Ontology and Linked Data of Chinese Great Sites Information Resources from the Users' Perspective

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Abstract: Great Sites are closely related to the residents' life, urban and rural development. In the process of rapid urbanization in China, the protection and utilization of Great Sites are facing unprecedented pressure. Effective knowledge organization with ontology and linked data of Great Sites is a prerequisite for their protection and utilization. In this paper, an interview is conducted to understand the users' awareness towards Great Sites to build the user-centered ontology. As for designing the Great Site ontology, firstly, the scope of Great Sites is determined. Secondly, CIDOC- CRM and OWL-Time Ontology are reused combining the results of literature research and user interviews. Thirdly, the top-level structure and the specific instances are determined to extract knowledge concepts of Great Sites. Fourthly, they are transformed into classes, data properties and object properties of the Great Site ontology. Later, based on the linked data technology, taking the Great Sites in Xi'an Area as an example, this paper uses D2RQ to publish the linked data set of the knowledge of the Great Sites and realize its opening and sharing. Semantic services such as semantic annotation, semantic retrieval and reasoning are provided based on the ontology.

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1.0 Introduction

The Great Sites is an important concept put forward from the perspective of heritage protection and management in China since 1980, as is mentioned by Meng (2009). It specially refers to the major historical and cultural sites protected at the national level, which are listed in the National Great Site Conservation Project Library. Liu and Tian (2021) divide Great Sites into 10 kinds: ancient human site, cave site, settlement site, city site, architectural site, cave-temple site, garden site, engineering site, handicraft site, and mausoleum site. The Great Site Area has a large number of tangible and intangible cultural resources, ranging from city sites, ancient buildings, to cultural customs, historical events, and so on. Its number accounts for about one quarter of these sites, but its scale far exceeds other immovable cultural relics. For the protection and utilization of Great Sites, China National Cultural Heritage Administration (2021) pointed out that the value-added utilization of it should be carried out based on sites, environments and their information resources.

The effective organization of the Great Site knowledge is the necessary requirement for cultural protection and knowledge dissemination. In this context, on the basis of ensuring the safety of the Great Site itself and its environment, making full use of their information resources, and giving full play to their social and cultural value have become the focus of the whole society.

Practically, most of the excavation fieldwork or site protection datasets in China are produced by government archaeology units, urban-rural development departments, and research institutes. Besides, there are many hundreds of these archaeological contractors who vary in their working practices. Datasets are often created on a per-site basis structured according to differing schema and employing different vocabularies, and, as a consequence, cross search, comparison or other reuse of the data in any meaningful way remains difficult. This hinders the reassessment of the original findings and reinterpretation in the light of evolving research questions of Great Sites. Meanwhile, researchers and staff from museums are developing an interest in exposing the data of Great Sites online to encourage interoperability and reuse. They propose that online dissemination of datasets should become common practice within related domains. Considering users' knowledge needs and awareness of Great Sites, employing an integrating ontology and publishing linked data, can be seen as one step towards resolving these issues.

Recently, fine granularity, semantization and the visualization of knowledge organization have been widely appreciated (Wang, Chang and Tan 2020; Liu, Lin and Xia 2018). Similarly, ontology and linked data have brought innovative methods and applications that help to reduce loss or waste of knowledge, and promoting better knowledge modeling and representation of Great Sites.

Therefore this paper intends to extract, organize and represent Great Site knowledge, and design an ontology of the Great Site for its protection and utilization from a users' perspective (hereinafter referred to as "the Great Site ontology"). Then taking the Great Sites in Xi'an Area as an example, this paper publishes the linked data set of these sites. Through the establishment of the ontology model and the release of the linked data, Great Site knowledge is organized in a scientific and effective way. Moreover, Zeng (2019) stated that the value of knowledge integration, dissemination and sharing in this field can be promoted, allowing cultural heritage institutions to make the heterogeneous contents of cultural heritage data semantically interoperable, supporting wider exploration and use of data in digital humanities research.

2.0 Related work

The information resources of historical sites are massive, diverse and heterogeneous. According to Micoli, Barsanti and Guidi (2017), they are updated dynamically with the development of protection and utilization activities. These intellectual links (e.g., people, places, time, themes) which exist in information resources of Great Sites vary from archaeology, geology, history to urban-rural development, ecological protection and so on (Wu, Yu and Zhang 2022; Wu, Zhu and Peng 2020; Zhu and Quan 2014). But previous studies did not fully deal with a method of collecting information and providing various contents through ontology and linked data for Great Sites, which is the main objective of this study.

There have been attempts to formulate the ontological status of historical buildings related to conservation practice and aimed at maintenance, reuse and sustainability, which conclude that more heterogeneous understanding (knowledge) is required (Tait and While 2009; Tibaut, Kaučič and Dvornik Perhavec 2018). Hernández et al. (2008) found that some ontologies for specific historical buildings have been developed by combining different information sources in standardized but also proprietary form (i.e. Semantic Wikipedia). Other ontologies have been progressively introduced to represent the heritage conservation process. Zalamea, Orshoven and Steenberghen (2016) presented an ontological model for the Built Cultural Heritage domain and applied it to a cathedral, more specifically for preventive conservation. Cacciotti et al. (2013) developed the Monument Damage Ontology in the context of the MONDIS project, which can coordinate a systematic approach to the documentation of damaged historical structures, their diagnosis, and possible interventions. HERACLES Ontology, whose classes are Material, Action, Damage, Effect, etc., was developed by Hellmund et al. (2018) for the preservation of tangible cultural heritage in the context of climate change.

These examples show the potential of applying ontology-based models to immovable cultural heritage representation, documentation, and analysis. However, previous studies simply concentrated on protection of historical buildings or one single architecture instead of connecting these buildings with historical sites utilization and regional development, which is clearly a weakness.

Nowadays, there are some top-level ontologies (like DOLCE, CIDOC-CRM and BFO) which describe very general concepts like space, time, matter, object, event, etc., i.e., independent concepts by a particular domain or problem. Among these, the CIDOC Conceptual Reference Model (CIDOC-CRM) is mostly referred to when describing historical sites. Kim et al. (2015) proposed the use of KCHDM, made with reference to CIDOC-CRM, which considers the characteristics of South Korean cultural heritage data. Its five super classes are "Actor", "Event", "Object", "Timespan", and "Place". Moraitou and Kavakli (2018) built the CORE ontology to preserve cultural heritage objects, extending the CIDOC-CRM ontology, thus taking advantage of its basic concepts and relations and ensuring interoperability with compatible cultural data and applications. Acierno et al. (2017) introduced in a CIDOC-CRM based ontology for its conservation process and defines four main knowledge domains (artefact, lifecycle, architectural heritage investigation process, actors).

