under ontology clarity, P37 under ontology understanding and P41 under the ontology metadata subcategory. OOPS! identified 186 classes and relations of XBO that did not have annotations as a case of P08 (missing annotations) ontology clarity subcategory. OOPS! detected that 79 of the classes had no **rdfs: label** and rdfs**: comment** annotation defined on classes such as **SingleStrandNecklace**. Furthermore, OOPS! identified that 91 classes and 16 data properties lacked an **rdfs: comment** annotation. The occurrence of P08 in XBO can be attributed to the fact that OOPS! does not recognise alternative annotations such as SKOS annotations. A large percentage of the classes were annotated using SKOS. As result, this led to a high occurrence of P08. Furthermore, OOPS! identified that the ontology was missing on the Web as a case of P37. In the context of ontology metadata subcategory, OOPS! detected that the XBO lacked a statement stating the information license applicable to the ontology as a case of P41 (no licence declared).

The errors detected in the diagnosis phase were then fixed in the ontology repair phase. In order to solve the lack of annotations in the XBO, the classes and data properties identified in Figure 5.8 were provided with the label annotation properties using **rdfs: label** to augment the SKOS annotations such as **skos: prefLabel** and **skos: altLabel.** As such terms that identified the classes and those that identified the data properties were added. Furthermore, the description annotation properties were added using **rdfs: comment** to repair the missing natural language definitions of ontology elements as shown in Figure 5.9.

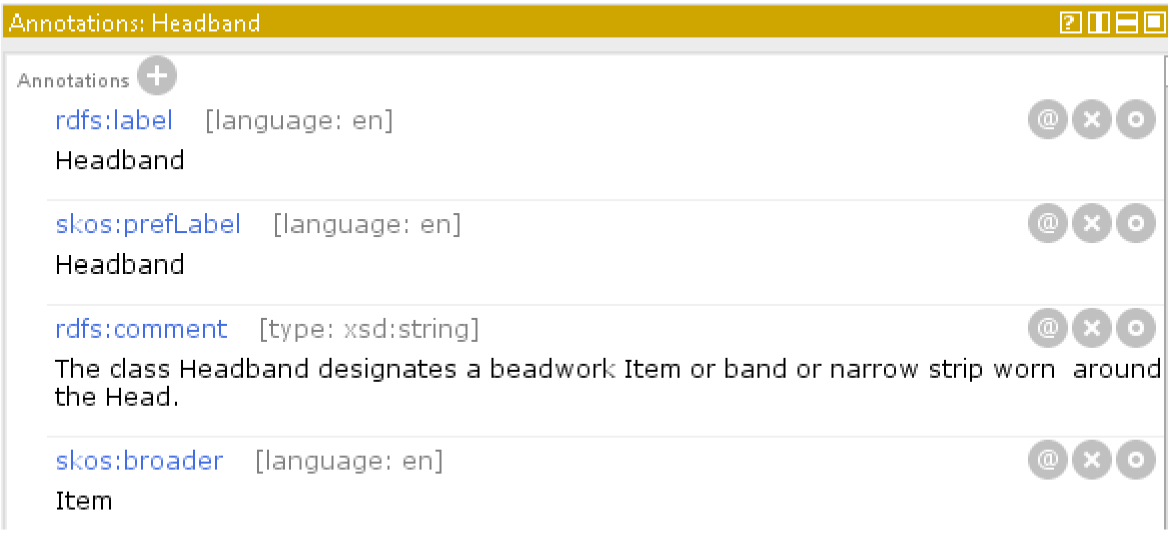


Figure 5.9: Class **Headband rdfs: label, skos: prefLabel and rdfs: comment**

In terms of rectifying the case of P37, the XBO was uploaded on GitHub repository and was published using GitHub and OnToology. This is detailed further under ontology documentation and publication in Section 5.3. As a final point, to solve P41 (no licence declared) a statement containing the license information was added on

XBO header using the **dcterms: license** metadata annotation as shown in Figure 5.10.

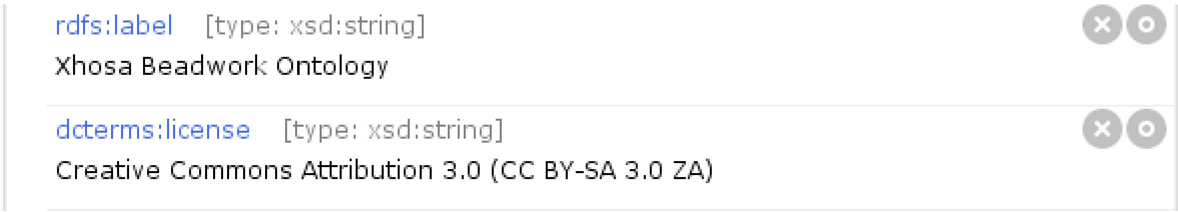


Figure 5.10: Ontology Annotation View Displaying the XBO Licence Added

As result, the anomalies detected by OOPS! in the ontology under usability-profiling dimension were repaired. These anomalies were found under the ontology understanding, ontology clarity and ontology metadata evaluation subcategories. It is also worth to mention that the XBO was checked using OWL reasoner Pellet each time the XBO was repaired under the usability-profiling dimension. Upon concluding the repairing phase, OOPS! software was rerun on XBO for the last time and no anomalies were detected under the usability profiling category. The ontology understanding, ontology clarity, and ontology metadata were successfully implemented in the XBO.

In conclusion, the evaluation of the XBO under the usability-profiling showed that to a large extent 77% of the XBO conformed to the usability-profiling dimension. However, a percentage of pitfall occurrence of 23% revealed that XBO, to a lesser extent did not adhere to the usability-profiling dimension. The 23% was recorded on pitfall P08, P37, and P41. The ontology was revised and these anomalies were solved and properly implemented in the XBO during the repair phase. Although

OOPS! was able to detect anomalies under usability-profiling dimension the structural pattern matching method in OOPS! was not able to scan for other annotation properties that were utilised in the XBO. For example, **skos: prefLabel** and **dcterms: description**.

5.1.4 Comparison of XBO to Gold Standard Ontologies

The XBO was evaluated against existing gold standard ontologies. There are two major advantages to the comparison-based approach. Firstly, the evaluation can be run automatically, and secondly, the evaluation can easily be repeated. However, Xhosa Beadwork is a domain in which ontological background knowledge is scant and therefore, standard ontologies are missing. As a consequence, the standard ontologies used for the comparative evaluation against the XBO are based on different subject domains and were randomly selected. The secondary evaluation procedure described in Section 5.1.3 was applied.

The selected standard ontologies that were used for the comparison evaluation are DOLCE and GoodRelations (GR). These ontologies were selected based on that they are existing, well-known and stable. As such, they were considered mature in the sense of being utilised in multiple ontology-based systems and whose development team had sufficient experience of ontology development. Besides the fact that these ontologies are actively used and maintained, they were chosen based on the thematic scope and formal rigor.

The evaluation was carried out as outlined in Section 5.1 and Section 5.1.3 within the OOPS! environment. The evaluation of the XBO against these two gold standard ontologies was assessed based on three criteria: structural, functional and usability profiling evaluation. The study used the OWL version of each ontology. The three ontologies XBO, DOLCE, and GR were uploaded on OOPS! website one at a time. All the three ontologies were then scanned for the prevalence of anomalies in all three dimensions, one at a time using OOPS!.

Once the diagnosis phase was done, OOPS! software generated a webpage of results for each ontology listing the pitfalls prevalent in each ontology according to each evaluation category. The webpage also listed how many times each detected pitfall appeared in the ontology and which features of the ontology were affected. The data was accumulated based on the OOPS! outcome. The data was analysed by calculating the: (i) percentage of pitfall occurrence and (ii) comparison of the percentages of pitfall occurrence among XBO, DOLCE, and GR within each evaluation dimension. For the three ontologies, the percentages under each evaluation category were then collated into 3D clustered column graphs.

5.1.4.1 Structural Dimension : XBO, XGR, DOLCE

In Figure 5.11, the XBO was compared to DOLCE and GoodRelations (GR) under the structural dimension evaluation category. As stated previously, in Section 5.1.3.1, the structural dimension is comprised of three subcategories, which are modelling decisions, wrong inference, ontology language, and no inference. The comparison of the three ontologies was against a catalogue of 23 pitfalls in total as defined the under structural dimension.

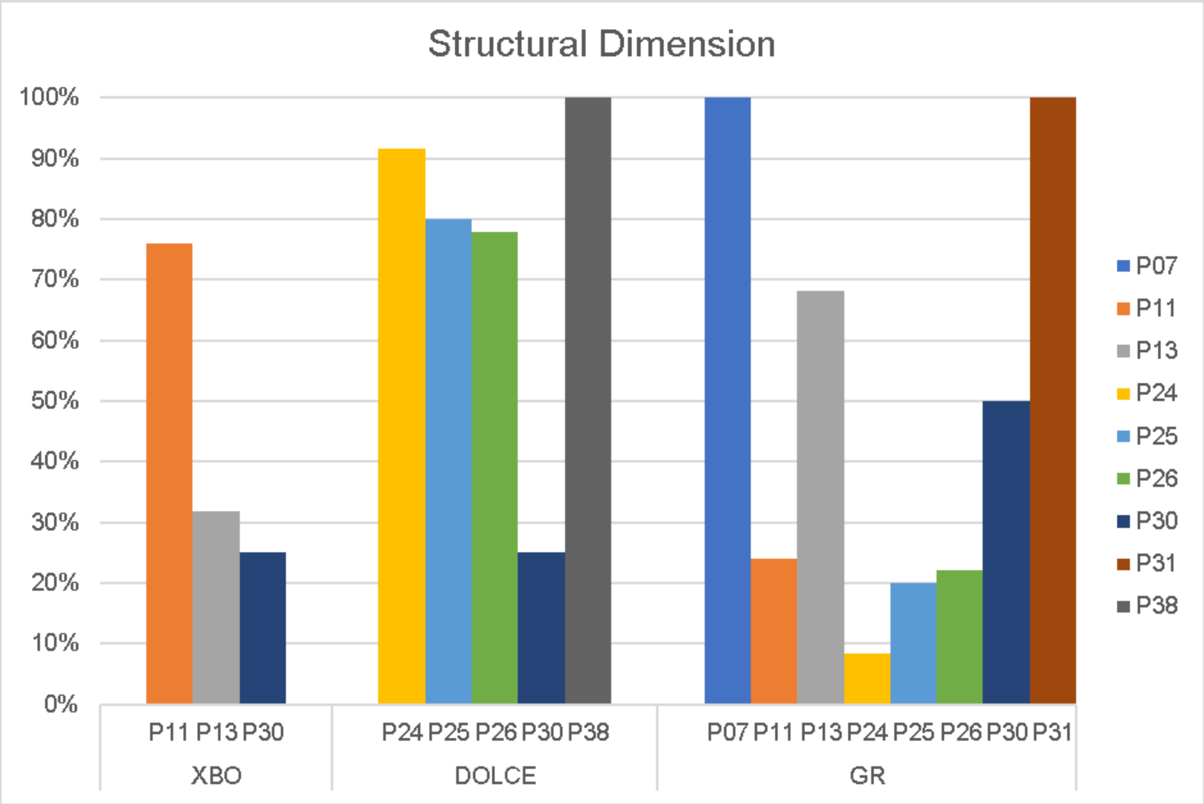


Figure 5. 11: Structural Dimension: Incidence of Pitfall Occurrence in XBO, DOLCE and GR

As shown in Figure 5.11, the structural dimension evaluation revealed that GR had a 23% occurrence of P11 on properties that had no domain or range. XBO scored 77% occurrence on the same pitfall, while DOLCE had a 0% occurrence of properties without a domain or range. As alluded to earlier in Section 5.1.3.1, the reason for such a high percentage on P11 in XBO was because on one hand domain and ranges were not completely declared on object properties as recommended by Horridge et al. (2004). The structural pattern matching detection method in OOPS!

