A Puzzle in 4D: Archiving Digital and Analogue Resources of the Austrian Excavations at Tell el-Daba, Egypt

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Abstract: Since 1966 Austrian excavations have taken place at Tell el-Daba in Egypt, an archaeological site revealing evidence from a society with contacts to many parts of the Eastern Mediterranean dating to the 12th–18th dynasties (early 2nd millennium BC). After 50 years of fieldwork campaigns, the Tell el-Daba archive at the Institute for Oriental and European Archaeology (OREA) at the Austrian Academy of Sciences (ÖAW) contains a huge and heterogeneous resource of digital and non-digital photographs, plans, drawings and written documentation. The 'A Puzzle in 4D' project aims to provide long-term preservation for the rich archaeological resources of this long-standing Austrian excavation project. The project is also a case study for the development of a repository for archaeological data at the Austrian Academy of Sciences. In this paper we provide an overview of the archaeological results of the excavations at Tell el-Daba and then describe the resources that were created throughout the excavations as well as the challenges we face preparing these resources for archiving. We introduce our data model and the requirements for the system architecture. We use the CIDOC Conceptual Reference Model (CRM) to model our data.

Keywords: Egypt, Tell el-Daba/Avaris, long-term excavation, legacy data, digitisation, archiving excavation data, CIDOC CRM

Tell el-Daba is an archaeological site situated in the eastern Nile delta regions of Egypt that has revealed archaeological evidence from the 12th–18th dynasties (early 2nd millennium BC).[5] Excavations at Tell el-Daba have shown the presence of a wealthy society with contacts to many parts of the Eastern Mediterranean. A unique connection to Minoan culture has been identified through the discovery of thousands of fragments of Minoan style wall paintings in two of the Tell el-Daba palaces, depicting e.g. scenes with bulls and bull-leapers, which have become a trademark of the site (Fig. 1).

Since 1966 excavations at Tell el-Daba have been carried out by Manfred Bietak for the Austrian Archaeological Institute (ÖAI), resulting in records from 50 years of fieldwork campaigns.[6] The archaeological discipline has seen major changes during this period of time, most notably a shift from analogue to digitally-born data caused by developments in information technology. As a result, the Tell el-Daba archive at OREA contains a huge and heterogeneous resource of digital and analogue photographs (Fig. 2), plans, drawings and written documentation.

Today, the preservation of parts of the datasets and information on Tell el-Daba is a major challenge to the institute. The negatives of black and white photos from earlier fieldwork campaigns are deteriorating and showing damage due to their age. Data loss may occur due to fragmented legacy research data (e.g. digital site maps) and incompatibility of formats as well as loss of knowledge about the spatial and temporal relationships of archaeological entities.

The aim of the 'A Puzzle in 4D' project is to provide long-term preservation for the rich archaeological resources of the Austrian Tell el-Daba excavation project.[7] The project is a case

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5 Bietak 1991a; Czerny 1999; Czerny 2015; Hein – Jánosi 2004; Forstner-Müller 2008; Müller 2008; Schiestl 2009.
6 Bietak 1996; Bietak et al. 2001; Bietak et al. 2012/2013; Bietak – Forstner-Müller 2006.
7 Aspöck et al. 2015.

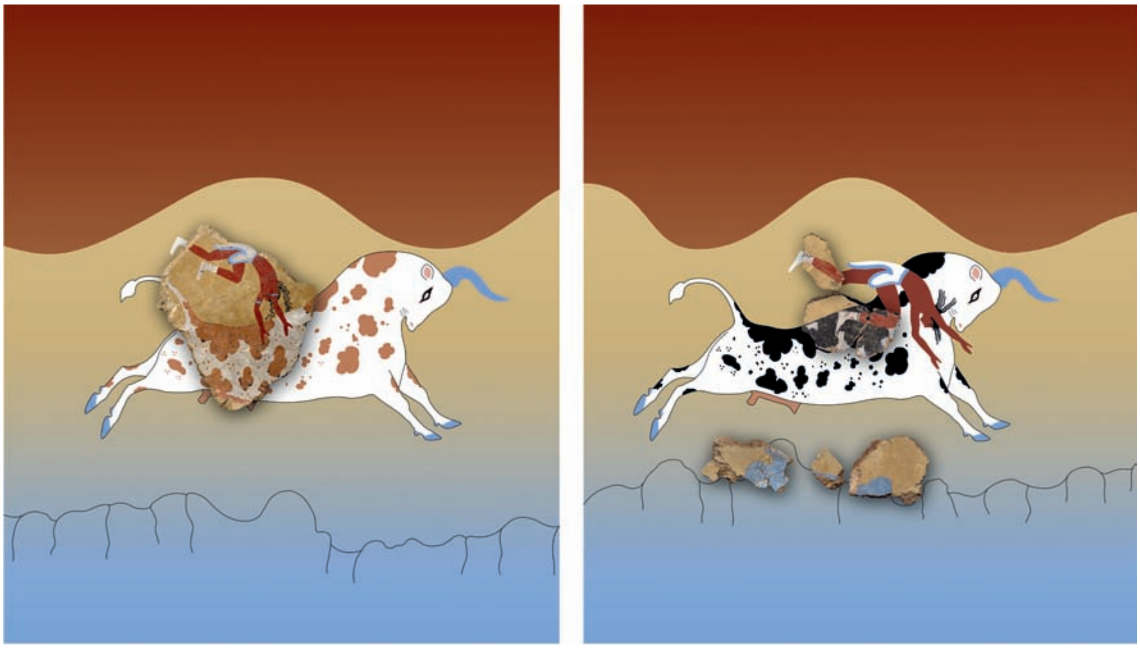

Fig. 1 Bull leaping frieze from area H/I (reconstruction)
(drawing: M. A. Negrete Martínez after Bietak et al. 2007, fig. 60)

Fig. 2 Excavations in area A/II in the year 1980 with the village of Tell el-Daba in the background
(M. Bietak, © ÖAW (ÖAI/OREA) archive)

study for the development of a repository for archaeological data at the Austrian Centre for Digital Humanities and Cultural Heritage (ACDH-CH), at the ÖAW. Digital and non-digital excavation data will be enriched with metadata and prepared for long-term archiving and open access online publication. In this paper, we report the ongoing work on the Tell el-Daba archive. We

