Architectural Heritage Online: Ontology-Driven Website Generation for World Heritage Sites in Danger

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Abstract. We introduce an online knowledge base for semantic representation and annotation of a world heritage site in danger. For this purpose we designed ontology inside the protégé tool with multiple metadata-based schemas to represent a knowledge base for heritage buildings and to annotate heterogeneous data sources. The ontology schema also references multiple bibliographies so it can gather the complex history of each building, or multiple coordinated locations of each building. We built an ontology-driven Website generation system "Bam3DCG" based on the Resource Description Framework graph exported from Protégé, and discuss practical problems for this type of system.

Keywords: Ontology Knowledge Model, Architectural Heritage, Heterogeneous Data Resources, Ontology-Driven Website Generation.

1 Introduction

In cultural heritage Websites, the quality of data and the level of reliable information it represents has an important role in increasing knowledge and proper awareness of tangible or intangible heritage sites. Complex historical background, various physical attributes, and different local and environmental characteristics give multiple-domain-related features to cultural heritage sites. The questions are how to effectively represent such complex knowledge of cultural heritage sites in an online database.

Architectural heritage data, as part of tangible heritage, contains information on heritage buildings. Historical background, constructional attributes, and location features represent information of a building. To represent such sophisticated information online, it is important to recognize different categories of data and conceptualize them in a standard schema. We introduce a metadata-based ontology knowledge model and a generated Website that conceptualizes a world heritage site (Citadel of Bam) by providing information of the site online.

The rest of the paper is structured as follows: Section 2 describes the attributes of heritage buildings and characteristics of our ontology knowledge model. Section 3 introduces the metadata-based ontology knowledge model, Section 4 discusses the generation of a Website for our target case study based on the ontology, and section 5 concludes the paper.

M. Ioannides (Ed.): EuroMed 2010, LNCS 6436, pp. 277–290, 2010.

2 Semantic of Heritage Buildings

To capture the semantics of a heritage building, it is important to verify major topics to precisely describe the building, such as its history, physical attributes, function, location, ownership, and preservation process. We introduce three of these categories that greatly influence the conceptualization of a knowledge model.

2.1 History and Dating

The first category, history, starts with a chronology of a particular building. An inscription can specify the construction date of a building, but in several cases such information is not available. Studying the architectural style or reviewing historical records can fulfill this goal. Type of decorations, constructional elements (arches or vaults), material (bricks), or organization (presence of a courtyard) can provide the necessary information to estimate the history of the building or its related period of construction. A record in a travelogue manuscript, such as a description by Ibn Hawqal [4] (travelled 943-969 AD) of the Citadel of Bam is another way to uncover the history of a building. In many cases a building does not represent a short period of time, but continues to change over different historical periods in different layers of construction or areas of expansion. The Citadel of Bam has a history starting from 500 B.C. until 1925 A.D. The chronology of such sites is a challenge that requires a multiple referencing approach.

Based on the above explanation, the history and dating of a building in a knowledge base has two characteristics: it must be able to give multiple dates or multiple historical descriptions to a building and it needs to link each historical record to its reference (both bibliographic or on site surveys) to validate the dating.

2.2 Physical Attributes

The type of building elements and structural components are important attributes for specifying the physical appearance of a heritage building. For the Citadel of Bam, these features represent desert architecture of the middle region of Persia. Most of the walls are load bearing. The characteristic feature of building components is types of coverings such as barrel, cloister or arched vaults. The type of arches also has a key role in representing different historical periods. Other components consist of floors, roofs and openings such as doors or windows.

Material and decoration are another subcategory and reflects the environmental characteristics of the site or historical background. The major wall and coating material of the Citadel of Bam is mud brick, mud-straw or chalk. Decorations are important attributes for distinguishing buildings (such as the house of a commander) or religious buildings such as mosques. The knowledge model for conceptualizing different categories of physical attributes of heritage buildings must provide a complete list of elements in a systematic way based on metadata standards.

2.3 Heterogeneous Data

Architecture is a type of visual knowledge. Its language corresponds more with drawings and images than with texts. Each database or knowledge base related to architectural heritage has a considerable amount of visual data with various data types. Architectural drawings made using Auto CAD or Micro Station, 3D models made by 3ds Max or Sketch Up, photogrammetric material made using Photo Modeler, different kinds of images such as on-site, landscape, aerial, and satellite photos, and different kinds of videos, such as Quick Time Virtual Reality, walk through, and aerial views result in heterogeneous datasets.