However, lack of standardization of spatial and temporal data in CIDOC-CRM limited the possibilities in terms of reasoning and workability. So other ontologies are introduced and applied to extend CIDOC-CRM for practical use. Nys, Van Ruymbeke and Billen (2018) proposed increasing the potentiality offered by the current scheme by including GeoSPARQL and OWL-Time in the framework. Meghini, Bartalesi and Metilli(2021) presented the Narrative Ontology which has been implemented as an extension of the CIDOC-CRM, FRBRoo, and OWL-Time, which is applied to the representation of knowledge about craft heritage.

Information resources for Great Sites cover a wide range of fields and contain a wealth of knowledge. Although researchers have been generally concerned with the specific activities and knowledge domains related to protection or utilization processes, the importance of dealing with them in an integrated way is often neglected. In order to deal with the complexity of representing Great Sites, the introduction and combination of multiple ontologies is reasonable.

To make heterogeneous cultural heritage data more interoperable and structured, an ever-growing number of cultural heritage institutions are adopting linked data principles. In recent years, there have been a few related projects that aimed to enhance the digital exploration of cultural heritage by utilizing linked open data and other technologies such as natural language processing, 3D visualization, like CulturalERICA (Machidon et al. 2020), Europeana, INCEPTION (Maietti et al. 2018), 3D-IMP-ACT (De Fino, Ceppi and Fatiguso 2020). Other projects, such as the study by Candela et al. (2019) or Quattrini et al. (2017) demonstrated how ontologies, together with linked data model such as Heritage Building Information Modelling (H-BIM), could be applied to enhance cultural heritage exploration. But there are not many research articles that present linked data of historical sites, let alone Great Sites.

So far, most ontologies of immovable cultural heritage focus on historical buildings, whose top-level ontology can also be reused for this study. But no ontology offers a holistic description for the Great Site and its protection and utilization. According to the connotation of Great Sites, the knowledge involves multi-domain and multi-source information, such as regional economic development, environmental protection and cultural objects protection. There has been no ontological model containing such a wide range of knowledge. So, there is a necessity to create a new ontology based on CIDOC-CRM and other ontologies. Based on this, this paper designs a Great Site ontology model, and publishes the linked data set of it.

3.0 An interview for user-centered ontology

Likavec, Osborne and Cena (2015) found that users are being considered in ontology development. Basu (2019) mentioned that a user-centered ontology can provide a vocabulary common to different stakeholders and thus optimize the interaction between practitioners and the expert system. Also, the use of an integrating ontology can be resource intensive and error prone for people other than experts in semantic technologies. So, the design and application of the ontology should take users from distinct domains into consideration (Binding et al. 2015). As for the Great Site ontology, it should be aimed both at specialized users looking for a concrete piece of information, and at general users, who just want to spend a while navigating without a particular objective. So, importance should be attached to the information demands and retrieval aims of diverse users. However, Walisadeera, Ginige and Wikramanayake (2015) thought that to date users' potential has not been fully explored. In this study, users' understanding and awareness of Great Sites deserved to be investigated because they lay the foundation for the top-level structure, classes and properties of the ontology. Thus, we conducted user interviews with different stakeholders in relative domains to figure out their understanding and awareness of Great Sites. The interviewees include: 6 students majoring in archaeology, 3 curators and practitioners in cultural relics departments, 4 researchers, and 3 site museum enthusiasts. The interview questions and results are shown in Table 1. These questions will serve as a "litmus test" and are used to gauge whether the ontology contains enough information to answer them.

The interviews found that interviewees are most concerned about the basic information, environmental, historical and cultural background of Great Sites. They also pay attention to their historical evolution in sites' different stages of the life cycle. Interviewees generally believed that the elements of a Great Site include relics, remains, natural environment and cultural landscape. Staff, curators and practitioners of museums and cultural relics departments pay more attention to the excavation, protection, management, utilization and research activities of Great Sites, especially the cases, technologies, measures, achievements, impacts, and planning. This understanding and awareness of Great Sites can be referred to especially when reusing ontologies and customizing classes and properties.

Interview questions	Interview results	
Q1: When you study or visit the Great Site, what information do you most want to know?	The site and its relics (6) Function (3) Area Temporal (9) Location (2) Environment (1) Historical events (7)	Cultural value (7) Academic value (2) Archaeological excavations (7) Site utilization (6) Site research (5) Site protection (8) Site Management (5)
Q2: Do you pay attention to the protection and utilization of Great Sites? If yes, what information are you concerned about?	Excavation technology (2) Protection measures (6) Protection Cases (3) Protection Achievements (7) Academic Achievements (2)	Utilization (4) Community impact (1) Departments and practitioners (1) Policies and plans (4)
Q3: What do you think are the components of the Great Site?	Relics (9) Remains (10) Natural environment (11) Cultural landscape (11) Practitioners (1)	Facilities (2) Management and research departments (3) Derivative products and services (1)

Table 1. Interview questions and results.

4.0 Designing the Great Site ontology

To achieve the stated research objective, this paper referred to ontology development methods such as the seven-step method (Noy and McGuinness 2001) and METHONTOLOGY (Fernández-López, Gómez-Pérez and Juristo 1997) and KBSI IDEF5 (Benjamin Perakath 1994) and designed the Great Site ontology model via steps as follows: (1) determining the scope of Great Sites; (2) reusing formal ontologies; (3) extracting knowledge concepts; (4) defining the classes, data properties and object properties.

4.1 Determining the scope of Great Sites

According to Liu and Tian (2021), one of the main characteristics of Great Sites is "large", which means (1) large sites extending from tens to hundreds of square kilometers in area, (2) rich in historical and cultural information, and (3) significant value and social influence. Therefore, Great Sites not only have representational features such as "large" scale and "high" value, but also have essential characteristics such as temporal continuity, spatial regionality, value inheritance, and cultural superposition, which need to be revealed and organized scientifically and effectively.

In this study, the Great Sites in Xi'an Area are selected in order to populate data values and instances of classes in the ontology. Xi'an, as one of the eight ancient capitals of China, has a total of 13 dynasties built their capitals here in history, forming an area of Great Sites featuring the history of Zhou, Qin, Han, and Tang. The Outline of the Overall Protection Plan for National Great Sites (First Batch) has designated Xi'an as a historical and cultural protection area, involving sites such as the Daming Palace Site, the Han Chang'an City Site, the Qinshihuang Mausoleum, and other important surrounding gardens, and tombs. The Area is 444.96 square kilometers, of which 150.91 square kilometers are under protection. And the area of immovable cultural relics is 142.54 square kilometers (Chinese Academy of Cultural Heritage 2016). In recent years, Xi'an has been exploring new practices and modes for the protection and utilization of Great Sites, and its ideas and principles have become more mature, gradually changing from protecting sites to cooperating with the protection, display and utilization. In this process, a large number of data have been generated for reference, providing rich and fine-grained knowledge concepts and examples.