(Villalón and Pérez, 2016) expected both domain and range on an object property to be defined in XBO. Thus, a high percentage of occurrence on P11 in XBO. With regard to P13 (inverse relationships not explicitly declared), XBO had a 32% occurrence of P13 in its relationships and a 68% occurrence was recorded in GR. DOLCE had 0% incidence of P13. P30 (equivalent classes not explicitly declared) revealed that GR had a 50% incidence of P30. On the same pitfall, XBO and DOLCE had a 25% occurrence meaning a lesser percentage of occurrence than GR. Furthermore, GR recorded a 100% incidence of pitfall P07 while XBO and DOLCE had 0% incidence of classes that merged different concepts in the same class.

The result on P24 showed on the ontology element level a 92% incidence of P24 in DOLCE while GR had 8% and XBO scored a 0% occurrence of P24. On pitfall P24 XBO outperformed DOLCE and GR. The result on pitfall P25 (defining a relationship an inverse of itself) revealed a high percentage of occurrence of 80% on relations in DOLCE. On the same pitfall, GR had a 20% prevalence of P25 while XBO had the lowest percentage of occurrence of 0% on P25. The incidence of pitfall P26 in DOLCE was 78%, GR had 22% while XBO had a 0% occurrence on P26.

Pitfall P30 revealed that there was a 50% occurrence of P30 in DOLCE and a 25% occurrence in GR on classes that did not have the definition of equivalent classes. Similarly, XBO had a 25% occurrence of pitfall P30 whereas DOLCE scored a higher percentage of 50%. P31 (defining wrong equivalent classes) revealed a 100% incidence of P31 in GR ontology. This showed that some of GR classes had been defined as equivalent when they were not equivalent. XBO and DOLCE had a 0% occurrence of P31 in their vocabularies. This outcome revealed that XBO outperformed the golden standard ontology GR. Regarding P38 (no OWL ontology declaration) DOLCE lacked OWL ontology declaration required to provide ontology metadata. As result, DOLCE had a 100% prevalence of pitfall P38 while both XBO and GR had a 0% incidence of P38. This meant that OWL ontology declarations were provided as recommended in XBO and DOLCE and not in GR.

A comparison of the overall percentages of occurrence of pitfalls under structural dimension for XBO with DOLCE and GR revealed a 13% for XBO, 22% for DOLCE and 35% for GR. XBO had the lowest percentage of pitfall occurrence under structural dimension in comparison to DOLCE and GR. In conclusion under the structural dimension, results indicate that XBO outperformed both DOLCE and GR. However, the outcome also revealed areas in XBO that needed revision such as P11 on properties that did not have a domain or range, P13 (inverse relationships not explicitly declared) and P30.

5.1.4.2 Functional Dimension : XBO, GR, DOLCE

To evaluate the functional dimension of XBO against that of DOLCE and GR the evaluation procedure described in Section 5.1.3 was applied. The functional dimension evaluation was undertaken on the three ontologies against a catalogue of 9 pitfalls spread over three evaluation subcategories. These subcategories are application context, real-world modelling and requirements completeness. The results of functional dimension evaluation on XBO, DOLCE and GR are shown in Figure 5.12 using a 3D clustered graph.

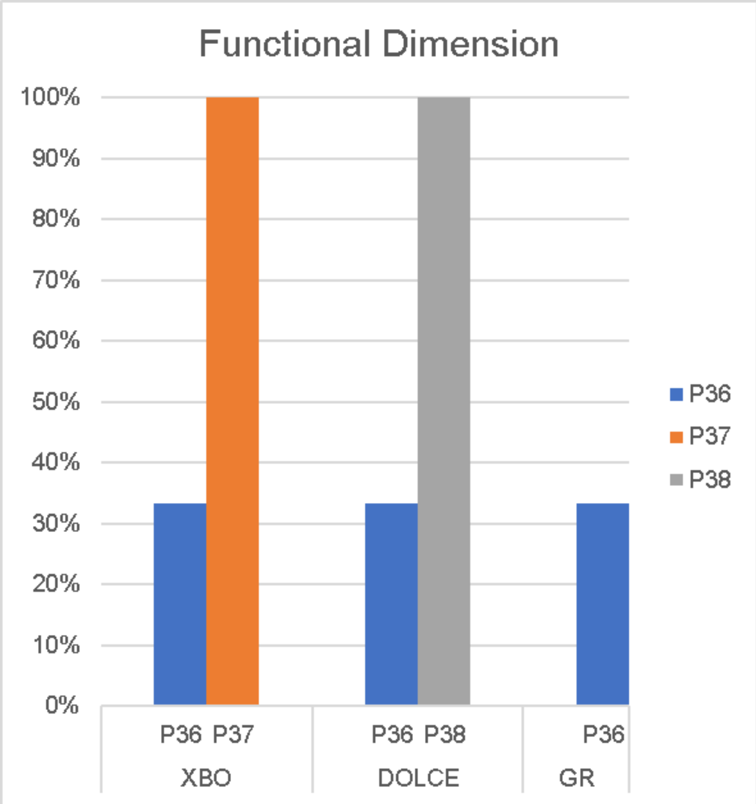


Figure 5.12: Functional Dimension: Incidence of Pitfall Occurrence in XBO, DOLCE and GR

The percentage of occurrence of pitfall P36 (URI contains file extensions) in XBO, DOLCE, and GR was 33%. The result revealed that on the application context level all three ontologies had each a file extension**. owl** included in the ontology URI. In other words, XBO had the same percentage of occurrence on pitfall P36 as the established ontologies DOLCE and GR. XBO had a 100% occurrence of pitfall P37 (ontology not on the web) whereas DOLCE and GR had 0% occurrence of P37. Furthermore, DOLCE had no OWL ontology declaration specified and this resulted in a 100% occurrence of pitfall P38 (no owl ontology declaration). On the other hand, ontologies XBO and GR both had a 0% incidence of P38. In this regard, XBO outperformed DOLCE.

With respect to the overall percentages of incidence of pitfalls in the functional dimension evaluation category, XBO and DOLCE both scored 22%, and GR had 11%. XBO was outperformed by GR but had the same percentage of pitfall occurrence as DOLCE. In addition, XBO did not have occurrences of anomalies under real-world modelling and requirements completeness subcategories as was the case with DOLCE and GR. All three ontologies had a prevalence of defects in the application context subcategory. The outcome demonstrated that the function dimension of XBO is competitive in comparison to standard ontologies DOLCE and GR. However, the results indicate that there is a need for revision and enhancement of the XBO on P37. The revision of XBO regarding P37 is the subject of Section 5.3.

5.1.4.3 Usability - Profiling Dimension : XBO, GR, DOLCE

The usability-profiling evaluation of the XBO with the standard ontologies DOLCE and GR was undertaken following the secondary evaluation procedure presented in Section 5.1.3. The adherence of XBO, DOLCE, and GR to recommended usability-profiling dimension was evaluated, alongside a catalogue of 13 pitfalls under three subcategories. The three evaluation subcategories are ontology understanding, clarity, and metadata. The percentages of pitfall occurrence under usability profiling dimension on XBO, DOLCE and GR are included in Figure 5.13.

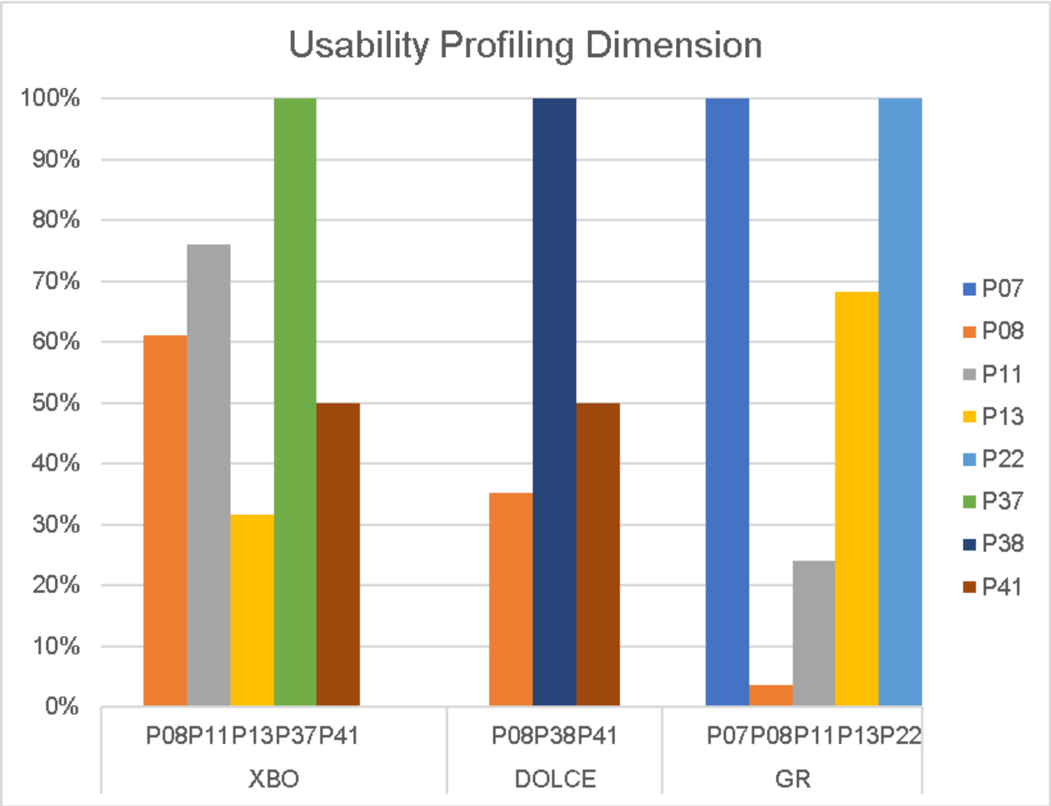


Figure 5.13: Usability Profiling Dimension: Incidence of Pitfall Occurrence in XBO, DOLCE and GR

GR had a 100% occurrence on pitfall P07 with different concepts merged in one same class. Pitfall P07 is contained under the ontology understanding subcategory. Both XBO and DOLCE had no different concepts mixed up in a single class. As such, they had a score of 0% occurrence on pitfall P07. At annotation level, the outcome on P08 (missing annotations) revealed that ontology elements in XBO had a 61% occurrence of pitfall P08. This meant that they had no human-readable annotation attached. DOLCE had a 34% incidence of P11 and GR had a 4% prevalence of P08 on ontology elements that lacked annotation properties that labelled them.

