An Ontological Approach to Creating an Andean Weaving Knowledge Base

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Andean textiles are products of one of the richest, oldest and continuous weaving traditions in the world. Understanding the knowledge and practice of textile production as a form of cultural heritage is particularly relevant in the Andean context due to erosion of clothing traditions, reuse of traditional textiles on commodities targeted at the tourism market, and loss of knowledge embedded in textile production. "Weaving Communities of Practice" was a pilot project that aimed to create a knowledge base of Andean weaving designed to contribute to curatorial practice and heritage policy. The research team gathered data on the chain of activities, instruments, resources, peoples, places and knowledge involved in the production of textiles, relating to over 700 textile samples. A major part of the project has been the modelling and representation of the knowledge of domain experts and information about the textile objects themselves in the form of an OWL ontology, and the development of a suite of search facilities to be supported by the ontology. This paper describes the research challenges faced in developing the ontology and search facilities, the methodology adopted, the design and implementation of the system, and the design and outcomes of a user evaluation of the system undertaken with a group of domain experts.

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1. INTRODUCTION

Andean textiles are products of one of the richest, oldest and continuous weaving traditions in the world. As the Pacific coastal regions of Peru, Chile and Ecuador are amongst the world's driest, many of these ancient fabrics are still extremely well preserved and these archaeological specimens provide a rich source of information about ancient Andean weaving techniques and structures [Bird et al. 1985; D'Harcourt 2002; Stone-Miller 1994; Dransart and Wolfe 2011]. Also encoded in the weavings is information about the ancient use of land and resources, and regional and historical identities [Arnold 2012; Silverman 2008].

Understanding the knowledge and practice of textile production as a form of cultural heritage is particularly relevant in the Andean context, for several reasons [Arnold and Espejo 2013]. First, urbanisation is eroding the knowledge of clothing traditions, especially those linked to rural areas and the idea of being 'Indian'. Second, the import of second-hand clothes and fabrics is undermining the regional production of cloth. Third, the recent trend of re-using traditional textiles as decorations on commodities (e.g. shoes and bags) branded as 'indigenous' and targeted at the tourism market leads to the fragmentation of the original products, thus causing the loss of the knowledge embedded in the product as a whole. Last, higher wages in the agro-industry sector are attracting workers to that sector, to the detriment of the traditional farming associated with textile production.

The "Weaving Communities of Practice" was a pilot project bringing together a multidisciplinary and transnational team of ethnographers, linguists, archaeologists, museum curators, weavers, art historians, cultural geographers and computer scientists with the aim of creating a knowledge base of Andean weaving designed to contribute to current curatorial practice and heritage policy. The project's qualitative approach took into account weaving terminology currently found in the Andean languages of Aymara and Quechua, obtained through a working group of Andean linguists and native language speakers. Additionally, small weaving models of techniques found in museum collections were prepared by the project's textile team. Based on this research, a new terminological model was developed, requiring a revision of existing textile records held in museums, both in the Andean region and elsewhere. A 20-page form specially designed by the project domain experts captures data relating to the complex chain of activities, instruments, resources, peoples, places and knowledge involved in the production of textiles [Arnold and Espejo 2010a; 2010b; 2012; 2013; Martins et al. 2013]. Primary data was gathered in the Aymara, Quechua, Spanish and English languages.

The innovative approach adopted and the translation work required necessitated a highly labour-intensive data gathering process in museums selected by the significance of their collections and their willingness to collaborate with the project team. Focusing principally on warp-faced weave (faz de urdimbre), which has created the most complex textiles in the Andes, the domain experts gathered information relating to over 700 textile samples, ranging from the Archaeological period (1800 BC – 1535 AD) to the Historical (1535 – 1900 AD) and Contemporary (1900 – present) periods, with production sites across Bolivia, Chile and Peru [Arnold and Espejo 2013].

A major part of the project has been the modelling and representation of the knowledge of domain experts and information about the textile objects themselves in the form of an OWL ontology, and the development of a suite of search facilities to be supported by the ontology. This paper describes the research challenges we faced in developing the ontology and search facilities, the methodology adopted, the design and implementation of the system, and the design and outcomes of a user evaluation undertaken with a diverse group of domain experts. Other aspects of the project, not discussed here, included the production of a detailed 'anatomy' of each textile sample in 3D, allowing researchers to visualise weaving structures in detail and more precisely than is possible in 2D; and the development of two graphical editors to help document different kinds of textile structures and techniques [Gyory 2012; Martins et al. 2013].

The contributions of this paper are:

—the methodology and processes used for developing the ontology — to the best of our knowledge, this is the first time that ontological modelling has been undertaken for the domain of Andean weaving;
—the technical approaches used to implement the ontology and search facilities;
—the design and outcomes of a user evaluation study conducted with a group of domain experts to assess the usability and usefulness of the ontology and the search facilities.

Related Work. There are many publicly available digital textile archives world-wide. For example, the American Textile History Museum (`http://www.athm.org/`) and the TEXMEDIN digital library (`http://www.texmedindigitallibrary.eu/`) offer keyword search over their extensive collections of textiles; the Textile Museum of Canada (`http://www.textilemuseum.ca/`) offers keyword search while also supporting browsing facilities according to textile type, region, materials, techniques, and period; and the University of Leeds International Textile Archive (ULITA) (`http://ulita.leeds.ac.uk/`) offers keyword search over a textiles collection organised according to several regions (European, Egyptian, Indian, Indonesian, Japanese etc.) but offers no section on Andean weaving. None of these resources captures the specific context of Andean textiles, whereas our archive is searchable by specific textile structures and weaving techniques unique to South America.

Ontologies allow the representation of both explicit and implied concepts and relationships relevant to a particular domain [Gruber 1993], and ontologies are being developed in many fields in order to provide standard terminologies and classifications for knowledge representation and sharing within communities. In the context of textile domains, ontologies targeted at the textile production industry are discussed in [Duque et al. 2009], while an ontology describing traditional Malay textiles is presented in [Nasir and Noor 2011]. However, to our knowledge, our project is the first that has undertaken ontological modelling for the domain of Andean weaving.

Outline of the paper. The remainder of the paper is structured as follows. The next section highlights the major research challenges we faced in undertaking this work. Section 3 describes the methodology and technical approaches employed for developing the ontology and search facilities. Section 4 gives an overview of the overall system and details of how the search facilities were implemented. Section 5 describes the design and conduct of a user evaluation of the system with a diverse group of domain experts. In Section 6 we discuss and analyse the results of this user evaluation and how the users' feedback was used to improve the system. In Section 7 we summarise the work reported here, highlighting achievements and identifying several areas of future work.

2. RESEARCH CHALLENGES

The information relating to Andean textiles can be very complex and even for a domain expert it is far from straightforward to model this domain knowledge. For example, existing classificatory systems of textile structures and techniques from the Andean region are based mainly on technical criteria developed in other regions of the world, which are insufficient [D'Harcourt 2002; Emery 2009; Rowe 1977]. One significant weakness is that previous studies focused principally on the longitudinal axis of the weave, thus identifying the textile techniques by counting the rows of the weft. However, in the case of warp face weave — which is a contemporary weaving technique widely used in Bolivia — weavers do exactly the opposite, applying counting to the horizontal axis of the weave [Arnold and Espejo 2012]. The knowledge of domain experts is also often incomplete, due to the fact that Andean textile collections are scattered around the globe, making it hard for individual researchers to gain a full perspective. Different experts may also disagree on how to model certain aspects of the knowledge related to textiles. For example, many museum collections and databases catalogue textiles following an art historical approach that focusses on iconography, patterns and colour, often omitting information about weaving techniques and structures, or their archaeological, historical and cultural associations [Martins et al. 2013]. Consequently, both the knowledge model and the data gathered for our project were rapidly evolving, particularly in the early stages of the research.

Due to these challenges we opted to develop an ontology rather than a relational database, or other structured database, to represent the domain knowledge and the data being gathered. An ontology gives more flexibility in integrating both domain knowledge and data as this becomes available and evolves. Moreover, an added advantage of ontologies is that formal reasoning can be applied to validate the evolving knowledge model.

The fact that our ontology was evolving throughout the project also had an effect on eliciting the functionality that would be required by users for the search facilities that it would support, as these facilities could not be decided upon until the ontology had itself reached a reasonably stable state. Moreover, the complexity of the knowledge domain meant that the user requirements relating to the search facilities were initially ill-defined, and highly dynamic and evolving as well.

In addition, we encountered problems such as cognitive mismatch between the domain experts and the computer scientists on the project (different groups understanding and describing the same real-world concept in different ways), and also modelling imprecision (occasionally the real world is just too complex to be mapped precisely into a computer model); these issues are also identified and discussed in [Gašević et al. 2009] as applying more generally to ontology development projects.

It therefore quickly became apparent that the ill-defined and changing software requirements ruled out a traditional, sequential software development methodology for developing the ontology and the search facilities that it would support, and that an iterative development approach would be needed in which domain experts participated in the requirements, design and evaluation aspects of the software development throughout the project.[1]

3. METHODOLOGY

Due to the interdisciplinary context and the complexity of a project such as this, it was clear that no single ontology development methodology would be sufficient. In fact, even for more traditional domains there is a lack of standardised processes. Nevertheless, there are attempts to formalise and integrate best practices. In our case we used a blend of different techniques that also appear in existing ontology development methodologies. We first give a brief overview of existing frameworks and their relation to our approach in Section 3.1 and then provide a description of our methodology in Section 3.2.

