3D Data Acquisition and UML Data Modeling on Archaeology GIS

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1. Introduction

The aim of this paper is to demonstrate the new trend of archaeology GIS in terms of methods of data acquisition and the modeling of archaeological data for creating databases. Archaeological sites, termed *archaeological features*, provide evidence of past human activities that occur at a certain location. There are various kinds of archaeological surveys, including distribution surveys, trench surveys, and excavation; the outcomes of these surveys are typically finalized in reports. The use of GIS has led to improved methods of surveying, excavating, and recording of archaeological research. GIS is most significant for archaeological features that require precise positional records.

Laser scanning technology is used for archaeological data acquisition with precise positioning and auto recording of the excavation of archaeological sites. In Section 2 we present the results of 3D recording using a laser scanner at the national heritage archaeological site of Tyre, Lebanon. In Section 3, we model archaeological data for creating archaeological databases using UML modeling based on the GIS standard ISO/TC211. The purpose of the archaeological data modeling is to share archaeological information worldwide.

2. Laser scanning of archaeological sites

2.1 Archaeological investigation in Tyre

The historic town of Tyre, Lebanon, was founded in 3000 BC and is a national heritage site. A joint Japan–Lebanon archaeological excavation group undertook an initial archaeological investigation in Sour (the old name for Tyre) from September 4 until October 4, 2000, under an agreement between the Director General of Antiquities Lebanon, Frédéric al Husseini, and a Japanese archaeological mission comprising the director, Ken Matsumoto, and the vice-director, Takura Izumi.

The archaeological investigation was undertaken by 11 Japanese project members, Ali Badawi, and three volunteer Lebanese archaeological students. The tasks of the investigators were to:

1. Conduct an archaeological survey of the ruins located to the west of the planned highway through Sour.

2. Conduct a distributed survey for collecting archaeological items in the area of the planned highway.
3. Measure Roman structures and tombs in Sour using a 3D laser image scanner. The archaeological sites were measured from September 20 to 26, 2000 by R. Shibazaki and T. Usui, members of the 3D laser-scanning group. The archaeological sites measured by laser scanning are shown on the map in Figure 1 and in the aerial photograph in Figure 2, which shows the Al Bass region, the city site, and the Ra Mali region.

2.2 3D measurement using a ground-based laser scanner

The purpose of our excavations is to perform 3D measurements of archaeological sites using a 3D ground-based laser scanner and thereby to produce virtual 3D models of the archaeological sites of a Roman chariot street, a Roman pedestrian road, aqueducts, and the hippodrome at the Al Bass Site, as well as the mosaic road at the city site. We also performed 3D laser scanning of two underground tombs in the Ra Mali region where the construction of a highway had been proposed by local government. The objective of making 3D measurements of the tombs is to preserve them as full-color 3D digital archaeological scenes prior to their demolition.

The LMS-Z210 3D scanner used in this project is produced by RIEGL Laser Measurement Company, Austria. The 3D sensor is specifically designed for the acquisition of 3D scanning via the transmission of a laser beam across a precise angular pattern. The resulting range measurements provide an accurate 3D representation of the archaeological scene. Figure 3 shows the 3D measurement points at the Al Bass site. We measured the Roman chariot street at the Al Bass site from seven points (AL01,AL03,AL05,AL09) on September 20, 2000, the Roman pedestrian road at the AL Bass site from five points (AL11, AL12–AL15) on September 20 and 21, the Roman aqueducts at the Al Bass site from four points (AL21–AL24) on September 21, and the hippodrome at the AL Bass site from one point (ALTrack) on September 21.

The measured range values represent the distance from the 3D scanner to the surface of the archaeological feature from which the laser was reflected. This process generates three types of information: the range, the signal amplitude, and the angle from the measurement point to the many reflected surface points that make up the archaeological site.

By repeatedly transmitting the laser beam several hundred thousand times per second while varying the transmission angle, we were able to compile a vast array of 3D points known as point-cloud data. Measurement accuracy was generally within several centimeters.