Such a high percentage of occurrence on P08 (missing annotations) in XBO can be attributed to the fact that the structural pattern matching detection method in OOPS! only recognises elements that have an **rdfs: label** or **rdfs: comment** annotation. However, OOPS! was not able to identify annotations that were represented by alternate properties, such as **skos: altLabel** in XBO. This contributed to a high percentage of occurrence on P08 in XBO as explained in depth in Section 5.1.3.3.

The result on P11 revealed a 76% occurrence on object properties in XBO that did not have a domain or range defined. GR had a 24% incidence of P11 whilst DOLCE had the lowest percentage of incidence on P11 of 0%. The high percentage of occurrence of 76% on P11 achieved by XBO can be attributed to the development approach espoused by Horridge et al. (2004) as already mentioned under Section 5.1.3.1. Furthermore, P13 (inverse relationships not explicitly declared) revealed a 32% occurrence of P13 in XBO. This was because some of the inverse relationships were not defined within the ontology. GR had 68% and DOLCE had 0% occurrence of pitfall P13. XBO outperformed GR and both were outperformed by DOLCE.

The outcome of P22 regarding usage of different naming conventions in an ontology revealed that GR had a 100% occurrence of P22. Ontologies DOLCE and XBO had no prevalence of P22. As such XBO had the lowest percentage of 0% on P22 together with DOLCE. Both XBO and DOLCE outperformed GR on pitfall P22. In addition, XBO had a 100% occurrence of pitfall P37 (ontology not on the web) while DOLCE and GR had a 0% occurrence on the same pitfall. Also, a 100% occurrence of pitfall P38 (no OWL ontology declaration) was recorded on DOLCE. This was because DOLCE did not have an **owl: Ontology** tag for metadata about the ontology declared. XBO and GR had a 0% prevalence of P38. XBO together with GR outperformed DOLCE on P38. The result on P41 (no license declared) showed that XBO and DOLCE did not contain licence information applicable to the ontology. As a consequence, XBO and DOLCE had each a 50% incidence of P41 whilst GR had 0% occurrence of pitfall P41. GR outperformed XBO and DOLCE on P41.

The comparison of the percentage of occurrence of a pitfall under usability profiling dimension for the XBO with DOLCE and GR revealed that on the overall DOLCE had a lower percentage of 23%, followed by GR with 31% and 38% for XBO. In general, the XBO was outperformed by DOLCE and GR. A possible explanation for such an outcome might be the growing usage of DOLCE and GR in real-world applications that might have pushed up their usability-profiling dimension development, unlike XBO. In addition, DOLCE and GR have been stable and actively maintained for a longer period. Hence, they have a mature usability profiling dimension.

Another possible explanation for this finding can be attributed to the high percentages achieved on P08 and P11. On P08 OOPS! failed to detect annotations represented using **skos: prefLabel** and **skos: altLabel** in XBO. On pitfall P11, object properties in XBO were not completely declared as recommended by Horridge et al. (2004). As a consequence, this contributed to a high overall percentage on XBO in comparison to DOLCE and GR. However, the percentage achieved by XBO is still within the competitive range and not far from that achieved by DOLCE and GR.

In addition, with respect to subcategory evaluation, XBO outperformed DOLCE under the ontology metadata subcategory. On the other hand, the outcome led to the discovery that there was a need to revise the usability profiling dimension of the XBO on P08, P11, P13, P37, and P41. The comparison-based evaluation revealed the unexpected conclusion that in some instances gold standard ontologies had a higher prevalence of modelling anomalies than XBO. As such XBO was at the least competitive in comparison with the selected standard ontologies DOLCE and GR.

5.3 Ontology Documentation and Publication

This section is focused on (a) documentation of the XBO into a human understandable and readable resource and (b) publication and sharing of the XBO within the Semantic Web. There are at least three valid reasons for doing such a task. Firstly, publication permits sharing and reuse of knowledge. Only published knowledge resources can be reused and expanded. Secondly, the publication and reuse guarantee perpetuity of the resource even after the research on the ontology has culminated. Thirdly, the more often a knowledge resource is used and reused, the more feedback can be expected on the resource. According to Pease et al. (2002), such feedback is important in order to maintain and improve the knowledge resource.

As discussed previously, the XBO was revised and enhanced through corrective development according to the outcomes of each evaluation category. At this stage, the evaluation of the XBO has been completed and the XBO was deemed ample for documentation and publication. In order to convert the XBO into a readable

HyperText Markup Language document (HTML), the ontology was converted into HTML using Live OWL Documentation Environment (LODE) web service (Peroni et al., 2012). LODE was used in this study because LODE is an open source software that can be used without the need for installation.

Before the ontology was uploaded on LODE the XBO was documented using ontology metadata. The ontology annotations have the ontology title, a summary description, links to other external resources, the names of ontology creators and information about the license etcetera. This metadata is intended to support the retrieval and usage of ontologies (Beißwanger, 2013). Documentation of this nature is also there to assist users in assessing the appropriateness of ontology for their application. For the representation of metadata annotations in XBO, the annotation properties from the Dublin Core were used as shown in Figure 5.14.

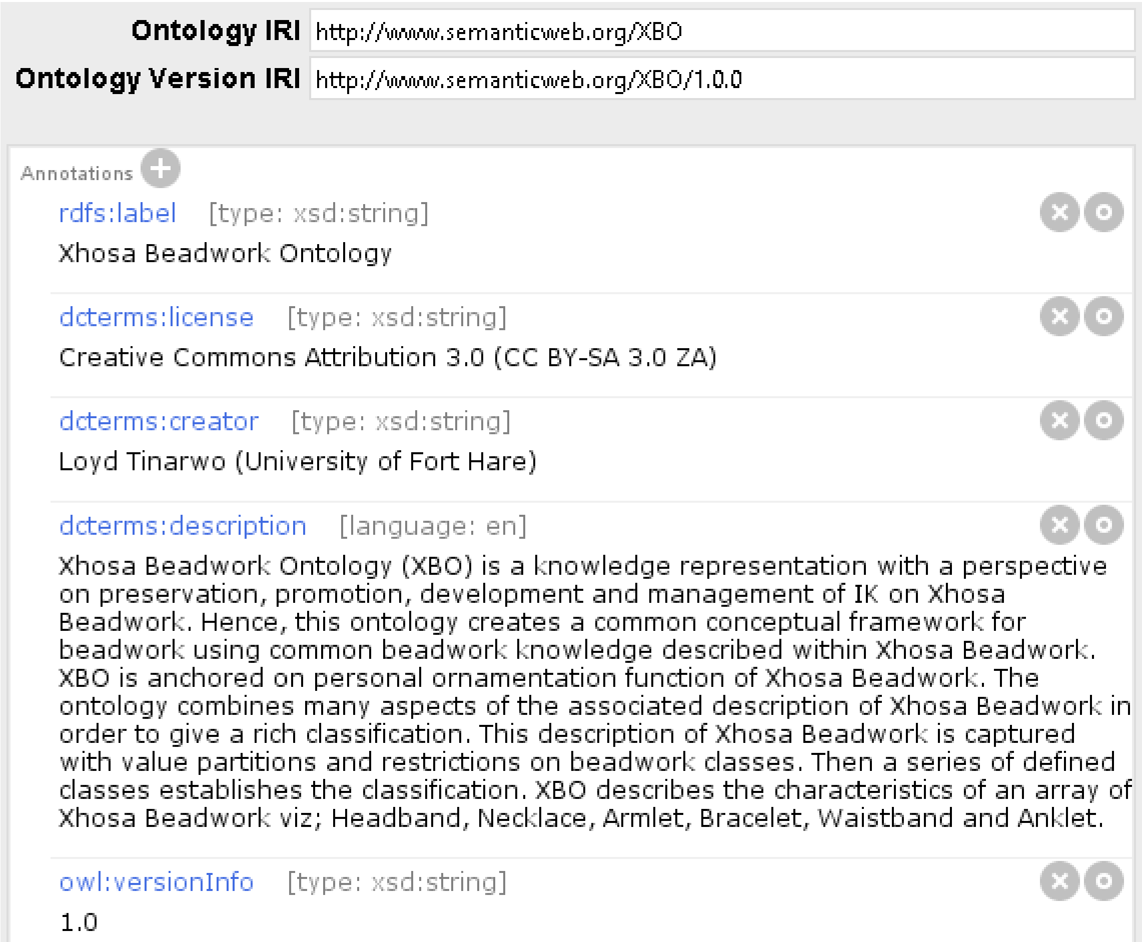


Figure 5.14: Ontology or Metadata Annotations in XBO Header

As shown in Figure 5.14 metadata annotations have been specified in the ontology. The **rdfs: label**, **dcterms: creator**, **dcterms: license**, **owl: versionInfo** are provided, specifying the name of the ontology developer, title, content description, and ontology license. Once the metadata annotations were defined, the ontology was uploaded into LODE to initiate the conversion. The conversion was performed using the OWLAPI. The ontology was then pre-processed so that it would be linearized into the RDF/XML format. With the semantic model loaded in memory, LODE was activated to perform direct documentation over the XBO. Then the LODE service automatically extracted classes, properties, instances, axioms and namespace from the XBO. These were then rendered into a navigable HTML document.

The result of exploiting these metadata annotations using LODE generated a full description of the ontology resources in readable and natural language. In Figure 5.15 title of the XBO, XBO IRI (Internationalized Resource Identifier), XBO Version IRI, the current version of the XBO, author and the ontology source are presented in the first segment of the documentation. The table of content and the introduction of the XBO are depicted in the second portion of the documentation.

Xhosa Beadwork Ontology

IRI:
http://www.semanticweb.org/XBO

Version IRI:
http://www.semanticweb.org/XBO/1.0.0

Current version:
1.0

Authors:
Loyd Tinarwo (University of Fort Hare)

Other visualisation:
Ontology source

Table of Content

Introduction

Xhosa Beadwork Ontology (XBO) is a knowledge representation with a perspe
Beadwork. Hence, this ontology creates a common conceptual framework for beac
is anchored on personal ornamentation function of Xhosa Beadwork. The ontology
to give a rich classification. This description of Xhosa Beadwork is captured witl
classes establishes the classification. XBO describes the characteristics of an arr
Anklet.

Figure 5.15: Main Page of Applying LODE Documentation Engine to the XBO

The third segment of the documentation included in Figure 5.16, refer to the description of the semantic resources of the XBO. These semantic resources include classes and properties. In Figure 5.16, IRI, description, ranges, domains, and restrictions are described for each semantic resource in the XBO. The entire XBO LODE documentation is presented in Appendix E.

