Heritage Science

RESEARCH

Open Access

Developing an ontological model for Xinjiang unearthed brocades

Yu Zhao[1,2], Zhou Li[1], Wenliang Li[2,3] and Junling Liu[4*]

Abstract

The Xinjiang unearthed brocade as a significant cultural heritage records the historical and cultural information of diverse ethnic groups, and it also influences cultural product development. However, the existing knowledge concerning these brocades is disorganized, fragmented, and incomplete, hindering a comprehensive understanding of their intricate relationships. To address these issues, this study has developed an integrated ontological model for Xinjiang's unearthed brocades (XJUBontology). By applying Conceptual Reference Model of International Committee for Documentation (CIDOC CRM) ontology and the Remanufactured Process Planning (RPP) approach, this XJUBontology comprises knowledge about both the brocades and their cultural derivatives, and knowledge in these two domains are able to be organized and refined. The implementation of XJUBontology in Protégé and validation via SPARQL queries not only centralize and manage Xinjiang unearthed brocade-related knowledge but also establish vital connections among this fragmented information. The contribution is to help in associating, managing, and sharing knowledge in the domain of Xinjiang unearthed brocades, providing a framework for establishing related data repository, and helping researchers, apparel and accessories designers, museums, and other cultural and tourism institutions to access a more systematic information to assist their works.

Keywords Xinjiang unearthed brocades, Cultural derivative, Ontological model, CIDOC CRM, RPP

Introduction

Brocade belongs to the category of highly ornate fabrics, typically be crafted using shuttle weaving techniques, and often incorporates colored silk threads, such as gold and silver [1]. The production of brocade dates back thousand years ago. In China, the brocade was first made during the Warring States period [2]. The brocade with its long history inherits various culture, highly manufacturing technique, aesthetics, and so on [3]. In Xinjiang province, as with its dry climate, many products of brocade have been unearthed from tombs [4, 5], and they were detected to be made ranging from Han dynasty to Yuan dynasty in China [1]. These brocades as cultural heritage are important for the historical study, and it is not only the valuable physical evidence for working on the history of the Silk Road trade, but also for investigating the economic and cultural exchange between the East and the West [1].

Xinjiang unearthed brocades were mainly found in archaeological sites and tombs such as the Loulan Relic Site, Astana-Karakhoja Cemetery, Niya Relic Site, Yuansha Ancient City and Yingpan Cemetery [1, 4]. These sites and tombs were respectively listed as the third batch of major cultural relics protection units in China in 1988 (State Council Document No. 5 of 1988), the fourth batch in 1996 (State Council Document No. 47 of 1996), the fifth batch in 2001 (State Council

*Correspondence:
Junling Liu
liujunling@nankai.edu.cn
[1] College of Sericulture, Textile and Biomass Sciences, Southwest University, 2 Tiansheng Road, Chongqing 400715, China
[2] China's Borderland Literature and History Research Center, Yili Normal University, 448 Jiefang Road, Yining 835000, Xinjiang, China
[3] School of Chinese Language and Literature, Yili Normal University, 448 Jiefang Road, Yining 835000, Xinjiang, China
[4] National Demonstration Center for Experimental Arts Education, Nankai University, 94 Weijin Road, Tianjin 300071, China

Document No. 25 of 2001), and the seventh batch in 2013 (State Council Document No. 13 of 2013). Moreover, Five Stars Rise in the East brocade as one of Xinjiang unearthed brocades was included in the initial group of Chinese cultural relics prohibited from exhibition abroad, as outlined in the official directive (Issued by the National Cultural Heritage Administration [2002] No. 5) in 2002. Three other Xinjiang unearthed brocades, including caftan of double-faced woollen patterned fabric with a Hel-lenistic pattern, checkered and animal pattern brocade, and caftan with eagle pattern, were also listed in the third batch of Chinese cultural relics prohibited from exhibition abroad (Cultural Relics Circular [2013] No. 1320). These indicate that Xinjiang unearthed brocades, as a category of discovered cultural relics, hold significant historical, artistic, and scientific value.

After archaeological excavations, most of those unearthed brocades were found to be made in the Han and Jin Dynasties, Wei and Tang Dynasties and Song and Yuan Dynasties. This reveals that Xinjiang unearthed brocades have a history of about 1600 years in China. It is noted that parts of unearthed brocades are fragmentary, but several pattern, color, wave, stitch, and other visual and material elements are still able to observed. The Xinjiang unearthed brocades with these preserved elements become a very rich cultural heritage of the region. For example, through investigating the craftsmanship and visual aspects, Five Stars Rise in the East brocade has been found with the quite high thread density and the great weaving complexity, making it a significant proof to Han Dynasty weaving technology [1]. The unearthed brocades with the pearl roundels pattern were revealed being famous during the Wei and Tang Dynasties [6]. Moreover, Xinjiang unearthed brocades with diversely visual and material elements are discovered with great cross-cultural impacts. For example, the boar's-head pattern found in the Astana-Karakhoja Cemetery brocades is a pattern influenced by the Sasanian style from Persia [7]. In addition, the Xinjiang unearthed brocades may reveal the economics, policy and social status of people in the region in a certain period of time [1]. In terms of observing these physical and non-physical features of Xinjiang unearthed brocades, there are quite a few cultural derivatives been developed, which inherit the rich culture of the region [8]. Furthermore, Xinjiang unearthed brocades made their way to Europe and America via the Grassland Silk Road and are now kept in museums. For instance, there's a Tang Dynasty parrot pattern brocade in the Berlin Museum of Arts and Crafts, and Yuan Dynasty lotus and hares brocades in the Cleveland Museum of Art in the United States. These brocades highlight the cultural exchange between China and the West countries [1]. Thus, Xinjiang unearthed brocades as precious heritage should be carefully understood.

The current studies regarding the unearthed brocades of Xinjiang include the information collection, technical analysis and digital storage. For information collection, through the comparison and data mining of the origin, design elements, structure and so on, the basic knowledge for unearthed brocades of Xinjiang were obtained [8–10]. For technical analysis, the high technology was applied for the dye analysis, fiber detection and history tracing of brocades, enhancing the professionalism of knowledge related to Xinjiang unearthed brocades [11–13]. For digital storage, the standardization of terminology related to brocades and the data storage methodology were investigated for applying and sharing knowledge of unearthed brocades of Xinjiang [14, 15]. These studies are important for establishing knowledge for understanding the unearthed brocades of Xinjiang. However, the current information about Xinjiang unearthed brocades is scattered, inconsistent and incomplete, and the storage tools were unorganized and inefficient, thus, making the knowledge of unearthed brocades of Xinjiang is unsystematic, and difficult to manage, display, share, and operate. Therefore, the creation of semantic web with adequate information becomes necessary.

Ontological model or ontology, as a common semantic web technology, is a formal representation of knowledge that expresses objective entities or concepts, along with their properties and associated relationships in a target domain, helping to facilitate knowledge organization, sharing, and reasoning in various fields [16–18]. Nowadays, ontology has been widely applied in the areas including medicine, construction, education and cultural heritage [19–21]. According to the characteristics of cultural heritage, the ontological model can mainly serve both tangible and intangible cultural heritage. For the former, common research objects are mainly historical buildings, handicrafts, including Castellina fortress and Rocca [22] and ceramics [23] etc. For the latter, the main research objects are knowledge and skills (e.g. Confucianism [24], and dancing for Laba tribe in northeastern India [25]). However, ontology is occasionally employed in the heritage textile. These ontologies organize information about the target heritage textiles themselves, such as patterns, materials, etc. [26], and can extend to encompass activities, individuals and locations [27]. Even though the knowledge that the current ontology of heritage textile does not cover too much, it is a good foundation for establishing a clearer and fuller ontology, and thus constructing the according knowledge repositories or databases. Xinjiang unearthed brocades as a heritage textile, and its knowledge can be managed through ontological approach. In this case, a database of Xinjiang

unearthed brocades can be further established, which is not only helpful for archaeologists to conduct works related to Xinjiang unearthed brocades, but also a good source for public to get the cultural information.