The 3D scanning data is then used to construct virtual 3D models of the archaeological sites. Figures 3–5 show the steps involved in constructing a virtual 3D model of an archaeological site using point-cloud data of varying range values.

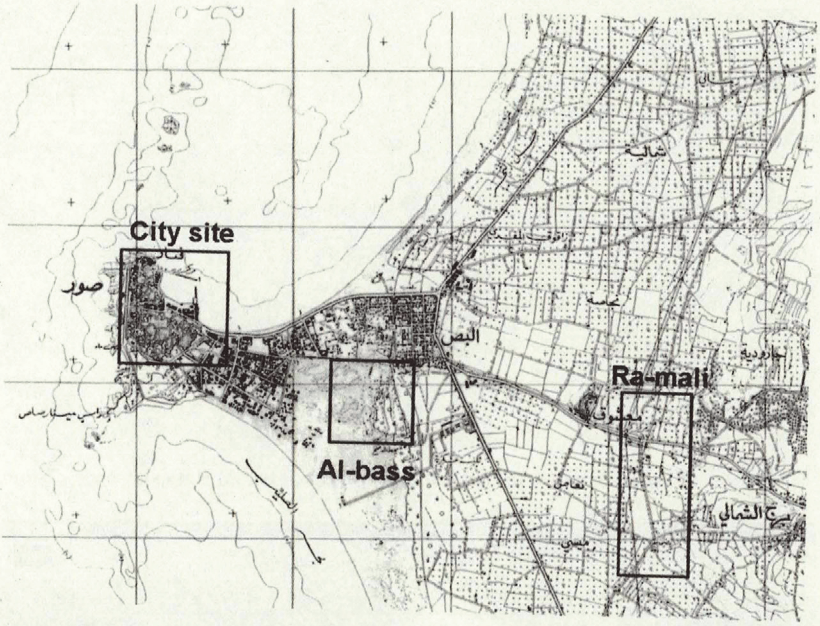

Fig. 1 Map of the Tyre showing the three areas scanned by 3 D scanner (black rectangles)