Such heterogeneous data require proper management in a knowledge base. They must be annotated by a standard attribute-set. Each piece of visual data needs to be connected with the textual descriptions representing information of the building in the knowledge model to disambiguate and validate it.

2.4 Knowledge-Based Schema for Heritage Buildings

We introduced different information aspects of heritage buildings needed for an advanced online web page. Any model for conceptualizing the above-mentioned aspects must have these major characteristics:

1. Provide multiple schemas to cover different attributes such as history, physical features, environment, management, and preservation.
2. Provide multiple bibliographic referencing.
3. Use metadata standards to describe building attributes or annotate the dataset.
4. Link every textual entity with visual data, such as images, movies, or architectural drawings, to validate the textual descriptions.

When a target building is selected, it is important to connect the different schemas mentioned above together with the visual dataset to easily navigate between various topics and acquire as much information of the building as possible. Weaving cultural heritage information into knowledge, which helps to develop an advanced knowledge model proper for the semantic web [1], is accomplished using advanced knowledge models. An ontology provides semantic relations between different topics in a hierarchical manner [3] and is appropriate enough to conceptualize information of heritage buildings.

3 Ontology for Heritage Buildings

To acquire semantic of the Citadel of Bam, we designed an ontology knowledge model called Bam 3D CG ontology using three major schemas: metadata-based schema, which is conceptualized using different metadata standards, referencing-based schema, which provides location or bibliographic attributes, and lexical-based schema, which provides terminological specifications for each heritage building. The architecture of the Bam 3D CG ontology is described in Figure 1. In the target ontology designed using the Protégé knowledge acquisition tool [15] as an RDF file [13], every piece of information or visual data is an entity connected to other entities by semantic links. These links are descriptive attributes of entities. Each homogeneous group of information is hierarchically categorized in classes with subclasses [10].

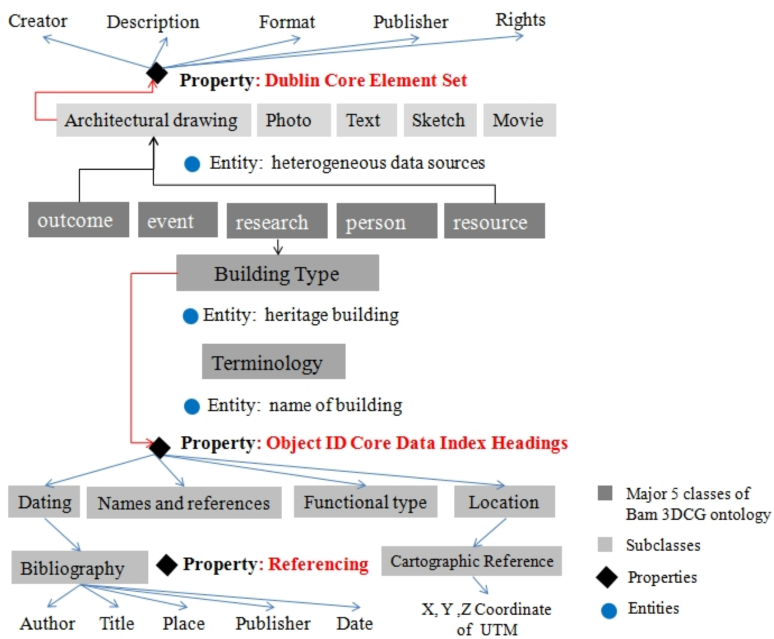

Fig. 1. Architecture of Bam 3D CG Ontology

3.1 Metadata-Based Schemas of the Ontology

Metadata standards provide a widely accepted list of elements to describe an object or data. A complete list of elements of metadata standards can help to precisely survey data in heritage sites because collecting data at such sites is complicated. It is important not to miss any information during a field survey by using a complete list of required information and an appropriate metadata standard. It is important to note that metadata standards are domain-based and focus on a specific field. If the target topic requires multiple domains for complete annotation and description, it is necessary to study different standards and select the desired topics and map between various metadata standards. For the heritage-building domain, we used part of the Core Data Index of Object-ID standard and the Dublin Core metadata standard to annotate visual data such as photos or videos. We describe how the schemas are modeled and connected in our ontology.