3.1 Existing Ontology Development Methodologies

A well-known methodology for ontology development is METHONTOLOGY [Fernandez-Lopez et al. 1997], which consists of six phases (specification, conceptualisation, formalisation, integration, implementation, and maintenance) and four activities (planification, acquiring knowledge, documenting, and evaluating). Due to the exploratory nature of our project, it was not possible to start off with a detailed specification. The specification became available step by step after progressing with other parts of the development, which meant that an adaptive and agile style of planning had to be adopted. Although the documentation has been revised and made it available via the project website (see `http:`

[1]The main domain experts involved in the project were Denise Y. Arnold (lead domain expert, anthropologist, Director of ILCA, La Paz) and Elvira Espejo (weaver, currently Director of Museo Nacional de Etnografía y Folklore – Musef, La Paz). Other domain experts in the project team were: art historians Miriam de Diego, Julieta Elizaga and Cristiana Bertazoni; archaeologists Claudia Rivera Casanovas (Bolivia) and Bárbara Cases (Chile); and linguists Juan de Dios Yapita, Efraín Yujra, María Juana Aguilar. For the complete project team please see `http://www.weavingcommunities.org/about/project-team`

//www.weavingcommunities.org/textile-processes), in hindsight using a full-fledged SKOS (Simple Knowledge Organisation System) may have been preferable. Other aspects of our methodology, however, are closer to the METHONTOLOGY framework. Before the implementation of our ontology in OWL [Bechhofer et al. 2009], a conceptualisation phase using yED graphs [yWorks 2013] was undertaken by the lead domain expert. The activity of acquiring knowledge played a central role and is described in more detail in Section 3.2. Integration of existing ontologies did not take place in our project. Towards the start of the project we did study CIDOC-CRM (http://www.cidoc-crm.org/), an ontology that provides a rich structure for describing the concepts and relationships relevant to the general cultural heritage domain. After studying this ontology and discussing it intensively with the domain experts, it became apparent that it was not appropriate for our project. Wanting to emphasise the view of communities of practice, we found CIDOC-CRM too museum-centric. Additionally, CIDOC-CRM completely lacks concepts to describe the textiles and techniques of Andean weaving and its context.

Another relevant methodology is UPON (Unified Process for ONtology building) [Nicola et al. 2005], which applies the Rational Unified Process to developing ontologies. This approach distinguishes five workflows (requirements, analysis, design, implementation, and test) and four phases (inception, elaboration, construction, and transition). While we adopted the iterative and incremental elements of UPON, we did not strictly follow its workflows and phases. Again, due to the exploratory nature of our project, the specification of the requirements was spread out over more time than is common. Nevertheless, important parts of other workflows, such as identification of relevant terms (analysis), bottom-up refinement of concepts and their relations (design), and testing the system using competency questions (test), were also part of our approach.

Finally, we also investigated the On-To-Knowledge Methodology (OTKM) [Sure et al. 2003], but found it too focused on the corporate and enterprise domains.

3.2 Overview of Our Approach

Figure 1 gives an overview of the whole ontology development process, the artefacts created, and the tools used.

In the first phase of the project (about 21 months) the domain experts gathered and analysed a large amount of data, most of it recorded in spreadsheet form, since this was a tool they were already familiar with.

In the next phase, the lead domain expert modelled the domain using yED graphs [yWorks 2013]. The reason for choosing to represent the ontological information contained implicitly within the spreadsheets in this intermediate visual form (rather than progressing directly to an ontology representation) was the greater ease, for the non-computer scientists on the project, of understanding and correcting the complex inter-relationships between concepts than would have been possible by moving directly to a more formal ontology representation.

After the completion of the yED graphs, we transformed them into the OWL ontology language [Bechhofer et al. 2009] by writing XQuery-based scripts to generate the T-Box, which is the terminological component of the ontology (i.e. containing the model of the domain). Here another advantage of using yED becomes evident: it is possible to directly process yED graph data using XQuery, as its file format uses the graphml markup language. The A-Box, which is the assertional component of the ontology (i.e. containing the data itself), was created directly from the spreadsheet data using a three-step approach that we detail in Section 3.5 below.

In addition to using XQuery to transform the yED graphs, we also wrote XQuery-based scripts to validate the outputs of each phase with respect to those from the previous phases. This allowed us to

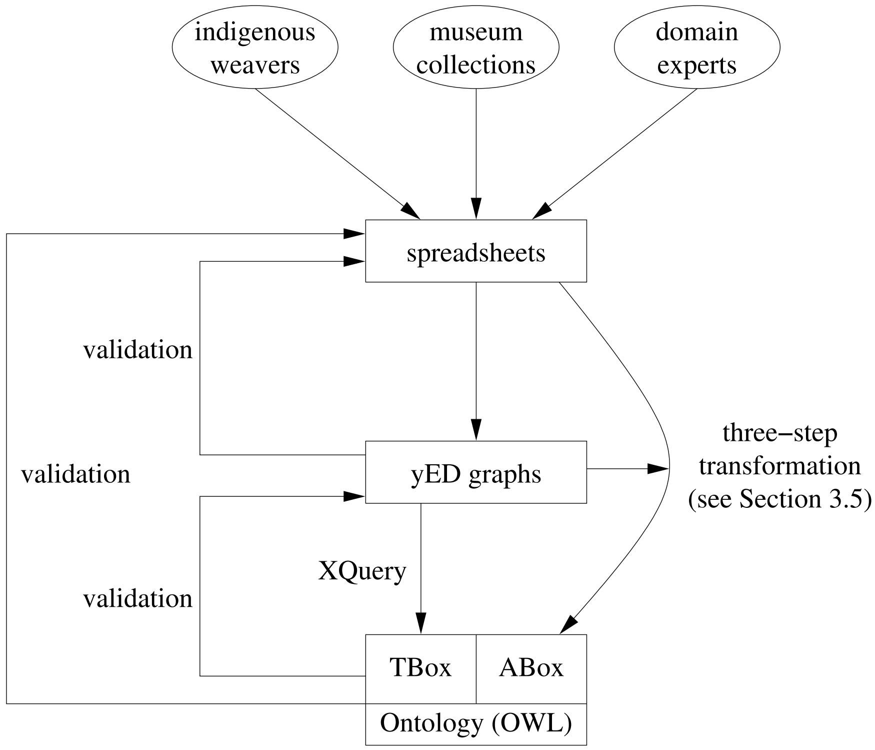

Fig. 1. High-level overview of the ontology development process

check the consistency of the artefacts constructed in successive phases and to correct any inconsistencies between them.

In Sections 3.3 to 3.6 below we discuss in more detail the methods of data gathering, domain modelling and ontology development. We then discuss in Section 3.7 the methods for developing the search facilities supported by the ontology.

3.3 Data Gathering

The data was collected incrementally by the project domain experts in collaboration with several museums holding extensive Andean textile collections[2]. It was sometimes necessary for the project domain experts to make return visits to a museum, in order to view specimens not available in previous visits or to clarify points of ambiguity.

The project domain expert teams also visited communities in the Andes in places such as Qaqachaka, Bolivar, Sacaca and Mollo in Bolivia, Puno, Pitumarca and Chawaytiri in Peru, and Colchane and Pisigacarpa in Northern Chile, interviewing active weavers, observing their techniques and styles, and examining their weavings. This information was complemented by historical research on linguistic terms [Arnold and Espejo 2013].

[2]The Museo Nacional de Etnografía y Folklore and the Museo Nacional de Arqueología de Bolivia in La Paz, Bolivia; the Museo Arqueológico y Antropológico de San Miguel de Azapa and the Universidad de Tarapacá in Arica in Chile; the Centro de Textiles Tradicionales del Cuzco in Peru; and the British Museum and Victoria and Albert Museum in the United Kingdom.

The knowledge elicitation process was greatly helped by having an expert weaver, Elvira Espejo, as a member of the project team, who was able to directly examine textile artefacts to gain first-hand information about their attributes. The fact that the domain experts were continuing to collate information and gain new insights as the project progressed affirmed our design decision to opt for the flexibility of an iterative development of an ontology.

During several project workshops and visits, interviews and informal meetings were held with several other domain experts to discuss and affirm the validity of the data being gathered[3].

The outcome of this extensive data gathering phase ultimately consisted of approximately 30 different spreadsheets, containing about 1000 rows in total. They include descriptions of 700 different textile objects in terms of type, size, form, colour, iconography, weaving techniques, structure, and archaeological and cultural associations. Also captured was data referring to museum collections and descriptions of the production process of the raw materials. The coverage and content recorded in the spreadsheets changed considerably during this period of data gathering, demanding constant information exchange between domain experts (DEs) and knowledge engineers (KEs) across two continents, which was all the more challenging due to different time zones and languages involved. There were several trips between the DEs and the KEs, a Wiki repository was set up to exchange information (using Mediawiki), Skype meetings were held regularly, and monthly summary reports were also exchanged between the DEs and KEs.

Due to the sheer amount of data being gathered, the project team opted to transform the domain knowledge into an ontology incrementally, prioritising the content of the different spreadsheets. Two key spreadsheets were identified and given the highest priority: the ProductoTextil spreadsheet, which stores information about the textile objects, and the Vocabulary spreadsheet, which contains a complete set of permissible words and phrases that can be used within the textile descriptions in ProductoTextil (excluding numbers and free-text descriptions).

3.4 Domain Modelling

At the end of the data gathering period, the information in the spreadsheets relating to key concepts, properties, relationships and example instance data was re-represented visually by the lead domain expert using the yED freeware tool [yWorks 2013]. The domain modelling was undertaken in Spanish in the first instance, with specialist terminology also being recorded in the Andean languages Aymara and Quechua. RDF support for localisation (using `rdfs:label`) was subsequently utilised in order to support English translations of the main modelling concepts.

