

# PUTTING THE PAST IN PLACE

A CONCEPTUAL DATA MODEL FOR A 4D ARCHAEOLOGICAL GIS

BERDIEN DE ROO



**Putting the past in place**  
**A conceptual data model for a 4D**  
**archaeological GIS**

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Faculty of Sciences  
Department of Geography

# Putting the past in place A conceptual data model for a 4D archaeological GIS

Thesis submitted in accordance with the requirements for  
the degree of Doctor of Science: Geomatics and Surveying

# Plaats maken voor het verleden Een conceptueel datamodel voor een 4D archeologisch GIS

Proefschrift aangeboden tot het behalen van de graad van  
Doctor in de Wetenschappen: Geomatica en Landmeetkunde

**BERDIEN DE ROO**

## **PROMOTORS:**

Prof. dr. Philippe De Maeyer  
Department of Geography, Ghent University

Prof dr. Jean Bourgeois  
Department of Archaeology, Ghent University

## **MEMBERS OF THE EXAMINATION COMMITTEE:**

Prof. dr. Ben Derudder (chairman)  
Department of Geography, Ghent University

Prof. dr. Veerle Fack (secretary)  
Department of Applied Mathematics, Computer Science and Statistics,  
Ghent University

Prof. dr. Philippe De Maeyer (promotor)  
Department of Geography, Ghent University

Prof. dr. Jean Bourgeois (promotor)  
Department of Archaeology, Ghent University

Prof. Dr. Peter Bogaert  
Department of Geography, Ghent University

Prof. dr. Claire Ellul  
Department of Civil, Environmental & Geomatic Engineering,  
University College London

Prof. dr. ir. Sidharta Gautama  
Department of Telecommunication and Information Processing, Ghent University

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# PREFACE — VOORWOORD

---

After four years of research and now my thesis is for the greater part finished, it is time to write the preface. That is how it goes with prefaces, they are usually written last, although mostly read first by the reader. In a preface, pursuing a PhD is compared often to a marathon, a cycling race or a journey. Having studied for five years and worked on a PhD for four years at the Department of Geography, a comparison of this research with the last is obvious. Furthermore, a preface traditionally is the place to acknowledge people who played an important role during this trip. Because most, if not all of them, are Dutch-speaking, I will continue this preface in Dutch.

---

Na vier jaar en nu het grootste deel van dit proefschrift is beëindigd, is het tijd om het voorwoord te schrijven. In een voorwoord wordt een doctoraat vaak vergeleken met een reis, en zeker bij een doctoraat uitgevoerd aan de Vakgroep Geografie ligt dergelijke analogie natuurlijk voor de hand. Nadat mij vier jaar geleden werd gevraagd of ik deze reis wou maken, heb ik na enige twijfel besloten deze unieke kans te grijpen. Prof. Philippe De Maeyer heeft samen met Prof. Jean Bourgeois de taak van reisorganisator en gids op zich genomen. Ik wil hen dan ook bedanken om mij met hun ervaringen bij te staan en voor mij de juiste contacten te leggen.

De bestemming van de reis hebben we kort daarna vastgelegd: de ontwikkeling van een datamodel voor een 4D archeologisch GIS. Omdat totaal onvoorbereid op reis vertrekken niet echt iets voor mij is, werd een eerste reisschema uitgewerkt. Gelukkig kon ik hiervoor rekenen op de reiservaring van Ann en Ruben. Samen met hen schreef ik het plan uit in de hoop wat extra budget te verdienen om deze reis aan te vatten. Waar het FWO andere reizen interessanter beoordeelde dan die van mij, heeft het BOF mij deze beurs wel toegekend. Bedankt Ann en Ruben om mij te helpen en BOF en dus de Belgische belastingbetaler om deze reis voor mij te bekostigen.

De bestemming ligt vast, de gidsen staan voor je klaar en het reisbudget is binnen: klaar om te vertrekken. Vol goede moed ben ik in oktober 2012 aan dit grote avontuur begonnen. Ik ben sindsdien op heel wat onbekende en minder onbekende plaatsen terecht gekomen. Het moet gezegd dat conferenties vaak – of dit geheel toevallig is of niet laat ik in het midden – op toeristisch interessante plaatsen worden georganiseerd, waardoor ik Southampton, Luik, Leuven, Istanbul, Milaan, Marseille, Concepción, Santiago, Parijs, Dubai, Girona, Kuala Lumpur en Albena mocht (her)ontdekken. Tijdens een reis ontdek en leer je heel wat nieuwe dingen. Zo leerde ik gaandeweg meer bij over archeologie. Daarnaast leerde ik onder andere een WebGIS bouwen en programmeren in Python, JavaScript en PHP. Voor dit laatste wil ik Bart en Michiel bedanken, bij wie ik met mijn technische vragen steeds terecht kon. Gedurende een reis

ontmoet je ook heel wat, vaak nieuwe, mensen. Thank you Carolina, Octavio, Ursula and Grace to make the three-month trip to Chile unforgettable. Gracias Grace for designing the cover. Sommigen zijn zo enthousiast dat ze zelfs meewillen gaan op jouw trip. Onder hen Coen, Britt, Alain, Samuel, Michiel, Bart, Kristien, Nico, Jean en Philippe, de coauteurs die hebben getracht het beste uit mijn papers te halen. Onder hen ook Bart en zijn collega's van Solva, Jasmine en haar collega's van Gate, Geert, Gunter en hun collega's van Stadsarcheologie Gent om mij steeds met volle enthousiasme te willen ontvangen en deel te nemen aan mijn gebruikerstesten. Onder hen ook de respondenten van mijn enquête en geïnterviewde Vlaamse archeologische organisaties, om mij de nodige achtergrondinfo te verschaffen. Onder hen ook David voor zijn onmisbare programmeerhulp het laatste jaar. Zij hebben er één voor één voor gezorgd dat dit geen individuele reis is geworden, maar een groepsreis. Om de administratie die bij het maken van deze tocht kwam kijken, in orde te brengen heb ik steeds kunnen rekenen op Helga.

Om iedereen op de hoogte te houden, pen je tijdens zo'n lange reis op regelmatige tijdstippen je ervaringen neer. Soms lijken er meer mensen geïnteresseerd dan je op het eerste zicht zou verwachten. Sommige van deze lezers tonen zich van hun meest kritische kant en hoewel hun kritische woorden in eerste instantie vaak moeilijk te aanvaarden zijn, blijkt achteraf dat ze toch (vaak) gelijk hadden. Hierbij dan ook een woordje van dank aan de 22 anonieme reviewers van de papers in dit doctoraat, aan de lezers van mijn artikelen en aan jou als lezer van dit proefschrift.

De plaatsen waar je tijdens een reis terechtkomt, vormen een verzamelpunt voor reizigers die elk een andere reisbestemming hebben, maar wel dezelfde ervaringen delen. Op de S8 heb ik in deze vier jaar verschillende van deze medereizigers ontmoet en hun verhalen en ondervindingen waren elk op hun manier nuttig en ontspannend. Hoewel dagelijks de middagpauze een moment van afleiding was, werd in de loop van deze reis ook een wekelijks ontspanmoment ingelast met lokale versnaperingen. Hierbij wil ik dan ook de taartje-van-de-weekcollega's bedanken voor het in stand houden van deze aangename traditie. Binnen de groep van medereizigers die ik op de S8 mocht leren kennen, zijn er toch een aantal met wie ik een nauwere band heb opgebouwd. Of we nu lang of kort dezelfde plek hebben gedeeld, Eline, Pepijn, Annelies, Britt en Samuel bedankt om van bureau 120.061 'the best office' te maken. Het beste bureau want hier konden zowel kleine als grote zorgen worden gedeeld, konden grappen worden uitgehaald en kon vooral veel worden gelachen, en dit elke reisdag opnieuw. Soms is het ook nodig de reis eens even te vergeten en te ontspannen. Kathleen, Thijs, Jeroen, Nikita, Niels en Sofie bedankt om ervoor te zorgen dat dit kon.

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Dank jullie wel allemaal!

*Berdien De Roo  
Erondegem, mei 2016*



“If we knew what it was we were doing,  
it would not be called research, would it?”

**Albert Einstein**





# ABSTRACT

---

Archaeological heritage is highly pressured because of the increasing soil disruption caused by construction work, which forms the major cause of damage. In recent years, archaeology is integrated more and more in the spatial planning process as a result of the European Convention of Malta. Confronted with high time pressure in order to not delay the infrastructure or construction work and high pressure to confine costs to be able to compete, archaeological organizations are nowadays mainly concentrating on recording data. However, the reuse of these archaeological data, which may contain very valuable information about our past, is very limited because of their inaccessibility and specific data structures. An archaeological data infrastructure, which is based on a common conceptual data model, may overcome these exchange and integration issues. Therefore, this research aims at developing a conceptual data model that is specifically designed to suit the needs of the archaeologists and particularities of 4D archaeological data. Through an online user survey, meetings with archaeologists working in Flemish commercial and governmental organizations, a document-analysis of the Flemish Immoveable Heritage Decree insights were gained in the current procedures for data storage, analysis and exchange in archaeology. The feasibility and suitability of 4D, i.e. combining 3D and time, analyses proposed in the survey were assessed. An algorithm for the automatic creation of a Harris matrix and its integration in a web-based management and research application has shown successful for theoretical data sets. Furthermore, the study proved the practical and technical feasibility of extending a virtual globe towards a 4D archaeological GIS by developing a prototype and performing user tests. Next, a conceptual data model that fits the gathered requirements is proposed: Archaeological DATA Model. This flexible, linkable and extendable data model is then approached from the broader context of the archaeological workflow by developing a user-friendly web-based management and research infrastructure. This elementary archaeology-specific geodata infrastructure could also incorporate the Harris matrix and 4D GIS applications. In this research, it is argued that such an infrastructure could facilitate the registration of 4D archaeological data in such a way that it leads to a scientific data source, which is easy for an outsider to understand and can be reused for gathering additional insights in our past and taking well-thought decisions on spatial planning, among others.



**“It is hard to fail, but it is worse  
never to have tried to succeed.”**

**Theodore Roosevelt**



# 1

## INTRODUCTION

---

The archaeological heritage concealed in our ground is an important, and in some cases the only, source of information about the past. It is a testimony to past societies and their social, cultural and economic habits and practices. It is the result of, and furnishes evidence for, centuries of human activity. The pressure on this heritage, however, is increasing due to expanding spatial – urban – development, beginning after the Second World War (Demoule 2012). After all, everyone needs space not only to live but also to work, move and relax. Built-up areas have been increasing faster than the population in Western Europe (Kasanko et al. 2006). In Flanders, the proportion of built-up area has exceeded 26.5% since 2012 (Statistics Belgium 2016), while the overall European share is only 4.7% (Eurostat 2013). In this regard, Flanders is one of the frontrunners in Europe. Because soil disruption by construction work is acknowledged as the major cause of damage (de Boer 2009, p. 77, Agentschap Onroerend Erfgoed 2016, p. 78), archaeological heritage is thus highly pressured.

Since the 1960s, European concern about archaeological heritage has increased. On 6 May 1969, the Council of Europe signed the ‘European Convention on the Protection of the Archaeological Heritage’ in London. This convention, often referred to as the Convention of London, attempted to curb illicit excavations, ensure scientific publication of the results and raise public awareness of archaeological heritage (Council of Europe 1969). Although illegal excavations by so-called treasure hunters posed the largest threat at first, the increasing infrastructure projects soon took over this position (Draye 2007). On 16 January 1992, the Convention of London was adapted to fit the evolved planning policies and the prevailing archaeological context. The new treaty, referred to as the Convention of Malta or Valletta Treaty, mainly aims at the more integrated preservation and protection of archaeological heritage (Council of Europe 1992). This treaty prioritises the preservation of archaeological heritage *in situ*, i.e., at its found location. However, if impossible, damage or destruction of the found remains must be avoided. To this end, the treaty stresses the necessity of interaction between archaeology

and spatial planning. The convention was ratified by 44 of the 47 Council of Europe member states and by the Holy See, an observing member, between 1993 and 2015 (Council of Europe 2016). However, its principles began to be adopted more quickly. The consequences have been noticeable since the late 1990s and early 2000s, when 80% of the member states had signed the treaty.

Archaeological practice in Europe has changed drastically since the adoption of the Convention of Malta. Because infrastructure work tends to threaten the heritage in the ground, archaeological fieldwork became a necessary part of it and a development-led archaeology has arisen. This process has resulted in a substantial increase in the number and size of archaeological investigations in the last two decades (De Clercq et al. 2012, Vanmontfort 2012). Consequently, a market has emerged for archaeological companies (Kristiansen 2009). The organization of this archaeological market varies among the European countries. In general, these various market implementations can however be traced to two approaches: (i) the capitalist or market model and (ii) the social or public model (Kristiansen 2009). This division is based on the question of whether “the state consider[s] archaeological work to be a service” (Willems and van de Dries 2007, pp. 10–11). The United Kingdom, the Netherlands and Flanders, for instance, consider archaeological work as a service and thus have a capitalistic archaeological market organization, while France and Sweden maintain the social model (Willems and van de Dries 2007, Kristiansen 2009). In both models, however, the government that makes policy and legal decisions on archaeology is separated from the executors of these decisions (Kristiansen 2009). Hence, the government now acts as an ‘intermediary between public and private developers and archaeological excavators’ (De Clercq et al. 2012, p. 29). These archaeological excavators are organised in semi-public or private companies in the social and capitalistic models, respectively. In the latter, the developer appoints the excavator mostly based on the cheapest bid, while in the first, government selects the excavator. What is common to both market models is the application of the rule ‘the disturber pays’, which is a translation of the ecological principle ‘the polluter pays’.