Metadata of Heritage Buildings and Integration inside Bam 3D CG Ontology. To describe the attributes of heritage buildings, we selected the Core Data Index, which is part of the Object ID standard. “Object ID is an international standard for describing cultural objects as a metadata standard containing specific items.” [5,6]. The Core Data Index to Historic Buildings and Monuments of Architectural Heritage is a part of Object ID that focuses specifically on buildings.

The Core Data Index template inside the ontology provides the structure of data input and is conceptualized as follows. Each of the nine headings, such as Names and References, Location, Functional Type, and Dating, which are obligatory headings, is a class. Subclasses are those sub headings in the Core Data Index that have attributes in the third sub level, such as Administrative Location, Address, and Cartographic Reference, as subclasses of location. Every subheading that has attributes is a property or slot in the ontology. Each of the nine headings is defined as slots and takes instances from the class with the same name from the template. The template class provides the schema and structure, and the property class provides connections between different headings by using instances to weave every piece of information together.

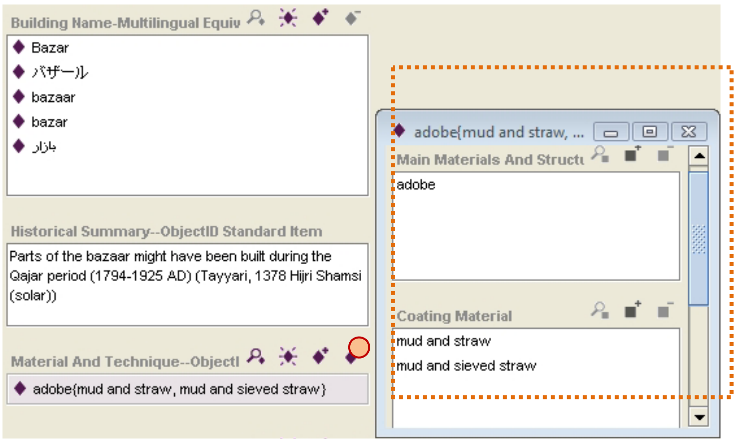

Fig. 2. Interconnected instances of Core Data Index template of Bam 3D CG ontology, bazaar

In conceptualizing properties or slots inside the schema, it is important to note which kind of information will be collected under it. If it is an explanation, then the *slot value* will be a *string*, and data is directly input (such as *coating material* in Figure 2). If several pieces of information with different attributes are available, the *slot value* will be an *instance*. This instance will be a link to connect different pieces of attributes. The form on the left side of Figure 2 is connected to the slot *Material and Technique* by an instance. This instance specifying *main material and technique* is adobe and *coating material* is mud and straw. Instances can connect several pieces of attributes and their information in the schema and can be freely selected from different classes. We integrated the Core Data Index schema inside the Bam 3D CG ontology. We modified the complete schema of the Core Data Index and selected those headings that had available information, as shown in Figure 2.

Metadata of Buildings Digital Data and Integration inside Bam 3D CG Ontology. To describe and catalogue visual data, consisting of photos, videos, architectural drawings, and sketches, we used the Dublin Core Metadata Element Set, which is a standard vocabulary of fifteen properties for use in resource description [14]. The Dublin Core element set is less complicated to conceptualize inside the ontology schema than the Core Data Index of Object ID since one level of headings is available. We defined a class named Dublin Core, and each element, such as Contributor and Creator, is a slot with a value-type string and directly gathers information about the data.

Figure 3 shows integration of the Dublin Core element set inside the Bam 3D CG ontology. We had several images taken of the Citadel of Bam before and after the earthquake. Each photo is annotated using the Dublin Core schema as presented in the first box. It is important to note that we modified the slot values of the Dublin Core schema for those attributes that are related to the names of persons from slot value *string* to *instance* since they take instances from another schema related to people inside the Bam 3D CG ontology, as shown in properties of "Rights" in Figure 3. All data is restored in the repository and linked with the ontology schema as a file path in the local file system (slot image in Figure 3).The schema resolves syntactic differences between different distributed heterogeneous data sources. The Resource Description Framework (RDF) converts all types of data into RDF data using the reference ontology [8].

3.2 Referencing Schemas of Ontology

For online representation of the information of each heritage site, two major references are necessary. The first one specifies the location of the target site using the standard Spatial Referencing Systems. The second one that provides referencing to multiple bibliographies is necessary to validate historical research.