In this paper, the study aims to address the issue of scattered and unsystematic knowledge regarding Xinjiang unearthed brocades by applying ontology technology to integrate this fragmented knowledge and construct an ontological model to help develop a database for Xinjiang unearthed brocades, The overall framework comprises the ontological model development, implementation and validation. The rest of the paper is organized as follows: the second section presents the related works. The third section is the methodology for ontological model development. The fourth section interprets the implementation of the ontological model. The fifth section discusses the validation. The last section is the conclusion, discussion and future perspectives.

Related works

This section contains two major areas relevant to the study, which include the knowledge of Xinjiang unearthed brocade and ontology for cultural heritage. It is to be noted that in this paper, the term "knowledge" is used instead of the term "information", though literature may use either of them. Their definition refers to [28, 29], which is that information is only about a phenomenon, but knowledge is about a phenomenon along with its underlying cause.

Knowledge of Xinjiang unearthed brocades

The knowledge of Xinjiang unearthed brocades mainly has two kinds, including the knowledge of Xinjiang unearthed brocade itself, and the knowledge of cultural derivative of Xinjiang unearthed brocades. For the former one, the knowledge of unearthed time, archaeological event, excavation site (including site number), unearthed brocades terminology, brocade types, brocade dimensions, brocade colors, periods of manufacturing brocade, patterns of brocade, and inscriptions on brocade have been quite commonly studied [2, 10, 12], and by employing these knowledges, evolution, cultural significance and cultural exchange regarding to Xinjiang unearthed brocades have been investigated [1, 3, 8]. However, these knowledge and application are mainly about a specific type of Xinjiang unearthed brocade or a particular time period, and the whole knowledge of Xinjiang unearthed brocades is missing, resulting in the related application incomplete and non-systematic. For the latter one, the term of cultural derivative in our study refers to a product that is designed by referring a particular cultural source [30]. A few studies have covered the knowledge of cultural derivative of Xinjiang unearthed brocades, but they only focus on products of cultural derivative with integrating the physical elements and cultural meaning of Xinjiang unearthed brocades [31]. It is noted that these cultural derivatives not only inherit certain physical features of Xinjiang unearthed brocades, but also may extend to be with advanced production technology, creative design method, innovative material development, and so on, for example, some cultural derivative of Xinjiang unearthed brocades not only uses the colors, patterns and inscriptions of Xinjiang unearthed brocades, but also adopts modern technologies such as printing and bronzing techniques, combined with modern design concepts, reflecting the cultural value and economic potential of Xinjiang unearthed brocades. Thus, the well knowledge of cultural derivative of Xinjiang unearthed brocades should involve information of manufacturing and designing product, and by adding information of cultural derivative of Xinjiang unearthed brocades, a more thorough knowledge of Xinjiang unearthed brocades can be covered.

Ontology for cultural heritage

Ontologies for cultural heritage are specialized knowledge structures that help organize and represent information related to the preservation, documentation and study of cultural heritage [32]. These ontologies provide a structured framework for capturing the complexities of cultural heritage, including its artifacts, historical context and related concepts. In terms of different types and forms of cultural heritage, ontologies are various. For example, for the architecture heritage, CIDOC Conceptual Reference Model (CIDOC CRM), Getty Art and Architecture Thesaurus (AAT), Industry Foundation Classes (IFC), Lightweight Information Describing Objects (LIDO), and Spatial Planning and Archaeology Ontology (SPAR) are usually employed. Except CIDOC CRM, other ontologies have their specific use, such as AAT with good description of architectural heritage objects and artworks is more suitable for museums and libraries [22], SPAR with spatial data is more often used for managing information of spatial planning [33]. Moreover, for digital cultural heritage, CIDOC CRM, Preservation Metadata Implementation Strategies (PREMIS), Resource Description Framework (RDF), and Object Reuse and Exchange (ORE) are commonly used to help organize and describe digital heritage artifacts, metadata and associated concepts. It can be noted that CIDOC CRM is a quite generic ontology for cultural heritages. Besides the common functions for ontology of defining a core set of concepts and relationships, CIDOC CRM is event-centric, time-based, semantically interoperable, and it has been approved to be a robust and versatile framework for capturing information about

heritage culture [32]. Thus, the application of CIDOC CRM becomes promising to be used for organizing the knowledge of Xinjiang unearthed brocade itself.

Moreover, CIDOC CRM is extensibility, which allows CIDOC CRM for extensions to accommodate domain-specific knowledge while maintaining compatibility with the core model. There are quite a few extensions of CIDOC CRM in the domain of cultural heritage. For example, CIDOC CRM for Buildings, Sites, and Monuments (CRMba) is an ontology designed to precisely address the documentation and representation of buildings, archaeological sites, monuments, and related architectural and heritage entities [34]. Moreover, CIDOC CRM Archaeological Extension (CRMarchaeo) specifically tailored to archaeological data and the documentation of archaeological sites, objects and events [35]. CIDOC CRM Geospatial Extension (CRMgeo) is used to support geospatial and location-based information for cultural heritage sites and landscapes [36]. It can be noted that in terms of the specific requirement for the knowledge of cultural heritage, CIDOC CRM can be extended to apply to a more targeted domain for cultural heritage.

In terms of cultural derivative aforementioned, the extension of ontology for heritage textile based on CIDOC CRM should add the domain of product. It is noted that the cultural derivative is kind of in a like-new condition based on heritage textile, and it should involve the redesign, remanufacture and process planning. Remanufactured Process Planning (RPP) is a systematic approach to plan and optimize the processes involved in remanufacturing [37]. Remanufacturing is a sustainable manufacturing practice that involves the refurbishment and restoration of used, worn, or end-of-life products to like-new condition [38], and it helps to conduct a related manufacture in terms of the requirements of the economics, culture, environment and so on. RPP has been used in the ontology very often. For example, He et al. has developed an RPP based on ontology for product [39]. This ontology is able to identify size, shape, material, price, problem description, and problem solution for manufacturing, which makes the remanufacture and product display to be more efficient. Moreover, Hu et al. has developed an end-of-life (EoL) ontology in terms of RPP [40]. This ontology can clarify product, subassembly, functional part, fastener, connection mode and disassembly type for manufacturing, leading the remanufacture to be more decision-making centered. Though few of RPP application is related to heritage textile, based on the current study, RPP seems promising to be used in the ontology for cultural derivative of Xinjiang unearthed brocades to identify this type of product, including its process time, process parameters, craft and so on. Therefore, the integration of CIDOC CRM and RPP will be a good try for ontology modelling for knowledge of Xinjiang unearthed brocades.

Methodology

In this section, the model of integrating ontology of CIDOC CRM and RPP for the knowledge of Xinjiang unearthed brocades is described in details.

Domain and scope

The goal of the study is to create an integrated model with CIDOC CRM and RPP for the heritage of Xinjiang unearthed brocades. The model is mainly in the domain of Xinjiang unearthed brocades, and it is extended to the product domain, where the knowledge of cultural derivative of Xinjiang unearthed brocades is covered. It is noted that this integrated ontology is helpful for researchers, apparel and accessories designers, museums, and other cultural and tourism institutions to access a more systematic information to assist their works.