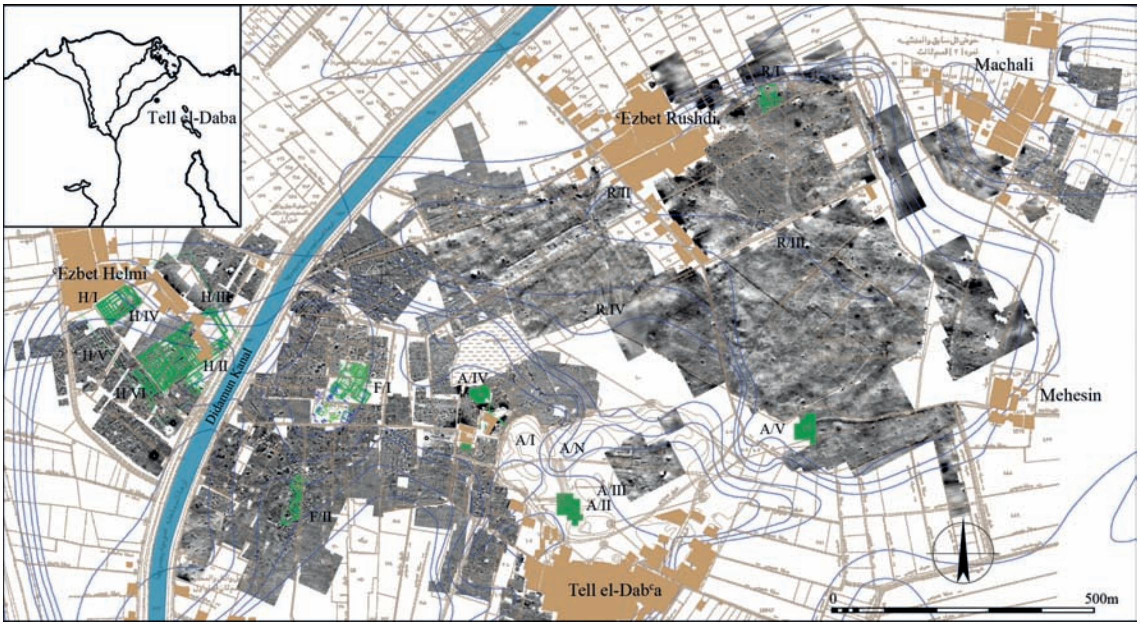

Fig. 3 Geomagnetic map of Tell el-Daba with excavation areas marked in green (© ÖAW (ÖAI/OREA) archive)

provide an overview of archaeology at Tell el-Daba and the resources resulting from 50 years of excavation. An outline of the challenges of the project is followed by a description of our work so far, including a preparatory phase, data modelling and testing of software.

After 50 Years of Excavations at Tell el-Daba: Archaeological Results

The archaeological site of Tell el-Daba, ancient Avaris, is situated on the eastern most of the five ancient Nile branches. Today the tell lies on the Didamun canal about 7km north of the modern town of Faqus in the Egyptian province of Sharkiyya (Fig. 3). Twenty phases of occupation at Tell el-Daba covered nearly 900 years of Egyptian history from the early 12th dynasty (c. 1980/70 BC)[8] to the early Ptolemaic period.[9] With a size of about 2.5km², it was one of the largest towns in the Eastern Mediterranean during the first half of the 2nd millennium BC, when the site was one of the most important trading centres in this area.

From 1966 to date, with a short interruption due to the Arab–Israeli war from 1970–1975, the site was investigated by the ÖAI under the directorship of Manfred Bietak and his successor Irene Forstner-Müller. During that period, fieldwork took place in nine different areas, revealing a continuous stratigraphy from the early Middle Kingdom to the New Kingdom (c. 1980/70–1410 BC)[10] (Tab. 1). With its mixture of Egyptian and Near Eastern Bronze Age culture, Tell el-Daba is important for chronological research in the region providing a link between Egyptian and Near Eastern chronologies.[11] Research on ancient Egyptian culture highly benefits from the excavations at Tell el-Daba, as the site reveals evidence about all aspects of human life in an ancient harbour town, from temples and palaces to simple living quarters and cemeteries (Fig. 4).

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8 Czerny 1999.
9 Lehmann 2015.
10 After Kitchen 2006.
11 Bietak 1991b; Bietak 2013; Kopetzky 2010.

	Dynasties and Kings	absolute Chronology (after: Kitchen 2000/2006)	Tell el-Daba Phases
	12th dynasty	c. 1980/70–1800/1790 BC	
	Amenemhat I		N
	Senwosret I		Hiatus
	Amenemhat II		M
	Senwosret II		L
	Senwosret III		K I
Middle Kingdom	Amenemhat III		I H
	Amenemhat IV		
	Sobeknorfu		
	13th dynasty	c. 1800/1790–1650/40 BC	G/4
			G/1–3
			F
			E/3
Second Intermediate Period	**15th dynasty** = Hyksos kings	c. 1650/40–1530 BC	E/2
			E/1
			D/3
			D/2
	18th dynasty	c. 1550–1295 BC	
	Ahmose		D/1
	Amenophis I		
	Thutmosis I		
	Thutmosis II		
	Hatschepsut		
	Thutmosis III		C/3 C/2
New Kingdom	Amenophis II		
	Thutmosis IV		
	Amenophis III		
	Amenophis IV		
	Semenchkare		
	Tutanchamen		
	Ay		
	Horemheb		C/1
	19th & 20th dynasties = Ramesside Period	c. 1295–1070 BC	B
Third Intermediate Period			Hiatus
Late Period	**26th dynasty** = Persian period	664–525 BC	A/3
			Hiatus
Ptolemaic Period		332–30 BC	A/2
Roman Period			A/1

Tab. 1 Egyptian chronology and the phases of Tell el-Daba (Kopetzky 2017)

At Tell el-Daba a planned settlement dating to the early Middle Kingdom (c. 1970 BC) is the first preserved archaeological evidence (Fig. 5). Founded at the eastern frontier of the Nile delta, it was built as a bulwark against nomads from the east but at the same time was very likely

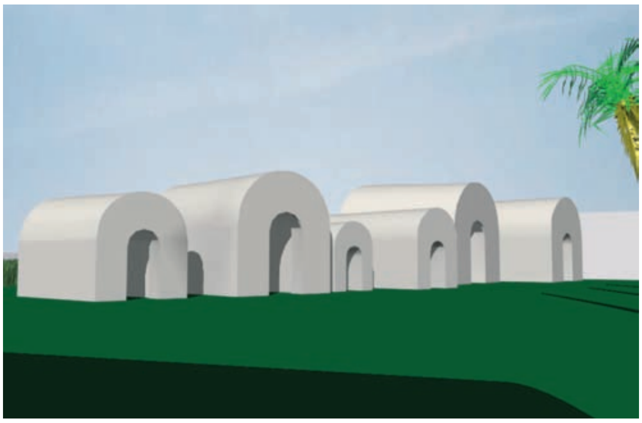

Fig. 4 Reconstruction of early 13th dynasty tombs in area F/I (Schiestl 2009, pl. 32/a, courtesy of Robert Schiestl)

used as a starting point for expeditions and a trading outpost.[12] After a short hiatus the town was extended, and an enclosed settlement with houses arranged in insulae was built (c. 1900 BC). Parts of these buildings were replaced by a temple founded by King Senwosret III in the first half of the Middle Kingdom (c. 1870 BC).[13] After Senwosret III, people from the Near East who can be identified by Middle Bronze Age material culture settled in Tell el-Daba (c. 1825 BC). They conducted trade between Egypt and the Levantine coast and brought with them a new way of life and foreign beliefs. Evidence of these can be found in the architecture and burial traditions. In the following three centuries, a unique culture from traditional and incoming influences developed at Tell el-Daba that was specific to the north-eastern Nile delta and today is known as the Hyksos culture. The city of Avaris transformed into one of the most important ports in the Eastern Mediterranean as well as a transshipment centre for Egypt.