4.2 Reusing formal ontologies

Formal ontologies provide a common and extensible semantic framework for multi-domain information integration, according to Tibaut and Oliveira (2022), and they can realize the understanding and sharing of Great Site knowledge in different domains. In this way, these ontologies can be reused as the "semantic glue" to mediate among different sources of Great Site information.

According to the results of research and interviews in 3.0, Great Site knowledge includes its basic characteristics such as relics, function and area, and knowledge about persons, places, events, objects, time, etc. These concepts are consistent with CIDOC-CRM. CIDOC-CRM, developed by the International Committee for Documentation, is a theoretical and practical tool for information integration in the field of cultural heritage (https://www.cidoc-crm.org/). Semantic description of cultural heritage information is already widely structured through CIDOC-CRM and its different extensions. This shared understanding of cultural heritage information has already proved its usefulness. CIDOC-CRM is based on an event-centric information modeling, which means other classes like persons, concepts, and places are connected to each other via events (Araújo et al. 2018; Ranjgar et al. 2022). The top-level knowledge concepts of the Great Site ontology can correspond to the classes of CIDOC-CRM, such as E21 Person, E74 Group, E53 Place, E5 Event, and E70 Thing.

Regarding the use of data types and data properties specifically developed for temporal information, CIDOC-CRM offers the possibility to implement individual types of E50 Date. According to the interview results, researchers attach more importance to sites' different stages of the life cycle which are described by a wider range of time span. However, data types, as xsd:gYear, which has a more frequent use in cultural domain, are not yet supported in CIDOC-CRM. Currently, data properties targeting these data types come from CIDOC-CRM: E52 Time Span. This statement affects the domain of classes that need to be strictly subclasses of E52 entities. Considering this, OWL-Time Ontology was introduced to describe temporal information of Great Sites. Time Ontology in OWL provides a vocabulary for expressing facts about ordering relations among instants and intervals (https://www.w3.org/TR/owl-time/). It represents temporal information by allowing for representation of concepts evolving in time (referred to as "dynamic" information) and of their properties in terms of qualitative descriptions in addition to quantitative ones (i.e., dates, time instants and intervals) (Batsakis et al. 2017). According to the level of granularity considered in this study, the concept of time in Great Site ontology can be represented by the Temporal class of the Time ontology and the simplest constituting element of time is the year. These are so called Instant and refer to the time: Instant. At least two time: Instant constitute an interval (time: Interval). Each temporal entity is defined by datatype properties. These properties store year, month, day, etc.

So, this study reuses 5 classes, and customizes 6 classes: Great Site, Historical Event, Historical Actor, crm: Thing, crm: Place, crm: Person, crm: Group, Protection and Utilization Activity, Information Resource, time: Temporal.

4.3 Extracting the knowledge concepts

The connotations and extensions of Great Sites are rich, involving multi-domain knowledge. But because they are stored in separate files or databases and the legacy database schemas involved are often created on a per-site basis, cross searching or reusing this data remains difficult. Therefore, with experts' advice, thesaurus, papers, databases and other multi-source documents collected and analyzed, the top-level structure and the specific instances are determined to construct a framework of knowledge concepts for the protection and utilization of Great Sites.

4.3.1 The top-level structure of knowledge concepts

This step was utilized to build a hierarchy with the most general classes, and specialize afterwards. To obtain a reasonable and scientific structure, we consulted domain experts, who can prevent defects spreading to subsequent design and implementation activities through validation (Walisadeera, Ginige and Wikramanayake 2015). Most of the concepts are collected and directly modeled into the ontology.

(1) Analyzing thesauri, dictionaries, laws and regulations, such as Ginco, FISH Vocabularies, Getty Vocabularies, the UNESCO World Heritage Center Glossary, the Encyclopedia of China, the Dictionary of Chinese Archaeology (Archaeology Editorial Board 1986), and the Law of the People's Republic of China on the Protection of Cultural Relics.

(2) Consulting ten experts from the Institute of Archaeology, China Academy of Social Sciences, China Academy of Architectural Design, Hubei Provincial Center for the Protection of Ancient Buildings, Wuhan University, Sichuan University, Northwest University, Shaanxi Normal University School, Hunan Provincial Museum, etc. The experts were from diverse fields (archaeology, history, geography, sociology, digital humanities, urban design, information management, etc.), but all of them had previous experience working on Great Sites.

(3) Determining the top-level structure of the knowledge concepts. It is divided into two dimensions: the description of Great Sites, the activities of protection and utilization. Some significant concepts are shown in Figure 1 (the third-level concept has not been fully developed).

4.3.2 The specific instances of knowledge concepts

This step is applied in order to enrich and populate the structure by extracting low-level knowledge concepts. Taking Great Sites in Xi'an Area as an example, this paper uses natural language processing to construct an initial corpus, then extracts knowledge concepts and instances in the corpus, and finally generalizes and clusters them, for which the top-level structure of knowledge concepts serve as a guide.

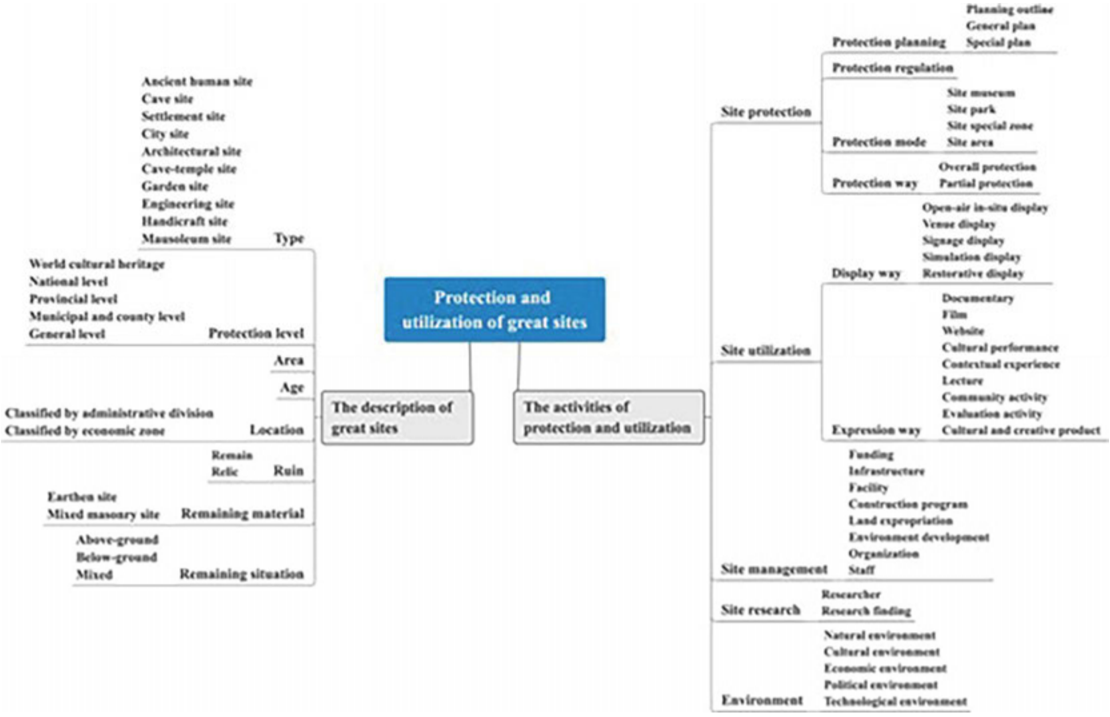

Figure 1. The top-level structure of knowledge concepts.