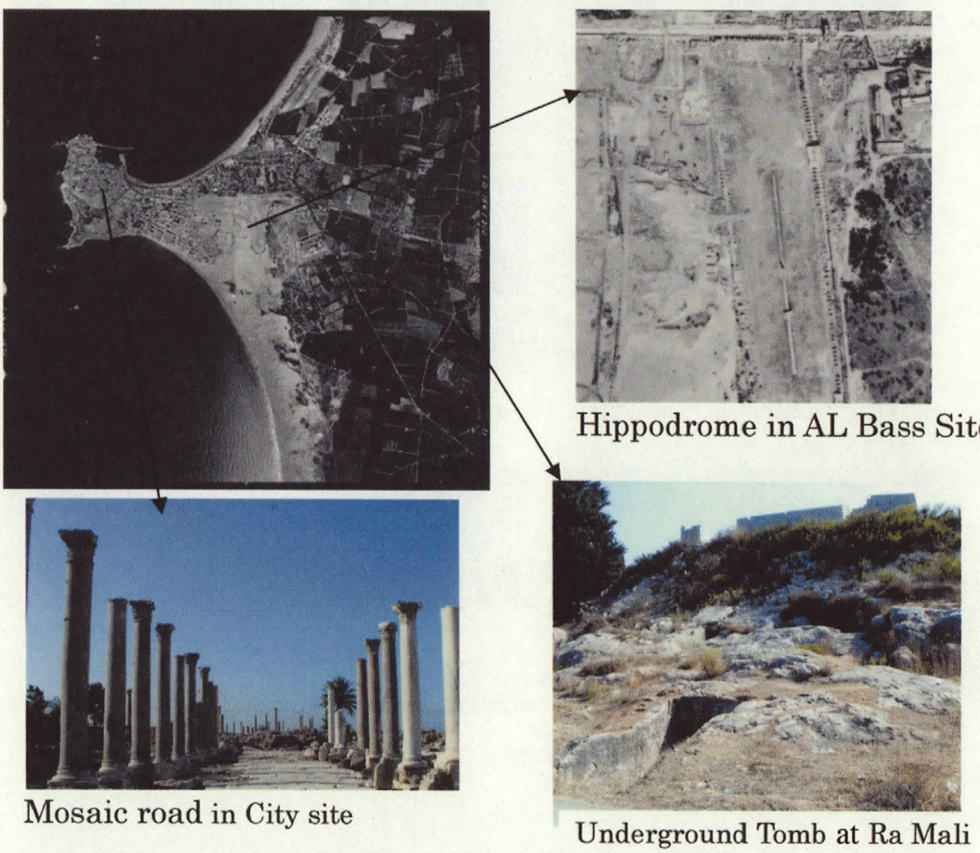

Fig. 2 Aerial photograph of the Tyre and locations of three archaeological sites

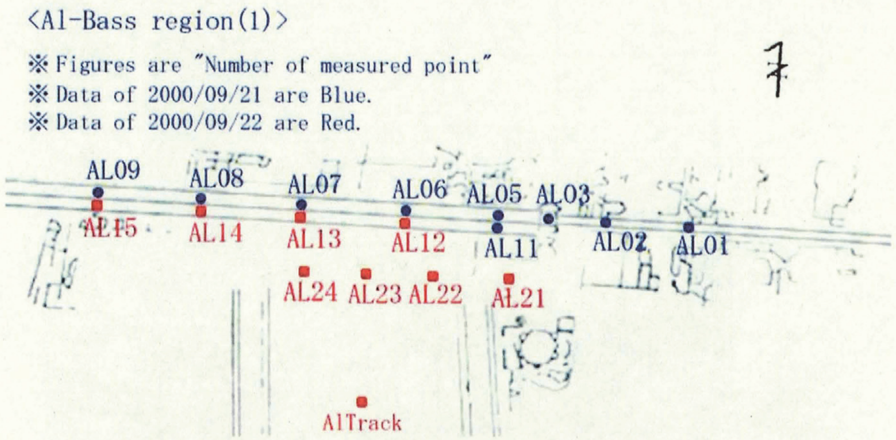

Fig. 3 Locations pf measurement points at the Al Bass site

Fig. 4 Range Image of the Roman chariot street at the Al Bass site, as displayed at the Al Bass site

Fig. 5 Panoramic view of a true-color image of the Roman chariot street at the Al Bass site

The operating software of the 3D scanning sensor is 3D-RiSCAN software, and this is used to perform sensor configuration, data acquisition, and data manipulation. Three types of image models (range image, intensity image, and RGB true-color image) are generated in the original 3D-RiSCAN format. A 3D-RiSCAN license is required for visualization of the images.

The many export functions of 3D-RiSCAN enable the transformation of LMS-Z210 row data to other general data formats such as VRML, TXT, DXF, BMP, VTK, PIF, OBJ, and STL without the need of a visualization license.

In this report we used Cosmo Player 3D viewer software for visualizing the 3D range image exported from 3D-RiSCAN in VRML format. The 3D range image model of the Roman chariot street was constructed using Cosmo Player, as shown in Figure 4.

We took many digital photographs and thereby constructed the panoramic true-color image. Figure 5 shows a panoramic true-color image of the Roman chariot street.

Figure 6 shows images of the two underground tombs. We scanned from five points within the Stone Coffin tomb and from three points within the Patterned Grave tomb. The range image is shown in Figure 7, with three target points used for rectifying each of the range images, which themselves comprise many points. Figure 8 is a panoramic true-color image of the Stone Coffin tomb.

By measuring the size of the coffin and the internal structure of the grave, we can preserve a digital version of the grave even though the tombs will be destroyed during construction of the proposed highway. The purpose of the 3D laser measurement is to preserve the archaeological site in digital format so that the site can be measured in detail following the excavation survey and to provide a record of the site.