When modelling real-world concepts there are often different options in making choices about which modelling constructs to use. One recurring decision was whether to model a concept as a class or as an individual. When domain experts express their knowledge in sentences such as “X is a Y”, this could mean that X is a subclass of a class Y or that X is an instance of a class Y. For some entities, such as physical entities, resolving the ambiguity was straightforward: physical entities are clearly individuals e.g. stating that “the Victoria & Albert Museum is a museum”. For non-physical entities however, it is sometimes less obvious. For example, when faced with the statement “red is a colour” should we model the colour “red” as a class or as an instance? Depending on the context, both may be plausible: if we interpret “red” as a family of shades of red, then modelling it as a class makes more sense; however, if we think of a specific shade of red, e.g. having a certain RGB value, then this could be represented as

[3]Ann Pollard Rowe, from the Textile Museum in Washington D.C., Sophie Desrosiers, from the École de Hautes Études en Sciences Sociales (EHESS) in Paris, Helen Wolfe, from the British Museum in London and Penelope Dransart, from the University of Wales, Trinity St. Davis.

an individual. A pragmatic approach to this problem was developed and followed by the project team, with the following heuristics being used as guidelines for the domain modelling:

—to be modelled as classes:
  —all entities that are families of things; for example, the family of all kinds of red colours;
  —all entities that need to be conceptually differentiated further; for example, a collective term for a set of styles, cultural affiliations, techniques, structures, motifs;
—to be modelled as individuals:
  —all physical entities; for example, museums, countries, persons (e.g. donors);
  —all non-physical entities that cannot have instances or subclasses; for example the most specific colours, most specific styles, most specific cultural affiliations, most specific techniques, most specific structures, most specific motifs;
—irrelevant instances of classes should not be modelled, for example:
  —there should only be a colour individual of a certain RGB value in the ontology if there is a textile object that displays this colour;
  —only countries, museums and people that are relevant in the context of the project should be recorded in the ontology;
  —no individuals are modelled relating to animals, materials, fibres or threads.

The yED diagrams produced by the lead domain expert were of two types — those relating to concepts, properties and the relationships between them (corresponding to the terminological component, or T-Box, of the ontology) and those relating to instance data (corresponding to the assertional component, or A-Box, of the ontology). About 25 diagrams were produced in total. The number of concepts in each diagram ranged from 10 to 300; the number of class/superclass relationships from 10 to 300 and the number of properties from 5 to 100.

An iterative process of validation of the yED diagrams and the spreadsheets then followed, undertaken collaboratively with the lead domain expert. Inconsistencies within the diagrams, and between the diagrams and the spreadsheet data, were identified and corrected. A set of XQuery-based validation scripts were developed to compare each spreadsheet with the Vocabulary spreadsheet, producing a report of the vocabulary inconsistencies. These reports were used to manually correct the spreadsheets and the yED diagrams as necessary. The overall aim of this iterative validation and correction process was to ensure that the modelling of the knowledge domain within the yED diagrams and the spreadsheets was consistent and captured as closely as possible the consensus amongst experts in the Andean Weaving field.

At the end of this process of validation of the yED diagrams and spreadsheets, work began on developing the ontology and the search facilities that it would support.

3.5 Ontology Development

The ontology representation language chosen was OWL Lite, which is a sublanguage of OWL [Bechhofer et al. 2009]. OWL Lite, as well as OWL, has several advantages: it is a widely accepted standard ontology language, includes all the modelling primitives required by the project, and is supported by numerous open source software tools. A major feature is its formal semantics, allowing formal reasoning over OWL/OWL Lite descriptions. Although OWL Lite has certain restrictions concerning expressiveness compared to OWL, it guarantees termination and efficiency of reasoning processes. Moreover, the constructs included in OWL Lite, which provide the basic building blocks for constructing subclass hierarchies, are sufficient for our purposes.

The T-Box of the ontology is restricted to subclass axioms and domain/range restrictions, which can be interpreted as implicit existential/universal restrictions. However, it does not contain any explicit existential/universal restrictions or role axioms, apart from transitivity. The final versions of the T-Box yED diagrams were automatically transformed into an OWL representation by developing XQuery scripts that took yED graphml files as input and produced RDF/XML files as output. For example, the RDF fragment below was the outcome of an automatic transformation process (using XQuery scripts) defining subclass axioms between various classes of *periods* (the identifiers Period_1, Period_39, etc. were automatically generated by our scripts). For ease of readability, we use the OWL Manchester syntax [Horridge et al. 2006] to describe parts of the ontology:

```
Class: Period_1
    Annotations:
        rdfs:label "Period"@en,
        rdfs:label "Periodo"@es

Class: Period_39
    Annotations:
        rdfs:label "Periodo Arqueológico"@es,
        rdfs:label "Archaeological period"@en
    SubClassOf: Period_1

Class: Period_40
    Annotations:
        rdfs:label "Historical period"@en,
        rdfs:label "Periodo Histórico"@es
    SubClassOf: Period_1

Class: Period_41
    Annotations:
        rdfs:label "Periodo Contemporáneo"@es,
        rdfs:label "Contemporary period"@en
    SubClassOf: Period_1
```

The A-Box of the ontology contains only atomic class and role assertions. Only a few facts of the A-Box were represented in the yED graphs (e.g. class assertions about countries), with the majority of the A-Box facts being contained within the spreadsheets. These spreadsheets were transformed into RDF in three steps:

(1) Transforming the spreadsheet data into an equivalent XML format, using XQuery scripts. XQuery was chosen for this purpose due to its powerful querying and transformation capabilities on structured and semi-structured data.
(2) Transforming the initial XML format into an intermediate XML format, using a set of 'interpretation templates' that were manually derived from the yED diagrams. The interpretation templates are themselves encoded as XML files and they specify which pairs of columns in the ProductoTextil spreadsheet constitute a relationship. All cells belonging to one textile object are automatically grouped into an XML fragment, termed a 'frame', representing the relationships between all parts the object as well as relationships between the object and other entities in the knowledge base.
(3) Transforming the XML intermediate format into RDF.

To illustrate the cross-linking process in Step 2, we show below an excerpt from the ProductoTextil spreadsheet relating to information about the textile object ILCA_ASU004, which is held in a row of ProductoTextil. Notice that there is a column of ProductoTextil containing the textile ID and one containing the period:

...	ID	place of production	...	chronology	period	...
...	ILCA_ASU004	Ayllu Tinkipaya	...	1990-2010 AD	Republicano Tardío (1900–now)	...

The following extract of an interpretation template specifies the scheme that relates textile objects to periods:

```
<subject top-concept="ILCA_textile_object" col="ID">
    <predicate name="produced_during">
        <object col="period"/>
    </predicate>
</subject>
```

This template can be understood as an instruction on how to transform a given line in the spreadsheet into a set of assertions, specifically in this example: 'Take the value X of the cell from column `ID` (attribute `col="ID"`) and assert that (i) X is of type `ILCA_textile_object` (attribute `top-concept= "ILCA_textile_object"`) and (ii) X is `produced_during` (`<predicate name= "produced_during">`) the value of the cell in column `period` in the same row (attribute `col="period"`)'. Hence, applying this template to the data displayed in the above table yields the following frame representing a class and a property assertion (the identifier Period_38 has been automatically generated; `period3093` references the column `period` of row 3093 in the spreadsheet):

```
<subject id="ILCA_ASU004" top-concept="ILCA_textile_object">
    <predicate name="produced_during">
        <object ref="Period_38" register-ref="period3093">
        </object>
    </predicate>
</subject>
```

The RDF description generated from the above frame fragment in Step 3 is:

```
Individual: ILCA_ASU004
     Types: ILCA_textile_object
     Facts: produced_during period_38
```

Using the OWL Ontology Metrics tool from the University of Manchester (`http://mowl-power.cs.man.ac.uk:8080/metrics/`), we determined the following numbers relating to the ontology (if a certain aspect does not appear in the table, it is not present in the ontology)[4]:

[4]The ontology source files are available from `http://www.weavingcommunities.org/about/software`.

Aspect	Count
Classes	2,616
Object properties	50
Data properties	18
Individuals	44,287
Logical axioms	121,212
SubClass axioms	1,290
Entity annotation axioms	10,425
Class assertion axioms	29,029
Object property assertion axioms	74,319

3.6 Formal Reasoning for Model Validation

A final observation about the ontology development process is that using an ontology language such as OWL to represent the knowledge model makes it possible to apply formal reasoning to validate the model. As an example, we look at an excerpt of the class hierarchy of textile products. This class hierarchy is present within the spreadsheet ProductoTextil, in which every textile product is described using a number of columns, among them columns called type, subclassification, group, subgroup and subsubgroup. The table below shows fragments of two entries from the spreadsheet. This information was used by the domain expert to create a class hierarchy in yED. During this step, the assertion that Apero and Prenda are disjoint was also added, which implies that Costal and Bolsa agropastoril must both be disjoint with Bolsa.

...	type	subclassification	group	subgroup	subsubgroup	...
...	Apero	Apero de tela	Bolsa agropastoril	Costal	-	...
...	Prenda	Accesorio	Bolsa	-	-	...

Transforming this knowledge into OWL allows us to use the HermiT reasoner (`http://hermit-reasoner.com/`) of the Protégé ontology editor (`http://protege.stanford.edu/`) to validate this part of the ontology. Given below is the model fragment describing the Apero and Prenda class hierarchy:

```
Class: Textile_1
Annotations: rdfs:label "Producto textil"@es

Class: Textile_2
Annotations: rdfs:label "Apero"@es
SubClassOf: Textile_1
DisjointWith: Textile_6

Class: Textile_3
Annotations: rdfs:label "Apero de tela"@es
SubClassOf: Textile_2

Class: Textile_4
Annotations: rdfs:label "Bolsa agropastoril"@es
SubClassOf: Textile_3

Class: Textile_5
Annotations: rdfs:label "Costal"@es
```

Class	Aymara	Quechua
Bolsa	qhañi, wayaqa, ...	wayaqa, wayuña, ...
Bolsa agropastoril	qhañi, wayaqa, ...	wayaqa, wayuña, ...
Costal	wayaqa, kustala, ...	jatun wayaqa, jatun wayqa, ...

Fig. 2. Excerpt from the Equivalences table associating classes to terms in Aymara and Quechua

```
SubClassOf: Textile_4

Class: Textile_6
Annotations: rdfs:label "Prenda"@es
SubClassOf: Textile_1
DisjointWith: Textile_2

Class: Textile_7
Annotations: rdfs:label "Accesorio"@es
SubClassOf: Textile_6

Class: Textile_8
Annotations: rdfs:label "Bolsa"@es
SubClassOf: Textile_7
```

Thus far everything seems fine. However, the domain experts had also modelled relationships between different kinds of textiles via a translation table called "Equivalences" — see Figure 2. In this table, one or more terms in Aymara and Quechua are associated with each class of the class hierarchy. In order to formalise the domain experts' interpretation of the "Equivalences" table, each term was modelled as a class on its own. For example, we created a class called `Aymara_wayaqa`. Furthermore, following the domain experts' view, we defined an equivalence between a class of the class hierarchy and a term class if they appear in the same row of the table. For instance, we have `Bolsa = Aymara_wayaqa`, `Bolsa agropastoril = Aymara_wayaqa` and `Costal = Aymara_wayaqa`.