During the last quarter of the Middle Kingdom (c. 1790/80 BC) a palace-like mansion was constructed with a garden and tombs, which testify to the wealth of its owners (Fig. 4).[14] It seems that at the end of the Middle Kingdom (c. 1710/1700 BC), an epidemic struck the city and killed a large part of its population. In the following Second Intermediate Period, Tell el-Daba and a part of the eastern Nile delta separated politically from the Egyptian crown and formed the Kingdom of Avaris. In one part of Tell el-Daba a cultic centre emerged with a series of temples of Near Eastern and Egyptian layouts surrounded by large cemeteries.[15] Huge villas show the economic success of the inhabitants of Tell el-Daba at that time (c. 1700–1650 BC).[16] The following period is known as the Hyksos period (c. 1650–1530 BC). The names of the Hyksos kings, the 'lords of the foreign countries' were documented by Manetho, an Egyptian priest, who wrote the first Egyptian history in the 3rd century BC. At Tell el-Daba the Hyksos kings constructed a huge palace of Near Eastern style.[17] The residential areas were densely populated, with tombs partly built under the houses and used as family crypts.[18] In this period trade with the Levantine regions and other parts of Egypt declined,[19] whilst exchange of goods with Cyprus boomed.[20] After the conquest of Avaris by King Ahmose, the first ruler of the New Kingdom (c. 1530 BC), the Egyptians expanded the harbour and most likely based their naval fleet there.[21] Large Egyptian-style palaces were now constructed at the area which is now Ezbet Helmi (Fig. 6). An important discovery was that the wall paintings in these palaces are very similar to those found in the palaces of Minoan Crete (Fig. 1). This shows a unique connection between Egyptian and Minoan culture at that time. A massive fortification wall was built on top of the palaces in the middle of the New Kingdom.

12 Czerny 1999.
13 Czerny 2015.
14 Schiestl 2009.
15 Bietak 1991b; Müller 2008; Forstner-Müller 2008.
16 Bietak 1996.
17 Bietak et al. 2012/2013.
18 Hein – Jánosi 2004; Forstner-Müller et al. 2015.
19 Kopetzky 2010.
20 Maguire 2009.
21 Bietak 2017.

Fig. 5 Two units of the planned settlement in area F/I – n/17
(M. Bietak, © ÖAW (ÖAI/OREA) archive)

Relicts of the Ramesside era are found all over Tell el-Daba, whether it be the massive enclosure wall of the Seth temple, vineyards, pits or slipper coffins. Finally, in the early Ptolemaic period the construction of tower houses, the ancient Egyptian equivalents to modern skyscrapers, represents the last chapter of the more than 17 centuries of rich history of Tell el-Daba.

Excavation Resources: analogue and digital data

During the last 50 years, over 80 excavation and study seasons have been undertaken at Tell el-Daba, first by the University of Vienna and from 1973 by the ÖAI. The vast majority of resources is kept at the archives of the OREA Institute in Vienna and smaller collections are held by ÖAI in Vienna, at their Cairo branch, and at the excavation house in Tell el-Daba.

The excavation methodology at Tell el-Daba, a combination of excavation in arbitrary spits and stratigraphic removal, has remained unchanged throughout the 50 years of excavation.[22] A major change in the documentation methodology occurred in 1996 on the other hand, with the introduction of the locus system. The locus system is often used in Near Eastern archaeology and was introduced by Mortimer Wheeler.[23] In many instances a locus corresponds to the definition

[22] Aspöck et al. 2015.
[23] Aspöck et al. 2015.

Fig. 6 Plan of Palaces F, G and J and building L in Ezbet Helmi (plan: N. Math, © ÖAW (ÖAI/OREA) archive)

of a stratigraphic unit, but generally a locus is defined at each excavation.[24] At Tell el-Daba, the surface of each new excavation area was defined as Locus 1 (L1). Further changes in the documentation methodology took place as part of technological advances in the field, as increasingly digital documentation methods have been used. For example, the first computer has been used on site to maintain a simple database from the late 1980s. Since 2000, analogue cameras have slowly been replaced by digital ones, field drawings have been digitised using AutoCAD during the post-excavation process and in 2004/5 a Microsoft Access database for field protocols was created and has been in use since. Therefore, after 50 years of excavation, the Tell el-Daba archive at OREA consists of a large and heterogeneous set of analogue and digital resources (Tab. 2). In some instances, one type of resource exists in different formats, i.e. analogue, digitised (scans) and born digital. For example, the field protocol, which contains the descriptions of archaeological features, exists in paper format, scans and partly as entries in a database. Parts of the field drawings have been digitised using AutoCAD, some have been scanned, whereas others still exist as paper copies only (Fig. 8). Also some of the analogue photos from the earlier campaigns (black and white negatives or colour positives) have been digitised as part of previous research projects.

24 Masur et al. 2014.

Analogue resources (estimates)	Digital resources
• 45000 slides • 15000 photos • 200000 black & white and coloured film negatives, of which about 2/3 are of 36×24mm format and the rest are 6x6 cm film negatives • 10000 field drawings consisting of plana, sections and details on millimetre paper • 4500 drawings in ink based on field drawings and maps as well as reconstructions • 15200 pencil find drawings on special artists' paper • 8000 find drawings in ink on tracing paper • 5 files of field protocol	• field photos (from 2003) • find photos (from 2001) • databases of wall paintings • database of field protocol (from 2005) • databases of animal bones, flint, botanical remains, 14-C samples, seal-impressions • data of geophysical investigations (geomagnetic, georadar) • data of 3D-scanning of area H/III • videos

Tab. 2 Tell el-Daba resources curated at OREA, ÖAW (© A Puzzle in 4D 2017)

The Challenges of Archiving Resources from a Long-Term Archaeological Excavation

As we have seen above, 50 years of excavation at Tell el-Daba created a huge amount of heterogeneous digital and analogue resources (Tab. 2). A series of challenges arose for the digital archiving of these resources, including conceptual and technical tasks as well as establishing a retention policy.

One of the first challenges we faced was to decide which resources would be given priority in our project. As we have seen in the previous section (Tab. 2), the legacy of around 50 years of excavation is a huge resource, impossible to process in its entirety within this project. Therefore, we had to identify information and resources which may be endangered, for example because of deteriorating carrier materials or the danger of loss of contextual information about finds or features. Endangered materials included film negatives from the 1960s, when excavations started and which show evidence of damage. Hence, photos from the earlier excavation campaigns were given priority for digitisation in this project. Notably, our first case study represents the purely analogue era of fieldwork, and a second one characterises when digital documentation methods were also in use to see how analogue traditions were carried over into the digital age.

A somewhat related issue is that several Tell el-Daba resources existed in multiple forms, which requires the establishment of a policy to decide which resources are preserved and in what way. Parameters for which resources should be selected for long-term preservation concerns documents with multiple versions, such as those created during the post-excavation process of digitising plans and drawings. Deciding which versions of data should be preserved was necessary, and specifically so-called preservation intervention points had to be defined.[25] For example, pottery was drawn in pencil on cardboard during Tell el-Daba excavations (Fig. 7). In most cases these pottery drawings are reconstructions of pots based on pottery sherds. At a later stage, these drawings were converted into ink drawings either by drawing directly on the cardboard over the pencil drawings or by using tracing paper, which preserved the original pencil drawing. The ink drawings were fit for publishing. A large number of these ink drawings had already been scanned into a digital format. Therefore, in some cases information about the same pottery find had been documented in three different analogue and digital formats. In some cases, however, researchers disagreed about the reconstruction of sherds, and therefore pencil and ink drawings may contain differences, or there may be different ink drawings of the same pencil drawing. This is just one example in which defining parameters and ways to preserve