(1) Building the initial corpus. This exercise collected 24 archaeological reports and briefings, 106 journal papers, 3 books, 7 site management planning and regulations, 7 official websites of Great Sites, 9 project documents and reports as data sources. With a combination of OCR and manual proofreading, an initial corpus for protection and utilization of Great Sites was built.

(2) Discovering and categorizing knowledge concepts and instances. First, use Jieba Chinese word segmentation and NLPIR-Paeser to perform dictionary word segmentation and new word discovery on the corpus, obtaining multiple "word/part-of-speech tags". Second, enrich the user dictionary and identify specific nouns such as Chinese dynasty, ancient official position, ancient people's name, etc. with the Bigrams function which can calculate the co-occurrence frequency of binary word pairs in the corpus. Third, output entities such as persons, things, events, time, places through named entity recognition. Finally, artificially categorize and supplement knowledge concepts and instances.

(3) Generalizing and clustering knowledge concepts and instances.

Through this approach, we obtained diverse knowledge concepts such as 5 Great Sites, 42 historical events, 63 historical actors, 14 places, 96 protection and utilization activities, etc. which we could select as needed for modeling as classes, properties and instances.

4.4 Defining classes, data properties and object properties

Though we have got an abundance of knowledge concepts, they are still isolated and lost, they lack rich semantic information, and the relationships between knowledge concepts have not been fully revealed. To solve this, based on the reused ontology and acquired knowledge concepts above, this paper reuses some concepts from authoritative metadata and ontologies, and customizes some classes and properties to build the whole ontology model. The ontology contains 11 classes, 29 subclasses, 98 data properties, 77 object properties. These abundant properties help promoting semantic relationship between classes, reaching semantic benefits.

4.4.1 Existing controlled vocabularies

The reuse of well-established existing controlled vocabularies which have been already well defined by specialized communities and organizations prevents unnecessary duplicated work. The usability and applicability of these vocabularies are guaranteed by standardization processes and agreements. Several vocabularies are therefore introduced into the Great Site ontology.

(1) The Dublin Core Metadata Element Set establishes a vocabulary for cross-domain resource description (https://www.dublincore.org/specifications/dublin-core/dces/)

which includes creator, date, description, language, publisher, etc.

(2) The Friend of a Friend (FOAF) Vocabulary Specification (http://xmlns.com/foaf/spec/) and Shanghai Library Names (SHLNames) Authority Ontology (http://data.library.sh.cn/ont/ontology/tree?g=http://ont.library.sh.cn/graph/shlnames) describe information about people and the connections between them, such as foaf:name, shl:officialPosition, shl:createdWork.

(3) GeoNames integrates geographical data such as names of places, population and others (https://www.geonames.org/about.html). It is used to describe the properties related to the location of Great Sites.

(4) VRA Ontology is a data model for the description of works of visual culture, designed as a means to enable linked data (https://s3.amazonaws.com/VRA/ontology.html). It is used to describe the physical form, historical and cultural background of archaeological relics of Great Sites.

(5) Schema.org(https://schema.org/), an RDF vocabulary for structured data on many domains, namely schema:alter nateName (e.g., "Emperor Jiaqing" as alternative name to "an emperor of the Qing dynasty"), and schema:sameAs (to semantically link different URI resources describing the same individual).

4.4.2 Classes and data properties

Based on previous work, this paper defines 11 classes and their data properties, as shown in Table 2. The classes of the Great Site ontology are organized by a flat hierarchy which enables researchers to choose easily a level of generality of terms that is appropriate for actual situations, considering the fact that the various types of Great Sites have distinct characteristics which should be defined by properties. Data properties relate classes to literal data (e.g., strings, numbers, datetimes, etc.) and the datatype or range of them is literal. Since most of concepts and instances are literal data, experts suggest customizing and reusing related data attributes because they are simpler to create and edit with only a domain class and a datatype to be selected.

(1) Great Site. It refers to the large sites and their cultural landscapes that reflect the political, religious, industrial, agricultural, historical and cultural information at various stages of development in ancient Chinese history, with large scale, significant value and far-reaching impact (National Cultural Heritage Administration and Ministry of Finance of the People's Republic of China, 2005). This class includes 10 subclasses of ancient human site, cave site, settlement site, city site, architectural site, cave-temple site, garden site, engineering site, handicraft site, and mausoleum site.

(2) Historical Event. It includes historical events related to the prototypes of Great Sites. It can be divided into two types. One includes construction, destruction, restoration and other events that directly cause changes in the prototypes of Great Sites. The other is the natural disasters, political, economic, cultural, military, diplomatic events behind the changes of Great Sites with far-reaching effects.

(3) Historical Actor. The class includes the designers, builders, owners and destroyers of the Great Site, as well as the initiators or participants of the historical events that caused changes to the site.

(4) crm: Thing. It is used to describe remains and relics. It can reflect the historical function and cultural context of Great Sites. For example, the orderly and symmetrical distribution of remains at ancient city sites can express the political culture of "imperial supremacy". The shape, craftsmanship, materials, and burial objects of mausoleum reflect the patriarchal culture of "strict hierarchy".

(5) crm: Place. It is the geographical data involved in the life cycle of a Great Site which is used to describe the location of other classes. By revealing the correlations of Great Sites, Historical Event, Historical Actor, and other classes in the horizontal spatial dimension, the axis of historical narrative is transformed from ephemeral genealogy to co-temporal relationships (Jessop 2008).

(6) crm: Person. It reveals important people involved in the protection and utilization of Great Sites, including archaeologists, members of archaeological excavation teams, daily management and maintenance personnel, researchers, and those who formulate protection planning and management regulation.

(7) crm: Group. It describes institutions or organizations for the protection and utilization of Great Sites, including China National Cultural Heritage Administration, provincial cultural heritage bureaus and local governments, land departments, finance departments, tourism departments, site protection and management agencies, various museums at all levels, historical and archaeological research institutions, relevant associations and enterprises, etc.