3. Archaeological data modeling in creating a database for sharing information

3.1 Characteristics of archaeological information

In archaeology, it is information concerning artifacts and remains at archaeological sites that is the most essential resource in investigating past human activity. However, the procedure for recording information differs for different archaeologists. Whether or not to interpret an excavated hole as a pillar hole is dependent on the experience of the excavation team. Furthermore, after excavation of a site, most sites are then covered with soil or buildings and the information is available only via reports, drawings of archaeological features, or photographs. The sharing of information requires the establishment of standardized recording methods and database structures. However, Japanese and European archaeologists use different excavation recording methods in terms of archaeological information.

In Europe, stratified layers uncovered during excavation surveys are classified into units of stratification based on stratigraphy, and each unit of stratification is recorded by

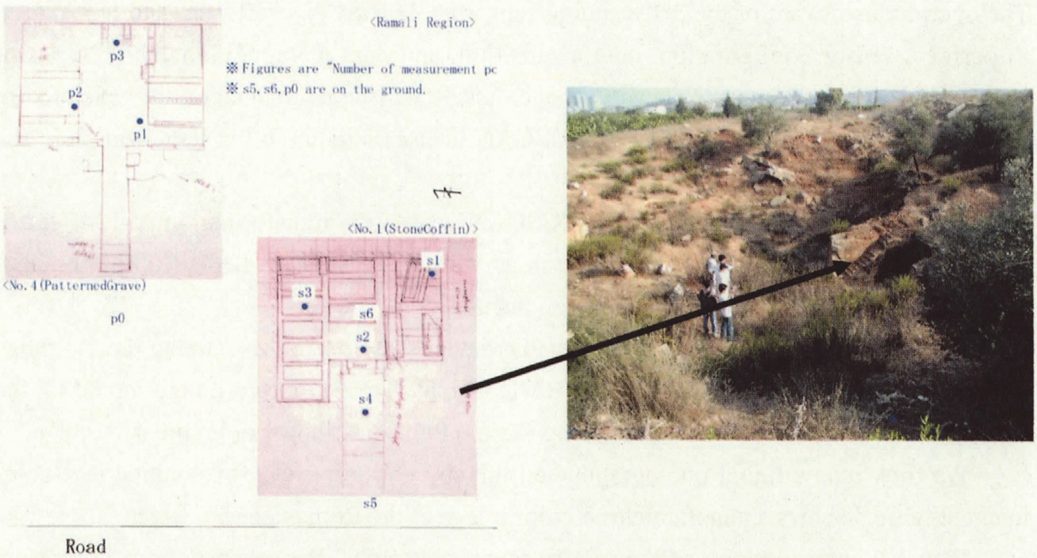

Fig. 6 'Maps of the two underground tombs scanned in the Ra Mali region: the No.4 Pattern Grave tomb software

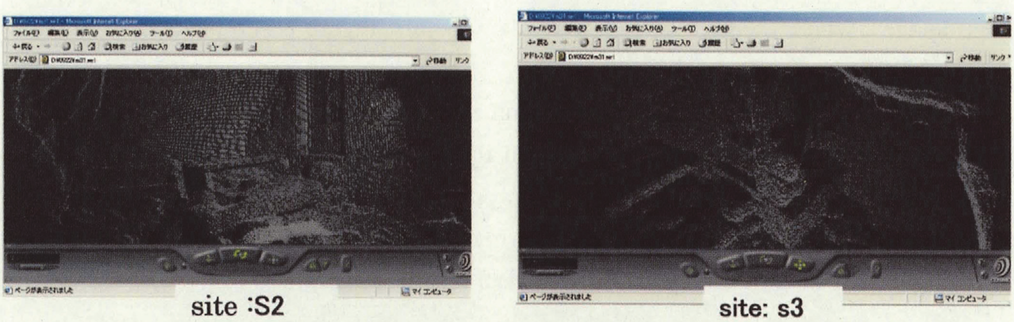

Fig. 7 View of the range image of the No.1 Stone Coffin tomb, as shown using Cosomo Player