Integrated ontology development

Based on the aforementioned literature, core categories that constitute the basis of the Xinjiang unearthed brocades mainly have 10, This study developed a top-down hierarchical structure by grouping these core categories into superclasses and subclasses, as well as reflecting their relationships or properties in the domain of Xinjiang unearthed brocades. In Fig. 1, in terms of CIDOC CRM in version 7.2.3, CRM entity is defined as superclass in the CIDOC CRM framework in this study. Moreover, in terms of above 10 categories, period, event, place, physical thing, time-span, human-made feature, human-made object as subclasses of CRM entity are employed. The definitions and examples for them are shown in Table 1. Among these subclasses, several of them are direct, and others are indirect. Direct subclasses are those directly connected to the superclass, while indirect subclasses require a connection through other subclasses. For example, in Fig. 1, period and physical thing are indirect subclasses of CRM entity, as they are connected to CRM entity through either temporal entity or persistent item, and event is direct subclass of period.

Properties connecting two different subclasses in the domain of Xinjiang unearthed brocades, indicate the relationships between them [17]. As it shown in Fig. 1, quite a few properties were used in the brocades part of XJUBontology, and Table 2 gives the explanation for these properties, including their domain, range, and accordingly examples.

Knowledge of RPP for the cultural derivative of Xinjiang unearthed brocades interprets a bunch of information describing the remanufacture and planning process

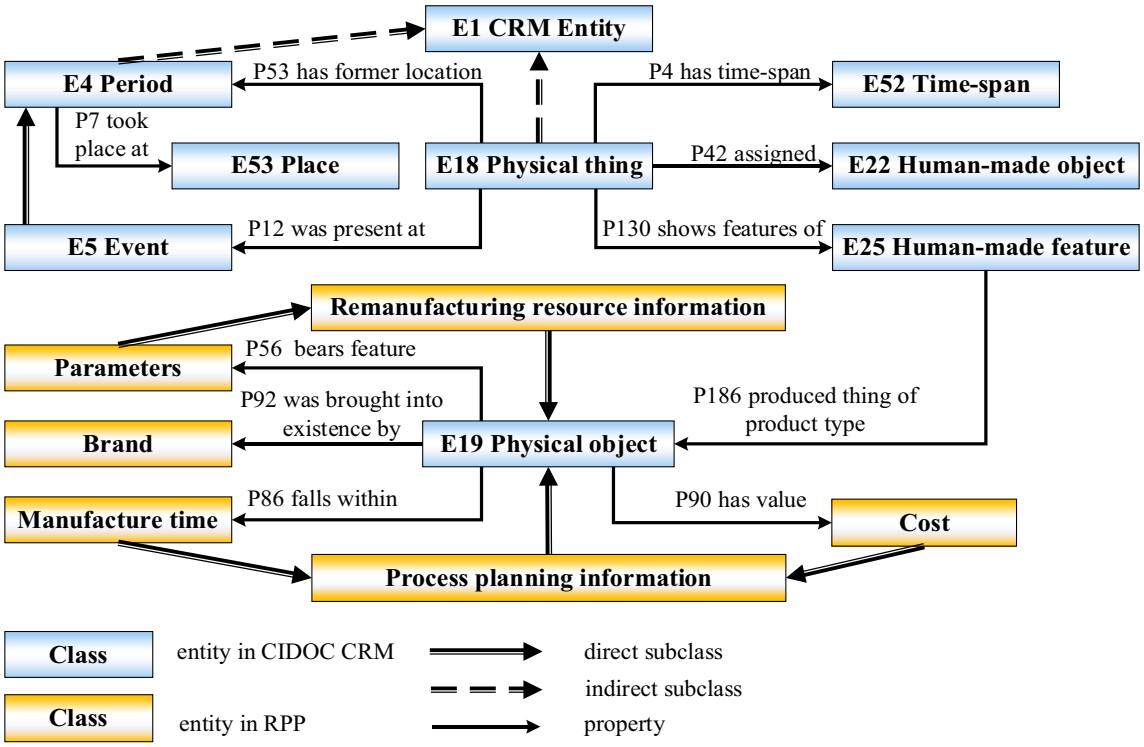

Fig. 1 The structure of XJUBontology

Table 1 Definition of core categories of Xinjiang unearthed brocade

Subclasses	Example	Literature source
E4 period (unearthed time)	1995	[41]
E5 event (archaeological event)	Sino-Japanese Joint Research of the Niya Site	[41]
E53 place (excavation site)	Astana-Karakhoja Cemetery	[41]
E18 physical thing (unearthed brocades terminology)	Five Stars Rise in the East	[41]
E52 time-span (periods of manufacturing brocade)	Han and Jin Dynasties	[41]
E25 human-made feature (brocade dimensions, colors, patterns and inscriptions)	Length is 35 cm, width is 41.3 cm, red, blue, white, yellow, plant pattern, animal pattern and inscription of 延年益寿大宜子孙	[42–44]
E22 human-made object (brocade types)	Pillow	[42–44]

Table 2 The properties of Xinjiang unearthed brocades

Properties	Domain	Range	Example
P4 has time-span	E18 physical thing	E52 time-span	The Yan Nian Yi Shou Chang Bao Zi Sun has time-span of Han and Jin Dynasties
P7 took place at	E4 period	E53 place	The archeology for Yan Nian Yi Shou Chang Bao Zi Sun was in the year of 1980 and took place at the Loulan Relic Site
P12i was present at	E18 physical thing	E5 event	Wang Hou He Hun Qian Qiu Wan Sui Yi Zi Sun was present at the Archaeological activities of the Sino-Japanese Joint Research of the Niya Site
P42 assigned	E18 physical thing	E22 human-made object	Shi Wu Ji Jin Yi Er Qin Chuan Zi Sun is assigned to be a type of pillow
P53 has former location	E18 physical thing	E53 place	Hu Wang has former location in the Astana-Karakhoja Cemetery (Hu Wang was unearthed in the Astana-Karakhoja Cemetery)
P130 shows features of	E18 physical thing	E25 human-made feature	Shi Wu Ji Jin Yi Er Qin Chuan Zi Sun shows the features of its color, size, pattern, and inscription

in the domain of product (Fig. 1). Referring to the superclass, subclass, and properties in CIDOC CRM, a physical object is defined as the superclass in the integrated ontology in the aspect of RPP, as it can refer to any product of cultural derivative. Moreover, even though quite a few information related to remanufacture and planning process, in terms of cultural derivative Xinjiang unearthed brocades, only major information, including process planning information, remanufacturing resource information, brand, cost, production time, and parameters are determined to be described in the knowledge of RPP, and this information is treated as a subclass in the integrated ontology. Process planning information refers to the planning of product production according to constraints, which has subclasses of cost and production time. The Cost is the expenses of producing cultural derivative of Xinjiang unearthed brocade. Production time is the time consuming for the produce cultural derivative of Xinjiang unearthed brocade. Remanufacturing resource information denotes the resource information required for produce cultural derivative of Xinjiang unearthed brocade, and it has subclass of parameters. Brand refers to the brand owner of cultural derivatives (Table 3).

As it shown in Fig. 1, quite a few properties were used in RPP of XJUBontology, and Table 4 gives the explanation for these properties, including their domain, range, and accordingly examples.