(8) Protection and Utilization Activity. It contains 4 subclasses: Site protection, Site utilization, Site management and Site research. These subclasses are chosen mostly based on the user interview in 3.0. These activities should be based on the basic principle of "archaeological support, protection first, reasonable utilization" focusing on the cultural connotation of Great Sites, coordinating with local social and economic development.

(9) Environment. It contains 5 subclasses: natural environment, economic environment, cultural environment, political environment and technological environment. The natural environment, such as temperature, humidity, ultraviolet light, etc., causes changes in the sites and their remains. The political environment, such as the formulation of policies and regulations, may promote the development of Great Sites. The economic environment (e.g., GDP, tour-

Class	Subclass	Data Property
Great Site	Ancient human site Cave site Settlement site...	site_name, protection_level, remaining_material, remaining_status, area
Historical Event		event_title, event_process, event_effect
Historical Actor		actor_name, schema:alternateName, gender, shl:briefBiography, shl:speciality, shl:courtesyName, shl:pseudonym, shl:nativePlace, shl:birthday, shl:deathday
crm:Thing	Remains Relic	vra: title, protection_level, vra:description, measurements, material, technique
crm:Place		shl:country, shl:province, shl:city, shl:county, shl:town, village, zone, gn:name, gn:alternatename, gn:postal code, gn:longitude, gn:latitude
crm:Person		foaf:name, foaf:gender, foaf:mbox_shalsum, schema:telephone, shl:officialPosition, degree, shl:officialExperience, shl:createdWork, shl:birthday, shl:deathday
crm:Group		group_name, group_location, group_description, group_web, schema:telephone
Protection and Utilization Activity	Site protection	protection_planning, protection_regulation, protection_mode, protection_way
	Site utilization	display_way, expression_way
	Site management	funding, infrastructure, facility, construction_program, land_expropriation, environmental_development
	Site research	research_finding
Environment	Natural environment	geologic_feature, topographical_feature, climate, disaster
	Cultural environment	cultural_industry, religion, tradition, educational_level
	Economic environment	city_area, city_population, gdp, financial_revenue, financial_expenditure, tourism, disposable_income
	Political environment	law, policy
	Technological environment	internet_technology, digital_technology, cultural_relics_restoration_technology
Information Resource	bibo:Book bibo:Article...	dcterms:title, dc:subject, dc:creator, dc:description, dc:publisher, dc:language, dcterms:date
time: Temporal	time:Time instant	shl:temporal, time:year, time:month, time:day
	time:Time interval	time:years_duration, time:months_duration, time:days_duration

Table 2. Classes, data properties of the Great Site ontology.

ism development, financial support, etc.), the cultural environment (e.g., customs, religion, tradition, etc.) and the technological environment (e.g., preservation technology, digital technology, etc.) also have an impact on the protection, utilization and display of Great Sites.

(10) Information Resource. It is the information collection presenting whole or partial Great Sites protection and utilization activities such as monographs, papers, newspapers, reports, pictures, audios and videos, etc.

(11) time: Temporal. There are two subclasses, Time instant and Time interval, which are used to describe the time information of all persons, events and things in the life cycle of the Great Sites, so that the knowledge of Great Sites can be supplemented and enriched from the vertical temporal dimension.

4.4.3 Object properties

Defining object properties can accurately represent the semantic relationship networks of knowledge concepts. The object properties in this ontology are shown in Table 3. We divide object properties into 4 types: inheritance relation, spatio-temporal relation, subordinate relation, action relation. Some object properties relate individuals to other individuals, such as "hasSpouse/hasFellow". Some connect classes because there is a need to enforce a particular constraint by creating an inverse property like "isDescribedBy/describes". Others assert the same relationship in both classes, with the most common example being related terms like "foaf:knows". The classes and their relationships in the ontology are shown in Figure 2.

Type	Relation/Object Property	Type	Relation/Object Property
Inheritance relation	is-a	Action relation	isDescribedBy/describes
	isPartOf		isDamagedBy/damages
	isInstanceOf		wasDestroyedBy/destroyed
Spatio-temporal relation	time:after/before/hasTemporalDuration/hasTime		isDiscoveredBy/discovers
	crm: isLocatedOnOrWithin/tookPlaceAt		isDiggedBy/digges
Subordinate relation	crm:contains		isExpressedBy/expresses
	crm:isCurrentOrFormerMemberOf		isExpropriatesBy/expropriates
	shl:creatorOf/directorOf		isExcavatedAt/excavates
	outcomeOf		isFundedBy/funds
	isSubordinateTo		wasGivenBy/gave
Action relation	foaf:knows		isInfluencedBy/influence
	hasCulturalEnvironment/hasEconomicEnvironment/...		crm: wasModifiedBy/modified
	hasCulturalInfluence/hasEconomicInfluence/...		isManagedBy/manages
	hasSpouse/hasFellow		wasOwnedBy/owned
	hasActivity		crm: wasProducedBy/produced
	hasRemain/Relic		isProtectedBy/protected
	hadEvent		isPlannedBy/plans
	crm: participatedIn		isRepairedBy/repairs
	wasBoughtBy/bought		isStudiedBy/studies
	isDisplayedBy/displays		isUsedBy/uses

Table 3. Object properties of the Great Site ontology.

5.0 Publishing linked data in Great Sites

Linked data is data structured and interlinked with each other. Machines can better read, interpret and reuse linked data to respond to human queries in the Semantic Web environment (Hallo et al. 2016), so that we can connect cross-domain Great Site knowledge into a knowledge network through linked data. This study cleans and stores the knowledge concepts and instances obtained in 4.3.2 in the relational database based on the ontology. Then we strive to follow FAIR principles and five-star principles of Tim Berners-Lee (Guerrini 2013), publish and disseminate linked data in Great Sites to support multiple methods for accessing and querying data.