BodyRegion[c]

IRI: http://www.semanticweb.org/XBO#BodyRegion

BodyRegion is a ValuePartition that describes only values from subclasses further partitioned.

is equivalent to

Ankle[c] **or** Arm[c] **or** Head[c] **or** Neck[c] **or** Shin[c] **or** Waist[c] **or** Wrist[c]

has super-classes

ValuePartition[c]

has sub-classes

Ankle[c], Arm[c], Head[c], Neck[c], Shin[c], Waist[c], Wrist[c]

is in domain of

placementRegion[dp]

Figure 5.16: Documentation of XBO Semantic Resources Using LODE Documentation Engine

An ontology may be published by putting the ontology on an accessible and free website. On the other hand, the ontology can be submitted to a repository such as GitHub. The second variant comes with the advantage of increasing the visibility of the ontology. In addition, the second method does allow the use of the repository such as searching, browsing and comparing of ontologies (Noy et al., 2009). To make the ontology publicly available, XBO was submitted on GitHub repository using the uploading approach on the corresponding website and published using OnToology. The current release version of XBO is 1.0 in OWL DL is available on GitHub repository. Furthermore, the XBO was successfully documented using LODE version 1.2 and was shared and can be understood using HTML visualization.

5.4 Conclusion

This chapter presented the evaluation of the ontology that was produced in this study. The structural dimension, function dimension, usability profiling dimension and logical consistency dimension of the XBO have been assessed including comparison-based evaluation. Embedded in this evaluation was the corrective development of the XBO based on the evaluation outcome that emerged under each evaluation dimension. In this sense, the XBO was enhanced under the ontology repair phase as triggered by the outcome of the diagnosis phase. The adoption of corrective development prompted the improvement of the XBO and permitted the ontology to evolve towards a valuable knowledge representation of Xhosa Beadwork. In addition, the chapter presented the documentation and publication of the XBO. The consequence of the evaluation in this chapter has demonstrated that the ontology developed and the knowledge represented are of the required standard hence addressing the third objective of the study as expressed in Section 1.2. Besides, the evaluation outcome revealed ontologies as a sufficient and viable solution to the scourge of IK disintegration in the domain of Xhosa Beadwork. In the following chapter, the conclusion of the study is featured.

Chapter 6: Conclusion and Future Work

In this chapter, the study is concluded. The overall aim of this study was to develop an ontological model for Xhosa Beadwork in marginalised rural communities of the Eastern Cape Province. Accordingly, before the study presents the synthesis of study findings it is deemed important to allude to the objectives that underpinned this study which are the following:

1) *Undertake a systematic literature review on the existing ontology development and ontology evaluation methodologies.*
2) *Develop an ontological model based on Xhosa Beadwork for the formalisation and sharing of Indigenous Knowledge.*
3) *Undertake an ontology evaluation of the ontological model for Xhosa Beadwork. This was done to ensure that the knowledge represented and the ontological model are of the required standard for knowledge sharing and reuse within the Semantic Web.*

In Section 6.1 objectives of the study are reviewed. The contributions of the study are abridged in Section 6.2 as well as the limitations of the ontological model followed by possible future research of the study in Section 6.3.

6.1 Summary of the Study

The overall aim of this study was to develop an ontological model for Xhosa Beadwork in marginalised rural communities of the Eastern Cape Province. The development of the ontological model was motivated by the current lack of defined ontological background knowledge that structures Xhosa Beadwork in the context of IK management. This ontological model was developed with the goal of structuring the domain knowledge into a consistent reusable body of knowledge promoting an efficient sharing of a common understanding of Xhosa Beadwork in a computational form.

In Section 2.2, the study found out that an inherent weakness of the ontology development methodologies was the lack of detailed methodological guidance on ontology data analysis. They do not spell out how to conduct a comprehensive ontology terminology identification, extraction, and organization. In this study, domain, taxonomic and componential analyses were used for ontology data analysis in order to provide terminology to the XBO as presented in Section 3.3.

The study followed three distinct phases in the development of the XBO. These are data collection, data analysis, and data representation within AR. The study used NeOn methodology, the iterative and incremental ontology life cycle in the development of XBO as described in Section 3.4. NeOn and the iterative-incremental development ontology cycle provided a structured approach to reach a coherent and comprehensive ontological. The XBO is an OWL 2 DL ontological model developed using the Protégé-OWL modelling system. The scope of the ontological model covered personal ornamentation Xhosa Beadwork and not all the concepts in Xhosa Beadwork. The XBO was enhanced as necessary throughout the entire study. The enhancement corresponded to the incorporation of object properties, axioms, restrictions, data and annotation properties as needed.

The XBO was then evaluated. The evaluation was centred on ascertaining the effectiveness of the XBO so as to find out whether the XBO is a comprehensive ontological model for Xhosa Beadwork and is of the required standard. The study used a (semi) automatic approach based on OWL reasoning mechanism Pellet and OntOlogy Pitfall Scanner. While undertaking the evaluation, the study discussed structural, function, usability-profiling and logical consistency dimensions of the XBO including comparison-based evaluation.

Embedded in this evaluation was the corrective development of the XBO based on the evaluation outcome that emerged under each evaluation dimension. In this sense, the XBO was enhanced under the ontology repair phase as activated by the outcome of the diagnosis phase. The adoption of corrective development prompted the improvement of the XBO and permitted the ontology to evolve towards a valuable knowledge representation of Xhosa Beadwork. Lastly, the XBO was documented and published.

6.1.1 Revisiting Study Objectives

The objectives of the study provide the structure of this section, each objective as stated in Section 1.2 is recalled, answered and discussed according to the full scope of this study.

Objective 1: *Undertake a systematic literature review on the existing ontology development and ontology evaluation methodologies.*

A systematic literature review was undertaken on ontology development and ontology evaluation methodologies. The study found that an inherent weakness of most of the current mainstream ontology development methodologies is the lack of detailed methodological guidance on data analysis particularly identification, extraction, and organization of ontology terminology. In order to address this gap, the study proposed domain, taxonomical and componential analyses methods to support ontology data analysis in the mainstream methodologies for ontology development.

The methodologies for ontology development that addressed ontology evaluation have mostly relied on the CQs method as a mode for ontology evaluation. Some of these methodologies use other techniques as well and some do not regard ontology evaluation hence, they do not provide comprehensive methodological support. The most complete ontology development methodology on evaluating ontologies is NeOn having some approaches with specific guidelines. NeOn regards evaluation of ontologies as a supportive function that should be undertaken throughout the entire ontology development. On ontology evaluation methodologies, the study concluded that, though some of the methodologies provided an extensive range of evaluation dimensions, they lacked methodological guidance for undertaking ontology evaluation. Furthermore, the majority of the ontology evaluation tools had a small number of anomalies that could be identified through automatic detection and were based on a limited ontology evaluation scope. However, the study found that OntOlogy Pitfall Scanner! had automatic technological support with a broad pitfall catalogue including providing guidance on repairing them.

Objective 2: *Develop an ontological model based on Xhosa Beadwork for the formalisation and sharing of Indigenous Knowledge.*

An OWL 2 DL ontology was developed based on Xhosa Beadwork called Xhosa Beadwork Ontology (XBO). The XBO is a domain ontology that encompasses the definition of ontological and non-ontological information that describe Xhosa Beadwork. The ontological model was constructed in order to formalise and support IK in the domain of Xhosa Beadwork in the marginalized rural communities of the Eastern Cape Province. This knowledge representation was developed using the NeOn methodology and the iterative-incremental development ontology cycle within the ambit of AR. The study followed three distinct but integrated phases, namely, collection, analysis, and representation of data in developing the XBO. These phases were guided by AR with each phase as an AR cycle focused on planning, action, observation and reflection.

During XBO development, the study established that the main limitation of the NeOn methodology was that it did not have methodological guidance to support data analysis on identification, extraction, and organisation of ontology terminology. To address this weakness, the study employed domain, taxonomic and componential analyses in undertaking ontology data analysis for XBO. This enabled the study to identify, extract and organise concepts, relations, instances and attributes in the domain of Xhosa Beadwork. The domain analysis method was used to identify the main concepts while taxonomic analysis method was used to discover and reveal the internal structure of the classes. In addition, a taxonomic analysis method was used to organize concepts into a hierarchical structure and generated the Xhosa Beadwork Taxonomy (XBT). On the other hand, the componential analysis method was utilized for the systematic searching, sorting, and grouping of attributes associated with the concepts. The scope of the ontology covered personal ornamentation beadwork and not all the concepts in Xhosa Beadwork. The subsets of Xhosa Beadwork that are represented in the XBO are **Headband**, **Necklace**, **Armlet**, **Bracelet**, **Waistband**, and **Anklet**. The XBO was successfully constructed and used to illustrate ontologies as a viable solution in representing Xhosa Beadwork and in IK management.

Objective 3: *Undertake an ontology evaluation of the ontological model for Xhosa Beadwork. This was done to ensure that the knowledge represented and the ontological model are of the required standard for knowledge sharing and reuse within the Semantic Web.*

Xhosa Beadwork Ontology (XBO) evaluation was undertaken to ascertain the effectiveness of the XBO so as to guarantee that the develop ontology was of the required quality standard. The study used a (semi) automatic evaluation approach comprised of evaluating the structural, functional, and usability-profiling dimensions of the XBO including the logical consistency and comparison-based evaluation. In the first step, the logical consistency of the ontology was accomplished using a reasoning mechanism. The ontology was found to be consistent based on the logics defined in the XBO. The logical consistency evaluation was run throughout the development of the XBO. In the case of inconsistencies that were detected, each inconsistent class was repaired prior to continuing with XBO development.

In the second step, a three-stepped approach was used. The structural, functional and usability-profiling evaluation of the XBO was undertaken using OntOlogy Pitfall Scanner (OOPS!). OOPS! was effective in discovering a dimension of the XBO that needed improvement. Anomalies detected in each dimension were fixed. In the third step comparison-based evaluation of the XBO was undertaken based on 2 gold standard ontologies. The evaluation of the XBO against the gold standard ontologies was assessed based on three criteria: structural, functional and usability-profiling evaluation utilizing OntOlogy Pitfall Scanner. The comparison-based evaluation showed that XBO had a competitive level of architecture and semantics when compared to the standard ontologies. However, the outcome also revealed the need for revision and enhancement of the XBO. Furthermore, comparison-based evaluation showed an unexpected outcome, those gold standard ontologies despite being established, in some instances had a higher prevalence of modelling anomalies than XBO.

Although OOPS! was effective in the evaluation of the XBO, the study found that the structural pattern matching method in OOPS! was not able to detect alternative annotation properties that were used in XBO such as those provided by SKOS and DC. The evaluation involved ontology diagnosis phase and ontology repair phase consecutively executed and then repeated guided by the iterative-incremental ontology development life cycle. The overall evaluation outcome revealed the ontological model as an adequate representation of the Xhosa Beadwork proving the claim that an ontology can indeed represent IK in the domain of Xhosa Beadwork. In addition, the XBO was documented into a human understandable and readable resource and was published. This facilitated knowledge sharing and reuse of the XBO within the Semantic Web.

6.2 Contributions of Study

There are three significant contributions that were made by this current study to the existing body of scientific knowledge. Firstly, the findings of this study emanating from **Objective 1** (*Undertake a systematic literature review on the existing ontology development and ontology evaluation methodologies),* have exposed some of the limitations of the contemporary methodologies that are used to develop ontologies. The study established that there is a lack of methodological support for data analysis for the identification, extraction, and organisation of ontology terminology in most of the mainstream ontology development methodologies.