Geo reference of Heritage Buildings. As part of the ontology schema from the Object-ID Core Data Index, we provided the X, Y, and Z coordinates of each building located in the Citadel of Bam according to the Universal Transverse Mercator (UTM) Spatial Referencing System (Figure 4). For each property, a string slot is created and the complete schema is connected by an instance to the main body of the ontology by the slot that takes its name from the Core Data Index sub heading, named Cartographic Reference, as part of the heading Location. For each building one location is proposed as the middle point of the courtyard (as shown in Figure 4), or middle point of major dome on the roof. If the building is linear, such as the surrounding wall, several points on the edges are proposed.

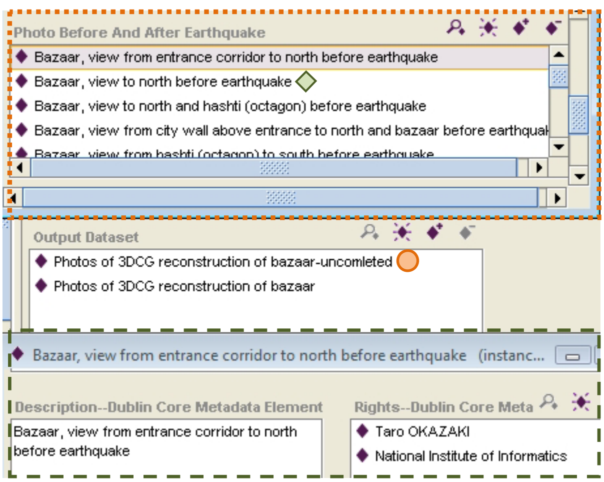

Fig. 3. Part of ontology for annotation of photo using the Dublin Core Element Set

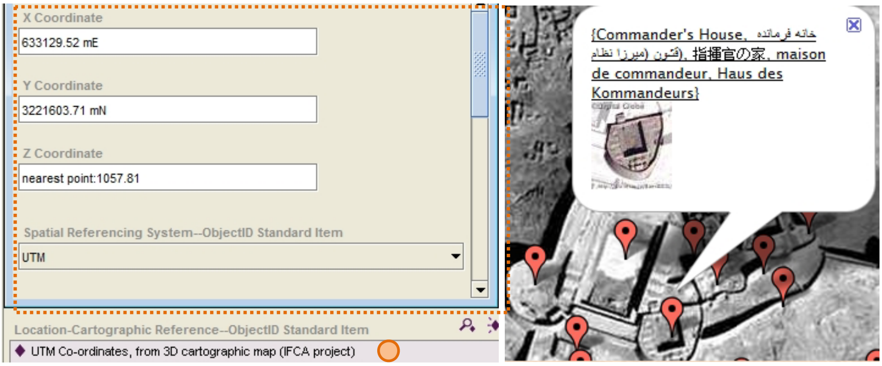

Fig. 4. Instances of coordinate referencing of building, commander's house

The location schema of Bam 3D CG ontology provides the UTM coordinates for around 52 buildings inside the Citadel of Bam (provided by the 3D Cartographic Map as IFCA project between (CNRS) and (NCC)). In the Website generated using this ontology, each location instance is referenced on the Google earth satellite images of the Citadel of Bam before and after the earthquake, as shown in Figure 4.

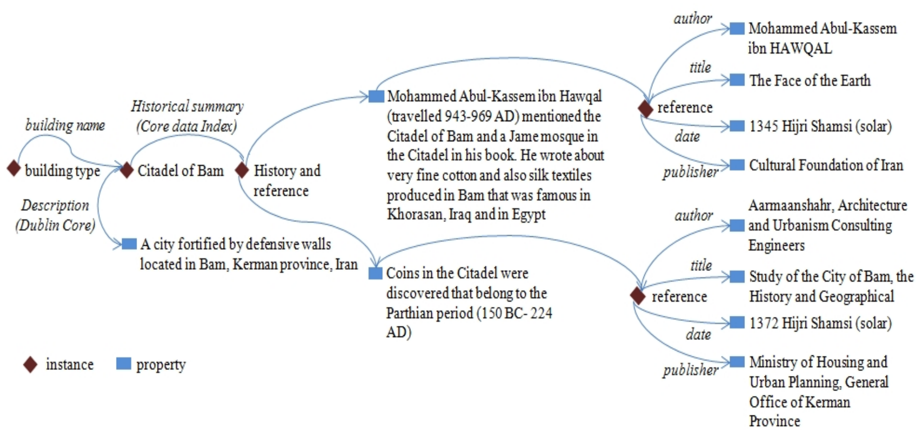

Fig. 5. Historical summery linked with multiple references

Multiple Historical References Bibliographic Attributes. We previously described the conceptualization process of bibliographic schema of the ontology [7]. Its main characteristic is the ability to provide multiple referencing to historical material to determine the dating and history of each building by defining different instances, as shown in Figure 5. The bibliographic schema is linked to the body of the ontology together with the lexical schema that gives semantics to each building type.