25 ADS.

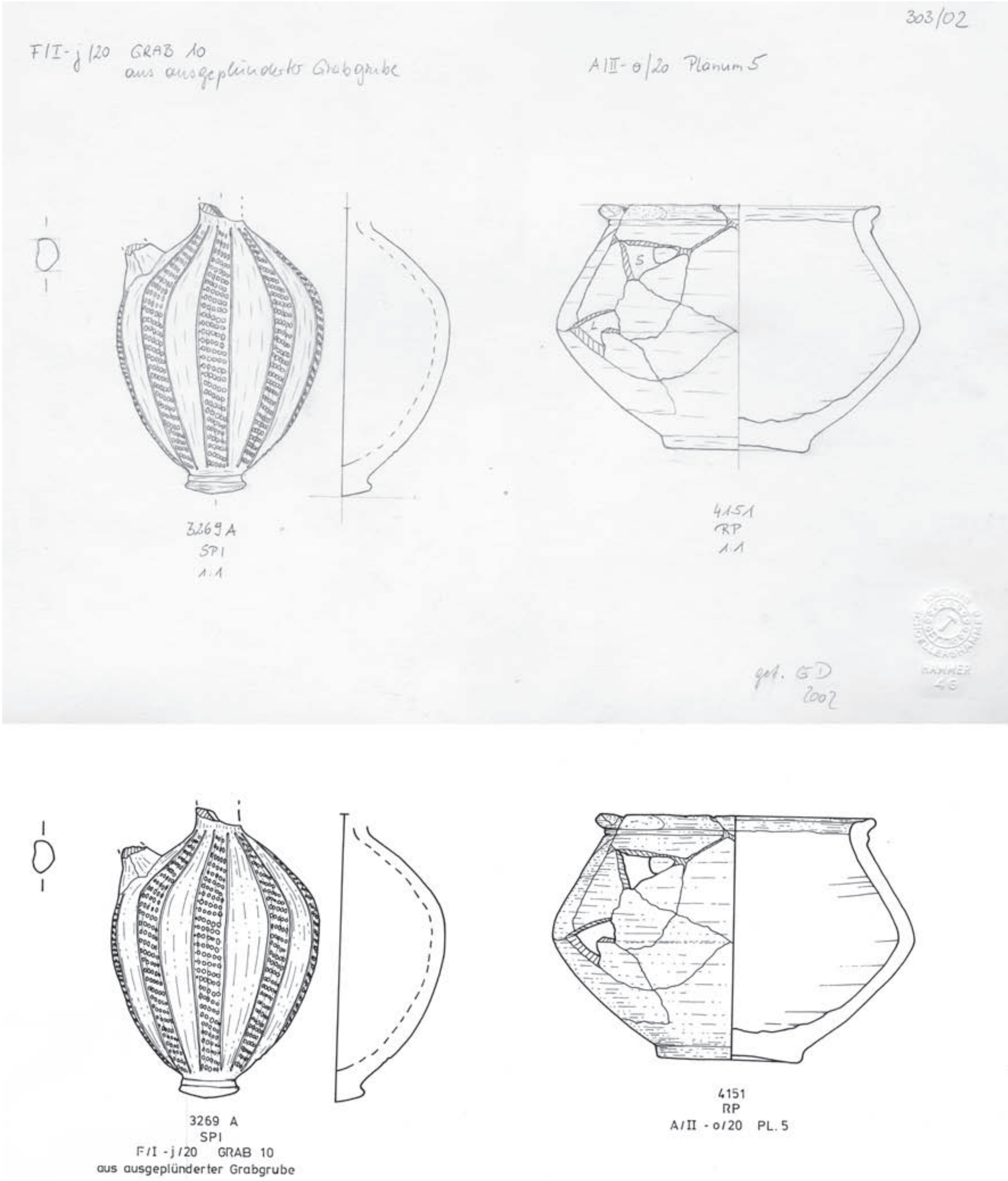

Fig. 7 Examples of field drawing of finds in pencil and in ink
(drawing: K. Kopetzky, © ÖAW (ÖAI/OREA) archive)

different formats and versions of one particular finding must account for multiple interpretations in order to avoid loss of knowledge.

As Jon M. Frey has nicely put it in his contribution to this volume, the resources of most excavations already function as an analogue form of a relational database.[26] The documents work together, but it is also usually possible to use any form of documentation as a point of entry to the recording system. The same holds for Tell el-Daba, where the documentation of the

[26] Frey, this volume.

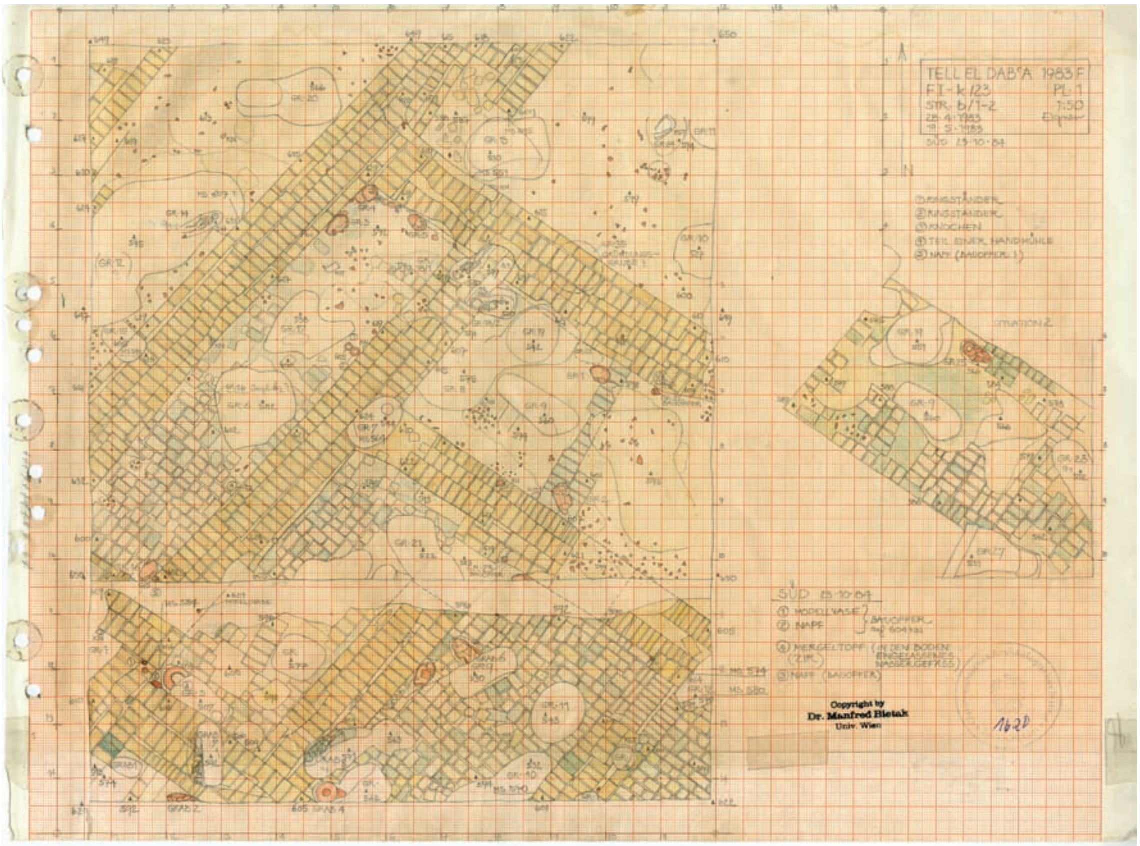

Fig. 8 Field drawing of square F/I – k/23 planum 1
(drawing: D. Eigner, © ÖAW (ÖAI/OREA) archive)

excavation process in the various types of resources (Tab. 2) is connected through consistent naming conventions of excavation areas and finds. The challenge was to understand how the physical reality of the excavations at Tell el-Daba was represented in the documentation of the excavation process. This provided the basis for the creation of a solid data model for the recreation of the Tell el-Daba archive, which currently is a mix of analogue and digital resources, in a purely digital form allowing to retrieve resources based on their metadata. We found, however, that data modelling was complicated by a series of factors. For example, analogue recording methods did not have the standards for entering data into a database, meaning that documentation handwritten by a large number of persons and teams over half a century of fieldwork did not always follow consistent protocol. For example, excavators may have put additional information on some resources, such as additional drawings of evidence discovered in a later campaign may have been added to a field drawing from a previous season, or several related field drawings were sometimes stuck together at a later stage to create an oversized map. Other concerns are potential omissions in the data. The conceptual challenge of the project was to create a data model that allows for all the complex relations between the different entities – and for all potential exceptions. For example multiple finds may be documented on one documentation item, but also one find may be documented by many documentations (N:N relationship). Different excavation campaigns were connected to some archaeological features. Excavation of for example a wall may have started in an earlier campaign but was completed in one of the subsequent campaigns, sometimes many years later.