Based on the above knowledge of CIDOC CRM and RPP, the integrated ontology for Xinjiang unearthed brocade (XJUBontology) was proposed, which can provide unified formal representations of the knowledge in the domain of Xinjiang unearthed brocades.

Create instances

Based on the aforementioned structure of XJUBontology, instance for all superclasses and subclasses should be mined and obtained from various sources related to Xinjiang's unearthed brocades and its cultural derivative, including printed publications (e.g. Silk Road Textiles and Embroidery Research—Xinjiang Volume, The Ancient Chinese Silk Material Design Department, and Xiyu Meishu Quanji 5—Fushi Juan), web resources (e.g. Wikipedia and China National Silk Museum website), electronic literature databases (e.g. journal paper databases, conference databases, and dissertation databases). The procedural of obtaining these instances is as follows: first, researchers conducted initial data mining from the aforementioned sources. Second, the initial data were classified based on the characteristics of Xinjiang unearthed brocades, and data which do not meet the subclasses were deleted, and the remaining data were kept. In the end, a total of 621 instances were extracted. Table 5 is the details of instances.

In Table 5, for apparel and accessories designers, museums, and other cultural and tourism institution, subclasses such as physical things, human body features, physical objects, and parameters reflect the artistic characteristics of Xinjiang unearthed brocades and their

Table 3 Definition of core categories of cultural derivative of Xinjiang unearthed brocades

Subclasses	Example	Literature source
E19 physical object	The cultural derivative of paper tape	[45]
Process planning information (cost)	The cultural derivative costs less than 50 yuan	[46–48]
Process planning information	The production time for cultural derivative is 2024s	[46–48]
Remanufacturing resource information	The remanufacture parameters of cultural derivative includes length, width, color, pattern, material	[46–48]
Brand	Xinjiang Museum and PYE	[46–48]

Table 4 The properties of cultural derivative of Xinjiang unearthed brocades

Properties	Domain	Range	Example
P56 bears feature	E19 physical object	Parameters	Refrigerator magnet bears feature of 5.5 cm long and 4.5 cm wide
P86 falls within	E19 physical object	Production time	The production time of the refrigerator magnet falls within 5 min
P90 has value	E19 physical object	Cost	The refrigerator magnet worthies the value of 32 yuan
P92i was brought into existence by	E19 physical object	Brand	The T-shirt was brought into existence by PYE
P186 produced thing of product type	E25 human-made feature	E19 physical object	Based the parameters of Five Stars Rise in the East, glasses cloth, cloth coaster, and tie can be produced

Table 5 The instances of Xinjiang's unearthed brocades and its cultural derivative

Aspect	Subclasses	Numbers of instances
Xinjiang unearth brocade	Period	22
	Event	11
	Place	17
	Physical thing	146
	Time-span	3
	Human-made feature	146
	Human-made object	146
Cultural derivative of Xinjiang unearth brocade	Physical object	32
	Process planning information	64
	Remanufacturing resource information	32
	Brand	2
	Cost	32
	Production time	32
	Parameters	32

artistic features presented in cultural derivatives, which have very important commercial transformation value. For researchers, subclasses such as period, event, place, and human body object reflect the historical information of unearthed brocades in Xinjiang, which has very important reference value.

Figure 2 is an example of applying instances for all superclasses and subclasses in XJUBontology. In the figure, physical thing presents the terminology of the brocade, namely, Yan Nian Yi Shou Chang Bao Zi Sun. Event shows the archaeological event of Xinjiang Cultural Relics Archaeological Research Institute's excavation at the Loulan relic site. Place displays the Loulan relic site and its archaeological site code (L.C.). Period represents the specific archaeological time of 1980s. Time-span indicates the production era as the Han and Jin Dynasties. Human-made object shows the feature type as a fragment. Human-made feature exhibits its color attributes (purple, blue, yellow, green, white), patterns (cloud pattern, dragon pattern, tiger pattern, demon-quelling pattern, bird pattern), inscriptions (延年益寿长葆子孙), and size information (length 56.5 cm, width 14.5 cm). These discrete pieces of information are connected through properties. For example, the

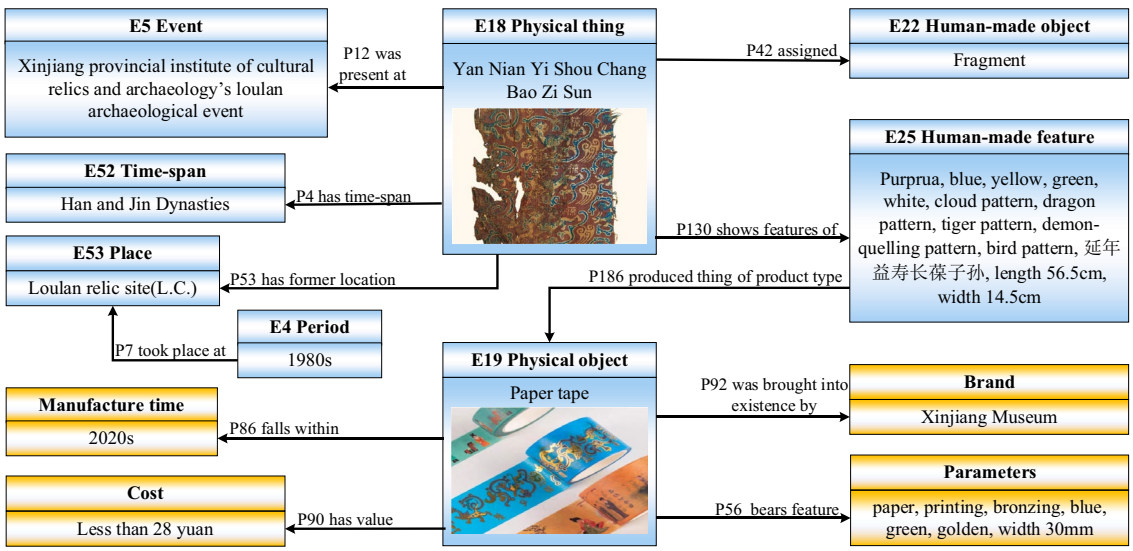

Fig. 2 An example of XJUBontology

property "has time-span" links physical thing and time-span, indicating that the production era of Yan Nian Yi Shou Chang Bao Zi Sun is the Han and Jin dynasties. The property "assigned" associates physical thing and human-made object, interpreting that Yan Nian Yi Shou Chang Bao Zi Sun falls into the type of fragments of Xinjiang unearthed brocade. The property "shows features of" connects physical thing and human-made feature, suggesting that Yan Nian Yi Shou Chang Bao Zi Sun displays its color, pattern, inscription, and size details. The property "was present at" associates physical thing and event, revealing that Yan Nian Yi Shou Chang Bao Zi Sun was discovered during the archaeological event of the Xinjiang Cultural Relics Archaeological Research Institute. The property "has former location" links physical thing and place, signifying that Yan Nian Yi Shou Chang Bao Zi Sun was unearthed at the Loulan relic site. The property "took place at" connecting period and place indicating that Yan Nian Yi Shou Chang Bao Zi Sun was discovered in 1980 at the Loulan relic site.