3.3 Lexical Schemas of Ontology

The multilingual lexical schema of the ontology provides the semantics of each building in different languages. We previously described this schema and its constraints in detail [7]. In the Bam 3D CG ontology for each building type, the multilingual equivalents accompanied by their lexical information are provided as shown in Figure 6.

4 Ontology-Driven Website Generation

To browse the RDF graph created on Protégé, we designed a Website generation and maintenance system so that people can browse knowledge bases using a standard Web browser. The Website “Bam3DCG” (http://dsr.nii.ac.jp/Bam3DCG/) has been open to the public since December 2008.

Fig. 6. Instances of multilingual building name in Bam 3D CG website

4.1 Architecture of Website

Referring to the model proposed in Intelligent Information Presentation System (IIPS) [9], we divide our system into three components, an ontology editor, ontology manager, and Website generator. For the ontology editor, we decided to use Protégé off the shelf to reduce the cost of developing a new system. A Web interface for managing ontology, such as WebProtégé and Ontowiki, were still premature at the time of system development, so we decided to use a stand-alone version of Protégé. This raises the problem of synchronizing ontology between the client and the server.

Insert, update, and delete actions on the knowledge base are done in the client side, and they have to be reflected on the server side to update the knowledge base on the Website. The update of the ontology can only be done offline, and users cannot update the ontology on the Web interface to avoid inconsistencies of the ontology. This is not a problem in our case because the Website is mainly designed for browsing, but

Web-based ontology management should be considered in a future version of Bam 3D CG as a portal to improve the usability of the system.

For the ontology manager and Website generator, we designed our ontology-driven Website generation system in a hierarchical layer structure, as depicted in Figure 7. The base layer is the Web application server, Tomcat, and we installed Web application frameworks, namely Apache Click and Velocity, on top of Tomcat. The RDF is managed using the semantic Web framework, Jena, and the RDF graph is stored in PostgreSQL. This architecture was chosen because of the ease of integration of various tools. We manage the data using the following steps. First the RDF graph exported from Protégé is uploaded to the system. The RDF graph is then parsed by Jena, and after applying some pre-processing steps, RDF triples are stored in PostgreSQL.

The problem is that the RDF graph cannot manage binary objects, such as images and videos, and can only maintain pointers to binary objects such as a file path in the local file system. This means that we need a separate uploading interface for binary objects in addition to the RDF graph. Currently, we use Secure Copy (SCP) for uploading binary objects and Hypertext Transfer Protocol (HTTP) for uploading the RDF graph. After pre-processing of the RDF graph and binary objects, they are stored in the database to support on-the-fly generation of HTML pages from stored data.

This uploading process, however, is not fully automated, and deletion or update sometimes requires administrator's intervention to manage existing data. Hence, we may need dedicated uploading software in the future that can manage both the RDF graph and binary objects using protocols such as Web-based Distributed Authoring and Versioning (WebDAV).