Another information integration challenge was the combination of analogue and newer digital resources with the goal to integrate them in order to be able to retrieve information no matter if the original documents were analogue or born digital. As described above, some types of resources may exist in several types of formats.

Next to the major intellectual task of defining a sound conceptual model, we needed to choose the right serialisation format to encode the metadata. There is large consensus that the long-term readability of metadata is best supported if information is structured according to existing standards and available in a structured, self-contained, human-readable serialisation format. This means that even though one will use any specific application with its internal data representation for data entry, it is crucial that this information can be retrieved without loss of information, ideally in an RDF- or XML-based serialisation, following well-established metadata standards like e.g. Dublin Core, LIDO, METS/MODS or CIDOC CRM.[27]

A similar but much more complex problem lies with the data itself, such as where there is a plethora of file formats for different kinds of data, many of which are opaque proprietary formats that may be rendered unreadable in the near future. Here we relied mainly on recommendations for archiving various document types and enumerating safe and problematic formats issued by various national research agencies and repositories.[28]

The ‘A Puzzle in 4D’ project is a case study for the development of a repository for archaeological data at the Austrian Academy of Sciences. Technological challenges concerning long-term preservation of digital resources involved aspects of data entry, storage and retrieval, or submission, archival and dissemination according to the Open Archival Information System (OAIS).[29] With respect to data entry by far the largest or most resource intensive task was the systematic cataloguing of the material, i.e. entering structured metadata for tens of thousands of individual documentation items and the archaeological objects they represent. A related aspect was the ingestion process, which must be a validating batch processing task able to handle large amounts of data and ensure correct linking of resources with corresponding metadata.

Finally, once the data was safely stored and archived, it also should be made accessible to the research community in a useful way. For us, this meant especially the possibility for deep semantic search in the data, i.e. discovery systems that allow queries based on the conceptual model to retrieve digital objects and information about their respective research/excavation context. Rich features should be implemented to browse through the material, i.e. creation of relations between related objects as links that allow connecting related finds, areas, documentation objects, involved persons, study seasons, etc.

Obviously, with all these challenges we were not alone and a growing number of repository solutions are readily available as technical solutions for exactly these tasks. There are the well-established domain-specific repositories for archaeology, most prominently the Archaeology Data Service[30] and institutional repositories as well as a growing number of generic repositories for research data. While these services are certified to provide reliable archiving options for research data, they usually consider as one item a whole dataset; i.e. they handle a collection of materials as a binary black box minted with metadata for the whole package, usually without a possibility for deep searching and browsing inside the package/dataset. This means that a researcher interested in for example a pottery find from a specific period would need to download the complete package, make sense of the inner structure and try to find her way through it to identify the maybe small but important piece of information of interest to her.

For deep searching and browsing we experimented with existing archaeological database systems, which promise a certain amount of standardisation and interoperability. In particular we explored Arches, which, building on CIDOC CRM as the underlying data model, sounded very promising for our needs.[31] With Version 3.0, however, we encountered major problems in getting

[27] Le Boeuf et al. 2015.
[28] ADS; UK Data Service; IANUS; BDA; DARIAH-DE.
[29] OAIS 2012.
[30] Condron et al. 1999; Richards 2006.
[31] Aspöck – Masur 2015.

the system running and unsurpassable obstacles in adapting the default setup to the specific needs of our project.[32]

Our Approach to Archiving Tell el-Daba Resources

The 'A Puzzle in 4D' project is a collaborative project among archaeologists, data specialists and technicians. Only a few have prior experience working on Tell el-Daba and knowledge of the archaeological evidence from the site, method of excavation and documentation. For this reason, we started our project by compiling a document we called 'The essential guide to Tell el-Daba'.[33] This document contains introductory information necessary for archaeologists, technicians and student assistants to start working on the Tell el-Daba resources within the project. It will also be a resource for those who later use the archive.

In the next step, digital and analogue files were analysed to identify the different types of resources, which information they contained (e.g. description of archaeological evidence in a square) and the characteristics of the respective information carriers (e.g. a 150 ppi scan of paper sheets now stored in Egypt). Digital files were ordered according to a set of criteria, for example time (a folder on autumn season 1977) or topic (geophysics data, animal bone data). We identified and removed duplicate files, but left the folder structure unchanged.

We collected so-called 'locus names', i.e. names of types of archaeological evidence such as pit or grave, for a Tell el-Daba thesaurus. For example, when a new excavation area was chosen at Tell el-Daba, its surface was always defined as Locus 1 (L1). Tombs, pits, floors and any visible archaeological feature are given locus numbers. Locus names and numbers appear across all types of Tell el-Daba resources. Locus names became the basis for the controlled vocabulary for metadata entry, which formed the basis for the project thesaurus.

User requirements for the Tell el-Daba archive were defined in focus group meetings with the OREA Tell el-Daba research group. A future generation of researchers and new projects will have the greatest benefit from the archive. Generally, resource discovery will be the priority (e.g. to find all resources from a specific area, see below). For ongoing research projects, however, contextual information such as the position of pottery finds, including altimetric data, would be useful to compare similar finds across different contexts and excavation areas. The Archaeological Information System (AIS) developed as part of the 'A Puzzle in 4D' project will be able to provide detailed contextual information on loci excavated in squares of excavation area F/I.[34]

A suitable case study area was selected for the development of the AIS, data model and workflows for digitisation and archiving, as well as for standards for metadata and semantics. Area F/I-j/21 was chosen because it contained types of archaeological evidence representative for Tell el-Daba (residential buildings, a palace, tombs, etc.). F/I-j/21 was excavated in 1979 and 1980, and the documentation at excavation was still fully analogous. Additionally, no copyright issues limit usage of resources from this excavation area, which was one of the crucial criteria.

Data Model

In order to organise and integrate the metadata of digital and analogue resources that are created in the course of the project a data model is needed to structure the metadata so that it is possible to retrieve resources related to specific archaeological research questions. Entity relationship models have been used widely to model archaeological data in relational databases like Postgres, MySQL

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32 Aspöck et al. 2016.
33 Aspöck – Kopetzky 2015.
34 Kucera et al., this volume.