This principle puts a great burden on archaeological companies. Although valid for both models, this pressure is particularly perceptible in the capitalistic model, where the rules of the free market apply and thus competition takes place. Archaeological enterprises are forced to limit the costs of their investigations to be able to compete. Once granted permission for the investigation, they feel the developer breathing down their neck to execute the fieldwork as fast as possible. Therefore, development-led archaeology mainly concentrates on the recording of the archaeological finds (Ford 2010, De Clercq et al. 2012). Given limited budgets and time, elaborate analyses and interpretations are disregarded, and a basic excavation report is the only available deliverable (Berggren and Hodder 2003, Van Liefferinge 2013). These preliminary reports, presenting site plans, overviews of the found artefacts and a primary interpretation, contain valuable information for future research. However, the accessibility of these excavation reports and their quality is often questioned by academia (Ford 2010, De Clercq et al. 2012,

Vanmontfort 2012). Furthermore, the sometimes thoughtless application of rather standardized methods in large-scale excavations and the growing discrepancy between excavation and data recording on the one hand and interpretation and report writing on the other hand are two other issues for which development-led archaeology is condemned (Berggren and Hodder 2003, De Clercq et al. 2012). These issues are the subject of debate between academia and commercial archaeology. In fact, the most important difference between the two is the starting point of their respective investigations. Academic archaeologists begin their investigations from a specific research question and intend to create new knowledge, whereas development-led archaeology focuses on recording all relevant information as best as possible to allow its future contribution to knowledge creation. Currently, the creation of new knowledge about our past is therefore fairly limited compared to the number of archaeological investigations (De Clercq et al. 2012). This fact lies at the basis of the prevailing public opinion on archaeology, which doubts the usefulness of the investment of so much time and money in research without significant, or for them marvellous, results (Ford 2010, De Clercq et al. 2012). A biased press that communicates almost exclusively about spectacular findings or the costs and delays of excavations causes this viewpoint (Kaeser 2008, Leonard 2013, Hassan 2014, Sels 2015).

It is thus clear that archaeology is no longer a purely academic activity driven by a particular research question. Despite the existing tension between academic and commercial archaeology, sometimes both parties work together and take advantage of the best of both worlds (Ford 2010). Universities are starting up spin-offs for the execution of development-led investigations and are performing the elaborate analyses and interpretations for which these commercial companies lack the resources (Ford 2010, De Clercq et al. 2012, Vanmontfort 2012). The large amounts of archaeological data becoming available currently because of development-led archaeology are very valuable from both a scientific and a socio-economic viewpoint (Ford 2010, Forte 2014). Although not immediately, these data can supply the topic of a broader archaeological research question investigated within an academic study. They also contain valuable information for other domains, such as spatial planning and tourism, and hence offer opportunities to create synergy with the economy and society (Wagtendonk et al. 2009, De Baerdemaeker et al. 2011). Furthermore, disseminating research results, even preliminary ones, to the public may lessen negative opinions and raise public awareness of both archaeological research and its necessity. Exchanging archaeological data or making them available for other domains is therefore of major importance. As the projects are funded by public resources – either directly or indirectly – this necessity is even more significant.

The use and future interpretation of these archaeological data are influenced by the way they are recorded and catalogued in the field (Labrador 2012). Because archaeological excavations are destructive by nature and thus unrepeatable, the fieldwork practices will accordingly determine the scientific, cultural, social and economic value. As the specific purpose of the data is unknown in advance, development-led archaeology mostly

attempts to describe the finds and their contexts as exhaustively as possible (Thomas 2006, De Clercq et al. 2012). However, increasing time pressure asks for rapid and efficient recording techniques. In this regard, digital technologies can be advantageous. They are currently widespread in archaeological fieldwork, especially for acquiring 3D spatial data, e.g., total station and GPS (Dell'Unto et al. 2013, Forte 2014, Stal et al. 2014). Although often still recorded by analogue methods on paper forms, thematic data are increasingly recorded digitally (Forte 2011). Vast amounts of born-digital spatial and thematic data can be acquired this way. However, once the recording and the stage of report writing are completed, these data are stored by the conducting organization (Snow et al. 2006, McKeague et al. 2012). The reuse and accessibility of these potentially very valuable primary data are thus hindered, even mostly prevented (Snow et al. 2006, McKeague et al. 2012). Even if the data sources are accessible, their reuse is hampered by the site- or organization-specific databases employed (Snow et al. 2006, Kansa and Kansa 2011, Ross et al. 2015). Standards, guidelines and data models might preclude these accessibility and integration issues. Although such regulations (e.g., ADeX and CIDOC CRM, see Section 7.2) do exist, they are often very specific in subject, region or temporal extent, causing their integration into larger projects to remain challenging (Snow et al. 2006, Ross et al. 2015). Therefore, data exchange and integration should be considered based on a broader context, i.e., the entire archaeological workflow. Given the increasing amount of digital data, a complete digital documentation process has been proposed by various researchers (Katsianis et al. 2008, Forte 2011, McKeague et al. 2012). For such a digital documentation process or 'flux of digital data' to enable the potential of archaeological data sets, a conceptual data model should be used as the basis of an integrated archaeological data infrastructure (Kintigh 2006, Katsianis et al. 2008). Such an infrastructure would facilitate the recording of archaeological fieldwork data in such a way that it forms a scientific data source, one that is easy for an outsider to understand and can be reused for gathering additional insights into our past and making well-considered decisions on spatial planning, among other uses.

The conceptual data model around which an archaeological data infrastructure should be built must fit the characteristics of archaeological data to facilitate various archaeological research purposes (Kintigh 2006, Katsianis et al. 2008, Ross et al. 2013). First of all, archaeology is inextricably bound up with space, as it seeks to amass knowledge of our past based on the remains found at specific places (Barceló et al. 2003, Tsipidis et al. 2005). Either an exact location in space or the spatial relationship to other objects may provide additional information for a certain object (Clarke 1977). Moreover, this spatial characteristic of archaeological data is intrinsically three-dimensional, as 3D archaeological objects are located in 3D space (Stal et al. 2014). The location is also used by archaeologists to create temporal reconstructions of past activities. Spatial relationships between the findings can be converted cautiously into relative temporal trajectories, which are generally presented as Harris matrixes (Harris 1979, Barceló et al. 2003). In addition to this manner of relative dating, absolute dating



is also used in archaeology. Thus, multiple temporal categories, including absolute time, site phase time, and excavation time may be ascribed to an archaeological object (Katsianis et al. 2008). The temporal aspect means that archaeological data are in fact 4D, i.e., 3D spatial and temporal. However, this temporal aspect cannot always be derived with absolute precision and mostly includes a certain degree of imperfection (Green 2008, de Runz et al. 2010). Not only the temporal categories but also shape, location, scale and functionality are affected by imperfection (Katsianis et al. 2008, Cripps 2012). The last, for instance, occurs when it is unclear what object a certain find is (part of). In addition, archaeological objects are widely diverse (Madsen 2003, Labrador 2012). In studying the activities of past societies, the whole range of objects (and their traces) that belong to a human civilization can be the subject of archaeological data: ranging from coins over postholes to houses and complete cities. These examples also illustrate that archaeological research is conducted at different scales. Generally, a distinction is made on three levels, from large to small scale: intra-site, inter-site and intra-structure (Deweirdt 2010). To conclude, archaeological data are characterized by a rather high level of complexity, which can be reduced to five factors: (i) the intrinsic 3D character of the data, (ii) the complicated concept of time, (iii) the inherent imperfection of the data, (iv) the wide variety of objects, and (v) the multiplicity of scale levels.

Although each of the five complexity factors outlined above must be considered in the management and analysis of archaeological data, the 3D spatial aspect has a key role. To arrive at well-grounded archaeological conclusions, spatial and thematic data should be handled simultaneously (Arroyo-Bishop and Lantada Zarzosa 1995, McKeague et al. 2012). Since the 1980s, Geographical Information Systems (GIS) have therefore been proven successful in archaeological research (Wheatley and Gillings 2002, Wagtendonk et al. 2009). GIS are increasingly utilized to analyse and interpret the relationships between features on a site. Typical applications include management of the inventorying of heritage locations, creating map overviews of excavations and to a lesser extent predictive modelling of site probabilities and route simulations (Conolly and Lake 2006). However, their use is not fully exploited today in archaeology precisely because of the specific characteristics of archaeological data. The intensive and progressive research on 3D GIS is mainly focussing on city modelling. Although numerous use cases of 3D city models already exist, which could be useful also for archaeological data (e.g., visibility of a landmark, enhanced research result presentation, urban planning) (Biljecki et al 2015), the subsurface characteristic of 3D archaeological data combined with its inherent imperfection makes it more complex and not easily administrable. Handling the third dimension or the different temporal categories, which differ from precise modern clock time, remains problematic in the available GIS packages (Green 2008, Wagtendonk et al. 2009, von Schwerin et al. 2013). The effort needed to force GIS to work for archaeological analyses therefore is mostly not commensurate with the obtained results (Wagtendonk et al. 2009). Furthermore, the simultaneous handling of spatial and thematic archaeological data is still not taken for granted in archaeology, as demonstrated by the wide range of projects that either seek to create splendid 3D

visualization but lack analysis capabilities or seek to structure archaeological data but neglect the 3D spatial character (von Schwerin et al. 2013). Furthermore, the developed tools are focused mostly on one particular phase of the archaeological workflow and/or centred on a specific type of archaeological data (Ross et al. 2013). Combining thematic and 3D spatial data from the beginning of the archaeological research process has, however, been verified to allow review of the process and to facilitate reflexivity (Berggren et al. 2015).

Considering the importance of the spatial aspect of archaeological data, it is clear that geographic applications are necessary for their management. Spatial data infrastructures (SDIs) can accordingly inspire the development of an archaeological data infrastructure (McKeague et al. 2012). SDIs seek to make geographic information available for a wide range of users and various aims. For this purpose, they not only comprise a technical infrastructure but also consider data policies, data and metadata standards and organizational aspects. Using digital technologies as part of an archaeological data infrastructure designed to manage the flux of data throughout the archaeological workflow would help to narrow the existing gap between fieldwork and post-excavation investigations (Berggren and Hodder 2003, Huvila 2014). Because various people with diverse technological skills participate in archaeological work, the digital tools and archaeological data infrastructure should be developed to avoid complexity and the consequent steep learning curve (Berggren et al. 2015).

For such an archaeological data infrastructure to be successful, archaeological enterprises, academia and government should participate in its development (Snow et al. 2006, Ross et al. 2015). As the archaeological sector is considered a niche market, commercial IT and software companies are not eager to invest in research and development regarding archaeology (Green 2008, Ross et al. 2015). Given that the turnover generated by archaeological companies is estimated to range between approximately 0.005% and 0.01% of the countries' gross domestic product (Schlanger and Aitchison 2010, De Baerdemaeker et al. 2011, Aitchison 2015), this limited interest is justifiable from an economic perspective. Employment rates and turnovers have experienced a stagnation between 2008 and 2012 due to the economic crisis, but in upcoming years a rise is expected again (De Baerdemaeker et al. 2011, Aitchison 2015). The archaeological sector is not only growing in direct economic terms but also in indirect value for such fields as tourism, urban planning and culture (De Baerdemaeker et al. 2011, McKeague et al. 2012, Bourgeois 2014). Although a wide range of application areas thus exists for such an archaeological data infrastructure, the primary target market, commercial archaeological organizations, remains limited. Therefore, scientific research should be conducted to begin the development of such an archaeological data infrastructure (Green 2008). This research should determine how archaeological data could be registered, analysed and exchanged efficiently while preserving respect for their scientific and social value. It is hoped that this attempt will stimulate commercial activities to enhance archaeological data recording, analysis and exchange by providing cost- and time-efficient tools that also facilitate ensuring the research quality.

## 1.1 RESEARCH OBJECTIVE AND APPROACH

### 1.1.1 Research objective and questions

The previous paragraphs have exposed some of the current trends and issues in archaeological research practice. The more integrated approach of spatial planning and archaeology has increased the amount of archaeological data acquired during recent decades. However, these data are not reused very often because of their limited accessibility and reusability. First, these data are mostly inaccessible to researchers and other interested parties because they are stored by the archaeological organization that conducted the fieldwork. Second, if accessible, the site- or organization-specific data structuring often makes these data difficult to understand. Many researchers have argued that complete digital archaeological documentation may overcome these exchange issues and make the data valuable even after the first report is written (Snow et al. 2006, Katsianis et al. 2008, Forte 2014, Huvila 2011, McKeague et al. 2012). Conceiving this complete digital documentation as an archaeological data infrastructure, including digital technologies and applications such as GIS, may also facilitate the thorough integrated analysis of the thematic, temporal and 3D spatial data. As commercial interest is limited, scientific research should initiate the development of such an infrastructure and digital tools.