A first result of formal reasoning for this model was that several classes of the same branch of the class hierarchy could not be proper subclasses. For instance, Costal was modelled as a subclass of Bolsa agropastoril, but it could not be a proper subclass, since the statements `Bolsa_agropastoril = Aymara_wayaqa` and `Costal = Aymara_wayaqa` imply the statement `Bolsa_agropastoril = Costal`. The interpretation of the Equivalences table for the Aymara term "wayaqa" described above extends the OWL model fragment by the following statements:

```
Class: Aymara_wayaqa
EquivalentTo: Textile_4
EquivalentTo: Textile_5
EquivalentTo: Textile_8
```

This result helped us to review the domain experts' interpretation of the Equivalences table, since the intention of the class hierarchy was to imply a proper subclass ordering and not to provide a list of potentially equivalent classes.

A further investigation revealed additional conflicts: following the domain experts' intuition, we modelled the top-level classes in the textile class hierarchy as disjoint (e.g. Textile_2 and Textile_6 above). However, the equivalence statements inferred from the Equivalences table not only led to inconsistencies within an individual branch of the subclass hierarchy but also across different branches.

Formal reasoning led to the conclusion that some classes must be empty in this model, namely those claimed to be equal and subclasses of disjoint top-level classes. For instance, the Equivalences table states `Costal = Aymara_wayaqa` and `Bolsa = Aymara_wayaqa` and hence `Costal = Bolsa`. On the other hand, Costal is a subclass of the top-level class Apero whereas Bolsa is a subclass of the top-level class Prenda and therefore they are disjoint (by the disjointness assumption of top-level classes). In conclusion, Costal and Bolsa must be equivalent and disjoint at the same time, i.e. they must be empty in this model. However, this was not intended by the domain experts and had to be resolved.

3.7 Developing the Search Facilities

For the search facilities to be supported, two major use cases were identified: (i) the need for the user to be able to browse through the ontology by navigating through its classification hierarchies; and (ii) the need for the system to be able to support a set of queries each targeting a specific research question that a domain expert may have. Powerpoint mock-ups drawn up by the lead domain expert were initially used as a tool for designing the user interface. The set of queries relating to (ii) were iteratively developed in collaboration with the domain experts and we list them in Appendix C. All of these queries were implemented (the PHP/SPARQL code is listed in the supplementary Appendix D) except for Queries 20 and 21 for which the date of first appearance of a technique or structure is required; these two queries could not easily be supported as time periods are currently represented as strings in the ontology and would need to be remodelled into a date format (we leave this as future work).

Following the production of the final version of the ontology at around month 39 of the project, the last phase of the project involved the development of the search facilities, and their evaluation with a broader group of domain experts, over a period of 6 months. In this phase, although we first implemented individually each of the queries identified for use case (ii) (except Queries 20 and 21), it subsequently became apparent that a more general querying facility would be able to support all of these queries, and more. We therefore designed a new, generic, querying facility that encompasses this more general functionality. We describe this and the browsing facility in more detail in Section 4.

4. SYSTEM IMPLEMENTATION

The website for the whole project has been created using the Plone CMS [Plone Foundation 2013] and can be viewed at `http://www.weavingcommunities.org/`. A tab labelled ‘Textile product search’ in the top-level webpage links to a Web Application that we have built on top of the ontology. This application supports the following facilities:

—Textile Browsing: allows the user to browse through different parts of the ontology by navigating through its classification hierarchies. This is use case (i) discussed in Section 3.7.

—Textile Search: allows the user to construct a query relating to one or more attributes of the textile objects as inputs and displaying a selected attribute for the output. This facility provides in a more general way all of the queries relating to use case (ii), except for Queries 20 and 21 — which could not be easily supported, as discussed in Section 3.7; and Query 9 — which required retrieval of the images relating to a single textile object by specifying its Textile ID. This latter query does not fall into the same querying pattern as the rest — since it takes as input an actual Textile ID — and so we supported it via a separate Textile Retrieval facility.

—Textile Retrieval: allows the user to see the full details of a textile or a 3D visualisation of a textile, as selected by the user from the full list of Textile IDs.

In addition to the ontology and the search facilities which are the topic of this paper, there are also web pages describing the project itself, the textile production chain, learning how to weave, instruments used, structures, techniques, and textile heritage.

To use the Textile Browsing facility of the Web Application, the user selects the Textile Browsing option from the main menu at the left-hand side of the user interface — see Figure 3. Having done that, the user can select one of the classification hierarchies listed (Colour, Component, Composition etc.) thereby opening up a sub-menu of subclasses of the selected class. Selecting one of these subclasses leads to the system displaying images within the main pane of the screen of all the textile objects that belong to this subclass. Continuing to select subclasses down a branch of the classification hierarchy repeatedly refines the set of textile objects being shown in the main pane. As a concrete example, suppose the user wishes to see which textiles were produced in the Early Intermediate period. The user first selects the 'Period' classification hierarchy, and then the 'Archaeological period' subclass of 'Period' — at this point, images of all the textile objects belonging to this subclass would be displayed in the main pane. The user refines their search further by selecting the 'Early Intermediate (200 BC-600 AD)' subclass of 'Archaeological Period'. Figure 3 shows the appearance of the screen at this point, together with the results returned (there are 9 textile objects falling into this category).

The user can now click on one of the images shown in the main pane and a new pop-up window will appear displaying details of that textile object. For example, clicking on the image in the middle of the second row of Figure 3 results in Figure 4 being displayed in a new window. In this window, the user can see the full data relating to the selected textile object, can zoom into the displayed image, and can browse through all the other images relating to this textile using the right and left arrows at the top of the page. In addition to the default Details tab, there are also tabs that allow the user to see a textual description of the textile object's composition and structure (General Description), a map showing the location of the collection it belongs to (Repository map), and maps showing the sites were it was produced (Production site map) and found (Find site map). We notice that each of the textile objects is identified by a unique Textile ID which is displayed at the top of the details window e.g. Figure 4 is showing the details of textile object ILCA_VAM003.

To use the Textile Search facility of the Web Application, the user selects the Textile Search option from the main menu at the left-hand side of the user interface — see Figure 5. This allows the user to set up a more complex query, consisting of a number of query filters and a selected type of query output. For example, suppose the user wishes to know: "What are the Find sites of textile objects produced in the Early Intermediate period and containing the colour blue?" This query has two filters: "produced in the Early Intermediate period" and "containing the colour blue"; and the output is a list of "Find sites". To set up the first filter, the user selects (in the same way in the Browsing example earlier) Period, then Archaeological period and then Early Intermediate (200 BC-600 AD). To set up the second filter, the user selects Colour and then blue. Figure 5 shows the appearance of the screen at this stage — the input filters are incrementally displayed at the top of the main pane as they are being constructed by the user. To choose the type of output, the user clicks on the pull-down menu under 'Select one output type' and then selects Find site. The output type is now displayed too at the top of the main pane.

The user is now ready to run the query and does so by pressing the 'Search' button. Figure 6 shows the appearance of the screen at this stage, with the final query being displayed at the top and the results listed below. We see displayed the list of query answers (Bolivia, Central coast, Nasca etc.). Since these are geographical locations, if the location information is available in the ontology we display the relevant map too. Next to each answer is displayed a *product details* link. Clicking on this opens up a new window showing images of the textile objects with that particular Find site (similarly to Figure 3). As in the Browsing facility, the user can now click on any of these images to see more details about this object.