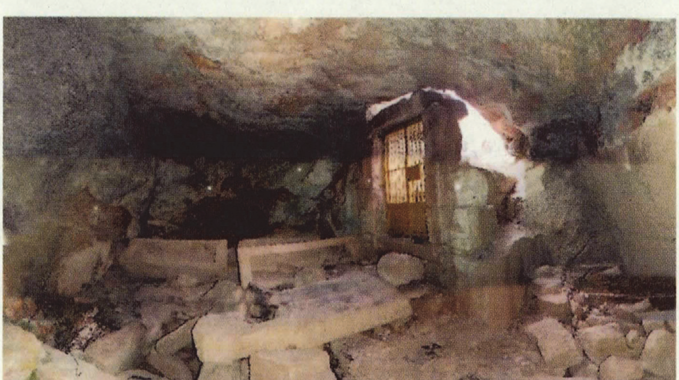

Fig. 8 Panoramic 3D true-color Image.of the No.1 Stone Coffin tomb

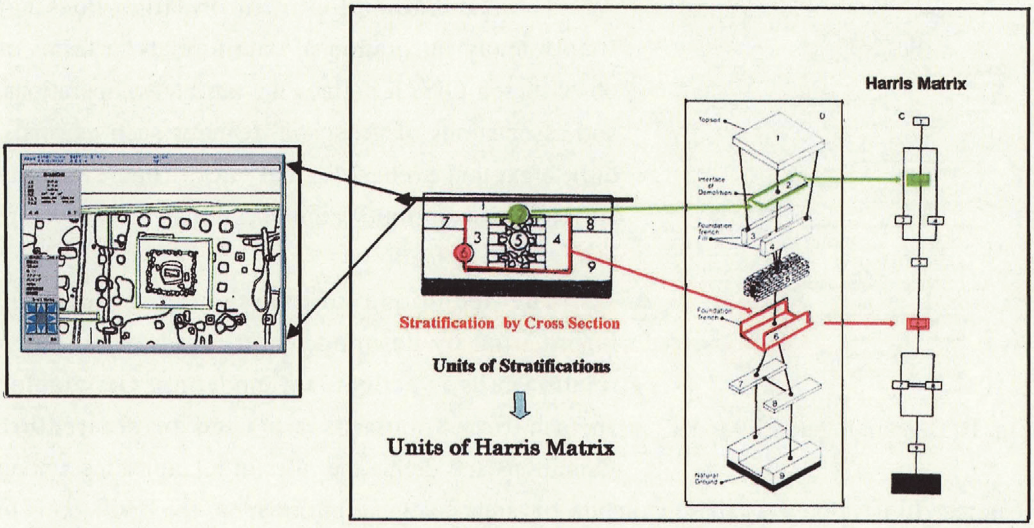

Fig. 9 Japanese-style drawing of archaeological features compared with the Harris Matrix approach

repeated observations of stratigraphic sequences. Remains are then objectively reported in a stratigraphic sequence diagram generally termed a *Harris Matrix* (Harris, 1989). This recording method enables the reproduction of excavation processes and provides archaeologists with many possible interpretations of the data.

In contrast, Japanese archaeologists first identify a feature surface that then becomes the basis of the survey, and each piece of remains is examined based upon geological transitions relative to the feature surface. The result is reported via drawings of archaeological features, as shown in the left-hand side of Figure 9.

Figure 9 shows the relationship between a typical drawing of an archaeological feature at 1:100 scale and stratification units from the Harris Matrix. The Japanese drawing is the section indicated by the arrow in Figure 9; the Harris Matrix presents the process of excavation in terms of units of stratification.

3.2 Necessity for archaeological information modeling using a geographic information standard

Differences in recording methods result in problems in sharing information throughout the world. The solution to this problem is to classify these differences, and to clarify the relationship between the different methods using a global standard of information transfer and understanding. Drawings of archaeological features in survey reports provide spatial information and the positional relationships of remains and artifacts. Thus, archaeological information that contains geospatial information and GIS play a significant role in data management and spatial analyses of archaeological information (Wheatley & Gillings, 2002).