5.1 Data storage and mapping

In this study, a MySQL database was used to store the data tables and inter-table relationships. It was selected for two reasons. Firstly, many traditional tangible cultural heritage information systems whose data can be linked into the Great Site ontology mainly use relational databases for data storage. Secondly, the D2RQ platform, which only supports relational databases, is used to convert the database into linked data afterward. The classes and data properties of the Great Site ontology were converted into a two-dimensional table structure, and the relationship between tables was established according to the object properties of the ontology. The MySQL database contains three elements: entity, relationship, and attribute. The data mapping process mainly includes the following three types: (1) Entity mapping. This means that the classes of the ontology correspond to the entities in the database. For example, classes such as Great Site, Place, and Person are entities in the MySQL database; (2) Relationship mapping. This refers to the correspondence between the object properties and the relationships between the tables. The relationships include one-to-one relationship, one-to-many relationship and

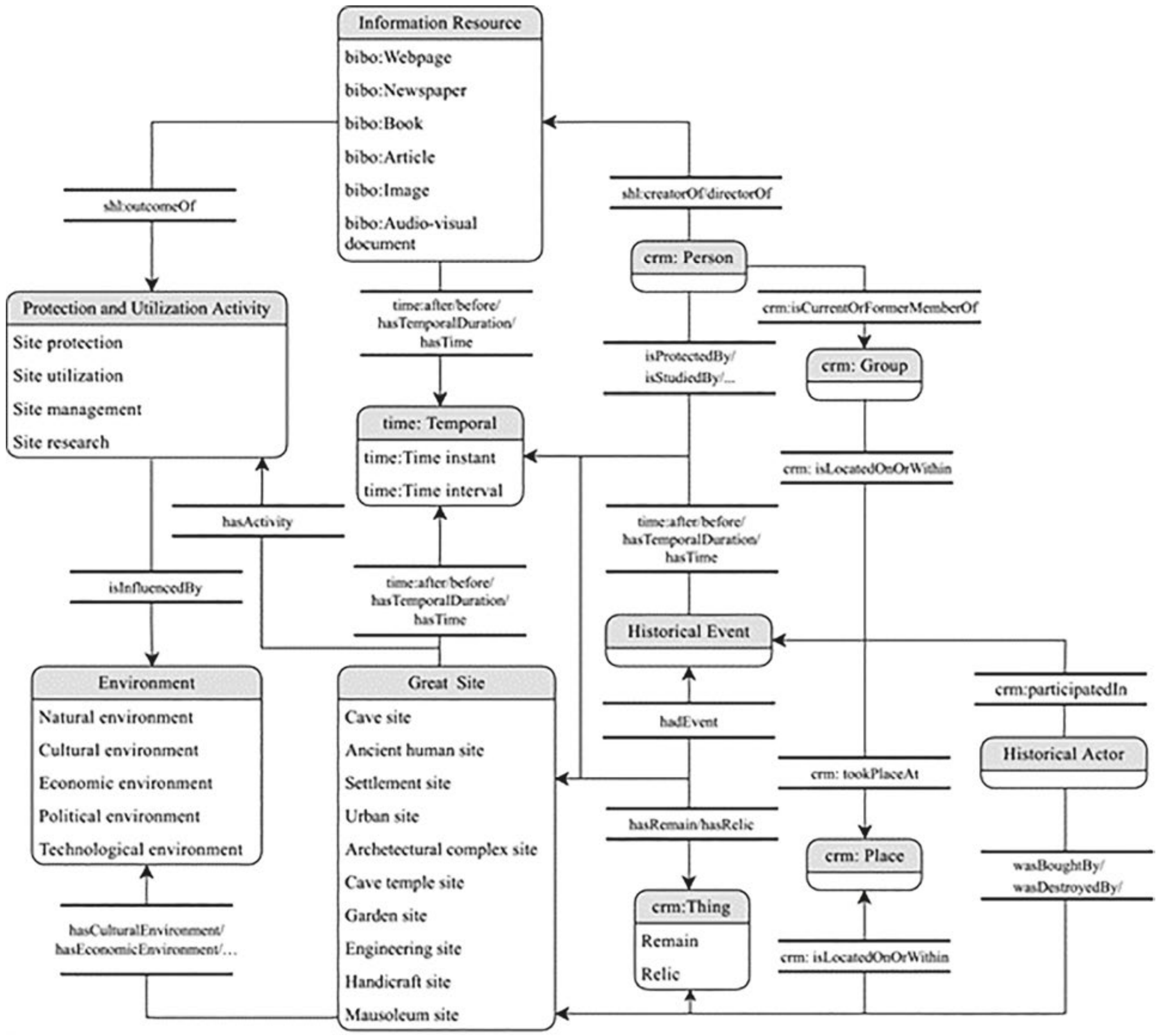

Figure 2. The classes and their relationships of the Great Site ontology.

many-to-many relationship, such as the one-to-many relationship between Great Site and Thing, and the many-to-many relationship between Great Site and Protection and Utilization Activity; (3) Attribute mapping. This means that the data properties correspond to the attributes of the database, and the attribute values are the instances extracted from the initial corpus.

5.2 Linked data publishing

Several languages and software tools are available to perform the mapping procedure from relational databases to RDF triples, as is mentioned by Hert, Reif, and Gall (2011). The D2RQ platform was chosen to map the database into linked data. An example of the mapping file is shown in Table 4. The mappings between table columns and their corresponding concepts are created using the command d2r: ClassMap. The mapping between the table columns to their corresponding properties is performed by using the command d2rq: PropertyBridge. In addition, in the mapping scripts each entity is associated with a Unique Resource Identifier (URI). In the example, the Great Site is mapped from the "great_site" table. The bridge between Great Site and Temporal is mapped through "temporal_id".

<table>
<tr><th>#mapping from great_site table to Great Site class</th></tr>
<tr><td># Table great_site
map:great_site a d2rq:ClassMap;
d2rq:dataStorage map:database;
d2rq:uriPattern "great_site/@@great_site.site_id|urlify@@";
d2rq:class vocab: great_site;
d2rq:classDefinitionLabel " great_site";</td></tr>
<tr><td>#mapping from attributes to data properties</td></tr>
<tr><td>map:great_site_site_name a d2rq:PropertyBridge;
d2rq:belongsToClassMap map:great_site;
d2rq:property vocab:great_site_site_name;
d2rq:propertyDefinitionLabel "great_site_site_name";
d2rq:column "great_site_site_name";</td></tr>
<tr><td>#mapping from relations to object properties</td></tr>
<tr><td>map:great_site_temporal_id__ref a d2rq:PropertyBridge;
d2rq:belongsToClassMap map:great_site;
d2rq:property vocab:great_site_temporal_id;
d2rq:refersToClassMap map:time_temporal;
d2rq:join "great_site.temporal_id => time_temporal.temporal_id";</td></tr>
</table>

Table 4. Data semantic mapping statement (part).

After mapping, the platform can deeply aggregate and display knowledge of the Great Site and its relationship starting from one knowledge entity of the Great Site. As shown in Figure 3, through "Han Chang'an City" instance, we can enter the linked data table of it, and URIs of instances such as Place, Temporal, etc. can be obtained.

6.0 Findings

The ontology and linked data of Great Sites can bring greater semantic benefit through semantic services such as semantic annotation, semantic retrieval; reasoning can be realized, thus providing references for knowledge descriptions and representation of Great Sites in a wider range.