Human-made feature and physical object are linked through the property "produced thing of product type", interpreting a cultural derivative has a design concept from the feature information in Yan Nian Yi Shou Chang Bao Zi Sun, resulting in a paper tape. Brand represents the brand of the paper tape is the Xinjiang Museum. Production time reveals the specific production year for the paper tape is in the year of 2020. Cost shows the specific production cost for the paper tape. Parameters provides information about the paper tape, including dimensions, width of 30 mm, colors in blue, green, and golden, materials of paper and adhesive, and crafting techniques such as printing and bronzing on the paper surface. It is noted that this paper tape cultural derivative provides strong adhesion, with soft and smooth texture, and residue-free peeling. It can be used to stick different materials, enhancing the layered effect of artworks, and it serves purposes such as decoration and embellishment of handicrafts. Up to now, this paper tape has demonstrated good market performance, selling hundreds of units annually [49]. These discrete pieces of information are interconnected through properties. For example, the property "bears feature" linking physical object and parameters indicates that the paper tape has the its production parameters including dimensions, colors, materials, and crafting techniques. The property "has value" associates physical object and cost, implying that the production cost of the paper tape should be less than 28 yuan. The property "was brought into existence by" connecting physical object and brand implies that the paper tape is a cultural derivative developed by the company under the brand of Xinjiang Museum. The property "falls within" links physical object and production time, indicating that the paper tape was produced in the year of 2020s.

Implementation

In this section, the XJUBontology was constructed by employing Protégé, which is an ontology editor that applies the Web Ontology Language (OWL). It is noted that Protégé is an open-source tool and very easy to access. OWL is a dedicated syntax designed for ontology development. Through Protégé and OWL, the XJUBontology was structured and stored in the Resource Description Framework (RDF), facilitating storage and management. Moreover, Fuseki, an Apache Jena component, was employed to host the RDF data, acting as a SPARQL server to enable efficient retrieval and querying of knowledge in the model using the SPARQL query language. Fuseki supports multiple dataset formats (such as Turtle, N-Triples, JSON-LD), simplifying the data import and export process. Meanwhile, Fuseki provides a user-friendly web interface for managing datasets and executing queries, which helps to quickly develop and test XJUBontology. This design allows for seamless execution of semantic queries. The architecture for this implementation is in Fig. 3. The screenshot of the ontology in Protégé is in Fig. 4. An example of executing SPARQL queries through Fuseki server is demonstrated in Fig. 5.

Validation

In this section, based on XJUBontology, the SPARQL server was employed to semantically retrieve information related to Xinjiang's unearthed brocade and its cultural derivatives. SPARQL is a query language composed of PREFIX, SELECT, and WHERE clauses. PREFIX simplifies IRI; SELECT specifies the desired results; WHERE defines the conditions for retrieval, usually constructed from subjects, predicates, and objects. The processes of the validation is to carry out the solutions for different types of queries from users. For example, if a user aims to explore available Xinjiang unearthed brocades, queries on the knowledge about them should begin with physical thing. In the SELECT statement, they can set the desired result as "?physicalThing" and in the WHERE statement,