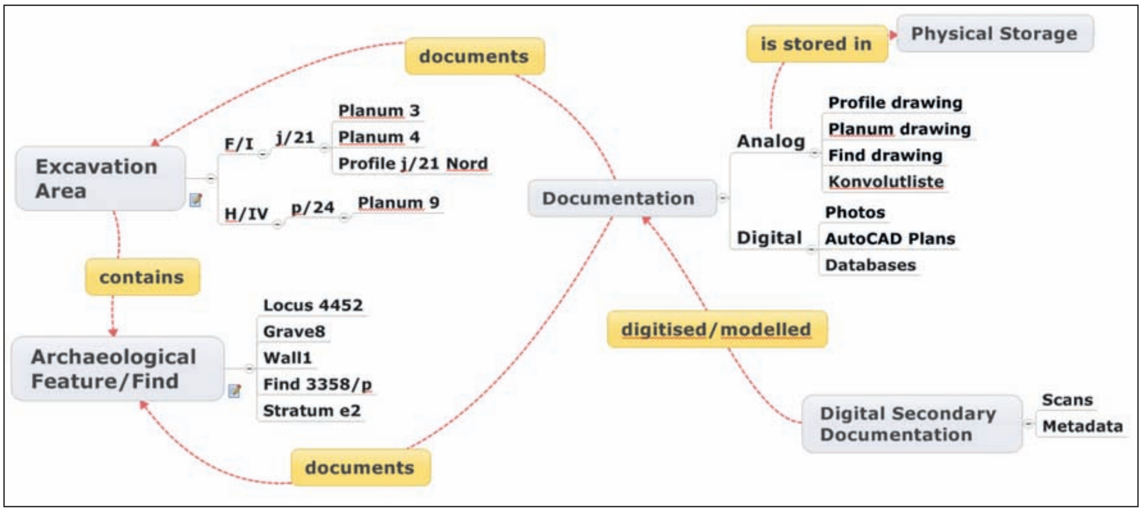

Fig. 9 Main categories of data model representing physical reality, documentation and digitising processes (Hiebel, Aspöck and Kopetzky 2017)

or MS Access. Recently, with the advance of semantic technologies, the use of ontologies as data models has increased in archaeology.[35]

We decided to use the CIDOC CRM ontology[36] as a conceptual background to model Tell el-Daba resources, the physical reality they document and the process of creating digital documentation from analogue sources. The CIDOC CRM is an ISO standard for cultural heritage documentation and was extended in the past few years to model archaeological excavations (CRMarchaeo), scientific observation (CRMsci) and digital provenance (CRMdig).[37] Through these extensions and the CIDOC CRM as a core ontology it is possible to create a network of information that is able to represent the complex relations that are created when the physical remains of activities in the distant past are excavated and documented and the documentation is digitised.

Analysing the available documentation and the process of digitising analogue sources we identified five main categories, which are distinct in their nature. These are:

- Excavation areas
- Archaeological features and finds
- Documentation (analogue or digital)
- Physical storage
- Digital secondary documentation

Figure 9 shows these main categories together with examples of types of documentation and the main relationships between them.

In very simple terms it can be said that the physical reality of archaeological features and finds from specific excavation areas is documented in analogue and digital documentation. We differentiate between features and materials created in archaeological times (the distant past) and features and areas created at the time of excavation by the archaeologists (e.g. excavation areas, squares). The CRMarchaeo extension models this differentiation in a detailed way. In the 'A Puzzle in 4D' project the documentation of archaeological features/finds and excavation areas will be processed to make it available in a digital format and to create homogeneous metadata that answers the following questions:

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35 Binding et al. 2015.

36 Le Boeuf et al. 2015.

37 CIDOC CRM.

- Which files document an *excavation area*? For example, which resources document the archaeological evidence and finds in area F/I, square j/21, Planum 3?
- Which files document *archaeological features/finds of a specific type*? For example, which resources do we have from tombs?
- Which files document a specific *archaeological feature/find*? For example, which resources document tomb 5 and walls in area F/I, square j/21?
- Which archaeological *features/finds of a specific type* are documented *in a specific area*?

In order to create homogeneous metadata, we had to define processes to create identifiers for the instances of our main categories. Therefore, we had to find in what context a piece of resource was unique to add the corresponding contextual information to the file name. For example, a tomb number (e.g. 'tomb 5') is unique within a square (e.g. square 'j/21'), which is unique to a specific area (e.g. area 'F/I'). Finally, adding our shortcut for the site Tell el-Daba created the unique file name for this specific digital object (e.g. 'TD_F/I_j21_tomb5'). Hence, for the excavation areas and archaeological features and objects the naming conventions established within the Tell el-Daba excavation and documentation methodology produced unique identifiers if contextual information could be added.

System Architecture and Test Implementation

To create, manage and query metadata and digital documents of the Tell el-Daba excavation documentation we identified five main components within the system architecture (Fig. 10).

The goal is to develop a system with open and specified interfaces between its components. The leading idea is that the data are the most important asset of the system, and it should be possible to choose different software products for each system component and, if necessary, replace them individually to improve specific processes.

For the test implementation we chose Microsoft Excel for metadata entry and management of the controlled vocabularies. The reasons were that we found the flexibility offered by Microsoft Excel an advantage compared to other systems and we could immediately start the metadata entry process. The Excel worksheets had to be customised to allow the entry of several identifiers in one

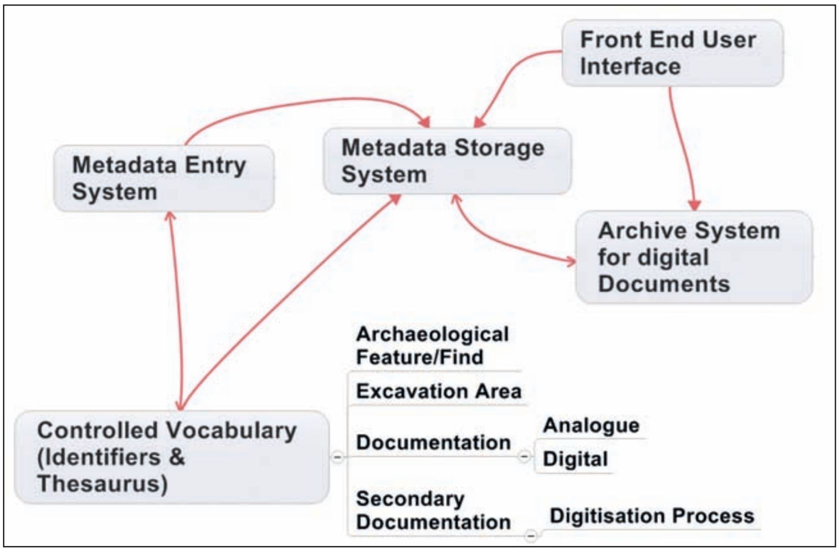


Fig. 10 Main components of the system architecture to create, manage and query metadata and digital resources of the Tell el-Daba excavation documentation analogue (Hiebel, Ďurčo and Aspöck 2017)

field from a dropdown menu to represent 1:n relations. This was realised using Visual Basic macros and Excel data validation functionality.

We used KARMA,[38] an information integration tool, to map metadata and vocabularies to the CIDOC CRM data model. Figure 11 shows how the metadata was mapped to the formal definitions of the CIDOC CRM ontology.