6.1 Semantic annotation

Based on the ontology, this study uses the knowledge concepts and instances obtained in 4.3.2 to semantically annotate the Great Sites in the Xi'an Area. Figure 4 mainly shows the annotation results centered on the Han Chang'an City Site and its relative sites. First, the "protection_level", "remaining_material", "remaining_status" and "area" are data properties of Great Sites. Secondly, classes are listed. The Historical Events related to "the Han Chang'an City" site include the "construction of Weiyang Palace". The relevant Historical Actor is "Xiao He". The Place is "Daxing West Road, Weiyang District, Xi'an City, Shaanxi Province". The Environments include "Longshouyuan Plain", "continental climate", "World Famous Historical City", etc. The Persons include "Li Yufang" and "Liu Qingzhu". The Group is "the Institute of Archaeology, China Academy of Social Sciences". The Protection and Utilization Activity is "site management". The relevant Information Resource is "Han

Figure 3 . Linked data of Great Sites(part).

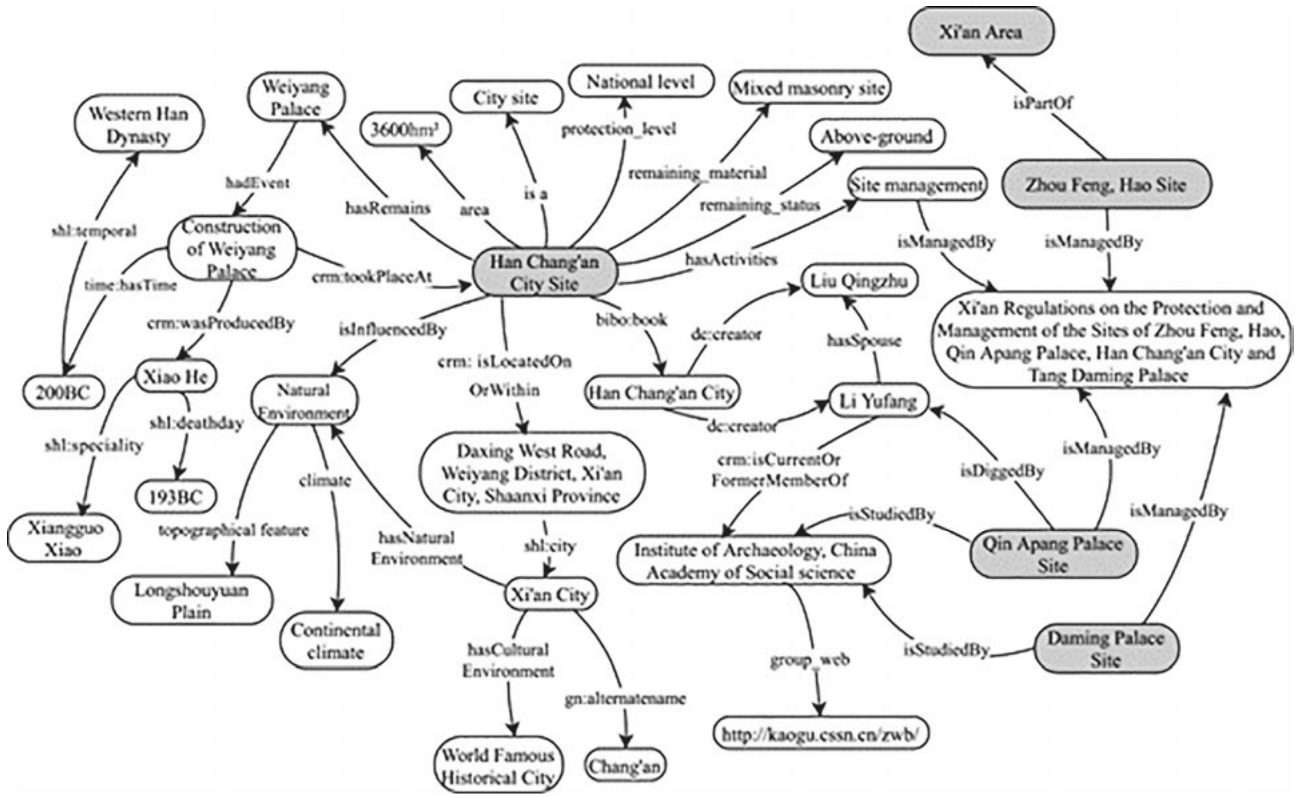

Figure 4. Results of semantic annotation of Great Sites in Xi'an Area(part).

Chang'an City", and the Temporal is the "Western Han Dynasty".

6.2 Semantic retrieval and reasoning

This study uses Protégé to instantiate the Great Site ontology. With the help of the conceptual hierarchy and logical reasoning of the ontology, we implement semantic retrieval and reasoning in order to obtain explicit and implicit knowledge of Great Sites.

6.2.1 Semantic retrieval

We can obtain the explicit knowledge required for the user's retrieval needs through the ontology based on SPARQL query. To query the names of Persons and their Groups studying the "Han Chang'an City Site", we enter the corresponding SPARQL query statement, and run it to get the results shown in Figure 5. Moreover, the instances of Person and Group that meet the user's needs can be returned through the transitivity of their relationships. For example, the relationship of "creatorOf" exists between Person and Information Resource, and the relationship of "describes" exists between Information Resource and Great Site, the list of Persons studying a Great Site can be obtained. Meanwhile, the relationship of "isCurrentOrFormerMemberOf" exists between Person and Group, so the list of Groups studying a Great Site can also be obtained.

6.2.2 Semantic reasoning

Semantic reasoning can explore the semantic relationship between variables and obtain implicit knowledge with specific object properties and their constraints. So, this service can expand the semantic relationship network and improve the retrieval recall rate.

The first example is adding object properties automatically. Figure 6 shows that "studies", whose domain is "crm:Person" and range is "Great Site", is the inverse of "isStudiedBy". As we add object property assertions "studies" "Han Chang'an City Site (汉长安城遗址)" to these researchers and then start HermiT reasoner, the "isStudiedBy" object property assertions will be added automatically to "Han Chang'an City Site (汉长安城遗址)" in Figure 7.