Aiming to contribute to the on-going research on archaeological data modelling and 3D archaeology, the general objective of this thesis is to

**DEVELOP A CONCEPTUAL DATA MODEL FOR ARCHAEOLOGICAL PURPOSES, IN WHICH THE PARTICULARITIES OF 4D ARCHAEOLOGICAL DATA AND THE REQUIREMENTS OF ARCHAEOLOGISTS TAKE A CENTRAL POSITION.**

Such a data model could form the basis of an archaeological data infrastructure, which in turn may contribute to the realization of complete digital documentation. This complete documentation may in turn facilitate the open use of data. As the spatial aspect and the temporal dimension are both of paramount importance for archaeological research, a 4D archaeological GIS could form part of such an archaeological data infrastructure to enable a thorough understanding of and insight into the spatio-temporal relationships of the remains of our past.

Based on this broad research objective, two main research questions (RQ) can be derived:

- 1. What are the general requirements for the analysis and structuring of archaeological data?**
- 2. How can these requirements be translated into an abstract data model that is extendible and enables future adaptation and advanced application?**

The first research question involves a thorough assessment of the user's needs in broad terms, i.e., a definition of the requirements of the archaeological world. This evaluation will be based on two focal points: (i) the current procedures for the storage, analysis and exchange of archaeological data and (ii) the feasibility and suitability of some proposed new 4D, i.e., 3D spatial and temporal, analyses. The second research question then focuses on the translation of the set of needs from RQ1 in the construction of a conceptual data model. During this translation, attention will also be paid to the ability of the model to fit into the archaeological workflow and thus form the basis of an archaeological information infrastructure. Consequently, these two general research questions can be further specified and formulated in four more concrete research questions:

**RQ 1a. What are the current procedures for archaeological data storage, analysis and exchange?**

**RQ 1b. Which newly proposed 4D analyses are feasible and suitable for archaeology?**

**RQ 2a. How can the requirements be translated into an archaeological data model?**

**RQ 2b. How can this data model be integrated into a broader context, i.e., the archaeological workflow?**

While the first research question (RQ 1a) focuses on the current practices regarding archaeological data, the second (RQ 1b) addresses future possibilities for 4D analyses. In RQ 1a, the aim is to list and compare the existing methods of storing, analysing and exchanging archaeological data, whether digital or analogue. Moreover, the state of the art of research concerning archaeological data storage, analysis and exchange will be investigated. As a result of the first research question, proposals for new analyses, particularly combined spatial and temporal analyses, may become clear. These newly proposed analyses will be the focus of the second research question (RQ 1b), determining their feasibility and suitability. The outcomes of RQ 1a and RQ 1b will form a thorough foundation for a more comprehensive archaeological data model. Considering the archaeologists' perspective on data storage, analysis and exchange as well as the current state of the art on these topics may increase the final chance of success and the adoption rate of the proposed data model. The third research question (RQ 2a) examines how the translation of these user needs into a data model should be addressed. Once such an archaeological data model is proposed, the aim of the fourth research question (RQ 2b) is to place its applicability in a broader context. In RQ 2b, the suitability of the model proposed in RQ 2a is tested as part of an archaeological data infrastructure.

## 1.1.2 Research approach<sup>1</sup>

To answer the four research questions outlined in Section 1.1.1, a methodology is proposed that is an extension of an existing methodology, described by Howard and MacEachren (1996), in a closely related field of research: geovisualisation. The goal of this research field is to visualize complex geographic data, which may comprise 3D data, data from a variety of sources, and temporal data, in a way that is understandable by humans. Consequently, this methodology may serve as a basis for the development of a conceptual data model that can underpin a 4D Archaeological GIS or archaeological information infrastructure.

Howard and MacEachren (1996) focus in their approach on Marr's (1982) theory regarding how humans represent and process visual information (cognition), which could thus drastically improve the usability of the final system for the end users (archaeologists). Usability is also the main goal of another methodology that is well known in the field of software engineering: the user-centred design (UCD) cycle (Maguire 2001, Maguire and Bevan 2002). Both methodologies will be described in the next sections, including their integration in a methodological framework for the development of a conceptual data model to underpin a 4D archaeological GIS.

### *1.1.2.1 Methodological framework based on human cognition*

Howard and MacEachren's approach (1996) consists of three levels of analysing: (1) the conceptual, (2) the operational and (3) the implementation level. The first level considers the system "as a connection to information" (Howard and MacEachren 1996, p. 61). Four questions need to be addressed for this level (Howard and MacEachren 1996, p. 61):

- (i) who is the system intended for?
- (ii) what requirements must be fulfilled by the system?
- (iii) what should be the result of working with the system?
- (iv) how can this objective be reached?

The second, operational, level "involves the delineation of the appropriate operations to match conceptual level goals" (Howard and MacEachren 1996, p. 62). The results of this level are independent of the implementation and thus of the software or hardware. In this level, the developers analyse what the system needs to do, but not how it will be accomplished. Howard and MacEachren (1996) also suggest distinguishing between data and phenomena and among spatial, temporal and attribute information. Finally, "the implementation level includes consideration of anything that the user will have to see and decipher in order to interact with the system" (Howard and MacEachren 1996, p. 62). This level corresponds to the final stage of the development of the system: analysing how

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<sup>1</sup> Modified from: DE ROO B., OOMS K., BOURGEOIS J., DE MAEYER P. 2014. Bridging archaeology and GIS: Influencing factors for a 4D archaeological GIS. In IOANNIDES M., MAGNENAT-THALMANN N., FINK E., ZARNIC R., YEN A.-Y., QUAK E. (eds.) *Lecture Notes in Computer Science*. 8740. Cham: Springer, pp. 186–195.

the operational level can be translated into code. At this stage, the design of the system, including the user interface, is considered.

### *1.1.2.2 The user-centred design cycle*

As the name implies, user-centred design (UCD), also called human-centred design, focuses on the future users of the system (Maguire 2001). This methodology originates from software engineering, where it was adopted to develop more user-friendly products by involving the user in every step of the design process (Nielsen 1993). Furthermore, it is an iterative or cyclic process during which the system or a number of its aspects are evaluated and subsequently improved (Figure 1-1). The methodology is recently being increasingly integrated in the development of GIS (Nivala 2007, Roth 2011).

This design process is specified in the ISO standard 9241-210:2010 and consists of four iterative design phases (Maguire 2001, p. 589):

- (i) understand and specify the context of use;
- (ii) specify the user and organizational requirements;
- (iii) produce design solutions;
- (iv) evaluate the design against the requirements.

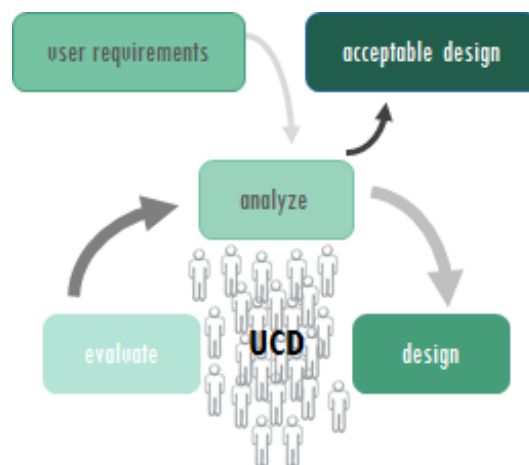


Figure 1-1 The user-centred design cycle

The first stage of the UCD cycle deals with understanding the use context: how will the system be used, in what setting will the system be used, who are the target users, and so on. This stage encompasses stakeholder meetings, task analyses and inquiry into the existing users (Maguire 2001). Second, the user requirements (Figure 1-1) need to be specified. This stage is of vital importance for the acceptance and use of the final system designed. These two initial stages correspond to the first level of analysis proposed by Howard and MacEachren (1996). Although commonly skipped, the phase of identifying the user needs is of great importance during the development process (Pfoser and Tryfona 1998, Zeiler 1999, Arp 2003, España et al. 2006, Tshipidis et al. 2011).

The third step in the UCD cycle involves the design of an initial prototype (Figure 1-1), which attempts to meet the previously described user requirements (Nielsen 1993, Maguire 2001). This initial prototype does not necessarily contain all features but is extended and improved during the subsequent cycles of the UCD process. Compared with the methodology proposed by Howard and MacEachren (1996), the development of the system is split up into different levels, the operations (including the spatial, temporal and attribute information) and the implementation on the other hand.

The fourth element of the design cycle is the assessment of the system (Figure 1-1). Depending on the evaluation of the system in this fourth stage, either a return to a previous step (first, second or third) is required or the system can be considered complete (Howard and MacEachren 1996). This evaluation typically involves the end users and thus improves the usability of the system for them (Nielsen 1993).

### *1.1.2.3 The proposed methodological framework*

The proposed methodological framework for the development of an archaeological conceptual data model will focus on the users' needs for the system and how to satisfy them on a higher level. The actual implementation phase will not be considered, as it must be executed by software engineers. However, prototypes may be developed to give an idea of the potential capabilities and stimulate the discussion with end users, thus eliciting additional user needs (Anastassova et al. 2007). The proposed framework thus consists of three pillars (Figure 1-2) corresponding to the main target points that can be derived from the combination of the two previously described approaches: (i) user-oriented, (ii) data-oriented and (iii) analysis-oriented pillars (Figure 1-2). By introducing the UCD approach (Maguire 2001) into the methodology of Howard and MacEachren (1996), the users (archaeologists) are placed in the centre of the framework. Thus, they will be involved in all steps of the product's development, also related to the data-oriented and analysis-oriented pillars.

The first, user-oriented, pillar corresponds to the conceptual level identified by Howard and MacEachren (1996) and includes the first two stages of the UCD cycle (Maguire 2001). The objective of this pillar is to identify the users' requirements and comprehend the purpose of the system (Figure 1-2). This pillar will result in "a description of the objectives and the external behaviour of the system, that is, 'what' the system must do without describing 'how' to do it" (España et al. 2006, p. 442). The four questions outlined by Howard and MacEachren (1996) should be answered, but further investigation is needed to fully understand the user requirements and the context of use. These questions can be answered by examination of the scientific literature, user surveys and interviews with both experts and non-experts (Maguire 2001).

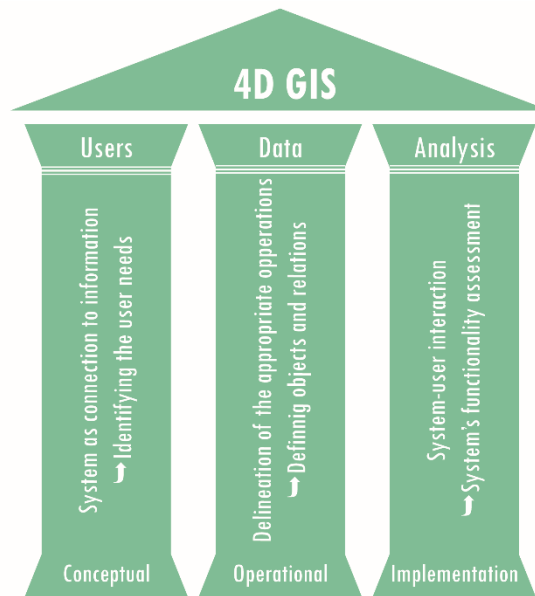


Figure 1-2 Three research pillars of the methodological framework for the development of an archaeological 4D GIS

The data-oriented pillar consists of the operational level and the third stage of the UCD cycle, *i.e.*, producing design solutions. In this pillar, an initial conceptual data model is developed, which implies the definition of the objects and relationships that will constitute the conceptual model (Figure 1-2) (Tspidis et al. 2011). This step also includes a focus on the operations, which the conceptual model should enable. Building a conceptual data model that meets all user requirements and that is applicable and suitable for all existing excavation sites and objects is not feasible in a single project or executable by a single person, as it requires a process of repetitious adjustments and modifications. Therefore, a bottom-up approach starting from individual case studies, which are subsequently aggregated, is proposed. This approach corresponds to the cyclic nature of UCD, which is repeated until an acceptable result is obtained for the end users.

Once a data model is built or extended with new information, the focus moves to the analysis capabilities of the third research pillar. The analysis-oriented pillar endeavours to avoid disregarding the system's functionality (Figure 1-2). This process is also included in the operation level and the third stage of the UCD cycle. It involves complex combinations of spatial, temporal and attribute analyses, possibly considering imperfections in the data.

Once the three pillars are addressed, the result of the functionality assessment will determine whether the system's design is ready for implementation and software development or requires further modifications by iterating again through the three research pillars. Based on the UCD approach, the functionality assessment is based on evaluations by the product's end users. Although a strict separation between the three pillars is almost impracticable, the sequence of the three pillars described above – user-data-analysis – is preferable.



### 1.1.3 Thesis outline

In the remainder of this thesis, the four research questions described in Section 1.1.1 are addressed according to the methodological framework (Section 1.1.2.3). As previously indicated (Section 1.1.2.3), an intertwining of the user-, data- and analysis-oriented research pillars may occur. The relationships between the research questions and the methodological framework are also slightly interlaced. While answering research questions 1a and 1b corresponds to the user-oriented research pillar, research question 1b also forms part of the data- and analysis-oriented pillar. Furthermore, research questions 2a and 2b correspond to the data- and analysis-oriented pillars, respectively.