To address this challenge, the study adopted a set of three data analysis methods with methodological guidance that support the identification, extraction, and organisation of terminology in the development of an ontology. These methods are the domain, taxonomic and componential analyses. As shown by the findings of this study, the inclusion of these three methods of data analysis enriched the process of ontology conceptualization which is a crucial activity in ontology development. The implication of this finding is that the domain, taxonomical and componential analyses should become integral components of the mainstream methodologies that are being used to develop ontologies. Based on the findings of this study, their future inclusion as in ontology data analysis will enhance the reuse and development of knowledgeable ontologies that provide intelligent support and facilitate efficient knowledge sharing.

The effectiveness and appropriateness of these three methods in ontology terminology identification, extraction, and organization in practice were demonstrated in a three-step procedure in the development of the XBO, carried out in the context of this study. Each method has a detailed procedure with associated subtasks specified. Such a detailed description facilitates the implementation of the methods, promoting use in practice and ease of their integration into the mainstream ontology development methodologies.

The second contribution made by this study to the existing body of knowledge on ontologies is derived from findings of **Objective 2** (*Develop an ontological model based on Xhosa Beadwork for the formalisation and sharing of Indigenous Knowledge*). The study successfully developed a taxonomy for traditional Xhosa Beadwork which is a first of its kind. This is a knowledge organisation system that provides the taxonomical knowledge through classification of Xhosa Beadwork into a logical structure. The taxonomy allows the description and hierarchical classification of Xhosa Beadwork using sets of collective characteristics and documenting the principles that enforce such classification. In existing literature on IK ontologies, there is no scholarly work that has developed a taxonomy specifically for Xhosa Beadwork. Accordingly, this study can be regarded as seminal in the field of ontologies focusing on Xhosa Beadwork. The taxonomy developed by this study forms a basis that will facilitate the sharing of a common understanding of Xhosa Beadwork, ease of retrieval of the information and promote the preservation of IK used in Xhosa Beadwork.

Lastly, the major contribution of this study to existing knowledge is the development of a validated Xhosa Beadwork Ontology based on **Objective 2** and **Objective 3**(*Undertake an ontology evaluation of the ontological model for Xhosa Beadwork. This was done to ensure that the knowledge represented and the ontological model are of the required standard for knowledge sharing and reuse within the Semantic Web*). In the literature on ontologies, there is no ontological model that has been developed to capture tacit knowledge in the domain of Xhosa Beadwork. As a result, a large amount of beadwork knowledge is being eroded as posited by Costello (1990). This is not some isolated phenomena but a scourge prevalent and affecting IK across South Africa. The study addressed this gap by developing and evaluating an OWL 2 DL ontology for Xhosa Beadwork called Xhosa Beadwork Ontology thereby adding to the ontological body of knowledge. This ontology is the third contribution of this study. The Xhosa Beadwork Ontology is a documented, reusable body of knowledge that will enable formalization and efficient sharing of Xhosa Beadwork in a computational form within the Semantic Web. The Xhosa Beadwork Ontology was developed and evaluated as a proof-of-concept to validate the ontological representation of Xhosa Beadwork as a viable solution that can reverse the anomalies of IK erosion plaguing South Africa.

6.3 Future Work

In relation to the subject matter of this study, the following have been identified as areas which can be a focus for further research:

a) IK on Xhosa Beadwork is often collected in the native language and automatic translation services are not yet readily available for all African languages (Anderson, 2016; Chavula and Keet, 2014; Chavula and Keet, 2015). At the same time manual translation is expensive and time-consuming. Since the XBO is a logical representation of a domain, it can be natural language independent. This study creates the opportunity to have a facility to browse, search and access the information in the XBO in different languages. For example, a query can be formulated in any supported natural language and the query outcome can be extracted and presented in any of the available 11 official languages in South Africa. The ability to query and browse IK based on different languages will be very beneficial in the context of Xhosa Beadwork. This will promote navigation of the XBO by the indigenous communities in their own language. This can be achieved in a myriad of ways including query expansion in different languages, multilingual ontologies and lexicalised ontologies that support Xhosa Beadwork. Though annotations were implemented in XBO there is still need for annotation of information in the XBO in different languages.

b) Xhosa Beadwork is a shared resource over various traditional communities such as Mpondo, Bomvana, Bhaca, Thembu, Mpondomise, Xesibe, Mfengu, Hlubi and Xhosa proper. The latter may be further subdivided into the Gcaleka and Ngqika (Costello, 1990). Given such a context, this study can be extended to enable collaborative knowledge generation. Using ontologies this can enable the communities to generate precise knowledge representations in Xhosa Beadwork through collaboration, using tagging and metadata. The content loaded can be tagged by the community to enrich the meaning and accessibility of Xhosa Beadwork using mechanisms such as semantic wikis and folksonomies.

c) During the development of the XBO, the study established that the main limitation of the NeOn methodology was that it did provide specific methodological guidance on ontology data analysis as to how to identify, extract and organise relevant ontology terminology. To address this weakness, the study proposed domain analysis, taxonomic analysis and componential analysis as methods appropriate for ontology data analysis. However, these methods are not yet equipped with a step-wise methodology. In this regard, there is the need for further research that specifically looks into the possibility of integrating these three methods into a step-wise methodology for ontology data analysis. It is envisaged that research of that nature will provide guidance by dividing data analysis into a set of phases and a series of steps and guidelines that can be followed in each phase. This will enable systematic identification, extraction, and organisation of ontology terminology during ontology development.

In the context of this study, the ontological model that has been developed has some limitations that ought to be taken into consideration when applying its findings. These limitations are summarised as follows:

d) The current XBO that has been developed by this study is based on Thembu Beadwork. However, Xhosa Beadwork is broad and diverse comprising various ethnic Xhosa tribes implying that the Beadwork of these tribes is also different. This study could be expanded to include classification information of other Xhosa tribes. The accurate classification of such information will enhance the comprehensibility of the knowledge and the accessibility and ease of retrieval of the information. Therefore, there is still a need for further research that classifies and formalise Xhosa Beadwork according to the various tribes that constitute the Xhosa speaking people.

e) Another limitation is that the XBO developed by this study only covers the beadwork knowledge on personal ornamentation. Accordingly, there is still need for further research that looks into the classification and formalisation of other knowledge in XBO. For example, Xhosa Beadwork on the decoration of clothing or garments and objects is not yet represented in the XBO. In this regard, the XBO can be extended to create a networked ontology that represents the entire Xhosa Beadwork.

f) Indeed, the current study did not address the incorporation of foundational ontologies into XBO such as DOLCE. This presents an opportunity for future research that can look into the feasibility of incorporating the XBO with other foundational ontologies. Alternatively, future research projects might as well explore the possibility of linking this ontological model with other ontologies or information systems that are related to Xhosa Beadwork domain such as SAHRIS. Closely linked to this, is research that will explore the reuse of ontologies such as multilingual ontologies for Bantu languages (Keet and Khumalo, 2014, Chavula and Keet, 2014, Chavula and Keet, 2015) and African WordNets (Anderson, 2016) is also warranted.

g) The XBO also lays the foundation for further research in designing and implementing web-based ontologies or ontology-based applications in the context of commerce to support socio-economic development and to practically show the value of ontologies in the marginalised rural communities.

Taking everything into account, this study has developed an XBO for Xhosa Beadwork. The developed XBO can now promote an efficient sharing of a common understanding of Xhosa Beadwork in a computational form. The study has also advanced the state of art in the methodological, taxonomical and ontological realm of ontology engineering and management of IK. The study introduced methodological support for ontology data analysis for the identification, extraction, and organisation of ontology terminology. In addition to this, solid knowledge resources have been developed in the context of this study. They comprise the taxonomical classification of Xhosa Beadwork and the Xhosa Beadwork Ontology (XBO). Every one of these resources contributes substantially to the existing ontological background knowledge on traditional beadwork and IK. In addition, they structure and formalize previously unstructured domain knowledge. The Xhosa Beadwork knowledge was transformed into a computational artifact that was made accessible and utilizable inside and outside the domain of Xhosa Beadwork. The outcome of the study has demonstrated that XBO is a legitimate, shareable and reusable semantic artifact supporting the formalisation and preservation of IK in the domain of Xhosa Beadwork.

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Appendix A Description Logics Terminology

Some Description Logic Concept Constructors Source: (Baader et al., 2003; Baader et al., 2005)

Name	Syntax	Semantics	Symbol
Top	$\top$	$\Delta^{\mathcal{I}}$	$\mathcal{AL}$
Bottom	$\bot$	$\emptyset$	$\mathcal{AL}$
Intersection	$C \sqcap D$	$C^{\mathcal{I}} \cap D^{\mathcal{I}}$	$\mathcal{AL}$
Union	$C \sqcup D$	$C^{\mathcal{I}} \cup D^{\mathcal{I}}$	$\mathcal{U}$
Negation	$\neg C$	$\Delta^{\mathcal{I}} \setminus C^{\mathcal{I}}$	$\mathcal{C}$
Value restriction	$\forall R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \forall b.\ (a,b) \in R^{\mathcal{I}} \rightarrow b \in C^{\mathcal{I}}\}$	$\mathcal{AL}$
Existential quant.	$\exists R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \exists b.\ (a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}$	$\mathcal{E}$
Unqualified number restriction	$\geqslant n\,R$ $\leqslant n\,R$ $= n\,R$	$\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}}\}\rvert \geq n\}$ $\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}}\}\rvert \leq n\}$ $\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}}\}\rvert = n\}$	$\mathcal{N}$
Qualified number restriction	$\geqslant n\,R.C$ $\leqslant n\,R.C$ $= n\,R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}\rvert \geq n\}$ $\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}\rvert \leq n\}$ $\{a \in \Delta^{\mathcal{I}} \mid \lvert\{b \in \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}\rvert = n\}$	$\mathcal{Q}$
Role-value-map	$R \subseteq S$ $R = S$	$\{a \in \Delta^{\mathcal{I}} \mid \forall b.(a,b) \in R^{\mathcal{I}} \rightarrow (a,b) \in S^{\mathcal{I}}\}$ $\{a \in \Delta^{\mathcal{I}} \mid \forall b.(a,b) \in R^{\mathcal{I}} \leftrightarrow (a,b) \in S^{\mathcal{I}}\}$	
Agreement and disagreement	$u_1 \doteq u_2$ $u_1 \neq u_2$	$\{a \in \Delta^{\mathcal{I}} \mid \exists b \in \Delta^{\mathcal{I}}.\ u_1^{\mathcal{I}}(a) = b = u_2^{\mathcal{I}}(a)\}$ $\{a \in \Delta^{\mathcal{I}} \mid \exists b_1, b_2 \in \Delta^{\mathcal{I}}.\ u_1^{\mathcal{I}}(a) = b_1 \neq b_2 = u_2^{\mathcal{I}}(a)\}$	$\mathcal{F}$
Nominal	I	$I^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$ with $\lvert I^{\mathcal{I}}\rvert = 1$	$\mathcal{O}$

Some Description Logic Role Constructors Source: (Baader et al., 2005; Baader et al., 2003)