KARMA created a knowledge graph to represent the information and exported it in Resource Description Framework (RDF), a standard model for data interchange on the internet that is able to relate logical statements within a network.[39] RDF is the foundation of the Linked Open Data (LOD) cloud, in which datasets are linked to each other on a global level.[40] The thesaurus portion of the controlled vocabularies was created with the KARMA tool as well and represented in Simple Knowledge Organization System (SKOS), a data model of the semantic web community for sharing and linking knowledge organisation systems such as thesauri, taxonomies, classification schemes and subject heading systems.[41]

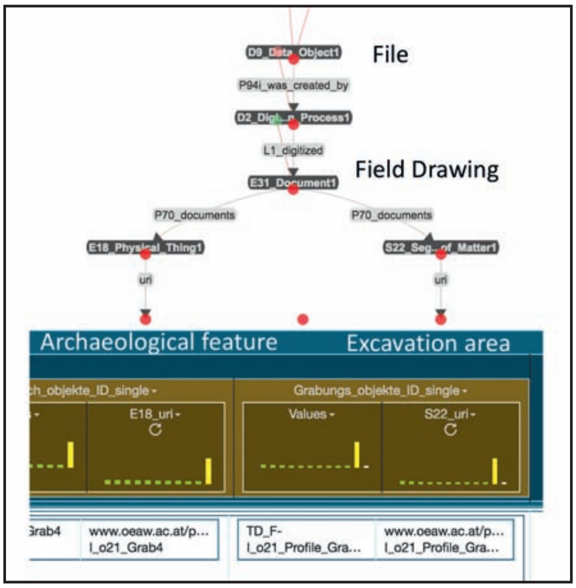


Fig. 11 Using the Karma tool to map the digitisation of a field drawing to CIDOC CRM and CRMdig (Hiebel 2017)

After the mapping process, the RDF data was ingested in a triplestore, which is a database to store and query RDF data. In the triplestore the linking of the resources (single described entities like a specific excavation area or the created SKOS concept of a 'tomb' from the archaeological thesaurus) took place, hence integrating metadata of different digital resources such as field drawings and photos. Resources were either linked on a class level (because they belong to the same CIDOC CRM class, e.g. 'document' or 'physical thing'), on the SKOS concept level (because the same thesaurus term was attributed to them, e.g. 'field drawing') or on an individual level (because they describe the same excavation area or archaeological feature/find, e.g. 'Site Tell el-Daba, area F/I, square j/21, Planum 3'). The correct linking in the triplestore was dependent on the creation of the right identifiers for instances of excavation areas, archaeological features/finds, analogue and digital documentation and secondary digital documentation. The data in the triplestore can be queried using the SPARQL[42] query language. To test the system and workflow we ingested the RDF representation of the metadata (created through mapping in KARMA from the tabular data in Excel files) of scanned field drawings and photos of the excavation areas F/I and A/II and created queries according to the requirements defined during data modelling. The results showed that this approach works.

One of the queries created a de-normalised export of data including excavation areas, archaeological features/finds and documents with their types and filenames. The query is listed below:

```
PREFIX p4d: <http://www.oeaw.ac.at/puzzle4d/>
PREFIX crm: <http://www.cidoc-crm.org/cidoc-crm/>
```

38 ISI.
39 W3C 2014.
40 LOD.
41 W3C 2009.
42 W3C 2013.

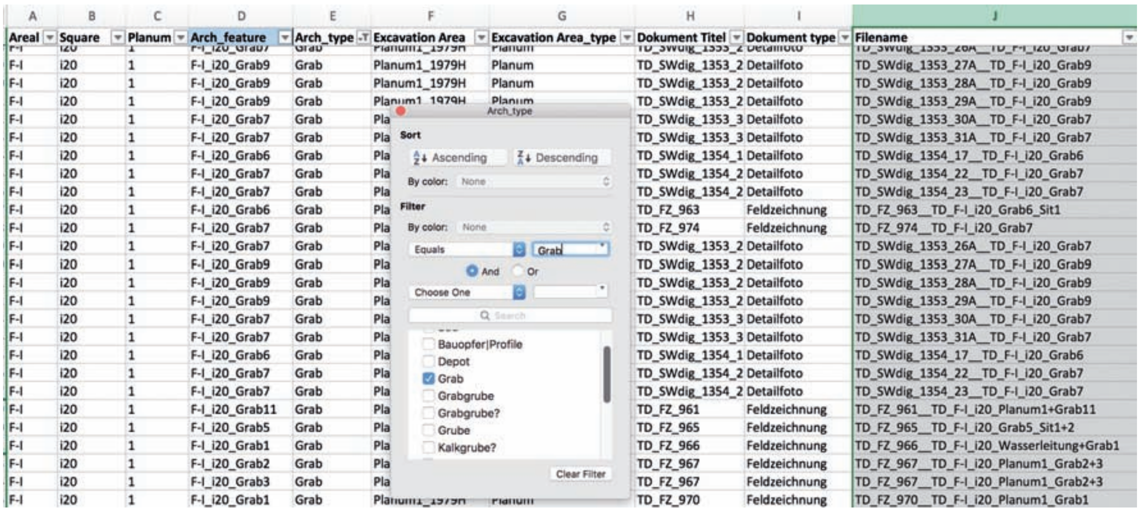
```
PREFIX crmsci: <http://www.ics.forth.gr/isl/CRMsci/>
PREFIX crmdig: <http://www.ics.forth.gr/isl/CRMdig/>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX skos: <http://www.w3.org/2004/02/skos/core#>
PREFIX geo: <http://www.opengis.net/ont/geosparql#>

select distinct ?areal_label ?planquadrat_label ?planum_label ?e18_label ?e55_e18_prefLabel ?s22_label ?e55_s22_
prefLabel ?e31_label ?e55_e31_prefLabel ?filename ?e22 ?e18 ?e31
where {
?d9 crm:P94i_was_created_by ?d2 .
?d2 crmdig:L1_digitized ?e31 .
?e31 rdfs:label ?e31_label .
        optional {
        ?e31 crm:P2_has_type ?e55_e31 .
        ?e55_e31 skos:prefLabel ?e55_e31_prefLabel . }
        optional {
        ?e31 crm:P70_documents ?e18 .
        ?e18 rdf:type crm:E18_Physical_Thing .
        ?e18 rdfs:label ?e18_label .
                optional {
                ?e18 crm:P2_has_type ?e55_e18 .
                ?e55_e18 skos:prefLabel ?e55_e18_prefLabel . }}
        optional {
        ?e31 crm:P70_documents ?s22 .
        ?s22 rdf:type crmsci:S22_Segment_of_Matter.
        ?s22 rdfs:label ?s22_label .
                optional {
                ?s22 crm:P2_has_type ?e55_s22 .
                ?e55_s22 skos:prefLabel ?e55_s22_prefLabel . }}
        optional {
        ?s22 crm:P89_falls_within ?s22_areal .
        ?s22_areal crm:P2_has_type <http://www.oeaw.ac.at/puzzle4d/E55/S22/Areal> .
        ?s22_areal rdfs:label ?areal_label}
        optional {
        ?s22 crm:P89_falls_within ?s22_planquadrat .
        ?s22_planquadrat crm:P2_has_type <http://www.oeaw.ac.at/puzzle4d/E55/S22/Planquadrat_Schnitt>.
        ?s22_planquadrat rdfs:label ?planquadrat_label}
        optional {
        ?s22 crm:P89_falls_within ?s22_planum .
        ?s22_planum crm:P2_has_type <http://www.oeaw.ac.at/puzzle4d/E55/S22/Planum> .
        ?s22_planum rdfs:label ?planum_label}
?d9 rdfs:label ?filename .}
```

The result was imported to Microsoft Excel, and a filter was used to search excavation areas, archaeological types and resource types for retrieval of documents and filenames representing graves in a specific excavation area (Fig. 12). With this test we could show that our approach was able to answer the questions we defined earlier.