The second example is inferring hidden relationships between persons and groups. Eelationships between researchers into the Great Sites have not been fully added yet. Researchers in the same institution should have the relationship of "hasFellow". So, we use the SWRL inference rules and the HermiT reasoner, as shown in Table 5. Through the

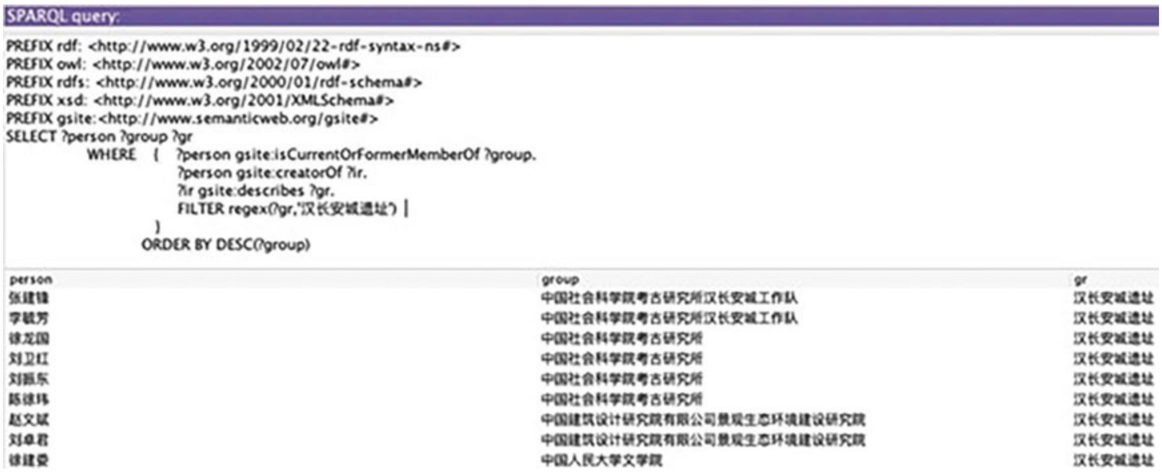

Figure 5. Search results of Person and Group studying the Han Chang'an City Site(part).

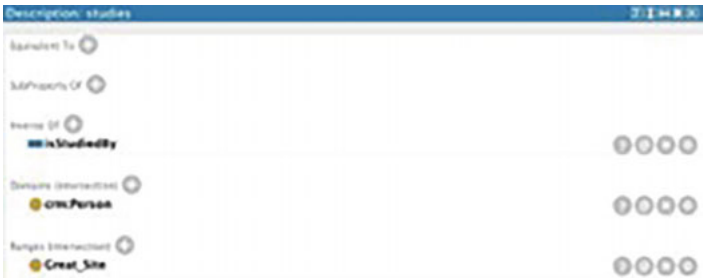

Figure 6. The "studies" object property and its inverse.

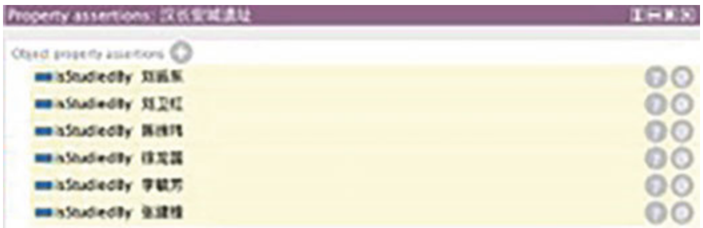

Figure 7. Adding "isStudiedBy" automatically.

institution and its sub-institutions, we match and reason "hasFellow" relationship of researchers. Taking "Li Yufang (李毓芳)" as an example, she once worked in the Han Chang'an City Team of the Institute of Archaeology, China Academy of Social Sciences, so she has a "hasFellow" relationship with "Zhang Jianfeng (张建锋)" who also works in the same institution. The Han Chang'an City Team is affiliated to the Institute of Archaeology, China Academy of Social Sciences, so "Li Yufang" also has a "hasFellow" relationship with "Liu Weihong (刘文洪)" and others in this unit, as shown in Figure 8.

7.0 Conclusion

Wu (2020) mentioned that the protection and utilization of Great Sites in China has gone through three stages of "passive protection, exploration for utilization, promoting protection by utilization" which rarely involve the excavation and expression of the knowledge semantic network behind the Great Sites. Aiming at this research gap, through ontology and linked data, this paper organizes, publishes and displays the diverse and heterogeneous Great Site knowledge. Firstly, we conducted an interview to have a better command of users' understanding of Great Sites to make sure that the ontology could be practical. Secondly, we defined

Rule1	gsite:isCurrentOrFormerMemberOf(?person1,?group)^gsite:isCurrentOrFormerMemberOf(?person2,?group)^differentFrom (?person1,?person2)-> gsite:hasFellow(?person1, ?person2)
Rule2	gsite:isCurrentOrFormerMemberOf(?person1,?group1)^gsite:isCurrentOrFormerMemberOf(?person2,?group2)^gsite: isSubordinateTo(?group1, ?group2)->gsite:hasFellow(?person1, ?person2)

Table 5. Adding "hasFellow" through reasoning.

Figure 8. "hasFellow" relationship between researchers.

classes, data properties and object properties to build the Great Site ontology. Thirdly, we used D2RQ to map the linked data based on the ontology model. Finally, semantic services based on the Great Site ontology were provided, aiming to improve the sharing, openness and influence of knowledge in this field.

Since the ontology is user-centered and takes different kinds of stakeholders' understanding into consideration, specific user groups or organizations could benefit from the practical use of it. For cultural departments, museums and related research institutions, based on the ontology, they can develop a portal in the first step, which is conceived to offer easy access to tangible cultural heritage or immovable cultural relics content gathered in the ontology. The portal could be semantically enhanced and contextually relevant. Afterward, more interactive applications could be proposed to catch the users' attention, for example, virtual museums. These systems would be beneficial in improving the quality of knowledge service and efficiency of information display in Great Sites.

For students majoring in related fields and site museum enthusiasts, since the Great Site ontology provides a structured knowledge representation for open large-scale Great Site datasets, it offers a quick view of the top-level structure of knowledge concepts and their expansion. These amateurs can obtain both fine-grained knowledge units and coarse-grained knowledge collections through browsing layer by layer and semantic retrieval.

As for curators, practitioners and researchers, the Great Site ontology aims to enable horizontal communication between disparate data sources, with related and/or potentially different domains (e.g., archaeology and geography). When they aim to retrieve or deduce the Great Site knowledge with semantic matching, the ontology can present the right content for the user's context, which is clean, properly structured, and integrated across multiple fields. In these fields, the ontology can be reused, interoperated and iterated, which can enrich linked data and semantic services for Chinese cultural information resources. In this way, the users are able to conduct interdisciplinary research and investigations according to the Great Sites.

This study has the following limitations. Firstly, the paper only sorts out basic knowledge elements and chooses several Great Sites as instances. Secondly, it mainly analyses knowledge from digital and printed articles and books, and the data extraction and ontology editing processes were performed manually. These tasks required interpretation by a domain expert, but this approach is not sufficient for handling vast amounts of cultural heritage data.

In the future, the granularity of knowledge organization needs to be further refined, and the linked data set should be further expanded to present the intricacies and nuances of the Chinese heritage resources in cultural heritage modelling. In addition, the ontology can be adapted or extended to include cross-cultural historical sites through a wider range of external vocabularies, dictionaries and standards.

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