This thesis consists of six research articles that have been published or submitted to peer-reviewed journals or books. Making up Chapters 3 to 8, these articles are complemented by a brief technical background in Chapter 2 and a discussion and conclusion chapter (9 and 10). Figure 1-3 gives an overview of these chapters, their contents and their relationships within the context of the research questions. Due to their separate publication, some overlap necessarily exists in these chapters, in particular with regard to the literature review and description of the overall thesis aim. However, this overlap allows the chapters to be read independently of each other. Below is a succinct overview of each chapter's contents.

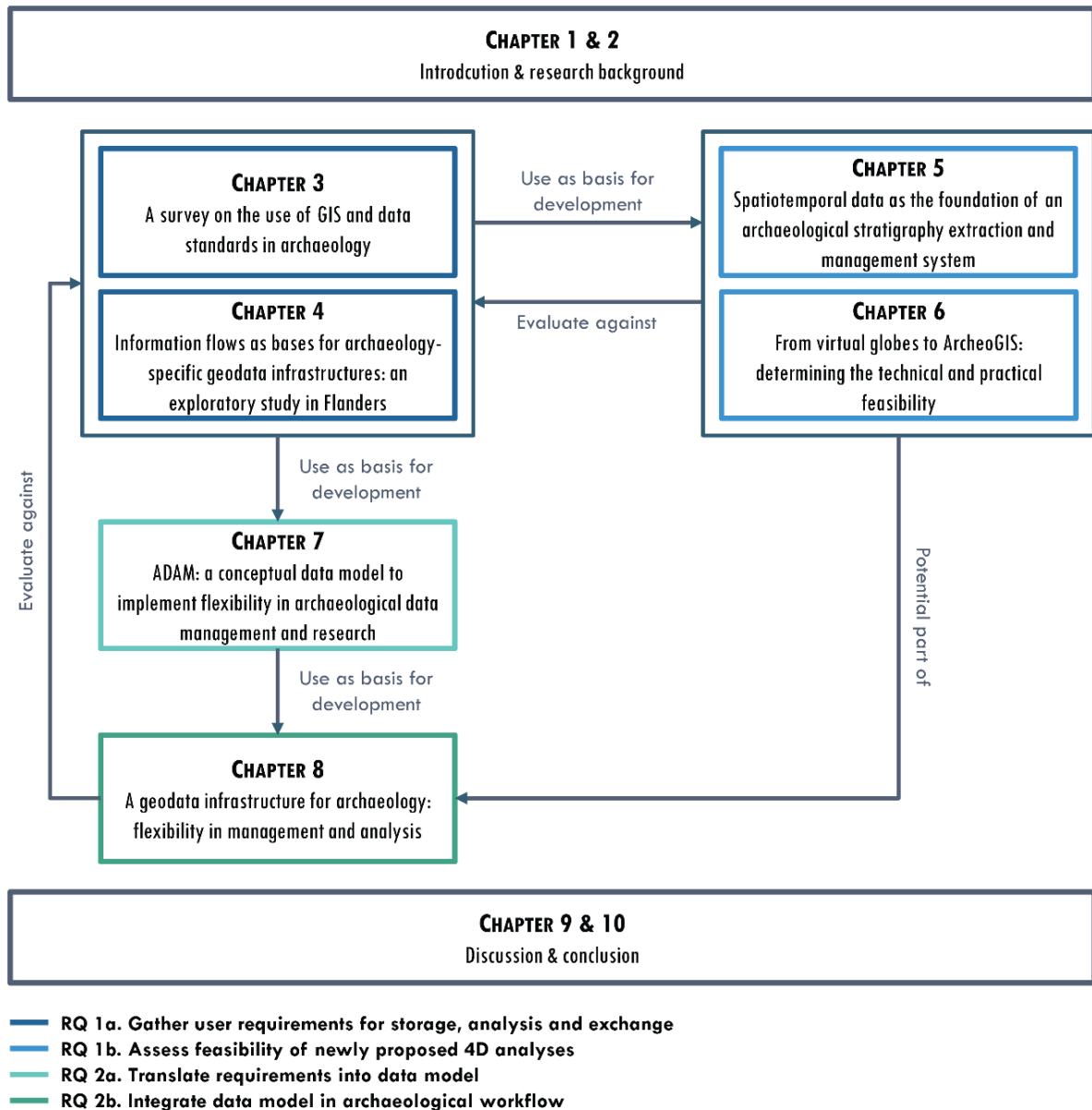


Figure 1-3 Thesis outline

**Chapter 2** provides some general background to facilitate a better understanding of the research context. First, it briefly outlines the current legislation and regulations regarding archaeology. Second, the consequences of the European Malta Convention, namely the rise of an archaeological market, the gap between recording and interpretation and the use of new technologies are delineated. Third, the five factors of archaeological data complexity are further clarified. Fourth, the data resources archaeology is dealing with are described. Finally, some background information is provided on Spatial Data Infrastructures.

Constituting the basis for the research conducted in the next chapters, Chapters 3 and 4 focus on the current state-of-the art in archaeological data storage, analysis and exchange. Together, they answer research question 1a.

**Chapter 3**, published in the International ‘Journal of Heritage in the Digital Era’ (De Roo et al. 2013), presents the results of an online survey of archaeologists and others dealing with archaeological data. Having reached a diverse, international public, the survey has revealed trends and issues in the current usage of GIS and data models, data storage and exchange and perspectives on 3D and 4D in archaeology.

**Chapter 4** describes the business processes and information flows in the Flemish archaeological sector. Meetings were organised with archaeologists working in commercial and governmental organizations to complement a document-analysis of the new Flemish Immovable Heritage Decree and an extended analysis of the survey results of Chapter 3. Thus, insights into how information is currently handled in the archaeological process are obtained in this chapter, which is published in the ‘Journal of the Association for Information Science and Technology’ (De Roo et al. 2016).

Although both the questionnaire and the stakeholder meetings provide an initial understanding of potential new analyses, further specification and user feedback on their potential implementation is needed. Therefore, two applications were created to answer research question 1b, on the one hand, and to complete the user-oriented pillar and make the transition to the data- and analysis-oriented pillars, on the other hand. Chapters 5 and 6, in which the ideas, implementations and evaluations of these two applications are described, have a bidirectional relationship with the user requirements already gathered in Chapter 3 and 4 (Figure 1-3).

**Chapter 5**, published in the ‘Journal of Cultural Heritage’ (De Roo, Stal, et al. 2016), presents an application for the automatic creation of Harris matrices by examining the spatial relationships between archaeological components. This chapter describes the methodology of the automated process and the design of its integration in a user-friendly management system for archaeological information using Free and Open-Source Software (FOSS) such as OpenLayers and PostGIS.

**Chapter 6** presents an analysis of the technical and practical feasibility of extending virtual globes to a 4D archaeological GIS. A prototypical application that allows the display and analysis of 4D archaeological data is developed against the background of the user requirements. Using this prototype, a usability test was performed with the employees of two Flemish archaeological organizations. Both the development of the prototype and the results of the user testing are described in Chapter 6, which is published in ‘Photogrammetric Engineering & Remote Sensing’ (De Roo, Bourgeois, et al. 2016).

According to the proposed methodological framework, the next part of the thesis focuses on the data-oriented pillar, considering the gathered user requirements as a basis and seeking to answer research question 2a.

**Chapter 7**, under review for publication in the ‘ACM Journal on Computing and Cultural Heritage’ (De Roo, Lonneville, et al. under review), suggests a novel conceptual data model specifically tailored to 4D archaeological data: Archaeological DATA Model or ADAM. As the description of this flexible and linkable data model may seem too abstract, this chapter also provides a potential database implementation and web application, which can serve as the basis of an integrated archaeological data infrastructure.

Although ADAM has been proposed to handle the user requirements, and a potential database implementation and application are provided in chapter 7, a more thorough assessment of ADAM as part of an integrated archaeological data infrastructure is needed to answer research question 2b. The two applications described in Chapters 5 and 6 can possibly be integrated into such an infrastructure. Furthermore, the development of such an infrastructure need to be evaluated against the user requirements proposed in the analysis-oriented pillar of the methodological framework.

**Chapter 8** presents how ADAM, described in Chapter 7, can constitute the basis for an archaeology-specific data infrastructure. Two case studies are presented, one on maritime heritage and one on an urban excavation, respectively. The applications developed, based on the suggestions given in Chapter 7, and their evaluation by the potential end-users are described in this chapter, which is published in the ‘Proceedings of the 16<sup>th</sup> International Multidisciplinary Scientific GeoConference – SGEM 2016’ (De Roo, Van Ackere, et al. 2016).

**Chapters 9 and 10** discuss and summarise the results of the individual chapters in light of the research questions and general research objective.

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# 2

## RESEARCH BACKGROUND

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### 2.1 ARCHAEOLOGICAL LEGISLATION AND REGULATIONS

Archaeological research is conducted within the framework and constraints of legislation and regulations. Therefore, this legislative context is described in the next paragraphs. Hereby, a shift is made from the global to the local scale. First, international-level legislation and regulations are described. Next, the framework is scaled back to the European level. Finally, the local-level legislative framework is described since this may play the most decisive role for the research. Because some of the chapters of this thesis relate to archaeology in Flanders, the Belgian and Flemish legislative and regulative context is discussed for the local level.

#### 2.1.1 UNESCO at the international level

The awareness of the sensitivity of archaeological heritage to destruction has been grown internationally since the economic developments after the Second World War (Demoule 2012). Aiming to “contribute to peace and security by promoting collaboration among the nations through education, science and culture” (UNESCO 1945), UNESCO also provides a forum to discuss issues on (cultural) heritage on an international level. As stated in its Constitution, signed in 1945, UNESCO may assist to conserve and increase the knowledge on our heritage “by recommending to the nations concerned the necessary international conventions” (UNESCO 1945, art. 1). For the adoption of these conventions, UNESCO is dependent on the ratification by its 195 member states and 10 associative members (UNESCO 2016a). From its foundation onwards, UNESCO’s work has resulted in a number of international conventions on the protection of our heritage (Table 2-1), which are legally binding between states and international organizations. Concerning archaeology, the so-called ‘Hague Convention’, signed in 1954, and the ‘World Heritage Convention’, signed in 1972, are the most important. The former has originated after the destruction caused by the Second World War and regulates how states should protect their cultural sites, monuments and other heritage, like libraries, in times of war or military

operations. In 1999, the ‘Hague Convention’ was reviewed to match more recent experiences, resulting in a ‘Second Protocol’. The ‘World Heritage Convention’ concerns the protection of cultural and natural heritage sites that have an exceptional and universal value. This Convention describes the kind of heritage that is considered of such exceptional value and thus might be qualified for inscription on the ‘World Heritage List’. The latter list, maintained by the in 1992 established World Heritage Centre, currently consists of more than thousand cultural, natural or mixed sites spread all over the world (UNESCO 2016b). However, Demoule (2012, p. 613) noted that only the most recognized sites are inscribed on the list while “nearly 1,000 archaeological sites from all periods are destroyed every day in the world as a result of development projects without preventive excavation”. Besides conventions, UNESCO also drafts recommendations (Table 2-1). In contrast to conventions, these are not legally binding, but rather invite the member states to adopt these principles and guidelines in their national legislation. The ‘Recommendation on International Principles Applicable to Archaeological Excavations’, signed in 1956 and also called ‘Recommendation of New Delhi’, is the most important regarding archaeology. This recommendation represented the first set of rules to protect archaeological heritage on an international level. It defines, among other things, rules for the excavation and legal protection of archaeological sites and international collaboration. For more information on the UNESCO recommendations, reference is made the UNESCO website (<http://portal.unesco.org>).

Table 2-1 UNESCO conventions and recommendations on archaeology and heritage

Date, Place	Title
14/05/1954, The Hague	<i>Convention for the Protection of Cultural Property in the Event of Armed Conflict</i> (also called <i>Hague Convention</i> )
05/12/1956, New Delhi	<i>Recommendation on International Principles Applicable to Archaeological Excavations</i>
14/11/1970, Paris	<i>Convention on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property</i> (also called <i>Paris Convention</i> )
16/11/1972, Paris	<i>Convention Concerning the Protection of the World Cultural and National Heritage</i> (also called <i>World Heritage Convention</i> )
16/11/1972, Paris	<i>Recommendation concerning the protection, at a national level, of the cultural and natural heritage</i>
24/06/1995	<i>UNIDROIT On Stolen or Illegally Exported Cultural Objects</i>
02/11/2001, Paris	<i>Convention on the Protection of the Underwater Cultural Heritage</i>
15/10/2013	<i>Charter on the Preservation of Digital Heritage</i>
17/10/2003, Paris	<i>Convention for Safeguarding Intangible Cultural Heritage.</i>
17/10/2003, Paris	<i>Declaration concerning the Intentional Destruction of Cultural Heritage</i>

Moreover, UNESCO has also led to the creation of a number of non-governmental and intergovernmental organizations. In this regard, the ‘International Council on Monuments

and Sites' (ICOMOS) was set up in 1965 as result of an international meeting of experts in Venice in 1964. The latter meeting also resulted in the 'International Charter for the Conservation and Restoration of Monuments and Sites' or 'The Venice Charter'. ICOMOS aims at "promoting the application of theory, methodology, and scientific techniques to the conservation of the architectural and archaeological heritage" (ICOMOS 2016). To realize this, ICOMOS drafts international charters that may act as guidelines and principles of good practice for both government and professional practitioners. An overview and the full texts of the charters adopted by ICOMOS can be found on the organization's website (<http://www.icomos.org/en/charters-and-texts>).