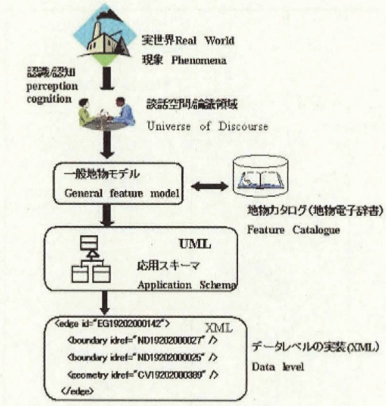

Fig. 10 Domain Reference Model

The standardization of information does not simply imply integration of data formats in terms of object-based GIS, it defines the attributes, operations, and associations of geospatial features such as roads, buildings, and archaeological sites. Their semantic attributes and operations are encapsulated into feature classes such as roads.

The technique of classifying geographic information by defining feature classes and class relationships is called data modeling. Geographic information standards are used to set feature definitions and define the rules of relationships among features. To develop a database structure for archaeological information, the first step is to define archaeological features based on geographic information standards (Usui et al., 2004).

The ISO/TC211 committee (http://www.statkart.no/isotc211/) organizes the standardizing of geographic information; the Japanese contact for standardizing geographic information is the Geographical Survey Institute (GSI). The geographic information standard is currently termed the ISO19000 series, in which unified model language (UML), a modeling language for object-based techniques, is recognized as the conceptual schema

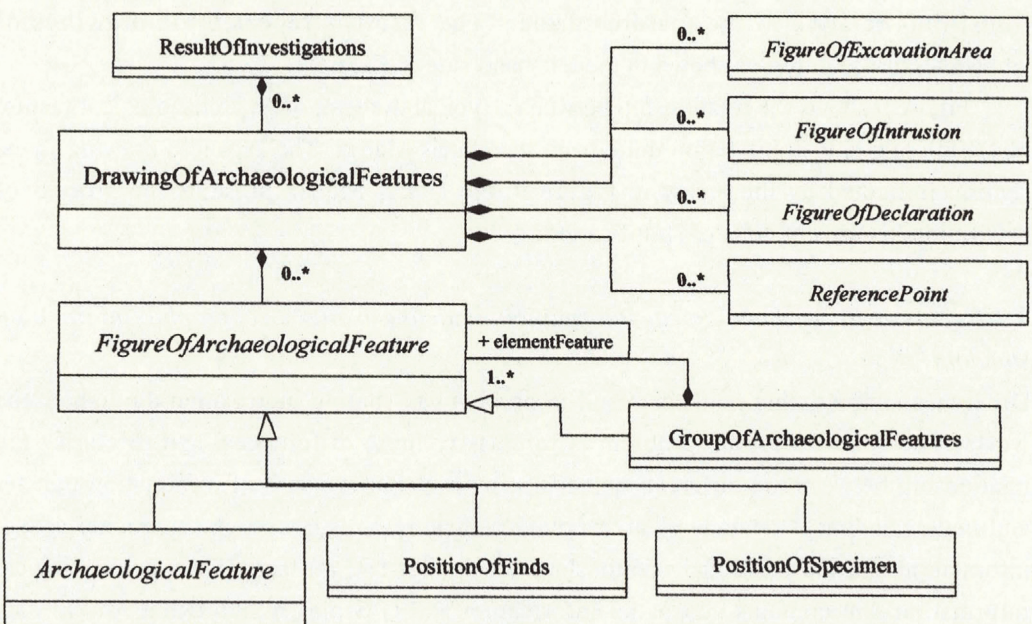

Fig. 11 Relations between Drawing of archaeological features and Harris Matrix

language for the standardization of geographic information. UML uses a diagrammatic representation known as a UML diagram.

Geographic information standards share a characteristic in defining the structure of a GIS database with conceptual models that generate real-world abstraction. This conceptual model is called a *General Feature Model.* Figure 10 shows the Domain Reference Model, which consists of four levels including the General Feature Model (GFM) that represents the step involved in modeling archaeological sites.