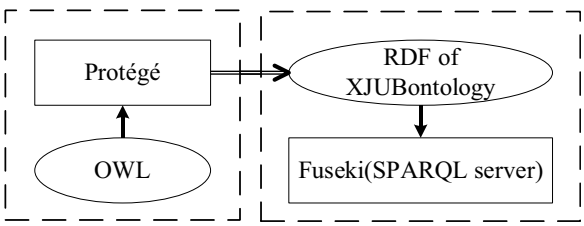

Fig. 3 The architecture for XJUBontology implementation

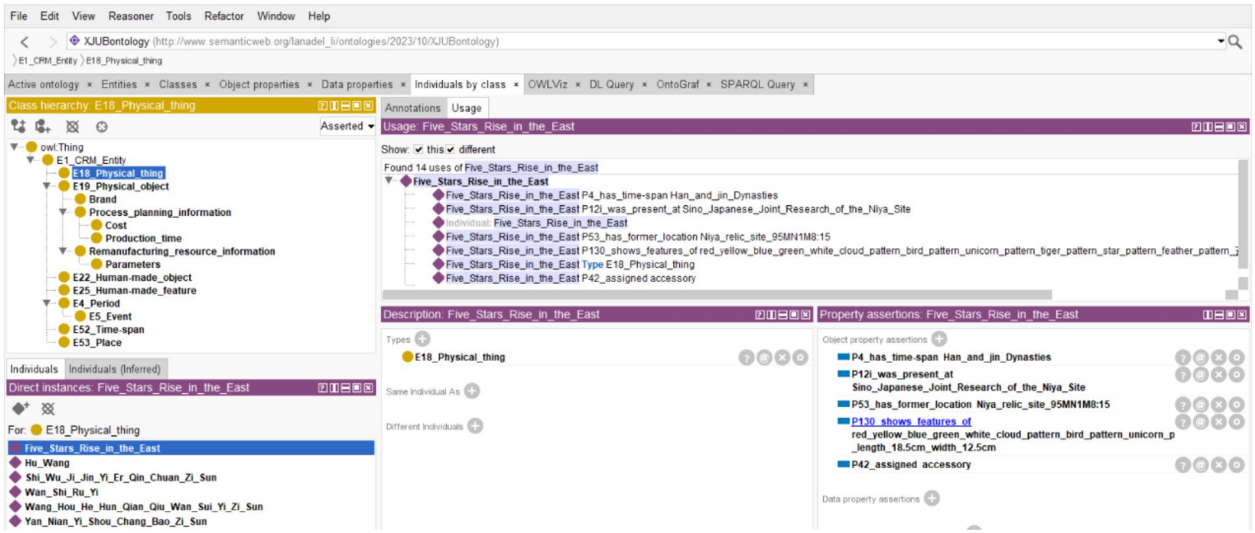

Fig. 4 The screenshot of the XJUBontology in Protégé

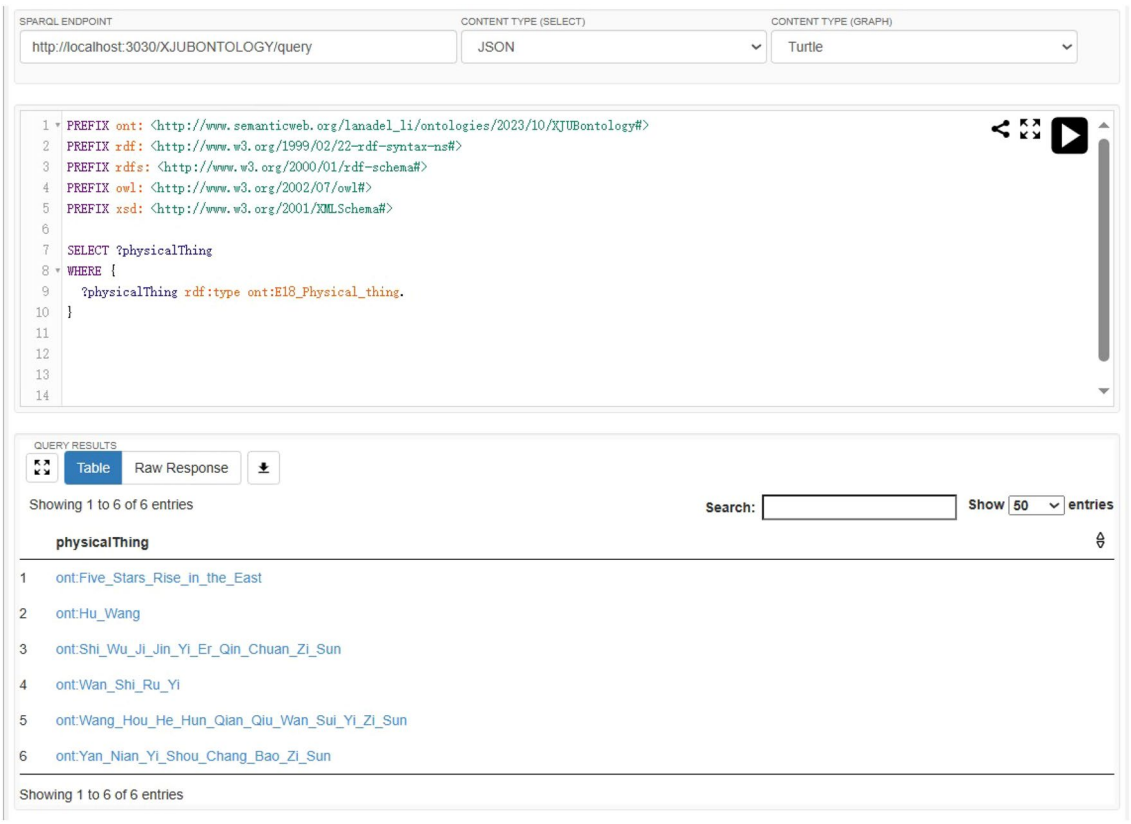

Fig. 5 An example of executing SPARQL queries through Fuseki server

specify that the retrieval result must satisfy the condition where "rdf:type" is "ont:E18_Physical_thing". Figure 5 is the screenshot of Xinjiang unearthed brocades terminology retrieval, and it displays a total of six terminology of Xinjiang unearthed brocades. If a user wants to explore any of these and seek additional information about it, they can start by querying the properties linked to that particular brocade. Assuming the user selects the

brocade "Five Stars Rise in the East" in the SELECT statement, they can set the desired result as "?properties" and in the WHERE statement, they can specify the condition as "ont:Five_Stars_Rise_in_the_East" (Table 6).

As shown in Table 6, Five Stars Rise in the East has five properties connecting to corresponding instance information. For example, the property P12i links to the specific event related to Five Stars Rise in the East, P130 connects to its human-made feature, P42 associates with the specific human-made object, P4 relates to its time-span, and P53 links to its place. A user can perform an instance query using any of these properties to acquire specific knowledge. If a user wishes to investigate the event linked to "Five Stars Rise in the East" within the XJUBontology, they can employ the P12i property, connecting "Physical thing" and "event". In the SELECT statement, they can set the desired retrieval result as "?instances", while in the WHERE statement, they can specify that the retrieval result should meet the condition of being associated with "ont:Five_Stars_Rise_in_the_East" through the property "ont:P12i_was_present_at" to acquire specific instances. Based on the example shown in Table 7, it is clear that "Five Stars Rise in the East"was discovered during the archaeological event of the Sino-Japanese Joint Research of the Niya Site.

In the example of Five Stars Rise in the East, understanding how its characteristics developed into cultural derivative via RPP is crucial information. By referring XJUBontology, the retrieve is continued by using P130 property to access the feature information of Five Stars Rise in the East (Table 8). In Table 8, the user will obtain information about the colors (red, yellow, blue, green, white), patterns (cloud pattern, bird pattern, unicorn pattern, tiger pattern, star pattern and feather pattern), inscription (五星出东方诛南羌), and dimensions (length 18.5 cm, width 12.5 cm) of the Five Stars Rise in the East brocade. If the user wants to understand what kind of cultural derivative arises from these features. they can directly employ the query method presented in Table 9 to acquire this information. In the SELECT statement, the user can set the retrieval result as "?properties" and "?instances", and in the WHERE statement, specify that the retrieval result needs to satisfy the condition of being associated with "ont:Five_Stars_Rise_in_the_East", encompassing all attributes and instances of cultural derivatives. As shown in Table 9, the cultural derivatives of Five Stars Rise in the East comprise a bookmark, car fragrance, coaster, knitwear, and paper tape, all linked to the "Five Stars Rise in the East" through the P186 property, users can use this query result to understand which cultural derivative has already been produced and find more information about it. Assuming the user selects one of these items (car fragrance) as a cultural derivative and seeks more RPP information about this product, the query statement is outlined in Table 10. In Table 10, the car fragrance possesses 4 properties connecting to respective instance information. For example, property P56 relates to the remanufacturing parameters of the car fragrance, P86 connects to the production time information, P90 is linked to the cost information, and P92i is associated with the brand information of the car fragrance. Users can use any of these properties to query the instances for specific knowledge. Suppose a user wants to understand the materials and crafting process used to create the car fragrance. In this case, the user needs to apply the property P56 for further inquiry, as shown in Table 11.

Table 6 The SPARQL query for returning the properties of a physical thing

```
SELECT ?properties
WHERE {
    ont:Five_Stars_Rise_in_the_East ?properties ?instances
}
properties
ont:P12i_was_present_at
ont:P130_shows_features_of
ont:P42_assigned
ont:P4_has time-span
ont:P53_has_former_location
```

Table 7 The SPARQL query for retrieving the event referring to a physical thing

```
SELECT ?instances
WHERE {
    ont:Five_Stars_Rise_in_the_East ont:P12i_was_present_at ?instances
}
instances
ont:Sino_Japanese_Joint_Research_of_the_Niya_Site
```

Table 8 The SPARQL query for returning the human-made feature of a physical thing

```
SELECT ?instances
WHERE {
    ont:Five_Stars_Rise_in_the_East ont:P130_shows_features_of
    ?instances
}
instances
ont:red_yellow_blue_green_white_cloud_pattern_bird_pattern_uni-
corn_pattern_tiger_pattern_star_pattern_feather_pattern_五星出东方
利中国诛南羌_length_18.5cm_width_12.5cm
```

Table 9 The SPARQL query for returning the physical object of a human-made feature

```
SELECT ?property ?instances
WHERE {
   ont:red_yellow_blue_green_white_cloud_pattern_bird_pattern_unicorn_pattern_tiger_pattern_star_pattern_feather_pattern_五星出东方利中国诛南羌_ length_18.5cm_width_12.5cm ?property ?instances
}
```

property	instances
ont:P186_produced_thing_of_product_type	ont:bookmark
ont:P186_produced_thing_of_product_type	ont:car_fragrance
ont:P186_produced_thing_of_product_type	ont:coaster
ont:P186_produced_thing_of_product_type	ont:knitwear
ont:P186_produced_thing_of_product_type	ont paper_tape

Table 10 The SPARQL query for returning the properties of a physical object

```
SELECT ?properties
WHERE {
   ont:car_fragrance ?properties ?instances
}
```

properties

ont:P56_bears_feature

ont:P86_falls_within

ont:P90_has_value

ont:P92i_was_brought_into_existence_by

Table 11 The SPARQL query for returning the parameters of a physical object

```
SELECT ?instances
WHERE {
   ont:car_fragrance ont:P56_bears_feature ?instances
}
```

instances

ont:length_2.1cm_height_7cm_zinc_alloy_PEperfume_enamel_color_red_yellow_blue_green_white

Conclusion, discussion, and future perspectives

In this paper, the ontological model called XJUBontology was developed, which integrated the ontology of CIDOC CRM and approach of RPP. This integrated ontology not only covers the knowledge of Xinjiang unearthed brocade itself, but also its cultural derivative, as well as their relationships, which effectively encapsulate the entire domain of Xinjiang unearthed brocades. Moreover, the implementation of XJUBontology using Protégé to instantiate instances and its validation through SPARQL server affirm its robust database and accessibility capabilities.