## 2.1.2 Council of Europe and recent interest of the European Union

At the European level, the main role concerning heritage policy is awarded to the Council of Europe (CoE). Founded in 1949, the CoE strives for "safeguarding and realising the ideals and principles which are their [the members'] common heritage and facilitating their economic and social progress" (Council of Europe 1949, art. 1). In this regard, multiple conventions on heritage and archaeology have been constituted by the CoE (Table 2-2). The most important convention for archaeology is the 'Convention for the Protection of the Archaeological Heritage (Revised)' or the 'Malta Convention' in short. This treaty, adopted in 1992, is a revision of the 'Convention of London' of 1969 to reflect the changes in archaeological practice and the pressure on the archaeological heritage caused by spatial development. The latter merely focussed on the avoidance of illicit excavations, the regulation of archaeological excavations, and the assurance of scientific publication (Council of Europe 1969). In addition to a better and more intensive integration of archaeology and spatial planning, the 'Malta Convention' also focuses on the funding for both research and publication, the raising of public awareness and the cooperation between European countries (Council of Europe 1992). Between 1993 and 2015, all Member States of the CoE except for Iceland, Montenegro and Luxemburg have signed the 'Malta Convention'. However, Luxemburg has signed the Convention in 1992, but has not yet ratified it. Furthermore, the Holy See as one of the six Observer States has also ratified the Convention. Once ratified, the Convention was converted into national law in approximately six months, except for Finland, Bulgaria and Hungary for whom it took 8 months, 21 months and 27 months respectively (Council of Europe 2016). The need for translation of the Convention into national or even regional (e.g., Belgium and Germany) legislation results in strong differences in the implementation (Kristiansen 2009). A major difference is the distinction between commercial and social market implementation, but also quality control and the social position of the archaeologist differ among the European countries (Kristiansen 2009, van den Dries 2015). In Section 2.2, a brief overview is given on the consequences of the 'Malta Convention' on the archaeological practice. During the years, the awareness of the social and economic value of cultural heritage, including archaeology, has arisen and this was in 2005 captured by the CoE in the 'Convention on the Value of Cultural Heritage for Society'. This 'Faro Convention' presents "heritage both as a resource for human development, the

enhancement of cultural diversity and the promotion of intercultural dialogue, and as part of an economic development model based on the principles of sustainable resource use” (Council of Europe 2005). This idea is recently also spread by the European Commission in a communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions ‘Towards an integrated approach to cultural heritage for Europe’ (European Commission 2014). This communication assesses and defines the value of cultural heritage for economic development, employment and social integration. This communication in fact answered the questions and necessities raised in the ‘Conclusions on cultural heritage as a strategic resource for a sustainable Europe’, which was the result of the Education, Youth, Culture and Sport Council meeting in May 2014 (Council of the European Union 2014). Even more recent, the European Parliament has also proclaimed its viewpoint on heritage in the framework of the policy of the European Union through the adoption of the ‘Resolution of 8 September 2015 towards an integrated approach to cultural heritage for Europe’ (European Parliament 2015). In this resolution, an integrated approach is preferred including not only cultural and historic aspects but also environmental, scientific, economic and social elements. Furthermore, the European funding possibilities for enhancement and preservation of cultural heritage are mentioned as well as the economic and strategic potential of cultural heritage (European Parliament 2015). For more information on the actions on Cultural Heritage of the European Union and in particular, the European Commission on Cultural reference is made the webpage of the latter (European Commission 2016a). For more information on the conventions and recommendations of the CoE, reference is made to Ballester (2001) and Pickard (2002) and the CoE’s webpage (<http://www.coe.int>).

Table 2-2 European conventions and recommendations on archaeology and heritage

Date, Place	Title	Date entry into force
19/12/1954, Paris	<i>European Cultural Convention</i>	05/05/1955
06/05/1969, London	<i>European Convention on the Protection of the Archaeological Heritage (also called Convention of London)</i>	20/11/1970
23/06/1985, Delphi	<i>European Convention on Offences relating to Cultural Property</i>	Insufficient ratifications
13/04/1989	<i>Recommendation of the Committee of Minister to Member States Concerning the Protection and Enhancement of the Archaeological Heritage in the Context of Town and Country Planning Operations</i>	
16/01/1992, Valletta	<i>Convention for the Protection of the Archaeological Heritage (Revised) (also called Convention of Valletta or Malta Convention)</i>	25/05/1995
27/10/2005, Faro	<i>Council of Europe Framework Convention on the Value of Cultural Heritage for Society (also called Convention of Faro)</i>	01/06/2011

### 2.1.3 Flanders at the local-level

Because of the federal state structure, policy on cultural heritage in Belgium is spread among the Regions and Communities. Immovable heritage and thus archaeological fieldwork falls within the jurisdiction of the Regions. A brief outline on the state structure and the division of the jurisdictions on heritage is found in Section 4.2.1. Both the international conventions adopted by UNESCO and the conventions at the European level played an important role in the creation of the Flemish heritage policy. Table 2-3 gives an overview of the dates when Belgium has ratified these higher-level legislations. The legislation and regulation has grown spontaneously at the Flemish level resulting in decrees and their implementing orders for each discipline (Anneels 2014, p. 17). To put an end to this fragmented legislation, a new ‘Immovable Heritage Decree’ (*Onroerenderfgoeddecreet*) has been adopted by the Flemish Parliament on 12 July 2013 (Vlaams Parlement 2013). This decree substitutes the ‘Law of 7 August 1931 on the conservation of monuments and landscaped’, the ‘Decree of 3 March 1976 to protect monuments and views of cities and villages’, the ‘Decree of 30 June 1993 on the protection of the archaeological patrimony’, the ‘Decree of 16 April 1996 on landscape conservation’ and their respective amendments (Vlaamse Regering 2013). Since the Immovable Heritage Decree forms the subject of a document-analysis in Chapter 4, reference is made to Section 4.2.1 and 4.4.1 for more information on its content.

Table 2-3 Date of Belgian ratification of the International and European conventions on archaeology and heritage

Title	Date of Ratification
<i>UNESCO Hague Convention of 1954</i>	14/05/1954
<i>European Cultural Convention of 1954</i>	11/05/1955
<i>European Convention of London of 1969</i>	02/12/1969
<i>UNESCO Paris Convention of 1970</i>	31/03/2009
<i>UNESCO World Heritage Convention of 1972</i>	24/07/1996
<i>European Convention on Offences relating to Cultural Property of 1985</i>	Not yet signed
<i>European Malta Convention of 1992</i>	8/10/2010
<i>UNIDROIT On Stolen or Illegally Exported Cultural Objects of 1995</i>	Not signed
<i>UNESCO Convention on the Protection of the Underwater Cultural Heritage of 2001</i>	05/08/2013
<i>UNESCO Convention for Safeguarding Intangible Cultural Heritage of 2003</i>	Acceptance on 24/03/2006
<i>European Convention of Faro of 2005</i>	Signed on 25/06/2012

## 2.2 CONSEQUENCES OF THE ‘MALTA CONVENTION’

### 2.2.1 An archaeological market: socialist or capitalist?

Since the concept of integrating archaeology and spatial planning was established by the ‘Malta Convention’ in 1992, it was implemented in various forms by the European countries who signed and later ratified the convention. Adhering to a changing economic climate in the 80s and 90s in Europe, some countries abandoned the idea that archaeology was the responsibility of the state (Demoule 2012). In that case, archaeology was considered a business that forms part of a competitive, free market. The variety of archaeological market organizations implemented since can roughly be divided into two categories: the capitalist and the socialist model (Kristiansen 2009). However, the European study ‘Discovering the Archaeologists of Europe 2014’ came to the conclusion that different models occur which cannot be simplified in these two categories (Aitchison et al. 2014, p. 48). The fact that these two categories are not strictly separated is also acknowledged by multiple authors (Willems and van de Dries 2007, van den Dries 2011, Willems 2014). Therefore, a 2D scheme is sometimes used as an alternative to the two categories. Two questions then allow categorizing the different implementations along the two axes. Willems and van den Dries (2007, p. 11) made use of the following two: “Does the state consider archaeological work to be a service, or does it not?” and “Does the state wish to control the quality of archaeological work or does it not?”. Similarly, Aitchison (2014, pp. 48–49) proposes to use the “funding source – public to private” and “the constitution of the delivery bodies – again public to private”. Generally, Scandinavian countries and France incline to the socialist model while in the other West-European countries archaeology is more commercially oriented (De Clercq et al. 2012, Demoule 2012).

Since the occurrence of capitalist archaeology in some countries, e.g., United Kingdom and the Netherlands, a debate is ongoing on the advantages and disadvantages of the various implementations. This discussion especially focuses on the quality of the archaeological research conducted under the rules of the free market, which is also called contract archaeology. Because taking part in this discussion is beyond the scope of this chapter, reference is made to Kristiansen (2009, 2016), van den Dries (2011), Demoule (2012) and Willems (2014). An overview of the Flemish archaeological practice in the light of the ‘Malta Convention’ is given in Section 4.2.3.

### 2.2.2 Data: is less more?

In addition to the rise of an archaeological market, either public or commercial, the ‘Malta Convention’ also had influence on the number of archaeological investigations and the amount of data gathered. Owing to the integrated approach, the number and scale of archaeological investigations has increased drastically since the ‘Malta Convention’ was translated into national legislations (de Boer 2009, De Clercq et al. 2012, Willems



2014). This increase is illustrated, among others, in Flanders by De Clercq et al. (2012, p. 33) who observed a rise of more than 450% in the permits issued in 2009 compared to 2004. Although they observed a limitation in the increase between 2007 and 2008 (De Clercq et al. 2012), the impact of the global economic crisis has not been as dramatic as in some other countries, such as Ireland and Russia (Schlanger and Aitchison 2010). However, the commercial archaeological sector is picking up (Aitchison 2015).

Stemming from the increasing number of archaeological investigations, the amount of archaeological data that is acquired nowadays is increasing significantly (Ford 2010, De Reu et al. 2013). However, the publication and accessibility of these data is not always as straightforward as it should be. The issues of knowledge-production and quality assurance of research conducted through contract archaeology are subject to debate, as mentioned in the previous section. This debate is ongoing between followers of the socialist versus the capitalist model, but also between academia and private archaeological enterprises (Ford 2010, Kristiansen 2016). An important role to assure the quality of the archaeological research is reserved for the state or local governments. Willems and van den Dries (2007, p. 4) clearly illustrate this:

“The 'archaeological market' is an artificial creation that exists because the state wants archaeological information and creates legislation that developers have to comply with in order to obtain permission for a project. The product bought from an archaeological contractor is of no inherent interest to a developer and moreover has to be delivered to, or at least shared with, the state, which is an additional motive for wanting to buy it as cheaply as possible. Thus, there is no economic impetus for quality of the archaeological product and, as Hinton and Jennings point out, the more competitive the market is, the more prices go down and the quality of the archaeological result is even more in danger.”

The issue of quality is also closely related to the issue of data accessibility and integration. While academics are publishing their research results in international journals, private organizations deliver their basic reports to the government and store them themselves (Ford 2010). Furthermore, the initially collected data on the field are similar. Academic research starts from a scientific question aiming to answer this at the end of the research. Preventive archaeology, mostly conducted by enterprises, does not have the initial research question, but attempt to collect as much data as possible to allow answering future research questions. However, more and more archaeological companies become conscious on this aspect. In this regard, links are established between universities and these private companies to allow for a more systematic study of the past (Ford 2010, De Clercq et al. 2012). Moreover, national governments are taking initiatives to disseminate the archaeological research reports to researchers, fellow companies and the public. In this regard, the 'E-Depot for Dutch Archaeology' (EDNA) and the British 'Archaeology Data Service' (ADS) are shining examples. On an international level, thus beyond national governments, 'OpenContext' and 'the Digital Archaeological Record' can be mentioned. For more information on these initiatives, reference is made to their respective webpages (ADS and University of York 2016, Alexandria Archive Institute

2016, DANS 2016, Digital Antiquity 2016), to Sheehan (2015) for a comparison of OpenContext and tDAR, and to Section 7.2 for more information on the data organization aspects of these initiatives. Furthermore, the 'Convention of Faro' will result in more widely dissemination of the research results to the public. In this regard, Wagtendonk (2009) noted that more and more local governments will spread their archaeological information via the Internet.