The Domain Reference Model consists of four levels. 1) The level of the first conceptual model extracts the universe of discourse on archaeological features from the real world. 2) The level of the GFM abstracts archaeological features and assembles catalogues of these features. It refers to a feature dictionary for archaeological information. 3) The application schema level depicts property and the relationships between archaeological features using UML. The database schema of archaeological information, archaeological features in this case, is created within this level. 4) The data level, which implements geometric and topological spatial objects as specific spatial datasets. In this last, or lowest, level, the archaeological information is encoded using XML. The archaeological database can be implemented at this level (Usui, 2003).

3.3 UML diagram of drawing of archaeological features and the Harris Matrix

Figure 11 explains the relationship between drawings of archaeological features by Japanese archaeologists and stratigraphic sequence diagrams or Harris Matrices favored by European archaeologists. An archaeological site class is made of an aggregation of Stratigraphic Structure and ResultsOfInvestigations. Components of Harris Matrix diagrams are SolidOfStratum classes and BoundarySurfaceOfStratum classes. In contrast, a drawing of archaeological features is a projection of BoundarySurfaceOfStratum. The class of BoundarySurfaceOfStratum can define the relationship of two systems: the drawing of archaeological features and the Harris Matrix stratigraphic sequence diagram.

The drawing of archaeological features plays a critical role in archaeological surveys and corresponds to the BoundarySurfaceOfStratum of the Harris Matrix, which is indicated by a horizontal arrow in Figure 9 (Murao et al., 2004).

Figure 12 shows the DrawingOfarchAeological Feature class and the FigureOfArchaeologicalFeatures class. The DrawingOfarchaAeological Feature class represents the excavation results, which consist of a ground plan, cross-section, and side view. The components of the DrawingOfArchaeologicalFeatures are categorized into the figures of archaeological feature, excavation area, intrusion, declaration, and reference point; the figures have a relationship of aggregation. FigureOfArchaeologicalFeatures is aggregated by archaeological feature, position of finds, position of specimen, and group of

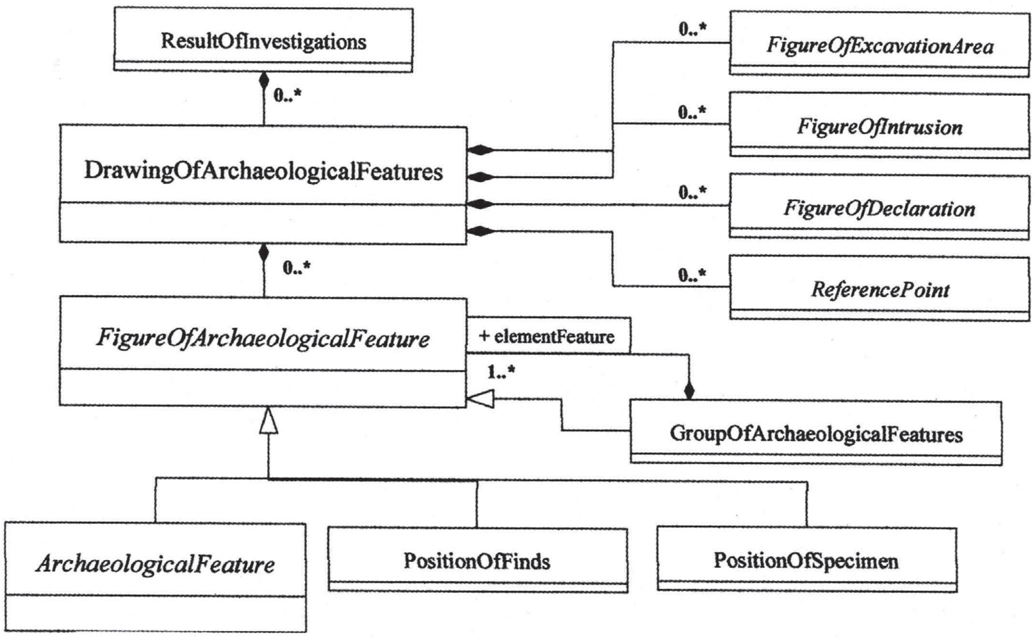

Fig. 12 UML diagram of drawing of archaeological feature, Figure of Archaeological feature and Archaeological feature