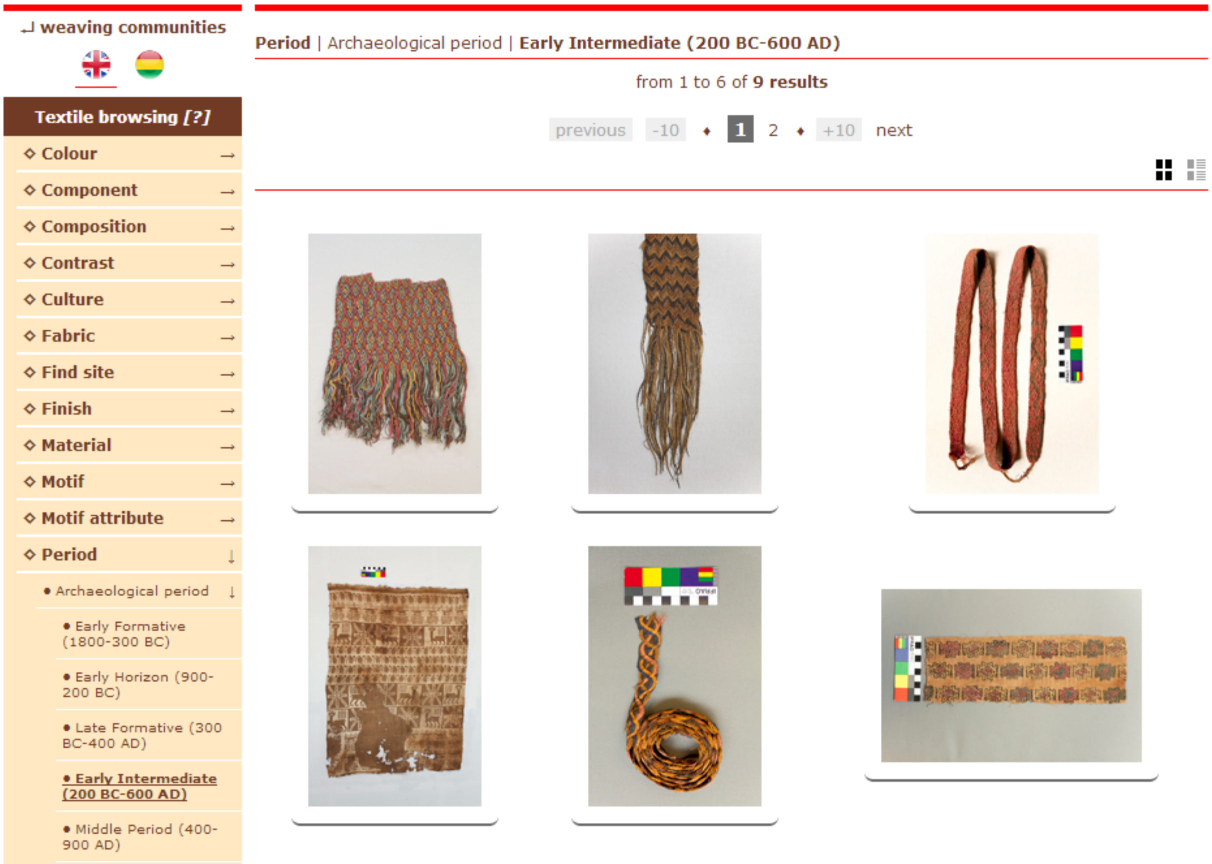

Fig. 3. The Textile Browsing facility allows the user to explore textiles by navigating through the classification hierarchies. Sources of textile samples clockwise from top left: British Museum [Am1954,05.448]; British Museum [Am1907,0727.4]; Museo Nacional de Arqueologia, La Paz [661]; Victoria and Albert Museum [CIRC.415-1932]; Victoria and Albert Museum [T.60-1965]; Museo Nacional de Etnografia y Folklore, La Paz [19351]. Photographs copyright of the Instituto de Lengua y Cultura Aymara (ILCA), La Paz.

Having set up a query, it is possible to change the type of its output and re-run it. For example, the previous query can be modified to find out "What are the Cultures of textile objects produced in the Early Intermediate (200 BC-600 AD) period and containing the colour blue?" by selecting Culture as the output type and then pressing Search again. It is also possible to modify a query by dropping one of the input filters. For example, our query can be modified to find "What are the Cultures of textile objects containing the colour blue" by clicking on the first filter to delete it and then pressing Search again. It is also possible to add more filters to the current query. By pressing 'Reset search' it is possible to set up a new query.

Finally, to use the Textile Retrieval facility of the Web Application, the user selects the Textile Retrieval option from the main menu at the left-hand side of the user interface. This option allows the user to view either the full details or a 3D visualisation of a textile. Viewing the full details of a textile corresponds to Query 9 in Appendix C, which is the only query (along with Queries 20 and 21) that is not encompassed by Textile Search. The system presents the user with the full list of Textile IDs

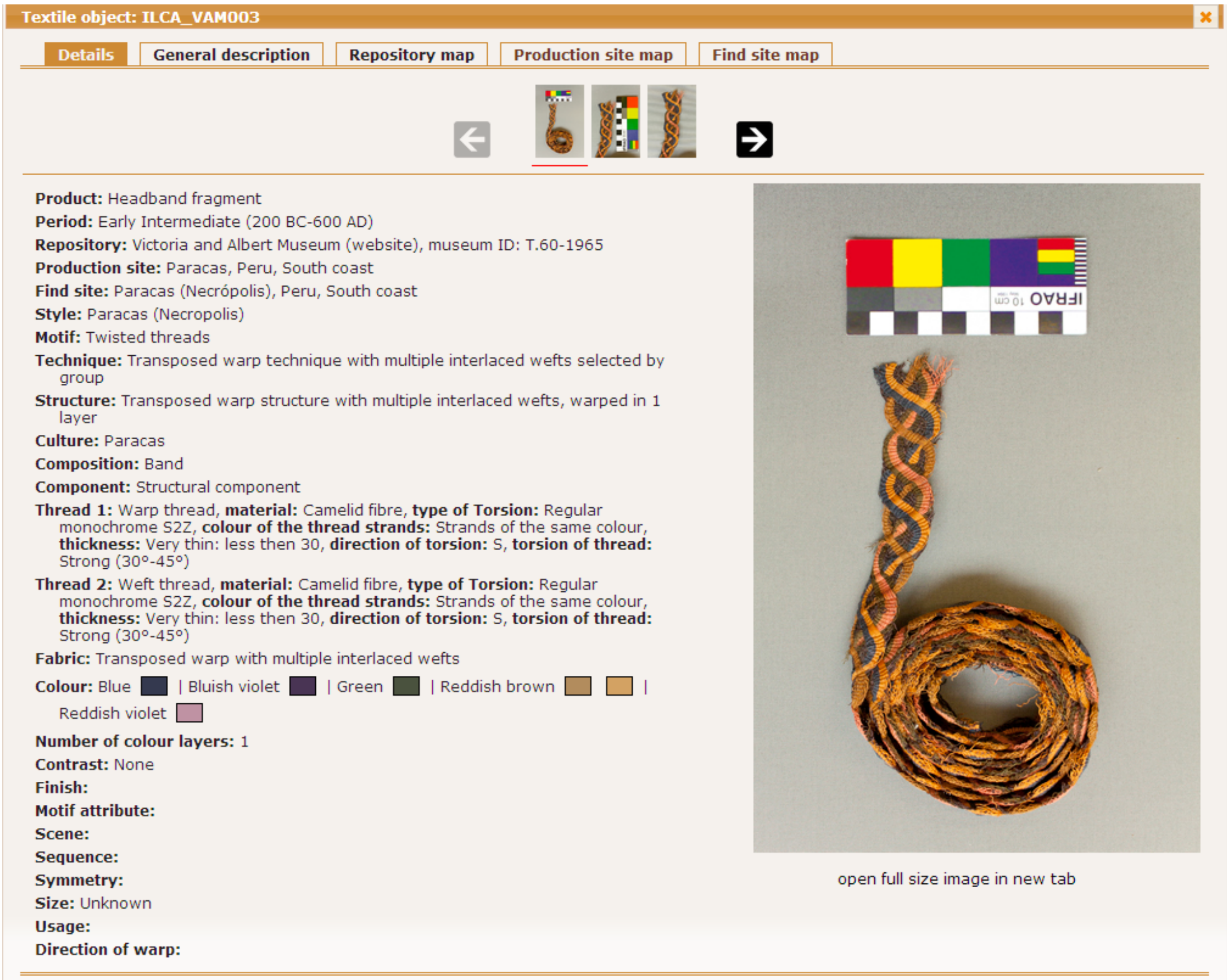

Fig. 4. Display of details of a textile object (ILCA_VAM003) in the Textile Browsing facility. Source of textile sample: Victoria and Albert Museum [T.60-1965]. Photograph copyright of the Instituto de Lengua y Cultura Aymara (ILCA), La Paz.

(in alphanumeric order) and the user selects the desired one. The details of the selected textile are then displayed similarly to Figure 4. If the user selects to view a 3D visualisation of a textile, then again the full list of Textile IDs is presented, the user selects the desired one, and the system displays a 3D model of the textile. This model can be manipulated (rotated and zoomed into) by the user to explore its structure and composition. Figure 7 shows an example 3D visualisation of a textile object. This facility is implemented using the JSC3D JavaScript library (`http://code.google.com/p/jsc3d/`) which exploits the canvas feature of HTML5 to perform rendering and user interactions. The use of JavaScript and HTML5 ensures compatibility with all modern browsers without the need to install any plugins.

The Apache Jena framework [Apache Software Foundation 2013] was chosen as a basis for our development because it provides a rich toolset for developing semantic web applications; it is open-source; it is widely used within the semantic web community, so there is a high level of peer support

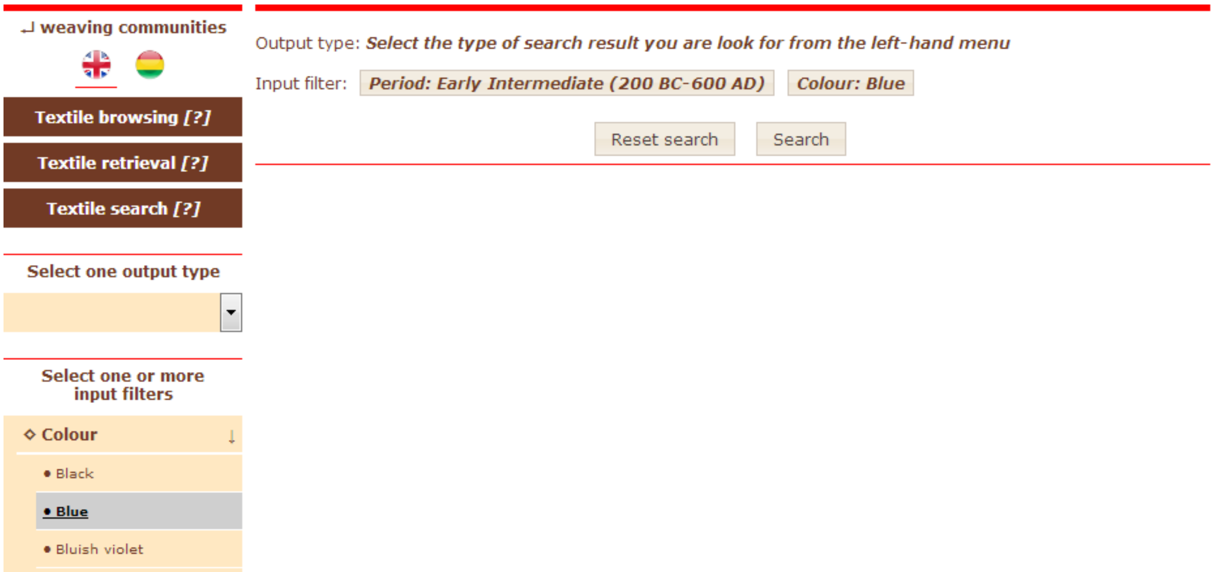

Fig. 5. The Textile Search Facility, with input filters selected and output type to be selected.

available for application development; and its SPARQL query server, Fuseki, is compliant with the W3C SPARQL 1.1 standard [SPARQL Working Group 2013].