### 2.2.3 Digital techniques: hindrance or flexibility?

A third major consequence of the 'Malta Convention' is the emergence of new methods and techniques. This primarily results from the increasing scale of the investigations, but also the time pressure is playing an important role (De Reu et al. 2013). Furthermore, in commercial settings the pressure to limit costs will also influence the methods and techniques used. Although the improvements of techniques and the development of new methods can be seen as advantageous and progressive for the discipline (de Boer 2009, p. 283, Guermandi and Rossenback 2013, p. vii), this evolution also forms matter for discussion (Berggren and Hodder 2003, Thomas 2006). There are two main points in this debate: (i) the digitalization and (ii) the use of fixed methodologies. The first point relates to the above-mentioned discussion on knowledge-creation in contract archaeology. Since preventive archaeology is confronted with immense time pressure, the registration of the data on the field has to be conducted as rapid as possible. Furthermore, as no scientific research question is known in advance, the data are registered as exhaustively as possible. These two elements feed the critique that in contract archaeology record making becomes an end in itself (De Clercq et al. 2012, p. 52). The use of digital technologies to increase the efficiency of the registration phase also links to the second debate point. As noted by Thomas (2006, p. 30) and Berggren and Hodder (2003, p. 425), by using digital technologies the risk of systematization and senseless registration is run. The latter risk is also associated with the prevailing gap between fieldwork and interpretation (Lucas 2001, Thomas 2006, Huvila 2014a). This division takes so far that field archaeologists are viewed as "non-thinking 'shovels'" (Berggren and Hodder 2003, p. 424). Although the separation of registration and interpretation can be justified from economic point of view (Conolly and Lake 2006), the interpretation of archaeological data is largely influenced by the way in which the registration is done (Labrador 2012). Therefore, the interpretation should be a continuation of the registration, in best case conducted by the same person. Although digital technologies are thus questioned, they also are praised for their flexibility, interactivity and reflexivity (Conolly and Lake 2006, Huvila 2014b, Berggren et al. 2015).

## 2.3 ARCHAEOLOGICAL DATA

Archaeological data are inherently complex. As stated by Schloen (2001, p. 130) "archaeological data are *spatially organized, temporally sequenced, and highly variable*". Furthermore, data imperfection affects archaeological data on multiple levels, e.g.,

dating, geometry, etc. (Green 2008, Katsianis et al. 2008). Inherent to the nature of the discipline, multiple scale levels need to be considered during archaeological research and thus, mark archaeological data (Tsipidis et al. 2011). From the foregoing, five factors can be deduced that characterize archaeological data: (i) variety of objects, (ii) three-dimensional spatial, (iii) temporal dimension, (v) imperfection and (v) multiple scale levels. All of these five elements are interrelated as shown in Figure 2-1. In the remainder of this section, each of these five particularities is discussed in some more detail.

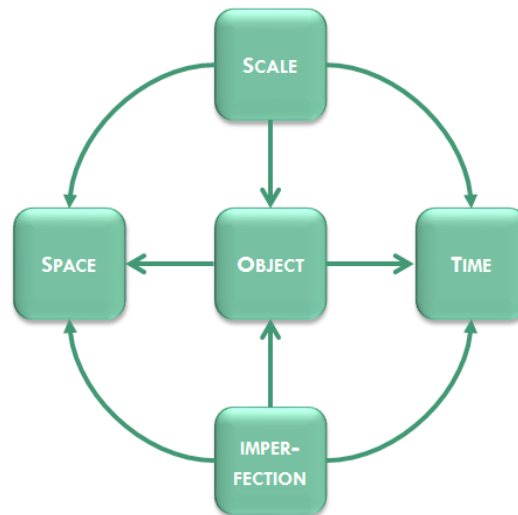


Figure 2-1 Five factors of archaeological data complexity

### 2.3.1 Wide variety of objects

The first factor needs little explanation, because it is clear from the aim and definition of the discipline. Archaeology is namely the study of human history through their material cultural or physical remains. Therefore, the whole range of objects that belongs to humans' culture has to be taken into consideration. This shows that the number of objects with which archaeological science has to deal is enormous, not to say endless (Schloen 2001, Madsen 2003).

### 2.3.2 Spatial data: the importance of the third dimension

Studying the activities and structure of humans at different scale levels, archaeology has similar objectives as geography (Conolly and Lake 2006, p. 12). This makes clear the importance of the spatial aspect for archaeology. The essence of the spatial dimension also appears from the application of maps at different scales during archaeological research. Since the 18<sup>th</sup> century, maps and ground plans are created and excavations are characterized by the accurate description of the finds' locations (Wheatley and Gillings 2002, Wagtendonk et al. 2009). Because archaeological excavations are vertically oriented, the third dimension is imperative to archaeology. Unlike in most

geographical applications, this third dimension relates to the depth instead of height and is thus oriented down wards.

In addition to the location of an archaeological artefact or feature, the 3D spatial aspect is also encountered in the object's shape and in the relationships between these archaeological objects themselves or between the archaeological object and environmental objects. First, archaeological research is conducted in 3D space and thus objects are found at a 3D spatial location. Second, these archaeological objects have, like all real-world objects, a 3D shape that can be used to study their morphology. Third, the spatial relationships of an archaeological object with other objects gives important information on the context in which the archaeological object was found. These three aspects of three-dimensionality, all play a substantial role in the analysis and interpretation process and therefore in the archaeological documentation. The shape of an object may for example give information on the functionality, whereas the depth or 3D spatial relationship between finds reveal important temporal indications.

The find location of artefacts and features is recorded during the fieldwork. While manual drawings and measurements are still used, spatial data are nowadays mostly acquired by means of land survey technologies, like total station and GPS. The use of these digital sensors has changed archaeological data recording in a quantitative way, since more data are gathered within a shorter period of time (De Reu et al. 2013; Stal et al. 2014). Furthermore, the use of these technologies allow for a better accuracy (Wheatley and Gillings 2002). Born digital data is obtained which comprises not only the two horizontal dimensions but also the third, vertical dimension. Consequently, nearly all spatial archaeological data are 3D. However, not all archaeological objects can be located in absolute terms. Small potsherds, for instance, may be acquired through a sieve sample. For these objects, indicating the exact position is impossible. Therefore, their relative location, thus their spatial relationship with other objects or features on the site, is stored (Schloen 2001).

Although spatial data are largely available in 3D, 2D representations still constitute the major deliverable (Wheatley and Gillings 2002, De Reu et al. 2013). Either the vertical or one of the two horizontal dimensions is in this case ignored. When the combination of both horizontal and vertical dimensions is of importance, a series of 2D maps are created (Figure 2-2), e.g., site plans for varying depths or a series of section drawings (Harris and Lock 1995). The same abstraction occurs when integrating the data in currently available GIS (Harris and Lock 1995, von Schwerin et al. 2013). Although in some cases the vertical dimension is stored as an attribute, this may cause problems when two objects share the same x and y coordinates but have different z values. This way, elaborate 3D analyses are impossible.

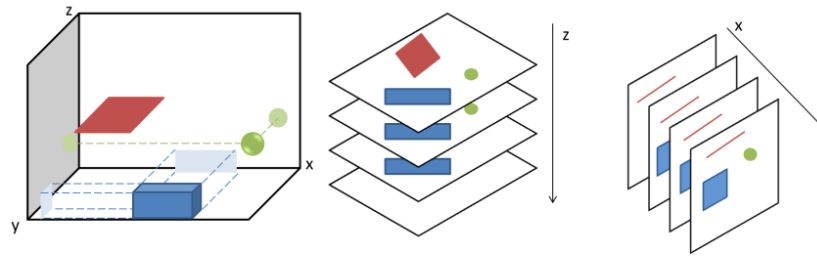


Figure 2-2 3D data as a series of 2D horizontal and 2D vertical maps

Nevertheless, by the use of 3D acquisition technologies as total station, GPS, and in particular laser scanning and digital photogrammetry an increase of 3D output products can be observed (Forte 2014; Stal et al. 2014). Digital elevation models, orthophotos and digital 3D models can be useful to support interpretations and geometric analysis, although the focus in the creation of these outcomes lays mainly on the visual representation (Forte 2014). Currently available 3D visualization tools mostly lack query or analysis capabilities (von Schwerin et al. 2013). Furthermore, linking thematic data to these 3D models or its components remains difficult and even their integration in a broader spatial or environmental context is sometimes difficult (von Schwerin et al. 2013). However, an increasing number of projects intends to combine both 3D models and spatial analyses as they appear in traditional 2D GIS. Giving a complete overview of this projects is beyond the scope of this chapter, but the *MayaArch3D* project (von Schwerin et al. 2013) and the *Çatalhöyük* project (Forte 2014) are two major projects that yield up positive results. A more thorough overview of 3D techniques and applications in archaeology is given by De Reu et al. (2013) and von Schwerin et al. (2013).

For a more theoretical overview of how the space concept is approached in archaeology, reference is made to Wheatley and Gillings (Wheatley and Gillings 2002, pp. 3–8, Conolly and Lake 2006, pp. 3–10).

### 2.3.3 Time: the fourth dimension<sup>1</sup>

Time is a core element in archaeological research, one of fundamental importance (Ramenofsky 1998). Besides the three spatial dimensions ( $x$ ,  $y$ ,  $z$ ), time makes up the fourth dimension archaeological data is concerned with. Although time is a complicated issue and causes frequently (conceptual) problems, the theoretical discussion about the temporal concepts has only recently arisen in the archaeological domain (Lucas 2005, p. 28). However, the number of discussions has multiplied the last three decades (Bailey 2007). Different directions occur in these discussions, but two main themes can be

<sup>1</sup> Modified from: DE ROO B., VAN DE WEGHE N., BOURGEOIS J., DE MAEYER P. 2014. The temporal dimension in a 4D archaeological data model: Applicability of the geoinformation standard. In U. ISIKDAG, ed. *Innovations in 3D Geo-Information Science, Lecture Notes in Geoinformation and Cartography*. Cham: Springer, pp. 33-55.

distinguished (Lucas 2005, Bailey 2007). The first theme is known in literature as ‘time perspectivism’ and deals with the measurement of temporal properties, and how resolution can influence archaeological questions and interpretations (Bailey 2007). The second direction concerns the consciousness of people in past societies about time (Lucas 2005, Bailey 2007). In this section, however, no attempt is made to contribute to these theoretical discussions, but rather to outline the temporal characteristics of archaeological data. For a detailed description and further references on these discussion themes, reference is made to specific review papers from Lucas (2005) and Bailey (2007).

Assigning phases to excavation objects or parts of sites is a fundamental task in archaeology (Koussoulakou and Stylianidis 1999, Cripps et al. 2004, Smedja 2009, Binding 2010). In this way, different objects are grouped together to give an idea of the story the site objects are telling (Cripps et al. 2004). Except from purely scientific dating techniques like dendrochronology and radiocarbon dating (Green 2008, Smedja 2009), in archaeology time is typically divided into stages and thus hypothesized as a discrete phenomenon (Smedja 2009). Mostly, the phasing is (partly) based on the stratigraphic sequence, thus, on the spatial distribution of the excavation objects in the 3D space (Cripps et al. 2004). Establishing a relative ordering is in most cases easier to perform and agree on than absolute dating (Binding 2010). However, Koussoulakou and Stylianidis (1999) have identified six items that can hamper appropriate phasing:

1. begin and end dates of a phase may be fuzzy;
2. limits of phases may be adjusted in the future due to changes in archaeological interpretations;
3. new phases can be found, where gaps existed;
4. new phases might appear within other phases;
5. an object assigned to phase A can later be reassigned to phase B;
6. it can be impossible to assign an object to a phase, at later time it can still be done.

Although Lucas (Lucas 2005, pp. 9–10) recognizes that phasing, or chronology in general, takes a considerable position in archaeological research, he is sceptical about the way in which it “affects the nature of archaeological interpretation”. He attributes this doubtful status of chronology to the uniform linear representation of time (Lucas 2005, p. 10). Green (2008, p. 38) summarizes the archaeologists’ conceptualizations of time in two key subjects, namely “the need to move beyond monolithic chronology and to take a more fluid stance which acknowledges multiple temporalities and non-linear models of change”.

Table 2-4 Temporal categories identified by Katsianis et al. (2008, p. 661)

Temporal categories	Description	Temporal concept	Examples
Excavation time	Recording time	Event	25/5/2003
Database time	Creation time in the information system	Event	#25-05-2003 00:00:00#
Stratigraphic time	Relative temporal distinction between deposits	Relative position	Layer X > (Is Later Than) Layer Y
Archaeological time	Cultural temporal categorization	Duration	Late Neolithic
Site phase time	Excavation chronological framework	Duration	Phase IV
Absolute time	Absolute chronology	Event	4700 BC +/- 150 years

All or some of these paths apply to different excavation objects depending on the interpretive objectives.

In addition to an assigned phase, other temporal values can be recorded for archaeological objects (Koussoulakou and Stylianidis 1999, Peuquet 2001, Katsianis et al. 2008). Analogous to other database recordings, a database time can be distinguished from valid or world time (Koussoulakou and Stylianidis 1999, Peuquet 2001, Green 2008, Katsianis et al. 2008). In this respect, Koussoulakou and Stylianidis (1999) define the time when an object is found as excavation time. Katsianis et al. (2008) distinguish excavation time and database time, where the latter is the time the recording is entered in the database (Table 2-4). Green (2008) suggests that valid time is the most important for archaeologist, while geographers sometimes pay more attention to database time. Peuquet's (2001) statement that "it is not always as simple as valid and database time" is illustrated by Katsianis et al. (2008) who deduct six potential temporal categories for archaeological finds (Table 2-4). In addition to site phase, database and excavation time, archaeological data may be characterized by an absolute time based on e.g., radiocarbon dating, archaeological time using cultural periods such as Middle Ages and stratigraphic time to indicate a temporal position (Table 2-4).