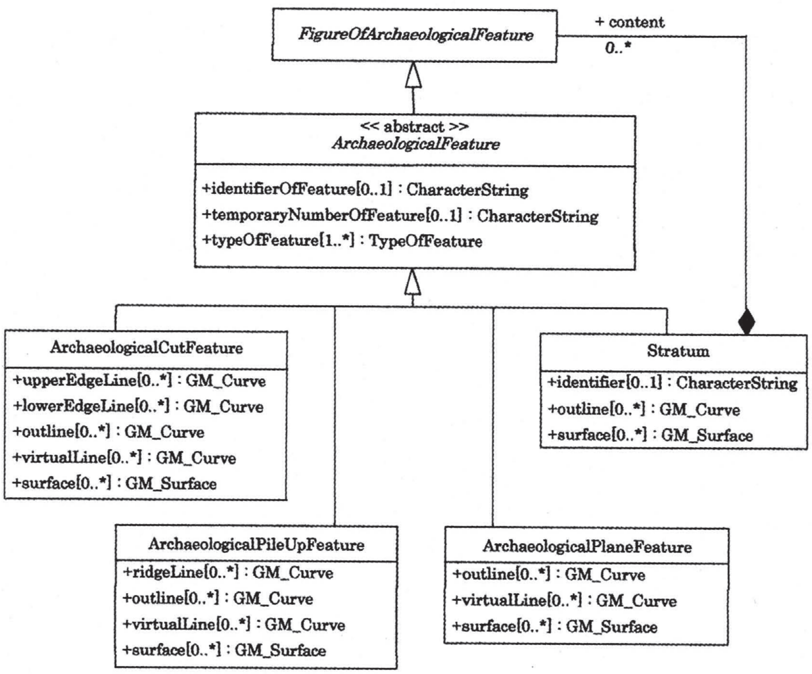

Fig.13 UML diagram of archaeological feature

archaeological feature.

Figure 13 provides a diagram of the archaeological feature class. The class enables the classification of whether the feature has a dent, swell, or planar surface relative to the boundary surface of the stratum. We name each condition the archaeological cut feature, archaeological pile-up feature, and archaeological plane feature.

The basic units of archaeological features at the lowest level are cut feature, pile-up feature, and plane feature, as shown Figures 9 and 13.

A UML diagram presents the schema of the database for archaeological information. We describe the database production process of archaeological information that meets geographic information standards.

4. Conclusions

New methods of archaeological data acquisition such as 3D ground-laser scanning will potentially lead to a change from traditional preservation methods to representation methods. However, laser scanning produces a large amount of point-cloud data, and archaeological objects are only extracted from the data with some difficultly. It is therefore necessary to clarify the definition of an archaeological object.

The object-oriented approach such as that described by GIS international standards (ISO/TC211) is especially well suited to structuring the attributes of archaeological objects such as archaeological cut features, archaeological pile-up features, and archaeological plane features, according to the requirements of archaeological typology for the sharing and distribution of data. The objective of the data model is to store archaeological data in a structure that allows combined as well as independent analysis.

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遺跡情報のＵＭＬによるモデリング
－地理情報標準による海外の遺跡情報の共有化－

碓井照子

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本論文は、世界と日本における考古学情報を共有化するために考古学遺跡に関するモデリングをおこなっている。最初の章では、考古学における遺跡情報の本質について説明をし、第２章では、発掘における日本式方法とヨーロッパのハリスモデルに関する違いを説明する。第３章では、GISにおける伝統的なレイヤー構造モデルとオブジェクト指向モデルを比較している。第４章では、地理情報の標準化におけるモデリング言語であるUMLを説明し、最後の章で、遺跡に関するUMLを利用したモデリングを日本と欧米のハリスマトリックスに関して実施した。このことにより、考古学情報の世界的な共有化が可能になると考えられる。