The Web Application was built using PHP following the Model-View-Controller design pattern [Leff and Rayfield 2001]. Fuseki is used as a middleware layer interfacing the application to the ontology. PHP-SPARQL-Lib, which is part of Graphite (`http://graphite.ecs.soton.ac.uk/sparqllib/`), was used to provide a PHP API to Fuseki. The multimedia resources (e.g. images) are stored on a conventional file server, with their filenames being referenced within the ontology. The Browsing and Search results are retrieved and displayed using AJAX calls.

The Web Application supports English and Spanish, both at the user interface level and within the ontology itself. We stress that the user interface menus are generated by reading from the ontology and are not hard-coded, thereby allowing extensibility of the application as the ontology evolves. The data retrieved from the ontology is displayed in the user's selected language by using an appropriate FILTER statement within the SPARQL queries generated by the application.

When a query is executed, the Controller component of the application sends the query parameters to the Model component, which executes the necessary queries over the Fuseki SPARQL endpoint. Having collected the query results, the Controller calls the View component appropriate for representing them and builds the web page to be displayed by the client web browser.

For the Textile Browsing facility, the system executes a SPARQL query that includes parameters reflecting the choices made by the user as they are navigating through a classification hierarchy. For the Textile Search facility, the SPARQL query is constructed incrementally as the user specifies the filters and the output type. To evaluate such a query, we retrieve the textile object IDs that satisfy each of the filters, we next create the intersection of these sets, and we then retrieve for each resulting textile object the value of the attribute that has been chosen by the user as the output type of the query. Display of the query results depends on the type of the chosen attribute. Most are textual strings (see, for example, the textile details shown in Figure 4). Locations are displayed as maps, using the Google Maps API V3 [Google 2013], and colours are displayed using a colour canvas.

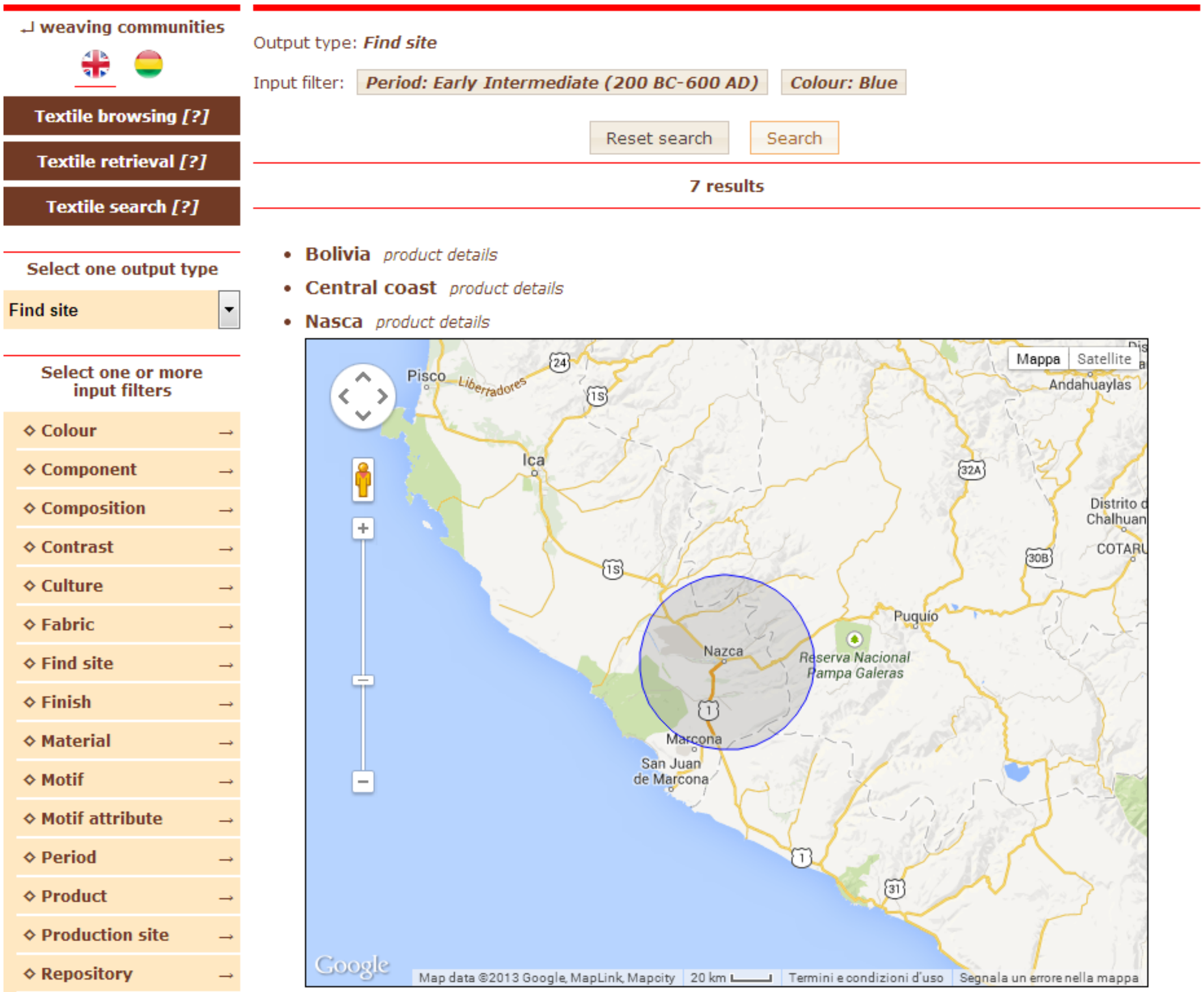

Fig. 6. Display of query results in the Textile Search facility, with input filters and output type selected. The map has been produced using the Google Maps API V3 [Google 2013].

5. USER EVALUATION

We recruited 25 volunteer evaluation participants via our networks of contacts with museums, researchers and textile practitioners. None of these people had had any prior involvement with the project, and Appendix A lists their backgrounds. We held several identically structured evaluation sessions each attended by a subset of the full set of participants. Several days before each session, its participants were sent an information sheet describing the aims and format of the session, and a consent form to sign and return. They were also sent the URL of the project website, so as to be able to gain some background into the aims of the project if they so wished (this was optional).

Appendix B shows the activities sheet that participants were asked to undertake individually during the evaluation session. Participants were asked to undertake two browsing tasks and three search tasks, to record their answers, and to answer a small set of questions regarding the ease-of-use of

Fig. 7. Example of 3D visualization of a textile object (ILCA_ASU002) using the Product 3D view option of the Textile Retrieval facility. Source of textile sample: Museo de Arte Indigena in Sucre [130-2007-E-M-PONCHO]. 3D image rendered in Sawu-3D editor developed by the Instituto de Lengua y Cultura Aymara (ILCA), La Paz. Textile image copyright of ILCA.

the Browsing and Search facilities. Participants were invited to add further comments if they wished. (At the time that most of the evaluation sessions were undertaken, the Textile Retrieval facility had not been fully implemented, so this was not included in the evaluation.) At the end of the five tasks, participants were also invited to answer a set of more general questions about the usability and usefulness of the system. In Appendix B we show the number of participants' answers falling into each answer category for each of the questions within the activity sheet, as well as the additional comments provided by participants.

Each evaluation session lasted approximately two hours. One of the members of the research team started the session by giving an overview of the aims and objectives of the project and then illustrating the Browsing facility on an overhead projector, browsing through the upper levels of the ontology structure and talking through the results being displayed in the main pane of the screen (this introduction took about 25 minutes). The participants were then invited to undertake individually Tasks 1 and 2 of the activity sheet sitting at their own computers. These tasks targeted the Browsing facility and required on average about 20 minutes for participants to complete. The research team member then illustrated the Search facility on the overhead projector, showing how to specify and modify an example query and talking through the query results (10-15 minutes). The participants were then invited to undertake individually Tasks 3, 4 and 5 of the activity sheet. These tasks targeted the Search facility and required on average about 25 minutes for participants to complete. The final 30 minutes of the session was spent by participants first filling out individually the General Questions on their sheet and then in a group discussion.

6. DISCUSSION OF THE USER EVALUATION

Looking first at the results of the Browsing Tasks 1 and 2, we see that 73% of responses were in the 'Very Easy' or 'Easy' categories, which is very encouraging considering that this was participants' first use of the system. The percentage of fully correct answers for these tasks was 72%, and of either fully or partially correct answers was 96%. The comments provided by some of the participants pointed to the two main sources of difficulty they had: (i) understanding the technical terms being used in the classification hierarchies, and (ii) navigating through the menu structure. This feedback has led us to subsequently add "hover-over" explanatory text in the user interface for each of the terms in the classification hierarchies and for each of the three main menu items (Textile Browsing, Textile Retrieval and Textile Search).

Participants' feedback from the first evaluation session also pointed to the possibly different understanding that different domain experts may have of the term "ontology" (see, for example, the comments from Participant 2 in the final question in Appendix B). Thus, although the term "ontology" continued to appear within the participants' activity sheet, we removed any references to it from the user interface of the system itself for subsequent evaluation sessions.

Looking next at the results of the Search Tasks 3, 4 and 5 we see that overall 82% of answers were fully correct, and 95% either fully or partially correct, reflecting participants' more accurate usage of the system as they became more familiar with it during the course of the session, despite the greater difficulty of Tasks 3-5 compared with Tasks 1 and 2.

We see that the percentage of responses falling in the 'Very Easy' or 'Easy' categories increased from 39% in Task 3 to 60% in Task 4 and 75% in Task 5. In parallel, the percentage of responses of 'Mixed Feelings' fell from 47% to 26% to 21%, and of 'Difficult'/'Very Difficult' from 14% in Tasks 3 and 4 to 4% in Task 5. These responses reflect participants' increasing confidence in using the Search facilities of the system. Looking at the comments provided by some of the participants, we see that the main source of difficulty was in navigating through the classification hierarchies in order to find the desired search term; however, participants' comments also show that these difficulties lessened with increased practice and familiarity. This feedback has led us to subsequently produce a video for the project website which demonstrates usage of the Browsing, Retrieval and Search facilities and contains several examples of navigation through the classification hierarchies (see `http://www.weavingcommunities.org/textile-product-search`).