Furthermore, a temporal value for an archaeological finding cannot be read on the object itself, but is the result of analysis and interpretation (Smedja 2009, de Runz et al. 2010, Tshipidis et al. 2011). Consequently, archaeological dates are often subjective, uncertain and imprecise (Green 2008, Katsianis et al. 2008, de Runz et al. 2010). This uncertainty is inherently linked to archaeological data in general (Katsianis et al. 2008, Cripps 2012, Section 2.3.4). An anteriority index is proposed by de Runz et al. (2010) to indicate the reliability associated to a specific date. Holmen and Ore (2010) presented an event-oriented system based on the CIDOC conceptual model that enables the detection of dating conflicts, the improvement of start and end dates and the display of chronologies.

More than a decade ago, Wheatley and Gillings (2002) concluded their book on the archaeological applications of GIS with some future research themes including temporal GIS. They emphasized the beginning interest and consciousness of archaeologists to incorporate the temporal dimension and its different conceptualizations in GIS (Wheatley and Gillings 2002, p. 242). In 2011, Green (2008, p. 102) concluded that “there has been significant—if to date niche—interest in TGIS from archaeologists”. He mentioned the research from Castleford, Daly, Lock and Harris as the most important ones, but noticed the theoretical ascendancy (Green 2008, pp. 92–103). In the remainder of this paragraph, the Harris matrix, which is a main temporal analysis tool that combines as well the third spatial dimension and forms part of the research conducted in Chapter 5, and the research of Green, as it is a very recent contribution to archaeological TGIS are shortly introduced.

Harris started from the geologic stratigraphic laws, such as the law of superposition, and re-expressed them in terms of archaeological applications (Harris 1989). In the matrix, three relationships are possible: (i) unlinked or no physical relationship (ii) later/earlier than or superposition and (iii) equivalence (Harris 1989, p. 36). Each of these relationships are graphically represented by single vertical (for the superposition) or double horizontal lines (for the equivalence) between their constituting elements, represented as boxes (Harris 1989, p. 36). Figure 2-3 shows a highly simplified example of a Harris matrix, where elements 1 and 3 are equivalent and for instance, element 4 is later than element 5. Since the temporal dimension is intrinsically related to the vertical dimension, the Harris matrix can be seen as a tool for spatio-temporal representation of a site and its elements. Green (2008) notes the multilineal character of the Harris matrix. However, the Harris matrix is criticized mainly because it only shows the temporality of the production and not the duration or temporality of the creation or the use (Lucas 2005, pp. 39–40).

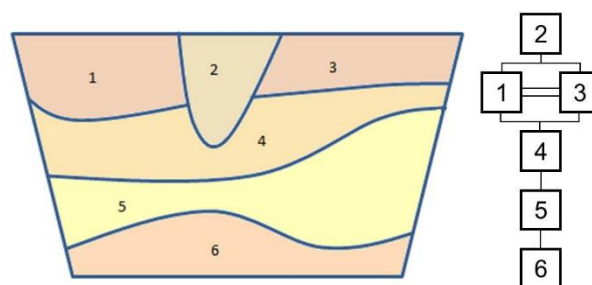


Figure 2-3 Example of a Harris Matrix

One of the most recent studies on archaeological temporal GIS is the research of Green (2008), which endeavoured to overcome the conventional neglect of time in GIS. For a detailed review of other archaeological efforts in TGIS research, reference is made to Green (2008, pp. 92–103). The aim of Green’s research is the creation of a fuzzy, temporal GIS (TGIS) that is specifically tailored to archaeological data (2008). He made



the condition to the system “to be flexible and powerful”, and to “remain within the software horizons of GIS-literate archaeologists” (Green 2008, p. 2). The emphasis was laid on handling the temporal uncertainty; input data consists of the minimum and maximum possible time (Green 2008). Green (2008) used different methods for the calculation of probabilities (standard percentage, normal distribution, *terminus post quem* and oxCal) in order to analyse uncertainties. The resulting fuzzy TGIS is an ArcGIS implementation, where the temporal dimension is stored as an attribute, thus resulting in a 2.5D solution (Green 2008). Both elements, the choice for ArcGIS and 2.5D, cause some limitations of the system, such as the inability to deal with stratigraphy and duration, and the lack of an animation tool (Green 2008, pp. 142–144). Anyway, it is difficult to call the result a ‘new fuzzy TGIS’, since it only encompasses some functionalities implemented in and available as a template in ESRI’s commercial ArcGIS.

### 2.3.4 Data imperfection: uncertain, incomplete and subjective data

Archaeological data are also inherently linked with imperfections. Imperfection is not only related to the temporal dimension as described above (Green 2008, Holmen and Ore 2010), but also affects space, scale, functionality, the concepts and attributes used, etc. (Katsianis et al. 2008, de Runz et al. 2010). Concerning the issue of data imperfection, several terms occur, for which various definitions can be found. Starting from general definitions, Table 2-5 indicates that most of the terms are closely related. However, some small differences in nuance can be denoted. Although ‘uncertainty’ is found in literature as a generic term, according to Smets (1997) and the definitions in Table 2-5, using ‘imperfection’ as an umbrella term is more appropriate.

Table 2-5 Terms with regard to data imperfection

Term	Definition
Imperfection	Not certain, precise <sup>a</sup> and complete <sup>b</sup>
Uncertainty	Arises from the state of knowledge of an agent which does not allow to decide about the truth of a statement <sup>a</sup>
Incompleteness	Arises from the absence of a value, is a lack of relevant information <sup>a, b</sup>
Imprecision	Arises from the existence of some form of vagueness or a missing value <sup>a</sup> , from a value which cannot be measured with suitable precision or from the lack of granularity <sup>b</sup>
Vagueness	Arises from the poor definition <sup>a,c</sup> , or the existence of multiple meanings <sup>a</sup>
Ambiguity	The confusion among concepts which have the same name, but more than one definition <sup>a,d</sup>

Sources: <sup>a</sup>(Smets 1997), <sup>b</sup>(Parsons 1996), <sup>c</sup>(Fisher 2005), <sup>d</sup>(Fisher 2000)

From the incompleteness of the data, uncertainty may arise for the functionality. For instance, finding only a small part of a pottery may result in uncertainty about its function, either culinary or ceremonial. The uncertainty of archaeological interpretations, in fact,

originates from the nature of archaeological research because the observations and findings constitute always an incomplete set of information. Barceló (2016, p. 105) stated that an archaeological interpretation is mostly an inverse problem, which “entails determining unknown causes based on observations of their effects’. The specific form, location and other observable attributes of an object are used to determine why this object was produced, used and distributed (Barceló 2016). However, these observations and especially the knowledge of the relationships between the objects always remain incomplete. In this regard and from the definitions given in Table 2-5, it can be concluded that uncertainty is connected with subjectivity. Besides incompleteness, which means a part or value is missing, imprecision may be at the basis of imperfect and more specifically uncertain data in archaeology (Smets 1997). From imprecision vagueness may occur. For instance, temporal information identified with a precision of a year results in vagueness on a smaller temporal resolution. In this regard, imprecision is related to granularity, as indicated in Table 2-5, and thus, to the multiplicity of scales that occur in archaeology. The terms given in Table 2-5 are also related to multivocality. This is the approach used in archaeology to stimulate the simultaneous expression of multiple and different interpretations on a given subject and to encourage a debate on the plausibility of each of these interpretations. Moreover, all the terms in Table 2-5 are related to subjectivity and interpretation (De Runz et al. 2010; Katsianis et al. 2008). In this regard, Crescioli et al. (2001) noted that the use of predefined categories and other software capabilities may introduce a false sense of objectivity, data perfection and certainty. To express the different imperfections in database, often interrogation marks are added to the end of a value. Because processing such values is impracticable in databases and intricate for programmers, it is a better idea to use one or more extra attributes to indicate the reliability of the data (Crescioli et al. 2001, de Runz et al. 2010). To conclude, data imperfection and uncertainty will always prevail. Therefore, at a certain level, data should be considered as perfect for a given purpose, in a particular time, etc., although this is not the case. Nevertheless, future users of the data should be able to recover the levels of imperfection contained in the data.

### 2.3.5 Multiple scale levels

Given the importance of the spatial dimension, archaeological research takes place at different scale levels. The most common classification for the spatial scales archaeological research is conducted at it this of Clarke (1977, pp. 11–15). This classification consists of three levels: the micro level, the meso or semi-micro level and the macro level. The micro level concentrates on the structures within a site and is therefore, also called the intrastucture level. A structure is a small testimony of human activity, such as a grave or a room. The complete site and its structures are subject of the meso level, also called the intrasite level. At this level, often the relationships between these structures and findings are studied and are, like site histories, attempted to reconstruct. Finally, the macro level focuses on multiple sites and their relationships. Therefore, this level is also named the intersite level. From micro to macro level, the influence of personal and cultural aspects

decreases while this of economic and geographic elements increases (Deweirdt 2010, p. 11). However, these three levels can further be refined according to the subject under study. The latter refers to another aspect of scale in archaeology, namely the object scale or the scale of a discrete object (O'Brien and Lyman 2000). Scales both larger and smaller than discrete objects occur in archaeology. The first refers to groups of artefacts, e.g., a building's shape that consists of a set of postholes, while the latter deals with scales that are smaller than the discrete object (O'Brien and Lyman 2000). Because the previous description is rather conceptual, the concept of scale related to objects can be summarized as the fact that found objects on a low level are part of or are used to reconstruct higher-level objects. In this regard, postholes can be used to reconstruct a building and a found potsherd will be part of a pot.

The scale issue not only concerns space and objects, but also influences the temporal dimension. In this regard, Bailey (2007, p. 201) reports the mixed use of the term 'time scale' for two different concepts. First, time scale may refer to the size of the phenomenon under study in temporal terms (Bailey 2007). Here, small-scale refers to a limited period of time. Second, time scale may be used for describing the measurement resolution. Here, long-term phenomena require a larger time scale than short-term (Bailey 2007). Bailey therefore argues to use time span and time resolution for the two concepts respectively. In this study, if referred to time scale, the second concept (i.e., resolution) is meant; else, this will be clear from the context.

## 2.4 ARCHAEOLOGICAL RESOURCES

In Section 2.2.2 it was already pointed out that the amount of archaeological data gathered are increasing because of the integrated approach of spatial planning and archaeology. Especially in this preventive archaeology, as much data are collected as possible since it not originates from an initial research question. To document the variety of archaeological objects, to capture the importance of the spatial dimension and to grasp the archaeological data complexity (Section 2.3), a diverse set of techniques is used in archaeology. The obtained archaeological data and the products delivered can roughly be categorized in spatial data resources and attribute data resources. However, a division could also be based on the way of capturing the data: written documentation, visual documentation and material documentation or finds.

### 2.4.1 Spatial data resources

During the archaeological fieldwork, the location of artefacts, contexts and other features is recorded through a wide range of techniques. Although using measuring tape and stepping of the terrain are still used, these spatial data are acquired more and more through land survey technologies like GPS and total station. The number of resources resulting from this diverse set of spatial data recording techniques is however limited. Wheatley and Gillings (2002) summarized these into four spatial data sources: survey

data, co-ordinate lists, maps and images (p.60). However, the category 'survey data' can be seen as raw data that will form the basis for the co-ordinate lists and in most cases also for the maps.

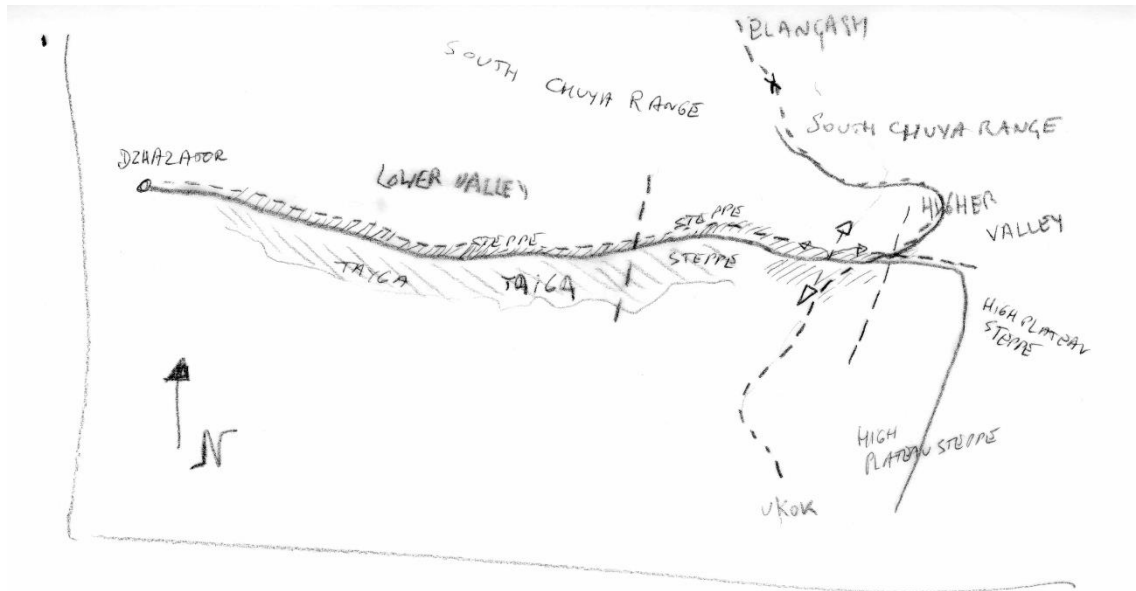


Figure 2-4 Example of a sketch of the site location (Dept. of Archaeology, Ghent University, Altay Mountains Survey Project)