The same exported data was used to implement a prototype of a web-based front end that accesses a SQL database, proving that the modular approach centred on a sound conceptual model helps to prevent a technological lock-in. During the project, the digital resources themselves resided on a shared file server. At the end of the project, the digital resources will be transferred to the new FEDORA-based ÖAW repository ARCHE.[43] Figure 13 shows the individual components of the prototype system architecture.

43 FEDORA; ARCHE.



Areal	Square	Planum	Arch_feature	Arch_type	Excavation Area	Excavation Area_type	Dokument Titel	Dokument type	Filename
F-I	i20	1	F-I_i20_Grab9	Grab	Planum1_1979H	Planum	TD_SWdig_1353_2	Detailfoto	TD_SWdig_1353_27A__TD_F-I_i20_Grab9
F-I	i20	1	F-I_i20_Grab9	Grab	Planum1_1979H	Planum	TD_SWdig_1353_2	Detailfoto	TD_SWdig_1353_28A__TD_F-I_i20_Grab9
F-I	i20	1	F-I_i20_Grab9	Grab	Planum1_1979H	Planum	TD_SWdig_1353_2	Detailfoto	TD_SWdig_1353_29A__TD_F-I_i20_Grab9
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1353_3	Detailfoto	TD_SWdig_1353_30A__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1353_3	Detailfoto	TD_SWdig_1353_31A__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab6	Grab	Pla		TD_SWdig_1354_1	Detailfoto	TD_SWdig_1354_17__TD_F-I_i20_Grab6
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1354_2	Detailfoto	TD_SWdig_1354_22__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1354_2	Detailfoto	TD_SWdig_1354_23__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab6	Grab	Pla		TD_FZ_963	Feldzeichnung	TD_FZ_963__TD_F-I_i20_Grab6_Sit1
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_FZ_974	Feldzeichnung	TD_FZ_974__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1353_2	Detailfoto	TD_SWdig_1353_26A__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab9	Grab	Pla		TD_SWdig_1353_2	Detailfoto	TD_SWdig_1353_27A__TD_F-I_i20_Grab9
F-I	i20	1	F-I_i20_Grab9	Grab	Pla		TD_SWdig_1353_2	Detailfoto	TD_SWdig_1353_28A__TD_F-I_i20_Grab9
F-I	i20	1	F-I_i20_Grab9	Grab	Pla		TD_SWdig_1353_2	Detailfoto	TD_SWdig_1353_29A__TD_F-I_i20_Grab9
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1353_3	Detailfoto	TD_SWdig_1353_30A__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1353_3	Detailfoto	TD_SWdig_1353_31A__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab6	Grab	Pla		TD_SWdig_1354_1	Detailfoto	TD_SWdig_1354_17__TD_F-I_i20_Grab6
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1354_2	Detailfoto	TD_SWdig_1354_22__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab7	Grab	Pla		TD_SWdig_1354_2	Detailfoto	TD_SWdig_1354_23__TD_F-I_i20_Grab7
F-I	i20	1	F-I_i20_Grab11	Grab	Pla		TD_FZ_961	Feldzeichnung	TD_FZ_961__TD_F-I_i20_Planum1+Grab11
F-I	i20	1	F-I_i20_Grab5	Grab	Pla		TD_FZ_965	Feldzeichnung	TD_FZ_965__TD_F-I_i20_Grab5_Sit1+2
F-I	i20	1	F-I_i20_Grab1	Grab	Pla		TD_FZ_966	Feldzeichnung	TD_FZ_966__TD_F-I_i20_Wasserleitung+Grab1
F-I	i20	1	F-I_i20_Grab2	Grab	Pla		TD_FZ_967	Feldzeichnung	TD_FZ_967__TD_F-I_i20_Planum1_Grab2+3
F-I	i20	1	F-I_i20_Grab3	Grab	Pla		TD_FZ_967	Feldzeichnung	TD_FZ_967__TD_F-I_i20_Planum1_Grab2+3
F-I	i20	1	F-I_i20_Grab1	Grab	Planum1_1979H	Planum	TD_FZ_970	Feldzeichnung	TD_FZ_970__TD_F-I_i20_Planum1_Grab1

Fig. 12 Query results in MS Excel using filter function to show all documents and files that represent graves in a specific excavation area (Hiebel 2017)

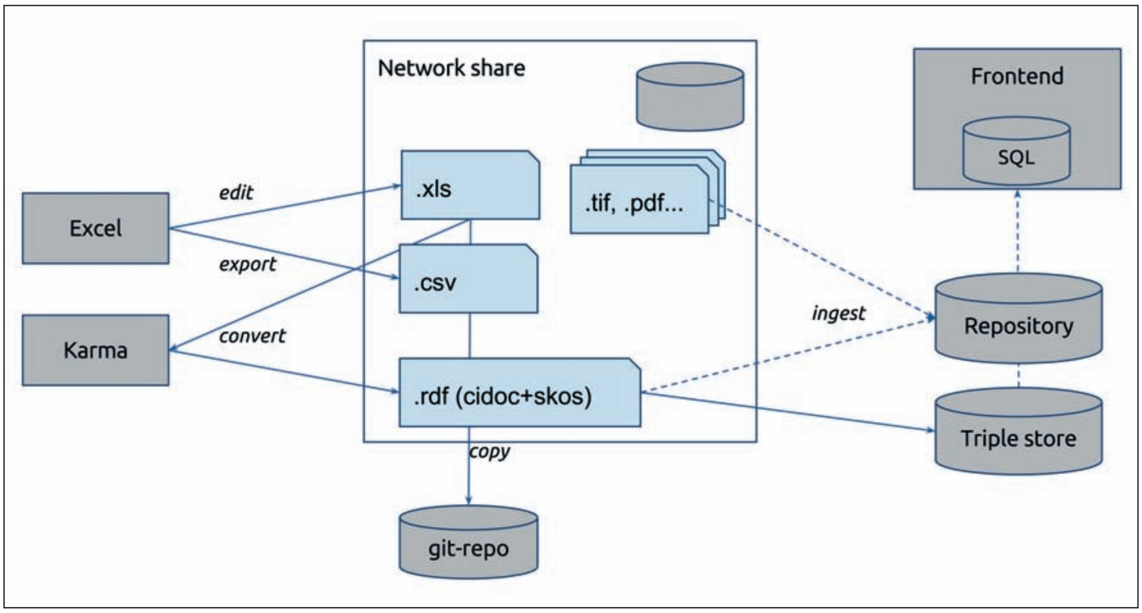


Fig. 13 Components of the prototype system architecture (Ďurčo, Hiebel and Aspöck 2017)

Concluding Remarks

In the first year of the project we have gained a thorough understanding of the Tell el-Daba excavation and documentation methodology, allowing definition of the data model and metadata fields. Metadata fields and their relations to each other were defined to represent all crucial information contained in the resources and relate the thousands of single documents to each other. To encode our metadata, we chose CIDOC CRM to represent the complex relations that were created as archaeological remains were excavated over a period of 50 years and documentation practices changed, most notably from analogue to digital. Using an international standard increases the chances for preservation of the semantics of the metadata in the future.

On an implementation level we have developed an approach to create, manage and query metadata information for the Tell el-Daba excavation documentation based on the CIDOC CRM data model. We used tools and specifications of the semantic web community for our test implementation, and so far, we were able to answer our questions.

We believe we have addressed the main challenges on a conceptual level and achieved an implementation level for the digital documentation of old excavation data in combination with new digital data. At the time of publication of this paper, which coincides with the near completion of the A Puzzle in 4D project, the digital resources are transferred to the ÖAW repository ARCHE.[44]

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