There was also a comment from one participant saying "Would be easier if you were able to type a search". Subsequent discussion with that participant revealed that this reflected a desire for a more familiar keyword-based search facility to be supported. Providing such a facility over the ontology would certainly be possible in the longer term, but was out of the scope of the research project timescale and resources.

Turning now to the General Questions at the end of the activity sheet, we see that most responses to the first five questions, which relate to the usability of the system, fell into the 'Very Easy' or 'Easy' categories. There were only two responses of 'Difficult' — one in the first question (relating to navigating through the ontology) and one in the third question (relating to knowing what to do next). The sixth and seventh questions in the General Questions section related to participants' perceptions of the usefulness of the system, firstly for themselves in their own role (sixth question) and secondly more broadly for other people or institutions (seventh question). For the former question there were 13 responses of 'Very Useful' and 4 of 'Useful'. For the latter question the responses were similar, with 15 responses of 'Very Useful' and 6 of 'Useful'. Both these results and the responses relating to the first five questions on usability are very encouraging and point to the longer-term usefulness of the system.

The textual comments provided by participants to the sixth and seventh questions give specific views on how the system could be used:

—Participant 2: think it could and will be a useful role for people working in this field [cultural studies] or with a strong interest in the topic. Certainly for those with a strong interest in textiles and/or that part of South America it is of considerable interest, particularly to staff, students and researchers based at universities, museums, galleries and so on.

—Participant 3: would show it to young people I work with who are engaged in language and culture maintenance/revitalisation, because of the discussions it would generate about classifying and transferring knowledge which is being lost in their community. It provides an excellent model for thinking about classifying other types of knowledge and has implications, for example, in revitalisation/maintenance projects with indigenous languages and knowledges. It helps provide an educational tool for institutions which do not have the resources themselves to disseminate knowledge and that represents resource transfer from north to south as well as intellectual cooperation.

—Participant 4: Looking at patterns and structures for inspiration and discovering the culture that they were produced in. For my students I could recommend that they looked at images relating to material, technique, culture and relative to their area of interest. The system provides a window into the textile methodology and design of other cultures.

—Participant 5: new methods of preserving (digitising) objects of material/non-material culture...Using this system gives a wide knowledge about the objects, with the description of smallest details. It would be of interest to archaeologists, anthropologists, in cultural studies, and to IT specialists.

—Participant 7: to get full and detailed information on products, including geography, period, design etc. Anthropologists working in this particular region may use the available information for all sorts of reason, including but not restricted to, studying techniques, motives woven on the products etc.

—Participant 10: In archaeology — development of earliest tools, from handaxes onwards. In folk costume and folk crafts.

—Participant 13: for patterns and information. Textiles studies; museums; different textiles and fashion slides.

—Participant 14: I am fascinated in fabric structure so would use this to research it e.g. twining. Also for design ideas — and for colour. Research into any of this subject for teaching purpose; for study; for researching what is going on and where there are gaps in practice today.

—Participant 15: Certainly as interested amateur, with a personal collection of Andean textiles. Could you link in with Ecuador institutions? They have done extensive cataloguing and digitalisation of cultural patrimony over recent years.

—Participant 17: Art and Design students — some material for designs — good photo images.

—Participant 22: I think having access to this database would be of particular usefulness for contemporary artists who work with and are interested in textiles.

—Participant 23: I can see this tool being useful for those who work in textiles/history/anthropology.

The group discussions held at the end of each evaluation session generally repeated and reinforced the individual comments recorded within the activity sheets, as well as suggesting some further minor improvements to the user interface which we have subsequently made, for example displaying the accession numbers for textile objects held in repository collections, and enhancing the scrolling capabilities in different parts of the visual display. Generally, the evaluation participants' response to the system was very positive. Several people mentioned that they found the system easier to use as the session progressed. Several people mentioned that they would need to get used to tailoring their own day-to-day terminology to that used within the system as they gained more experience with using the system. Finally, a few people pointed out that the tasks that they were asked to undertake in the evaluation session may be unrealistically difficult as regards assessing the ease-of-use of the system, since it would in fact be easier for them to use the system when investigating their own questions rather than understanding and carrying out the “test” questions in the activity sheet.

7. CONCLUSIONS

This paper has described work on designing, implementing and evaluating a knowledge base of Andean weaving that aims to contribute to curatorial practice and heritage policy. The paper has focussed on the representation of the knowledge of domain experts and the information about textile objects in the form of an OWL ontology, and the development of a suite of search facilities supported by the ontology. We have discussed the research challenges faced in developing the ontology and search facilities, the methodology adopted, the design and implementation of the knowledge base, and the results of a user evaluation of the system undertaken with a diverse group of domain experts.

Particular research challenges arose from the inherent complexity of the knowledge domain, including data in the Aymara, Quechua, Spanish and English languages; the fact that the knowledge of the domain experts was evolving as data was being gathered, translated, discussed and debated; and the fact that the domain experts came from several different academic disciplines and national cultures — ethnographers, linguists, archaeologists, museum curators, weavers, art historians and cultural geographers — each with their own perspectives, viewpoints and priorities. These features made the design and development of the ontology and search facilities much more challenging than ontology development projects in which the domain knowledge is relatively static and represents a single disciplinary viewpoint.

Being able to view digitised textile specimens from a range of different collections, together with the tools offered by the knowledge base for retrieving historical, geographical, archaeological, anthropological and material information about them, enables comparison between previously disconnected artefacts, with the potential to foster new insights[5]. We hope that the system will inspire a new generation of contemporary weavers in the Andean region through the recovery of ancient techniques, and facilitate more generally exchanges and dialogue between different textile traditions across the world.

The methodology and methods adopted for developing the system are generic, and could be applied in other knowledge domains where the views of experts may be incomplete and where the knowledge model may undergo significant changes as domain experts gain new insights during the data gathering phase.

Within the scope of a possible follow-on project, we envision the system being able to incorporate textile collections from other museums and similar institutions and making the knowledge base available to others, thereby expanding its reach and enabling us to test and further develop the approach taken to date. On the technical side this would mean implementing a protocol for exchanging ontological data with other systems. We aim to realise this for our system via an interface based on Open Knowledge Base Connectivity (OKBC) [Chaudhri et al. 1998]. OKBC is available on a wide range of platforms, supporting different programming languages, and offering network transparency to users. This of course will depend of further funding and interest of potential partners, which we plan to foster in the near future by holding small workshops with museum curators in London, and through the creation of a discussion forum on the project website for exchanging ideas with interested parties nationally and internationally.

[5]The Terms of Use of the system may be viewed at http://www.weavingcommunities.org/fair-use-policy

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A. EVALUATION PARTICIPANTS

Participant 1: Museum curator and researcher
Participant 2: Researcher in cultural studies
Participant 3: Researcher in indigenous languages
Participant 4: Textiles designer and lecturer
Participant 5: Researcher in cultural studies
Participant 6: Textiles practitioner, with interest in traditional textile methods
Participant 7: Researcher in cultural studies
Participant 8: Textiles practitioner
Participant 9: Interested in textiles
Participant 10: Researcher in languages, with interests in heritage and weaving
Participant 11: Cultural promoter
Participant 12: Researcher in international studies, with interests in weaving
Participant 13: Interested in textiles
Participant 14: Textiles practitioner, with interests in weaving structures
Participant 15: Researcher in Latin American geography, with particular interest in indigenous cultures
Participant 16: Textiles practitioner, with particular interest in South American textile traditions
Participant 17: Textiles practitioner
Participant 18: Curator of textile-related exhibitions
Participant 19: Anthropologist
Participant 20: Anthropologist
Participant 21: Artist/researcher
Participant 22: Art historian researcher
Participant 23: Digital art expert
Participant 24: Weaver
Participant 25: Curator of textile-related exhibitions

B. EVALUATION ACTIVITY SHEET AND RESULTS

Tasks Using Ontology Browsing

Start your web browser and connect to the Andean Weaving Ontology at the following URL:

`http://weaving.dcs.bbk.ac.uk/TextileProductSearch.php`

Task 1. What are the styles of textile objects containing the motif "With extended wings"?

Answers:	Fully correct: 20 Partially correct: 4 Wrong: 1

	very easy	easy	mixed feelings	difficult	very difficult
Specifying the query is	5	8	4	4	
Finding the answers is	6	11	3	4	
Using the detailed view of each textile object is	13	8			

Any other comment you wish to make	"I would need to spend a long time browsing in order to understand the linguistics comment you and where the search attributes are" "The menus would be easier to navigate if you were able to "hover" over them and the next set of options appeared next to the current menu"

Task 2. What materials are textile objects with style East Yampara made of? Which of these textile objects include the colour bluish violet? (Please identify them by their textile object catalogue number.)

Answers:	Fully correct: 16 Partially correct: 8 Wrong: 1

	very easy	easy	mixed feelings	difficult	very difficult
Specifying the query is	3	12	6	2	
Finding the answers is	7	9	6	2	
Using the detailed view of each textile object is	10	4	3	2	

Any other comment you wish to make	"Being pointed in the right direction in the beginning was a big help." "It is not so intuitive and kind of complex to get the answer, in terms that it is not so efficient to look into each product to find the material"

Task 3. What are the techniques used in textile objects produced by the Aymara-Quechua-North Charcas culture, with complex structural tabular finishing and major contrast?

Answers:	Fully correct: 20 Partially correct: 4 Wrong: 1 [This person actually gave no answer at all, as he/she could not locate the term "complex structural tabular finishing" within the ontology]

	very easy	easy	mixed feelings	difficult	very difficult
Specifying the query is		6	15	3	1
Finding the answers is	2	11	8	1	2

Any other comment you wish to make	"It was difficult because there are so many categories, but I can't imagine it could be different with all the information you have" "At the beginning it is not so easy, but once you get familiar it is kind of easy" "This could be more dynamic, step-by-step filtering whereby options automatically narrow as you click certain criteria" "I am not familiar with the 3 historical periods enough to be quick on that part of the search. Took a try+fail to find right information — it's just practice. Once achieved no difficulty." "Finding most of the information was pretty straightforward, but the complex structural tabular finishing into felt like it was a little bit too buried/hidden" "Would be easier if you were able to type a search"

Task 4. What are the colours of the textile objects made with a tubular warp-faced cloth during the Middle Horizon (600-900/1000 AD) period?