Name	Syntax	Semantics	Symbol
Universal role	U	$\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$	U
Intersection	$R \sqcap S$	$R^{\mathcal{I}} \cap S^{\mathcal{I}}$	$\sqcap$
Union	$C \sqcup D$	$R^{\mathcal{I}} \cup S^{\mathcal{I}}$	$\sqcup$
Complement	$\neg R$	$\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}} \setminus R^{\mathcal{I}}$	$\neg$
Inverse	R^{-}	$\{(b,a) \in \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}} \mid (a,b) \in R^{\mathcal{I}}\}$	-1
Composition	$R \circ S$	$R^{\mathcal{I}} \circ S^{\mathcal{I}}$	$\circ$
Transitive closure	R^{+}	$\bigcup_{n \geq 1}(R^{\mathcal{I}})^n$	$+$
Reflexive-transitive closure	R^{*}	$\bigcup_{n \geq 0}(R^{\mathcal{I}})^n$	$*$
Role restriction	$R\|_C$	$R^{\mathcal{I}} \cap (\Delta^{\mathcal{I}} \times C^{\mathcal{I}})$	r
Identity	$id(C)$	$\{(d,d) \mid d \in C^{\mathcal{I}}\}$	id

Some Terminological and Assertional Axioms Source: (Baader et al., 2005; Baader et al., 2003)

Name	Syntax	Semantics
Concept inclusion	$C \sqsubseteq D$	$C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$
Role inclusion	$R \sqsubseteq S$	$R^{\mathcal{I}} \subseteq S^{\mathcal{I}}$
Concept equality	$C \equiv D$	$C^{\mathcal{I}} = D^{\mathcal{I}}$
Role equality	$R \equiv S$	$R^{\mathcal{I}} = S^{\mathcal{I}}$
Concept assertion	$C(a)$	$a^{\mathcal{I}} \in C^{\mathcal{I}}$
Role assertion	$R(a,b)$	$(a^{\mathcal{I}}, b^{\mathcal{I}}) \in R^{\mathcal{I}}$

Appendix B Xhosa Beadwork Taxonomy

Class:	**DomainEntity**
SubClassOf:	**owl: Thing**
Description:	The class **DomainEntity** is a subclass of **owl: Thing**. The whole Xhosa Beadwork Ontology (XBO) is placed underneath **DomainEntity**. The class **DomainEntity** is used for housekeeping to manage routine tasks in order for efficient ontology modelling and functioning. For instance, class **DomainEntity** is a common super class in case of a property having multiple classes as domain or range. In this regard, the property is inherited or propagated to all other classes.
Subclasses:	**BeadworkEntity**, **PersonEntity** and **ValuePartition**.
Class:	**BeadworkEntity**
SubClassOf:	**DomainEntity**
Description:	This class is a subclass of **DomainEntity**. **BeadworkEntity** comprise concepts that represent objects or items of beadwork and the associated description of the beadwork **Item.**
Subclasses:	**Item**
Class:	**Item**
SubClassOf:	**BeadworkEntity**
Description:	This class is a subclass of **BeadworkEntity**. The term **Item** is used for concepts that represent a tangible or physical visible beadwork **Item**. This can be a collection or a single **Item** of beadwork.

Subclasses:	**Headband**, **Necklace**, **Armlet**, **Bracelet**, **Waistband** and **Anklet**.
Class:	**Headband**
SubClassOf:	**Item**
Description:	**Headband** is a subclass of **Item**. Class **Headband** designates a beadwork **Item** or article in form of a band or narrow strip worn on or around the forehead.
Subclasses:	**FlexibleHeadband** and **InflexibleHeadband**
Class:	**Necklace**
SubClassOf:	**Item**
Description:	This class is a subclass of **Item**. The class **Necklace** is a beadwork **Item** in form of a band or string that is worn around the **Neck.**
Subclasses:	**StrandNecklace, TabNecklace, TasselNecklace, CharmNecklace, ChokerNecklace** and **CollarNecklace**
Class:	**Armlet**
SubClassOf:	**Item**
Description:	**Armlet** is a subclass of **Item.** The **Armlet** is used to represent a beadwork **Item** in form of a band or ring or string or strip worn around the **Upper Arm** or high on the **Arm**.
Subclasses:	**FlexibleArmlet** and **InflexibleArmlet**
Class:	**Bracelet**
SubClassOf:	**Item**
Description:	This is a subclass of **Item.** The class **Bracelet** represent an **Item** of beadwork in form of a loop or band encircling or worn around the **Wrist.**

Subclasses:	**InflexibleBracelet** and **FlexibleBracelet.**
Class:	**Item**
SubClassOf:	**Waistband**
Description:	**Waistband** is a subclass of **Item**. Class **Waistband** represents an **Item** of beadwork designating a strip or band encircling and fitting around the **Waist**.
Subclasses:	**StrandWaistband**
Class:	**Anklet**
SubClassOf:	**Item**
Description:	This class is a subclass of **Item.** The class **Anklet** is used for concepts that represent an **Item** beadwork in form of a string or band or strip or ring worn around the **Ankle**.
Subclasses:	**FlexibleAnklet** and **InflexibleAnklet**
Class:	**ValuePartition**
SubClassOf:	**Item**
Description:	This class is a subclass of **DomainEntity.** The concepts in **ValuePartition** denote the information about a beadwork **Item** or **Person**. These concepts define the characteristics (or features or qualities or attributes) of an **Item** beadwork or **Person**.
Subclasses:	**Colour**, **Decoration**, **BodyType**, **Sex**, **Material**, **Age**, **Rank**, **Position**, **BodyRegion**, **Use**, **Quantity**, **Side**, **Size** and **Tribe**.
Class:	**Material**
SubClassOf:	**ValuePartition**
Description:	This class is a specialization of **ValuePartition.** The class **Material** is

	comprised of concepts that represent discrete pieces of materials used in the production of an **Item** of beadwork. The instances of class **Material** may denote properties of matter before its use, during its use, and as incorporated in a beadwork **Item**.
Subclasses:	**Natural** and **Synthetic**.
Class:	**Colour**
SubClassOf:	**ValuePartition**
Description:	**Colour** is a subclass of **ValuePartition**. The concepts of class **Colour** designate the quality of a beadwork **Item** with respect to light reflected by the beadwork **Item**, usually determined visually by measurement of hue, saturation, and brightness of the reflected light.
Subclasses:	**Primary, Secondary** and **Tertiary.**
Class:	**Tribe**
SubClassOf:	**ValuePartition**
Description:	Class **Tribe** is a subclass of **ValuePartition** representing concepts of social divisions in a traditional society. The social divisions consist of families or communities linked by social, or blood, with a common dialect and culture.
Subclasses:	**Pondo**, **Bhaca**, **Xhosa**, **Thembu**, **Fengu**, and **Bomvana**.
Class:	**Quantity**
SubClassOf:	**ValuePartition**
Description:	This class is a subclass of **ValuePartition**. Class **Quantity** represents terms that denotes the numeric value of **Quantity** such as the specification of how many or the total number there is of an **Item**

	of beadwork.
Subclasses:	**Single, Double** and **Multi.**
Class:	**Side**
SubClassOf:	**ValuePartition**
Description:	Class **Side** is a subclass of **ValuePartition**. Class **Side** is comprised of terms that represent an aspect to the **Right** or **Left** with reference to the trunk of the human body.
Subclasses:	**LeftSide** and **RightSide**
Class:	**BodyRegion**
SubClassOf:	**ValuePartition**
Description:	Class **BodyRegion** is a subclass of **ValuePartition**. The class **BodyRegion** comprise concepts that denote the anatomical areas or regions of the human body where a beadwork **Item** should be worn or placed.
Subclasses:	**Ankle**, **Arm**, **Head**, **Neck**, **Shin**, **Waist** and **Wrist**.
Class:	**BodyType**
SubClassOf:	**ValuePartition**
Description:	Class **BodyType** is a subclass of **ValuePartition.** Class **BodyType** is used for concepts that represent the general physical capability of the body of a beadwork **Item** in bending or stretching usually without breaking.
Subclasses:	**Flexible** and **Inflexible.**
Class:	**Position**
SubClassOf:	**ValuePartition**

Description:	The class **Position** is a specialization of **ValuePartition**. The concepts that make up class **Position** are those that represent a point or position where an **Item** of beadwork is located or placed. This is the point or **Position** that is occupied or should be occupied by a beadwork **Item**.
Subclasses:	**Upper**, **Middle** and **Lower**.
Class:	**Decoration**
SubClassOf:	**ValuePartition**
Description:	This class is a subclass of **ValuePartition**. Class **Decoration** is comprised of concepts that denote a decorative element or design or motif that serves as an ornament or **Decoration**, added to an **Item** of beadwork to enhance the appearance of or distinguish the beadwork **Item**.
Subclasses:	**Tab**, **Streamer**, **Tassel**, **Fringe**, **Charm** and **Strand**.
Class:	**Size**
SubClassOf:	**ValuePartition**
Description:	This class is a specialization of **ValuePartition.** Class **Size** is made up of concepts that represent the relative proportions of an **Item** of beadwork or physical magnitude or the overall dimensions according to which an **Item** of beadwork is made.
Subclasses:	**Small**, **Medium** and **Large**.
Class:	**Use**
SubClassOf:	**ValuePartition**
Description:	This class is a specialization of **ValuePartition.** The concepts

	contained in class **Use** are those that represent the category of **Use** for which the beadwork **Item** is intended or is considered suitable.
Subclasses:	**Ritual** and **Ceremony**.
Class:	**Rank**
SubClassOf:	**ValuePartition**
Description:	Class **Rank** is a subclass of **ValuePartition.** Class **Rank** is made up of concepts that conceptualize the relative position of a **Person** with respect to another **Person** or other **Person**s.
Subclasses:	**Royal**, **Noble** and **Common.**
Class:	**Sex**
SubClassOf:	**ValuePartition**
Description:	Class **Sex** is the subclass of **ValuePartition.** Class **Sex** consists of concepts that represent the total assemblage of reproductive characteristics or functions differentiating the **Male** from the **Female** organism. Class **Sex** includes two main categories **Male** and **Female** into which humans and most other living things are divided.
Subclasses:	**Male** and **Female**
Class:	**Age**
SubClassOf:	**ValuePartition**
Description:	This is a subclass of **ValuePartition.** Class **Age** comprise concepts that represent one of the stages of life such as the length of time that a **Person** has lived or a thing has existed from the beginning to any given time.
Subclasses:	**Adulthood, Adolescence, Childhood** and **Infanthood.**

Class:	**Adolescence**
SubClassOf:	**Age**
Description:	This is a subclass of class **Age**. **Adolescence** is a class that represents **Age** or phase of growth and development of a human being between **Childhood** and **Adulthood**.
Subclasses:	**EarlyAdolescence**, **MiddleAdolescence** and **LateAdolescence**
Class:	**Adulthood**
SubClassOf:	**Age**
Description:	This is a subclass of **Age**. Class **Adulthood** is a period or phase of growth and development in the lifespan of a human being in which the legal age of majority or the age of maturity has been attained as specified by law.
Subclasses:	**EarlyAdulthood, MiddleAdulthood** and **LateAdulthood.**
Class:	**Childhood**
SubClassOf:	**Age**
Description:	Class **Childhood** is a subclass of **Age**. **Childhood** comprise a stage of growth of a human being between birth and puberty or phase below the age of puberty.
Subclasses:	**EarlyChildhood, MiddleChildhood** and **LateChildhood.**
Class:	**Infanthood**
SubClassOf:	**Age**
Description:	This is a subclass of **Age**. Class **Infanthood** comprises concepts that designate a period or phase of growth and development of a human being from the period of birth up to or below the age of

	Childhood.
Subclasses:	**EarlyInfanthood** and **Toddlerhood.**
Class:	**PersonEntity**
SubClassOf:	**DomainEntity**
Description:	This class is a subclass of **DomainEntity**. Class **PersonEntity** comprise concepts that represent a **Person** or **Person**s as recognized by culture or the law of a country.
Subclasses:	**Person**
Class:	**Person**
SubClassOf:	**PersonEntity**
Description:	**Person** is a subclass of **PersonEntity**. Class **Person** contains concepts that denote a human being, regarded as an individual in the physical commonsense intuition. This is according to the law as the subject of rights and duties and as recognized by culture or country.
Subclasses:	**Man** and **Woman**.