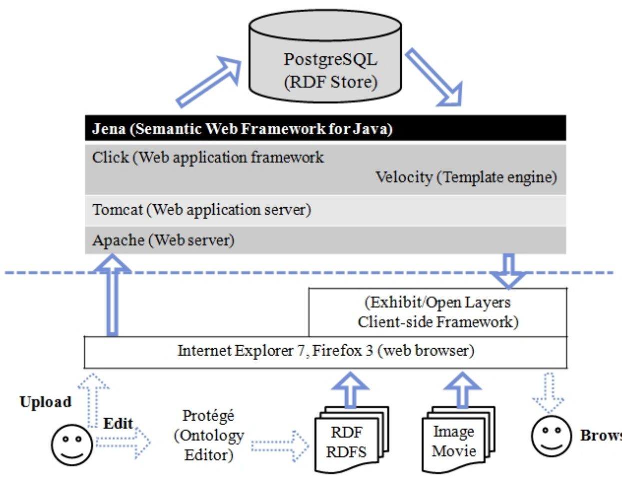

Fig. 7. Architecture of Website

The Web interface is designed using Cascading Style Sheets (CSS) and Javascript. The interface has five classes (Fig. 1) and four views, list (class), instance, hierarchy, and map. Instance view displays binary objects on the HTML page when it needs to display images and videos. Map view uses Google Maps to render spatial location of instances whenever they have spatial coordinates. We also introduced two satellite image layers into Google Maps so users can compare the Citadel of Bam before the earthquake, just after the earthquake, and the current status (default). Finally we also provide two searching interfaces, 1) search by terms for general users and 2) search by SPARQL (SPARQL Protocol and RDF Query Language) for advanced users. These functions also help users obtain resources directly from other resources.

4.2 Discussion

Representation of Resources. RDF is defined as a link of resources, so the natural unit of representation is a resource. We discovered, however, that this strategy does not produce intuitive representation in terms of HTML page generation. This is especially true for binary objects such as images and videos.

On the RDF graph, an image or a video is a resource that is linked from another resource. Hence, the representation of a non-binary resource may have a link to a binary resource, and traversing a link to a binary resource displays the binary object. This is not what a user expects, however. For example, the resource of a building and image resources of that building refer to the same real-world building (entity), so a user expects to see images and videos of the building on the HTML page of a building. If we follow the one-resource-per-HTML-page principle, however, a user needs to traverse links each time to see images and videos of the building.

Our solution to this problem is pre-fetching and embedding of resources that are linked from the resource in focus. That is, we do not just show a link to the resource, but actually fetch (upon request) the resource and embed it with a simple description. Figure 8 is an example of a resource page, on which users can see the image resource without traversing to the image resource page. From our experience this method is especially effective for multimedia resources such as images and videos.

Fig. 8. Pre-fetching and embedding of multimedia objects

This can be explained by the problem of entity identification. Photographs of a building and the description of the building actually describe the same real-world building using different representation forms. Another explanation is that photographs and videos are “appearance” variants of the entity specified by the resource. Hence, we feel that they should be viewed in the same HTML page to facilitate comparison and interpretation of the real-world entity. To support this idea, we need to differentiate the relationship of appearance variants from the general links that represent different entities.

Representation of Spatial Objects. Spatial objects are now represented with a point in a spatial coordinate. As a spatial reference system, we used both UTM coordinates, obtained from the 3D cartographic map (IFCA project between NCC and CNRS), and World Geodetic System 84 (WGS84), obtained by identifying buildings on Google Earth. We discovered, however, that WGS84 and UTM coordinates do not represent the same point on earth. The reason may be 1) UTM coordinates depends on a domestic datum, 2) coordinates on Google Earth (so-called Google Earth datum) are different from WGS84. We have not investigated this reason, but we decided to keep both coordinates, and use Google Earth coordinates to represent the point of buildings on Google Earth/Maps, as illustrated in Figure 9.

Another problem with spatial objects is the specification of regions. Currently, buildings are represented with points, but this is not enough, especially when representing a large building. A more problematic case is the surrounding walls of the citadel, because the wall surrounding the whole site cannot be represented by a single point. The system should support a mechanism to specify the geometry of an object on the map. One possible solution is to use Scalable Vector Graphics (SVG) to represent spatial objects. By providing an interface for drawing the boundary of spatial objects with polygons or polylines, and exporting the geometry into a SVG file, we can render the boundary of a geometric object on the map as a clickable element.

Practical Problems with Protégé. We used Protégé as the ontology editor. Here we discuss the problems we had with version 3 of the protégé. The first problem was on making the multilingual version of RDF. This is not a limitation of RDF as a specification but a limitation of Protégé, which does not support multilingual labels for instances. This problem may be solved using a Web Ontology Language (OWL) plug-in for Protégé, which supports multilingual labels. This solution is not easy, however, because we need to transform RDF to OWL. The second problem was, as already stated, the issue of binary objects. There are no built-in mechanisms to maintain the consistency of pointers to binary objects, so we use filenames of binary objects as one property of a resource. This is obviously not a good design, however, because this process is error-prone and tends to be inconsistent. One possible solution is to use a separate data management system, which maintains the Uniform Resource Locator (URI) and an access method of the object. The third problem was that Protégé treats the collection of properties as a bag of properties, but a user actually needs a sequence of properties because properties often have an intuitive order of importance. There are no mechanisms to support this requirement, so we implemented mechanisms to manage the order of properties when generating HTML pages. Another limitation involves the description of classes and properties because the RDF created on Protégé does not have a simple mechanism to do this.