The following conclusions can be drawn from the results: (1) the XJUBontology integrates the cultural heritage knowledge of Xinjiang's unearthed brocades, preventing biases and fragmentation in this knowledge and enabling its association, protection, and sharing; (2) the XJUBontology expands the knowledge about cultural derivative products related to Xinjiang's unearthed brocades, facilitating their connection with cultural heritage knowledge and providing a pathway for the modern transformation and innovative application of Xinjiang unearthed brocades.

The main contributions of this study include the following: (1) the developed ontological model and its implement with large instances enables the further studies related to the cultural heritage of Xinjiang unearthed brocade; (2) the development of the XJUBontology serves as a methodological reference for establishing and sharing data resources in other cultural heritage domains, such as folk arts, traditional crafts, and local customs.

The work nevertheless has some limitations that deserve further discussion. The first limitation is the definition of a few classes in the XJUBontology generally broad. For example, the class of human-made feature can be further decoupled into subclasses of dimensions, colors, patterns, and inscriptions, and so on. The future work can be taken to have more precise subclasses to interpret a clearer information and relationships. The second limitation is the limited number of instances for cultural derivatives of Xinjiang unearthed brocade. Future efforts should focus on accumulating a larger and more diverse set of instances to enhance the ontology's comprehensiveness. The third limitation is that XJUBontology lacks broad applicability, and future work can bring unearthed brocades from more regions of China to establish a wider ontology or expanding the linkage with other ontologies to make a much richer and smarter system for Xinjiang brocades, such that the brocades recommendation, monitoring, virtual exhibition,

or user question-answering assistants can be available to enhance the performance of the ontology [26, 50–52].

Abbreviations

XJUBontology	Ontology for Xinjiang unearthed brocade
CIDOC CRM	Conceptual Reference Model of International Committee for Documentation
RPP	Remanufactured Process Planning
AAT	Getty Art and Architecture Thesaurus
IFC	Industry Foundation Classes
LIDO	Lightweight Information Describing Objects
SPAR	Spatial Planning and Archaeology Ontology
PREMIS	Preservation Metadata Implementation Strategies
RDF	Resource Description Framework
ORE	Object Reuse and Exchange
CRMba	Conceptual Reference Model of archaeological buildings for documentation
CRMarchaeo	CIDOC CRM Archaeological Extension
CRMgeo	CIDOC CRM Geospatial Extension
EoL	End-of-life
OWL	Web Ontology Language
RDF	Resource Description Framework
IRI	Internationalized Resource Identifier

Acknowledgements
Not applicable.

Author contributions
Conceptualization: YZ and JL; investigation: YZ and WL; data preparation: ZL; analysis and software: YZ and ZL. All authors read and approved the final manuscript.

Funding
This research was financially supported by Open Project of China's Borderland Literature and History Research Center of Regular University's Humanities and Social Science Key Research Base of Xinjiang (Grant No. BJWSZ202201), the Fundamental Research Funds for the Central Universities (Grant No. SWU2109241), Ministry of University-Industry Collaborative Education Program (Grant No. 221000287112809), and Nankai University Experimental Teaching Reform Project (Grant No. 23NKSYSX06).

Availability of data and materials
Data available on request from the authors.

Declarations

Competing interests
The authors declare no competing interests.

Received: 28 November 2023 Accepted: 26 February 2024
Published online: 06 March 2024

References

1. Zhao F. The Silk Road and east–west textile culture exchange. In: A new phase of systematic development of scientific theories in China: history of science and technology in China, vol. 4. Singapore: Springer; 2021. p. 257–89.
2. Fu C, Cao W, Fu C, et al. Urban development over the spring and autumn and warring states periods. In: Introduction to the urban history of China. Palgrave Macmillan: Singapore; 2019. p. 79–90. https://doi.org/10.1007/978-981-13-8207-9_8.
3. Zhao F. Chinese ancient loom and textile types. In: A new phase of systematic development of scientific theories in China: history of science and technology in China, vol. 4. Singapore: Springer; 2021. p. 205–55.
4. Wu G. The relationship between Xinjiang late prehistoric archaeological cultures and other world cultures. In: Archaeological research on the societies of late prehistoric Xinjiang. Singapore: Springer Nature Singapore; 2022. p. 143–227. https://doi.org/10.1007/978-981-19-6889-1_3.
5. Xin XY, Bian XY. The ancient felting techniques in Xinjiang. Adv Mater Res. 2014;1048:309–12. https://doi.org/10.4028/www.scientific.net/AMR.1048.309.
6. Feng Z. The development of pattern weaving technology through textile exchange along the Silk Road. In: Global textile encounters. Philadelphia: Oxbow Books; 2014. p. 48.
7. Compareti M. The role of the Sogdian colonies in the diffusion of the pearl roundels pattern. Ērān ud Anērān, Webfestschrift Marshak 2003. 2003.
8. Payne RE. The Silk Road and the Iranian political economy in late antiquity: Iran, the Silk Road, and the problem of aristocratic empire. Bull Sch Orient Afr Stud. 2018;81(2):227–50. https://doi.org/10.1017/S0041977X18000459.
9. Xinjiang Provincial Institute of Antiquity and Archeology. Tomb 95MNIM8 at the Niya Site in Minfeng County. Xinjiang Chin Archaeol. 2002;2(1):238–41. https://doi.org/10.1515/char.2002.2.1.238.
10. Sun S, Wang MM. Effects of the Silk Road on Chinese fabric pattern design. Adv Mater Res. 2013;796:542–8. https://doi.org/10.4028/www.scientific.net/AMR.796.542.
11. Liu J, Mouri C, Laursen R, et al. Characterization of dyes in ancient textiles from Yingpan. Xinjiang J Archaeol Sci. 2013;40(12):4444–9. https://doi.org/10.1016/j.jas.2013.06.034.
12. Cheng Y, Zhou F, Zhao Y. Measurement and prediction of the international reputation of Chinese women's apparel and accessories. Text Res J. 2023;93(1–2):194–205. https://doi.org/10.1177/00405175221117618.
13. Kramell A, Li X, Csuk R, et al. Dyes of late Bronze Age textile clothes and accessories from the Yanghai archaeological site, Turfan, China: determination of the fibers, color analysis and dating. Quatern Int. 2014;348:214–23. https://doi.org/10.1016/j.quaint.2014.05.012.
14. Zhao F, Wang L. Glossary of textile terminology (based on the documents from Dunhuang and Turfan). J R Asiat Soc. 2013;23(2):349–87. https://doi.org/10.1017/S1356186313000291.
15. Chen T, Wang B, Jiang H. New archaeobotanical evidence for Medicago from the Astana Cemetery in Turpan, Xinjiang. Herit Sci. 2022;10(1):57. https://doi.org/10.1186/s40494-022-00694-6.
16. Vickery BC. Ontologies. J Inf Sci. 1997;23(4):277–86. https://doi.org/10.1177/016555159702300402.
17. Wang JW, Wang HF, Ding JL, et al. On domain modelling of the service system with its application to enterprise information systems. Enterp Inf Syst. 2016;10(1):1–16. https://doi.org/10.1080/17517575.2013.810784.
18. Zhang WJ, Lin Y, Sinha N. On the function-behavior-structure model for design. In: Proceedings of the Canadian Engineering Education Association (CEEA). 2005. p. 18–20. https://doi.org/10.24908/pceea.v0i0.3884.
19. Hawalah A. A framework for building an Arabic multi-disciplinary ontology from multiple resources. Cogn Comput. 2018;10:156–64. https://doi.org/10.1007/s12559-017-9460-x.
20. Ren G, Ding R, Li H. Building an ontological knowledgebase for bridge maintenance. Adv Eng Softw. 2019;130:24–40. https://doi.org/10.1016/j.advengsoft.2019.02.001.
21. Zhang J, Ren T. A conceptual model for ancient Chinese ceramics based on metadata and ontology: a case study of collections in the Nankai University Museum. J Cult Herit. 2024;66:20–36. https://doi.org/10.1016/j.culher.2023.10.012.
22. Colucci E, Xing X, Kokla M, et al. Ontology-based semantic conceptualisation of historical built heritage to generate parametric structured models from point clouds. Appl Sci. 2021;11(6):2813. https://doi.org/10.3390/app11062813.
23. Wei T, Roche C, Papadopoulou M, et al. An ontology of Chinese ceramic vases. In: 12th International conference on knowledge engineering and ontology development. SCITEPRESS-Science and Technology Publications. 2020. p. 53–63. https://doi.org/10.5220/0010110600530063.
24. Wang F, Wei T, Wang J. Ontology-driven cultural heritage conservation: a case of the analects of Confucius. Appl Sci. 2021;12(1):287. https://doi.org/10.3390/app12010287.