Appendix C XBO Competency Questions (CQs)

In this appendix we include the complete list of the CQs that were enumerated and used to guide the development of the Xhosa Beadwork Ontology (XBO). The CQs categories are loosely organized and not fixed. This activity was carried out in parallel with data collection. The 74 CQs were grouped into the following categories: Person Type (11 CQs), Person Description (11 CQs), Beadwork Type (15 CQs), Beadwork Description (22 CQs) and General (15 CQs). These CQs were stored in an MS Word file and then rewritten in a mind map tool Coogle as appears in Figure 4.1.

Specific CQs related to **Beadwork Type** are:

1. Which types of beadwork exist?
2. How many beadwork types are available?
3. What is the generic name of a type beadwork?
4. What is the local name of a type of beadwork?
5. What are the types of beadwork?
6. What are the common types of beadwork?
7. Is a beadwork of type Y a specialization of another?
8. What is the information about beadwork X?
9. What is the purpose of beadwork?
10. Are different types of beadwork available?
11. What types of beadwork are suitable for a person of type X?
12. What are the alternatives to beadwork X?
13. What beadwork is appropriate for task X?
14. What type of beadwork belong to tribe X?
15. What type of beadwork goes with each other or worn together?

Specific CQs related to **Beadwork Description** are:

16. What detail is necessary to identify beadwork?

17. What are the differences between beadwork?
18. What are the attributes of beadwork?
19. What is the composition of beadwork?
20. What kind of material is used to make beadwork?
21. What is the generic name of the material?
22. What is necessary to distinguish beadwork?
23. What is the local name of the material?
24. What is the meaning of beadwork?
25. Where is beadwork worn?
26. Which body regions are for wearing beadwork?
27. What is the name of the colour?
28. What is the local name of the colour?
29. What are the conditions for using beadwork?
30. How many beadwork colours are available?
31. What kind of occasions need beadwork?
32. Which colours are allowed on beadwork?
33. On which side is beadwork worn?
34. What tribes use beadwork?
35. Can you have beadwork with any combination of colours?
36. Does beadwork come in different sizes?
37. What is the meaning of the colours?
38. What quantity of beadwork X should be worn?
39. How much of beadwork should be worn?
40. How many types of material are there?
41. When does one have to wear beadwork?
42. What material is used to make beadwork of type X?
43. Which beadwork is for occasion X?
44. What types of conditions are there?
45. What is the name of a condition?
46. What is the use or usage of beadwork?

Specific CQs related to **Person Type** are:

47. What is the type of a person?
48. What are the existing types?
49. What is the type name?
50. What is the local name of a type of a person?
51. What is the generic name of the type of a person?
52. Who is eligible to wear beadwork X?
53. Does beadwork worn differ with person type?
54. Should a person of type X wear beadwork?
55. Who wears beadwork?
56. How many types of people are there?
57. What type of a person wears beadwork of type X?

Specific CQs related to **Person Description** are:

58. What are the characteristics or attributes of a person?
59. What is the age of a person?
60. What is the tribe of a person?
61. What is the name of a person of type X?
62. What is an age group?
63. What is the gender of a person?
64. What are the types of gender available?
65. What is the social rank of a person?
66. What is the marital status of a person?
67. What is the state or condition of a person?
68. What age is appropriate to wear beadwork?

The CQs in each category were composed into more general CQs. The general CQs are answered by composing answers associated to the specific CQs. The **general CQs** are:

69. Given a particular occasion, what is the appropriate beadwork?
70. Which features should one consider when choosing beadwork?
71. What kind of beadwork is used by the tribe X for birth ritual?

72. Similar beadwork search?
73. What type of beadwork is worn on body region X?
74. Given the information beadwork, to which gender does it belong?
75. How many types of beadwork contain material X?
76. Which beadwork contain material X?
77. Which occasions are appropriate for beadwork X?
78. Which combination of beadwork is suitable for occasion X?
79. What beadwork is better for task X given condition Y?
80. Find all beadwork shared by both male and female
81. Which beadwork is appropriate for the women of age group X?
82. What are the allowed beadwork colours for tribe X?
83. Which types of material are common?
84. Given information about beadwork X, on which body region should it be worn?
85. What quantity of beadwork of type X should be worn?
86. What kind of beadwork is the best choice for a person of type X?
87. Given information about beadwork X, on which side or position should it be placed?

Judging from these CQs, the Xhosa Beadwork Ontology will encompass knowledge on various characteristics and types of beadwork, characteristics and types of people, knowledge that matter when selecting the appropriate and recommended beadwork.

Consequently, we could say that the scope of the XBO should encompass details of the characteristics and components of beadwork, as well as definitions of custom and common types of beadwork.

Appendix D XBO Source Code

```
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.semanticweb.org/XBO#"
     xml:base="http://www.semanticweb.org/XBO"
     xmlns:dc="http://purl.org/dc/elements/1.1/"
     xmlns:owl="http://www.w3.org/2002/07/owl#"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
     xmlns:xbo="http://www.semanticweb.org/XBO#"
     xmlns:xml="http://www.w3.org/XML/1998/namespace"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:skos="http://www.w3.org/2004/02/skos/core#"
     xmlns:terms="http://purl.org/dc/terms/">
    <owl:Ontology rdf:about="http://www.semanticweb.org/XBO">
        <owl:versionIRI rdf:resource="http://www.semanticweb.org/XBO/1.0.0"/>
        <terms:creator rdf:datatype="http://www.w3.org/2001/XMLSchema#string">L
        <terms:description xml:lang="en">Xhosa Beadwork Ontology (XBO) is a kno
        <terms:license rdf:datatype="http://www.w3.org/2001/XMLSchema#string">(
        <rdfs:label rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Xhos
        <owl:versionInfo rdf:datatype="http://www.w3.org/2001/XMLSchema#string'
    </owl:Ontology>
```

```
<!--
///////////////////////////////////////////////////////////////////////////////////////
//
// Annotation properties
//
///////////////////////////////////////////////////////////////////////////////////////
 -->

<!-- http://purl.org/dc/elements/1.1/date -->

<owl:AnnotationProperty rdf:about="http://purl.org/dc/elements/1.1/date">
    <dc:description xml:lang="en-us">Typically, Date will be associated with
     availability of the resource.  Recommended best practice
     for encoding the date value is defined in a profile of
     ISO 8601 [W3CDTF] and follows the YYYY-MM-DD format.</dc:description>
    <dc:type rdf:resource="http://dublincore.org/usage/documents/principles/#
    <terms:hasVersion rdf:resource="http://dublincore.org/usage/terms/history
    <terms:issued>1999-07-02</terms:issued>
    <terms:modified>2002-10-04</terms:modified>
    <rdfs:comment xml:lang="en-us">A date associated with an event in the lif
     resource.</rdfs:comment>
    <rdfs:isDefinedBy rdf:resource="http://purl.org/dc/elements/1.1/"/>
    <rdfs:label xml:lang="en-us">Date</rdfs:label>
</owl:AnnotationProperty>

<!--
///////////////////////////////////////////////////////////////////////////////////////
//
// Object Properties
//
///////////////////////////////////////////////////////////////////////////////////////
 -->

<!-- http://www.semanticweb.org/XBO#hasAgeGroup -->

<owl:ObjectProperty rdf:about="http://www.semanticweb.org/XBO#hasAgeGroup">
    <rdfs:subPropertyOf rdf:resource="http://www.w3.org/2002/07/owl#topObjectPr
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Relat
    <rdfs:label rdf:datatype="http://www.w3.org/2001/XMLSchema#string">hasAgeGr
</owl:ObjectProperty>
```

```
<!--
///////////////////////////////////////////////////////////////////////////////////////
//
// Data properties
//
///////////////////////////////////////////////////////////////////////////////////////
 -->

<!-- http://www.semanticweb.org/XBO#ageGroup -->

<owl:DatatypeProperty rdf:about="http://www.semanticweb.org/XBO#ageGroup">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/XBO#Age"/>
    <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#double"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Spec
    <rdfs:label rdf:datatype="http://www.w3.org/2001/XMLSchema#string">ageGro
    <skos:prefLabel rdf:datatype="http://www.w3.org/2001/XMLSchema#string">ag
</owl:DatatypeProperty>

<!--
///////////////////////////////////////////////////////////////////////////////////////
//
// Classes
//
///////////////////////////////////////////////////////////////////////////////////////
 -->

<!-- http://www.semanticweb.org/XBO#Adolescence -->

<owl:Class rdf:about="http://www.semanticweb.org/XBO#Adolescence">
    <owl:equivalentClass>
        <owl:Class>
            <owl:intersectionOf rdf:parseType="Collection">
                <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Age"/
                <owl:Restriction>
                    <owl:onProperty rdf:resource="http://www.semanticweb.org/XBC
                    <owl:someValuesFrom>
                        <rdfs:Datatype>
                            <owl:onDatatype rdf:resource="http://www.w3.org/2001
                            <owl:withRestrictions rdf:parseType="Collection">
                                <rdf:Description>
                                    <xsd:minExclusive rdf:datatype="http://www.w
```

```
<!-- http://www.semanticweb.org/XBO#Armlet -->

<owl:Class rdf:about="http://www.semanticweb.org/XBO#Armlet">
    <owl:equivalentClass>
        <owl:Class>
            <owl:intersectionOf rdf:parseType="Collection">
                <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Item"
                <owl:Restriction>
                    <owl:onProperty rdf:resource="http://www.semanticweb.org/XBO
                    <owl:someValuesFrom rdf:resource="http://www.semanticweb.org
                </owl:Restriction>
            </owl:intersectionOf>
        </owl:Class>
    </owl:equivalentClass>
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/XBO#Item"/>
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">The cla
    <rdfs:label xml:lang="en">Armlet</rdfs:label>
    <skos:prefLabel xml:lang="en">Armlet</skos:prefLabel>
</owl:Class>



<!-- http://www.semanticweb.org/XBO#ChokerNecklace -->

<owl:Class rdf:about="http://www.semanticweb.org/XBO#ChokerNecklace">
    <owl:equivalentClass>
        <owl:Class>
            <owl:intersectionOf rdf:parseType="Collection">
                <rdf:Description rdf:about="http://www.semanticweb.org/XBO
                <owl:Restriction>
                    <owl:onProperty rdf:resource="http://www.semanticweb.o
                    <owl:someValuesFrom rdf:resource="http://www.semanticw
                </owl:Restriction>
            </owl:intersectionOf>
        </owl:Class>
    </owl:equivalentClass>
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/XBO#Necklace
    <rdfs:label xml:lang="en">ChokerNecklace</rdfs:label>
    <skos:prefLabel xml:lang="en">ChokerNecklace</skos:prefLabel>
</owl:Class>
```

```
Class rdf:about="http://www.semanticweb.org/XBO#Item">
owl:equivalentClass>
   <owl:Class>
       <owl:unionOf rdf:parseType="Collection">
           <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Anklet"/>
           <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Armlet"/>
           <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Bracelet"/>
           <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Headband"/>
           <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Necklace"/>
           <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Waistband"/>
       </owl:unionOf>

<!-- http://www.semanticweb.org/XBO#Sex -->

<owl:Class rdf:about="http://www.semanticweb.org/XBO#Sex">
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        <owl:Class>
            <owl:unionOf rdf:parseType="Collection">
                <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Fem
                <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Mal
            </owl:unionOf>
        </owl:Class>
    </owl:equivalentClass>
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/XBO#ValuePartiti
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Sex i
    <rdfs:label xml:lang="en">Sex</rdfs:label>
    <skos:altLabel xml:lang="en">Gender</skos:altLabel>
    <skos:altLabel xml:lang="xh">Isini</skos:altLabel>
    <skos:prefLabel xml:lang="en">Sex</skos:prefLabel>
</owl:Class>
```

```
<!-- http://www.semanticweb.org/XBO#Side -->

<owl:Class rdf:about="http://www.semanticweb.org/XBO#Side">
    <owl:equivalentClass>
        <owl:Class>
            <owl:unionOf rdf:parseType="Collection">
                <rdf:Description rdf:about="http://www.semanticweb.org/XBO#LeftS:
                <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Right:
            </owl:unionOf>
        </owl:Class>
    </owl:equivalentClass>
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/XBO#ValuePartition
    <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Side is
    <rdfs:label xml:lang="en">Side</rdfs:label>
    <skos:altLabel xml:lang="xh">Icala</skos:altLabel>
    <skos:prefLabel xml:lang="en">Side</skos:prefLabel>
</owl:Class>

<!--
///////////////////////////////////////////////////////////////////////////////.
//
// Individuals
//
///////////////////////////////////////////////////////////////////////////////.
 -->


<!-- http://www.semanticweb.org/XBO#Fringe -->

<owl:NamedIndividual rdf:about="http://www.semanticweb.org/XBO#Fringe">
    <rdf:type rdf:resource="http://www.semanticweb.org/XBO#Fringe"/>
</owl:NamedIndividual>
```

```
<!--
///////////////////////////////////////////////////////////////////////////////////////,
//
// Annotations
//
///////////////////////////////////////////////////////////////////////////////////////,
 -->

<rdf:Description rdf:about="http://www.semanticweb.org/XBO#Fringe">
    <rdfs:label xml:lang="en">Fringe</rdfs:label>
    <skos:prefLabel xml:lang="en">Fringe</skos:prefLabel>
</rdf:Description>
<rdf:Description rdf:about="http://www.semanticweb.org/XBO#Streamer">
    <rdfs:label xml:lang="en">Streamer</rdfs:label>
    <skos:prefLabel xml:lang="en">Streamer</skos:prefLabel>
</rdf:Description>
<rdf:Description rdf:about="http://www.semanticweb.org/XBO#Tab">
    <rdfs:label xml:lang="en">Tab</rdfs:label>
    <skos:prefLabel xml:lang="en">Tab</skos:prefLabel>
</rdf:Description>
<rdf:Description rdf:about="http://www.semanticweb.org/XBO#Tassel">
    <rdfs:label xml:lang="en">Tassel</rdfs:label>
    <skos:prefLabel xml:lang="en">Tassel</skos:prefLabel>
</rdf:Description>


<!--
///////////////////////////////////////////////////////////////////////////////////////
//
// General axioms
//
///////////////////////////////////////////////////////////////////////////////////////
 -->

<rdf:Description>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#AllDisjointClasses"/>
    <owl:members rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Ankle"/>
        <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Arm"/>
        <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Head"/>
        <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Neck"/>
        <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Shin"/>
        <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Waist"/>
        <rdf:Description rdf:about="http://www.semanticweb.org/XBO#Wrist"/>
    </owl:members>
</rdf:Description>
<rdf:Description>
```