Navigation for Browsing RDF Graph. The purpose of the Bam3DCG Website is to help users browse the RDF graph. The simplest implementation of the Website is to render each subject as one HTML page in which links to objects or literals are shown with predicates. This design is not easy to use, however, because information is fragmented into too small pieces, preventing users to understand information in a broader context. For the same reason, this interface design requires users to traverse links several times back and forth, and users gradually feel lost in the complex structure of the RDF graph. We tried to design a proper graphic site view specially for five major classes (digital reconstruction, reference, research, outcome, people). Each class is presented by a photo in the main page that is repeated on top of every page so the user can recognize the main category of information that is browsed (upper part of figure 9). Another solution is the pre-fetching and embedding approach described previously.

Fig. 9. Displaying spatial objects on Google Maps

4.3 Toward Linked Data

The current RDF graph is specially designed for our project. However, on the concept (class) level, we introduced domain ontologies developed in other communities to enhance interoperability between communities, as described in the previous sections. The next step is to enhance interoperability on the data (instance) level to integrate our knowledge base with a global information space called linked data. Linked data refers to a set of best practices for publishing and connecting structured data on the Web, leading to the creation of a global data space containing billions of assertions – the Web of Data [16]. For this purpose, we need the following four steps [12].

1. Use URIs as names for things.
2. Use HTTP URIs so that people can look up those names.
3. When someone looks up a URI, provide useful information, using the standards.
4. Include links to other URIs, so that they can discover more information.

In our case, task 1 is satisfied by using the ontology editor. Task 2 is superficially fulfilled, but still has an essential problem from the viewpoint of cool URIs [16]. The current URIs contains irrelevant information, such as date created and sequential numbers, which are not related to "things" as introduced in the step 1 of cool URIs. Hence they do not satisfy the policy of cool URIs such as simplicity, stability, and manageability. Task 3 is not satisfied because the current Website returns information only in HTML format, but not in RDF format. Finally, Task 4 is still in a preliminary stage. We incorporated some ID systems into our ontology, but we have not started linking with other linked data initiatives such as DBpedia. More important future contribution is to open our Website so that other people can link to our URIs.

5 Conclusion and Future Work

We introduced ontology-driven Website generation for semantic representation of knowledge of a World Heritage Site in Danger, the Citadel of Bam. We discussed multiple schemas of the ontology designed using different metadata standards or referencing systems and the interconnected entities linked with properties of each schema. We discussed the architecture of the ontology-driven generation of our target Website, Bam 3D CG, and the constraints in the process of converting the RDF file of the ontology linked with binary objects, such as photos, to HTML pages that a user can browse easily. The metadata schema designed in Bam 3D CG ontology is extensible to collect knowledge of other architectural heritage buildings. Our ontology-driven Website generation software is based on open source software libraries, so it is extensible to other heritage Websites. Our software was not designed as a general framework for heritage Websites, but some components are domain independent and allow reuse for such Websites. Finally, scalability of the Website largely depends on the RDF store shown in Figure 7. We are currently using PostgreSQL for the RDF store. PostgreSQL is a relational database management system (RDMBS), and it is well known that RDF, which is a collection of triples, does not match with the data model of a relational database, which is a collection of tuples. We can replace the RDF store to one optimized for triples, and this will improve the performance of the system to achieve scalability.

The Bam 3D CG Website presents information on the Citadel of Bam in an advanced knowledge model and links it with visual data such as photos or maps. We still have several studies to conduct regarding linked data, which is an important future step in making our infrastructure valuable to researchers and people around the world. We will also investigate how to extend ontology-based approach from a Website to a portal to which heritage-building experts can contribute and annotate data of cultural heritage by a web server for managing the ontology.

Acknowledgements. The supporting research project, 3D CG reconstruction of the Citadel of Bam is a collaborative project between the Digital Silk Road project of NII and Iranian Cultural Heritage, Handicraft and Tourism Organization (ICHHTO) lead by Prof. Dr. Kinji Ono. We would like to thank Associate Professor Dr. Frederic Andres for his support in developing the ontology. We also thank Mr. Tomohiro Ikezaki for developing the Website generation and management software and assistant professor Mohammad-Reza Matini for site view graphic design. This work was conducted using the Protégé resource.

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