Answers:	Fully correct: 20 Partially correct: 3 Wrong: 2

	very easy	easy	mixed feelings	difficult	very difficult
Specifying the query is	1	12	6	3	1
Finding the answers is	5	12	7	3	

Any other comment you wish to make	"Trying to find right category was experimental. The word 'cloth' threw me." "Again, to the uninitiated "made" could refer to either material or fabric as an output. Also, it is a little confusing that there are two Middle Horizon categories, initially I chose the wrong one!"

Task 5. What textile products are made of acrylic wool with a balanced weave structure, warped in 1 layer?

Answers:	Fully correct: 22 Partially correct: 3 Wrong: 1

	very easy	easy	mixed feelings	difficult	very difficult
Specifying the query is	6	11	6	1	
Finding the answers is	6	13	4	1	

Any other comment you wish to make	"It will take (me) a long time to find my way around and know what is contained in each attribute. I think I could need definitions of the key words used in the search menus" [N.B. these are actually available, by hovering over each word; and this feature was demonstrated to participants at the beginning of the activity] "Would say acrylic fibre — acrylic wool can is a contradiction in terms as acrylic is plastic!" "Again, see above re. confusion of material vs fabric concerning the term "made" " "The system does become easier to use once you understand how to search"

General Questions
About the Andean Weaving Ontology

Navigating through the Ontology is	very easy	easy 13	mixed feelings 11	difficult 1	very difficult
Accuracy of descriptions on screen is	very good 16	mostly good 7	mixed quality 1	mostly poor	very poor
Knowing what to do next is	very easy 3	easy 10	mixed feelings 11	difficult 1	very difficult
Understanding the search results is	very easy 12.5	easy 10.5	mixed feelings 2	difficult	very difficult
The response time of the system is	very good 24	mostly good 1	mixed feelings	mostly poor	very poor

Conclusion

Do you find the system to be a useful tool that you would use?	very useful 13	useful 7	mixed feelings 3	little useful 2	not useful

Please add comments of how the system would be useful to you in your role:

—Participant 1: Don't know whether I'd use it

—Participant 2: I think it could and will be a useful role for people working in this field or with a strong interest in the topic. The subject does not strongly coincide with my own research topics at the moment but as a structure/system it is excellent and could definitely have wider applicability.

—Participant 3: In my role it is not directly relevant but I would show it to young people I work with who are engaged in language and culture maintenance/revitalisation, because of the discussions it would generate about classifying and transferring knowledge which is being lost in their community.

—Participant 4: Looking at patterns and structures for inspiration and discovering the culture that they were produced in. For my students I could recommend that they looked at images relating to material, technique, culture and relative to their area of interest.

—Participant 5: The system is useful for me as I'm interested in new methods of preserving (digitising) objects of material/non-material culture of the [...] people. Using this system gives a wide knowledge about the objects, with the description of smallest details.

—Participant 6: I would formulate my questions using different words, so I would need to learn the language of the site. Then I would need to learn what is a subset of what, I don't need all the search levels. So this isn't a sit down and go website, some learning is necessary.

—Participant 7: It is easy to get full and detailed information on products, including geography, period, design etc.

—Participant 10: My special field of research is the Romani language, its variants, its gestural languages. The craft I am most familiar with is coppersmithing. I can imagine this type of system being used to search for copper objects and their patterns made by different Romani communities (presumably also ironwords, basketry) and the types of Romani caravas/wagons as well as their decorations (inside and outside).

—Participant 13: I love it. I am sure I will use for patterns and information. Some part are a bit confuse with all the filters (too many), but I think you only need to get use to them.

—Participant 14: As a textile artist I am fascinated in fabric structure so would use this to research it e.g. twining. Also for design ideas — and for colour.

—Participant 15: Certainly as interested amateur, with a personal collection of Andean textiles

—Participant 16: I think it is an excellent resource and the fact that it combines institutions collections is unique? But please add the institutions' accession numbers to each object, for each access on institutions website.

—Participant 17: A very good research resource — both for technical details and design.

—Participant 18: Example of textile documentation across collections. Of interest if a project covered this area of textiles. Of visual inspiration — good to be able to look in detail.

—Participant 19: I feel that, while not a personal interest, this is an incredibly helpful research tool for scholars and students studying this topic.

—Participant 20: Not really in my current role. I would like to use it a bit more to compare. The area maps of production — can they be combined?

—Participant 22: I appreciate the project, the gigantic effort in cataloguing, digesting and thinking textiles, but I find it a bit technical for my work as an art historian researcher. I can imagine a second phase where more of the cultural component, i.e. interpretation of the textiles, could be incorporated.

—Participant 23: I've worked on a Bolivia-American artist who does what she calls 'digital weaving', hence my interest in a digitisation project for Andean textiles. However, I don't work generally on textiles so probably wouldn't use the ontology further.

—Participant 24: As a professional weaver I am interested in textiles in general and would use the website just to look at the pictures but wouldn't necessarily use it professionally.

—Participant 25: My own academic research.

—Participants 8, 9, 11, 12, 21: No comment

Do you find the system to be a useful tool that could be used by other people/institutions?	very useful 15	useful 6	mixed feelings 3	little useful	not useful

Please add comments of how the system would be useful to others in their roles:

—Participant 1: Possibly — for Andean textile collections.

—Participant 2: Certainly for those with a strong interest in textiles and/or that part of South America it is of considerable interest, particularly to staff, students and researchers based at universities, museums, galleries and so on.
I think the term 'ontology' is quite a loaded one and has rather different connotations in an IT versus humanities context. It also strikes me as a slightly intimidating term, even for many working in academia, let alone those beyond the academy.
Also I think that some of the category/subcategory titles are perhaps not quite as intuitive/obvious as they could be e.g. 'iconography' is not what I was expecting; maybe 'internal structure' would have been more descriptive.
Finally, terms such as sequence, symmetry and motif all seem quite similar and it is not always immediately obvious which of these you would browse through first if looking for a particular design/pattern.
Also excellent 'live' linkages from the screens that show the individual textiles allowing linking through to info. on fabrics, materials etc.

—Participant 3: It provides an excellent model for thinking about classifying other types of knowledge and has implications, for example, in revitalization/maintenance projects with indigenous languages and knowledges. It helps provide an educational tool for institutions which do not have the resources themselves to disseminate knowledge and that represents resource transfer from north to south as well as intellectual cooperation.

—Participant 4: The system provides a window into the textile methodology and design of other cultures. It would be useful for textile designers, but some of the images are too small to see structures clearly.

—Participant 5: It would be of interest to archaeologists, anthropologists, in cultural studies, and to IT specialists.

—Participant 7: Anthropologists working in this particular region may use the available information for all sorts of reason, including but not restricted to, studying techniques, motives woven on the products etc.

—Participant 10: In archaeology — development of earliest tools, from handaxes onwards. In folk costume and folk crafts (the ones I am familiar with are those in the Slavonic and Scandinavian countries, especially Russia, where there is an enormous variety of them. Some of them being produced and worn to this very day. I'll find out whether any of those countries have created such databases).

—Participant 13: Group of textiles studies; museums; different textiles and fashion slides. I think it is a great data base, great pictures, great information. I am sure will be very useful.

—Participant 14: Research into any of this subject for teaching purpose; for study; for researching what is going on and where there are gaps in practice today.

—Participant 15: Could you link in with Ecuador institutions? They have done extensive cataloguing and digitalisation of cultural patrimony over recent years. See Ministerio de Cultura.

—Participant 16: For motifs to be used in design; for colour combination when designing textiles; for historical textile search. I am sure lots of textile people would find this site inspiring.

—Participant 17: Art and Design students — some material for designs — good photo images.
—Participant 19: Professors and students would benefit from this database for research.
—Participant 20: Librarians, museums.
—Participant 22: I think having access to this database would be of particular usefulness for contemporary artists who work with and are interested in textiles.
—Participant 23: I can see this tool being useful for those who work in textiles/history/anthropology. Perhaps calling it a database rather than an 'ontology' would be less off-putting for non-specialist users.
—Participant 24: Useful for its cataloguing and identifying textiles in all different categories.
—Participant 25: I think without a weaving knowledge and knowledge of the Andean cultures it would be much harder (I don't have latter).
—Participants 6, 8, 9, 11, 12, 18, 21 : No comment

C. RESEARCHERS' QUESTIONS

—Q1: In what find regions does technique $T appear?
—Q2: In what find regions does structure $S appear?
—Q3: In what find sites is technique $T found?
—Q4: In what find sites is structure $S found?
—Q5: What repositories hold textile objects with technique $T?
—Q6: What repositories hold textile objects with structure $S?
—Q7 What textile objects present technique $T?
—Q8: What textile objects present structure $S?
—Q9: What images are there of textile object $X?
—Q10: What motifs appear in textile object $X?
—Q11: What textile styles present technique $T?
—Q12: What textile styles present structure $S?
—Q13: What cultures are associated with technique $T?
—Q14: What cultures are associated with structure $S?
—Q15: What materials is textile $X made of?
—Q16: In what motifs does technique $T appear?
—Q17: In what motifs does structure $S appear?
—Q18: In what period does technique $T appear?
—Q19: In what period does structure $S appear?
—Q20: When does technique $T appear for the first time?
—Q21: When does structure $S appear for the first time?
—Q22: What cultures are associated with textile object $X and technique $T?
—Q23: What cultures are associated with textile object $X and structure $S?
—Q24: What colours are found in textile object $X with technique $T?
—Q25: What colours are found in textile object $X with structure $S?
—Q26: How many colour layers are found in textile object $X with technique $T?
—Q27: How many colour layers are found in textile object $X with structure $S?