Appendix E XBO LODE Documentation

Xhosa Beadwork Ontology

IRI:
http://www.semanticweb.org/XBO

Version IRI:
http://www.semanticweb.org/XBO/1.0.0

Current version:
1.0

Authors:
Loyd Tinarwo (University of Fort Hare)

Other visualisation:
Ontology source

Table of Content

Introduction

Xhosa Beadwork Ontology (XBO) is a knowle
this ontology creates a common conceptual
ornamentation function of Xhosa Beadwork.
description of Xhosa Beadwork is captured
describes the characteristics of an array of Xh

Classes

Adolescence Adulthood Age Ankle Anklet Arm Armlet Beadw
CharmNecklace Childhood ChokerNecklace CollarNecklace Colour
double left flexible anklet double left flexible armlet double left flexible bra
double right flexible anklet double right flexible armlet double right flexibl
double right inflexible bracelet double strand headband double strand ne
double tassel necklace DoubleStrandWaistband EarlyAdolescence Ea
flexible collar necklace FlexibleAnklet FlexibleArmlet FlexibleBracelet
inflexible collar necklace InflexibleAnklet InflexibleArmlet InflexibleBrac
large double tab necklace large flexible collar necklace large inflexible cc
large single strand necklace large single tab necklace LateAdolescence
LeftFlexibleBracelet LeftInflexibleAnklet LeftInflexibleArmlet LeftInflexil
MiddleAdolescence MiddleAdulthood MiddleChildhood Multi multi fri
multi left inflexible anklet multi left inflexible armlet multi left inflexible bra
multi right inflexible anklet multi right inflexible armlet multi right inflexible
multi tab headband multi tab necklace multi tassel necklace MultiStran
Primary Quantity Rank RightFlexibleAnklet RightFlexibleArmlet Ri
RightSide Ritual Royal Secondary Sex Shin Side Single sir
single left flexible bracelet single left inflexible anklet single left inflexible

Armlet^c

IRI: http://www.semanticweb.org/XBO#Armlet

The class Armlet is used to represent a beadwork Item in form of a

is equivalent to

Item^c **and** (isWornOn^op **some** Arm^c)

has super-classes

Item^c

is disjoint with

Anklet^c, Bracelet^c, Headband^c, Necklace^c, Waistband^c

Decoration^c

IRI: http://www.semanticweb.org/XBO#Decoration

Decoration is a ValuePartition that describes only values from subclasses partitioned.

is equivalent to

Charm^c **or** Fringe^c **or** Strand^c **or** Streamer^c **or** Tab^c **or** Tassel^c

has super-classes

ValuePartition^c

has sub-classes

Charm^c, Fringe^c, Strand^c, Streamer^c, Tab^c, Tassel^c

is in domain of

itemDecoration^dp

Item^c

IRI: http://www.semanticweb.org/XBO#Item

Item is used for concepts that represent a tangible or physical visible Item of bea

is equivalent to

Anklet^c **or** Armlet^c **or** Bracelet^c **or** Headband^c **or** Necklace^c **or** Waistband^c

has super-classes

BeadworkEntity^c **and** (hasAgeGroup^op **some** Age^c) **and** (hasBodyType^op
and (hasMaterial^op **some** Material^c) **and** (hasPosition^op **some** Position^c) **a**
and (hasSide^op **some** Side^c) **and** (hasSize^op **some** Size^c) **and** (hasTribe^o
some BodyRegion^c)

has sub-classes

Anklet^c, Armlet^c, Bracelet^c, Headband^c, Necklace^c, Waistband^c

is in domain of

commonName^dp, localName^dp

Necklace[C]

IRI: http://www.semanticweb.org/XBO#Necklace

The class Necklace is used represent a beadwork Item in form of a

is equivalent to

Item[c] **and** (isWornOn[op] **some** Neck[c])

has super-classes

Item[c]

has sub-classes

CharmNecklace[c], ChokerNecklace[c], CollarNecklace[c], StrandN

has members

ipenlote 1[ni], ipenlote 2[ni]

is disjoint with

Anklet[c], Armlet[c], Bracelet[c], Headband[c], Waistband[c]

Sex[C]

IRI: http://www.semanticweb.org/XBO#Sex

Sex is a ValuePartition that describes only values from subclasses

is equivalent to

Female[c] **or** Male[c]

has super-classes

ValuePartition[c]

has sub-classes

Female[c], Male[c]

is in domain of

sexType[dp]

is in range of

hasSex[op]

Sex^c

IRI: http://www.semanticweb.org/XBO#Sex

Sex is a ValuePartition that describes only values from subclasses

is equivalent to

Female^c **or** Male^c

has super-classes

ValuePartition^c

has sub-classes

Female^c, Male^c

is in domain of

sexType^dp

is in range of

hasSex^op

ValuePartition^c

IRI: http://www.semanticweb.org/XBO#ValuePartition

ValuePartition is a pattern that describes a restricted set of classes fr means that only members of the subclasses may be used as values BodyRegion, Decoration, Side and Quantity.

has super-classes

DomainEntity^c

has sub-classes

Age^c, BodyRegion^c, BodyType^c, Colour^c, Decoration^c, Material^c,

Data Properties

ageGroup bodyType commonName enthicTribe itemColour placementPosition placementRegion placementSide sexType

ageGroup[dp]

IRI: http://www.semanticweb.org/XBO#ageGroup

Specific Age group value of a Person or suitable age group value inte

has domain

Age[c]

Object Properties

hasAgeGroup hasBodyType hasChild hasColour hasDecor hasSex hasSide hasSize hasSpouse hasTribe hasUse

hasAgeGroup[op]

IRI: http://www.semanticweb.org/XBO#hasAgeGroup

Relates a Person or Item and the required Age group associated v
This allows specifying that a certain Item is valid only for a certain A

has super-properties

top object property

Named Individuals

Fringe Streamer Tab Tassel

Fringe[ni]

IRI: http://www.semanticweb.org/XBO#Fringe

belongs to
Fringe[c]

is disjoint with
Charm, Strand, Streamer, Tab, Tassel

is also defined as
class

Annotation Properties

alt label broader creator Date Description description

alt label[ap]

IRI: http://www.w3.org/2004/02/skos/core#altLabel

broader[ap]

IRI: http://www.w3.org/2004/02/skos/core#broader

creator[ap]

IRI: http://purl.org/dc/terms/creator

Date[ap]

General Axioms

All Disjoint Classes

double right flexible armlet[c], multi right flexible armlet[c], single right flexible ar

All Disjoint Classes

double right flexible anklet[c], multi right flexible anklet[c], single right flexible an

All Disjoint Classes

double strand headband[c], multi strand headband[c], single strand headband[c]

All Disjoint Classes

double right flexible bracelet[c], multi right flexible bracelet[c], single right flexible