25. Kalita D, Deka D. Ontology for preserving the knowledge base of traditional dances (OTD). Electron Libr. 2020;38(4):785–803. https://doi.org/10.1108/EL-11-2019-0258.
26. Lu L, Liang X, Yuan G, et al. A study on the construction of knowledge graph of Yunjin video resources under productive conservation. Herit Sci. 2023;11(1):83. https://doi.org/10.1186/s40494-023-00932-5.
27. Zhao Y, Dai F, Gupta MM, et al. Ontology modeling for intelligent computer-aided design of apparel products. Int J Autom Technol. 2016;10(2):144–52. https://doi.org/10.20965/ijat.2016.p0144.
28. Zhang WJ. An integrated environment for CADCAM of mechanical systems. Delft: Delft University of Technology; 1994. p. 1–263.
29. Yu HY, Ogbeyemi A, Lin WJ, et al. A semantic model for enterprise application integration in the era of data explosion and globalization. Enterp Inf Syst. 2023;17(4):1–23. https://doi.org/10.1080/17517575.2021.1989495.
30. Richards G, Wilson J. Developing creativity in tourist experiences: a solution to the serial reproduction of culture? Tour Manag. 2006;27(6):1209–23. https://doi.org/10.1016/j.tourman.2005.06.002.
31. Wen R, Hu X, Cao S, et al. The dissemination of Chinese potash-rich faience: investigation of faience beads from the Wupu cemetery, Xinjiang. Herit Scie. 2023;11(1):69. https://doi.org/10.1186/s40494-023-00901-y.
32. Barrientos F, Martin J, De Luca C, et al. Computational methods and rural cultural & natural heritage: a review. J Cult Herit. 2021;49:250–9. https://doi.org/10.1016/j.culher.2021.03.009.
33. Fauchald P, Tarroux A, Amélineau F, et al. Year-round distribution of Northeast Atlantic seabird populations: applications for population management and marine spatial planning. Mar Ecol Prog Ser. 2021;676:255–76. https://doi.org/10.3354/meps13854.
34. Moraitou E, Aliprantis J, Christodoulou Y, et al. Semantic bridging of cultural heritage disciplines and tasks. Heritage. 2019;2(1):611–30. https://doi.org/10.3390/heritage2010040.
35. de Haas T, van Leusen M. FAIR survey: improving documentation and archiving practices in archaeological field survey through CIDOC CRM. Fasti Online Documents & Research. 2020. p. 1–12.
36. Ranjgar B, Sadeghi-Niaraki A, Shakeri M, et al. An ontological data model for points of interest (POI) in a cultural heritage site. Herit Sci. 2022;10(1):1–22. https://doi.org/10.1186/s40494-021-00635-9.
37. Kin STM, Ong SK, Nee AYC. Remanufacturing process planning. Procedia Cirp. 2014;15:189–94. https://doi.org/10.1016/j.procir.2014.06.087.
38. Paterson DAP, Ijomah WL, Windmill JFC. End-of-life decision tool with emphasis on remanufacturing. J Clean Prod. 2017;148:653–64. https://doi.org/10.1016/j.jclepro.2017.02.011.
39. He Y, Hao C, Wang Y, et al. An ontology-based method of knowledge modelling for remanufacturing process planning. J Clean Prod. 2020;258:120952. https://doi.org/10.1016/j.jclepro.2020.120952.
40. Hu Y, Liu C, Zhang M, et al. An ontology-based product modelling method for smart remanufacturing. In: 2023 IEEE 19th international conference on automation science and engineering (CASE). New Zealand: IEEE; 2023. p. 1–6. https://doi.org/10.1109/CASE56687.2023.10260547.
41. Jing X, Tan F, Zhang M. Digital application of intangible cultural heritage from the perspective of cultural ecology. J Smart Tour. 2021;1(1):41–52. https://doi.org/10.52255/smarttourism.2021.1.1.6.
42. Hacıgüzeller P, Taylor JS, Perry S. On the emerging supremacy of structured digital data in archaeology: a preliminary assessment of information, knowledge and wisdom left behind. Open Archaeol. 2021;7(1):1709–30. https://doi.org/10.1515/opar-2023-0099.
43. Tzitzikas Y, Mountantonakis M, Fafalios P, et al. CIDOC-CRM and machine learning: a survey and future research. Heritage. 2022;5(3):1612–36. https://doi.org/10.3390/heritage5030084.
44. Catalano CE, Vassallo V, Hermon S, et al. Representing quantitative documentation of 3D cultural heritage artefacts with CIDOC CRMdig. Int J Digit Libr. 2020;21(4):359–73. https://doi.org/10.1007/s00799-020-00287-3.
45. Vlachidis A, Tudhope D. A knowledge-based approach to information extraction for semantic interoperability in the archaeology domain. J Am Soc Inf Sci. 2016;67(5):1138–52. https://doi.org/10.1002/asi.23485.
46. Bentaha ML, Voisin A, Marangé P. A decision tool for disassembly process planning under end-of-life product quality. Int J Prod Econ. 2020;219:386–401. https://doi.org/10.1016/j.ijpe.2019.07.015.
47. Chen D, Jiang Z, Zhu S, et al. A knowledge-based method for eco-efficiency upgrading of remanufacturing process planning. Int J Adv Manuf Technol. 2020;108:1153–62. https://doi.org/10.1007/s00170-020-05025-2.
48. Kim J, Park S, Kim HM. Optimal modular remanufactured product configuration and harvesting planning for end-of-life products. J Mech Des. 2022;144(4): 042001. https://doi.org/10.1115/1.4052389.
49. Yang J. Practice and reflection on the development of cultural and creative products in Xinjiang museums. Chin Mus. 2020;01:24–9.
50. Osman MA, Noah SAM, Saad S. Ontology-based knowledge management tools for knowledge sharing in organization—a review. IEEE Access. 2022;10:43267–83. https://doi.org/10.1109/ACCESS.2022.3163758.
51. Sevilla J, Casanova-Salas P, Casas-Yrurzum S, et al. Multi-purpose ontology-based visualization of spatio-temporal data: a case study on silk heritage. Appl Sci. 2021;11(4):1636. https://doi.org/10.3390/app11041636.
52. Xu L, Lu L, Liu M. Construction and application of a knowledge graph-based question answering system for Nanjing Yunjin digital resources. Herit Sci. 2023;11(1):222. https://doi.org/10.1186/s40494-023-01068-2.

Publisher's Note