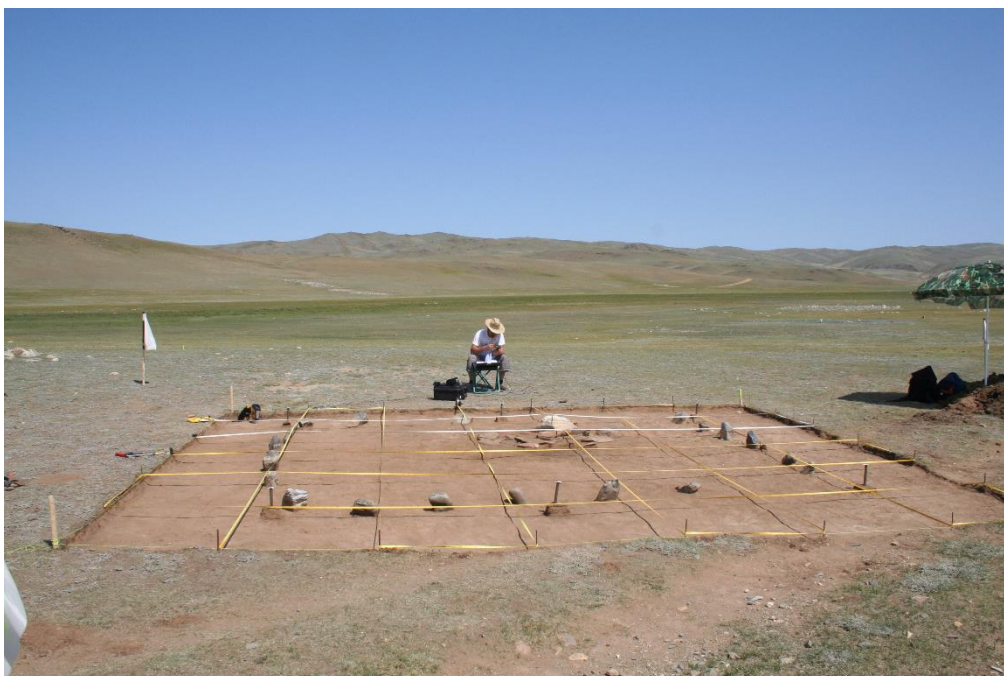


Figure 2-5 Grid marked off at an excavation in the Altay Mountains (Dept. of Archaeology, Ghent University, Altay Mountains Survey Project)

Although digital spatial acquisition techniques are widespread, spatial data are sometimes still registered in analogue way. To provide a clear overview of the site location and its characteristics mostly a sketch is made at the start of the fieldwork. Figure 2-4 shows an example of such a sketched map. In Figure 2-5, a grid was marked off to allow indicating the locations of finds and facilitating the analogue drawing. An example of such a drawing is given in Figure 2-6. Similarly, drawings are made of sections giving an indication of the vertical aspect and including colour indications for the stratigraphic layers (Figure 2-7). In substitution for or rather in addition to these analogue drawings, land survey techniques are used to create digital plans and maps (Figure 2-8 and Figure 2-9).

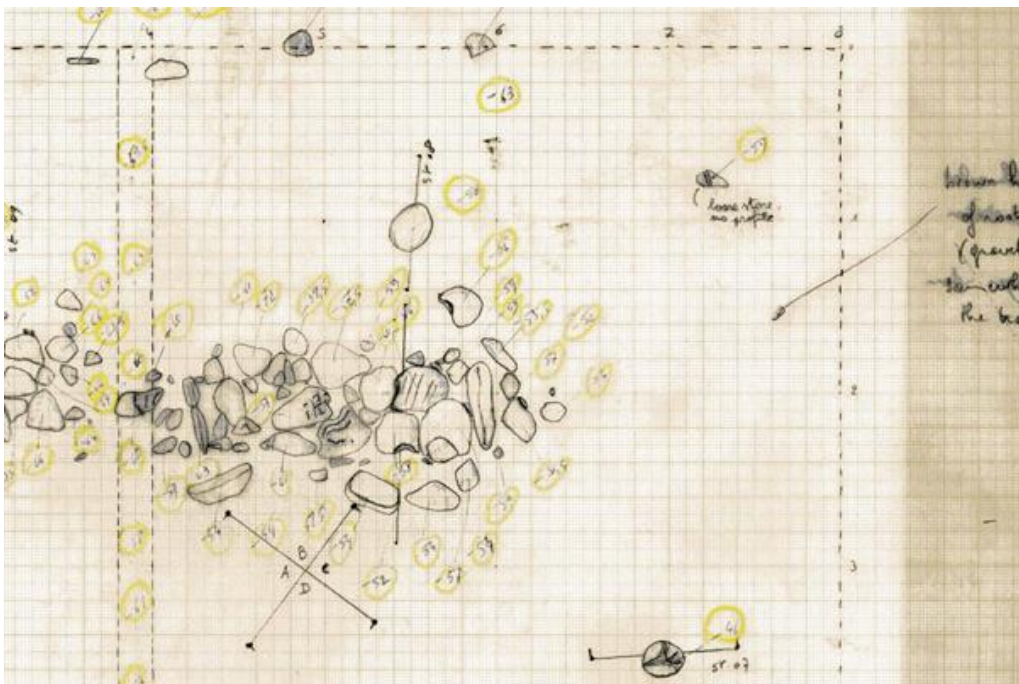


Figure 2-6 Example of an analogue excavation plan (Dept. of Archaeology, Ghent University, Altay Mountains Survey Project)

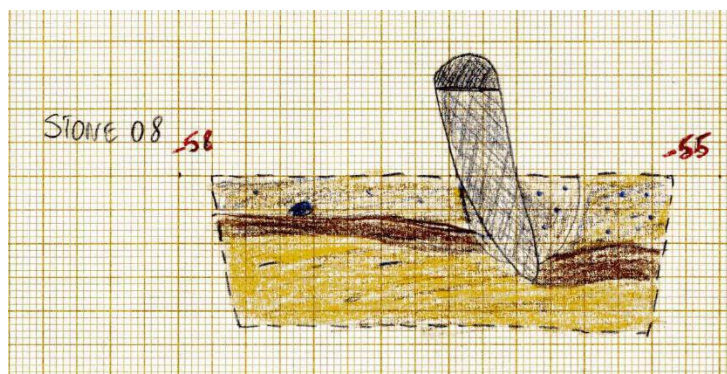


Figure 2-7 Example of a scanned section drawing (Dept. of Archaeology, Ghent University, Altay Mountains Survey Project)

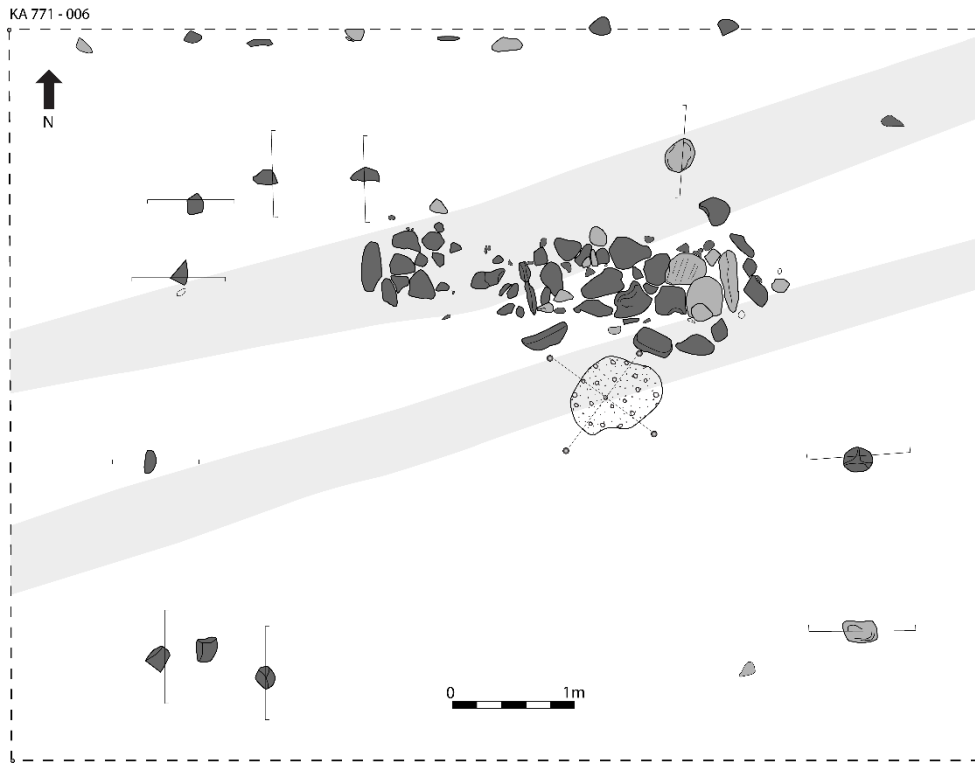


Figure 2-8 Example of a digital map of a dwelling with location indication of the vertical sections (Dept. of Archaeology, Ghent University, Altay Mountains Survey Project)

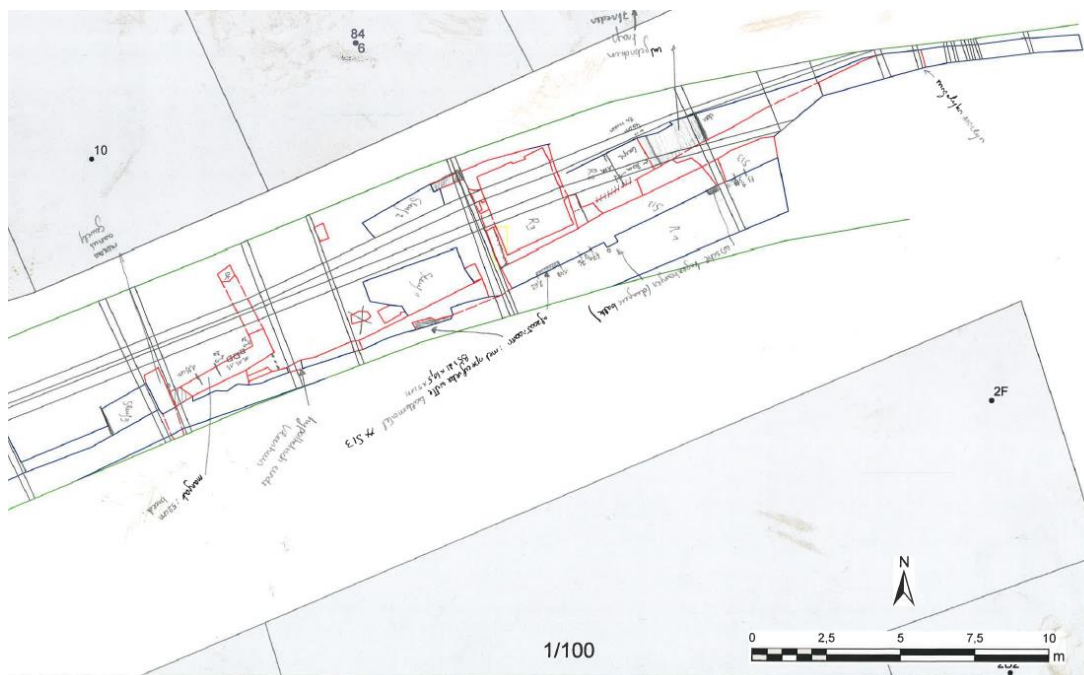


Figure 2-9 Example of a digital plan of an urban excavation (Ghent Archaeological Service)

In addition to survey data, the consequent coordinate lists and maps, images are an important source of archaeological spatial data. These images include not only aerial and terrestrial photographs but also images (or rasters) resulting from geophysical

surveys like GPR (Wheatley and Gillings 2002). Both aerial and terrestrial photographs can be used for photo modelling to create orthophotos (Figure 2-10) and 3D models (Figure 2-11) via the Structure from Motion (SfM) and Multi-View Stereo (MVS) algorithm. For more information on the use of photo modelling in archaeology and cultural heritage reference is made to Plets et al. (2012), von Schwerin et al. (2013), Lonneville et al. (2014) and Stal et al. (2014).



Figure 2-10 Example of an orthophoto (Dept. of Archaeology, Ghent University, Altay Mountains Survey Project)



Figure 2-11 Example of a 3D model created from terrestrial and aerial photographs (Dept. of Archaeology, Ghent University, Altay Mountains Survey Project)

### 2.4.2 Attribute data resources

In addition to spatial data that are acquired during the fieldwork, also non-spatial or attribute data are obtained. These attribute data describe the objects and may include information about the shape, colour, material, cultural characteristics, relationships to other objects, state of conservation, volume, etc. These are only a few examples and thus, form not an exhaustive list. Although a large part of the attribute data can be observed on the object, another important part is the result of interpretation (e.g., function) and further analysis (e.g., C14-dating). The most important resource of attribute data created during the fieldwork are the prospection or excavation record sheets or archives. This registration may be done either analogue or digitally in lists form (Figure 2-12) or digitally in a specially developed registration application.

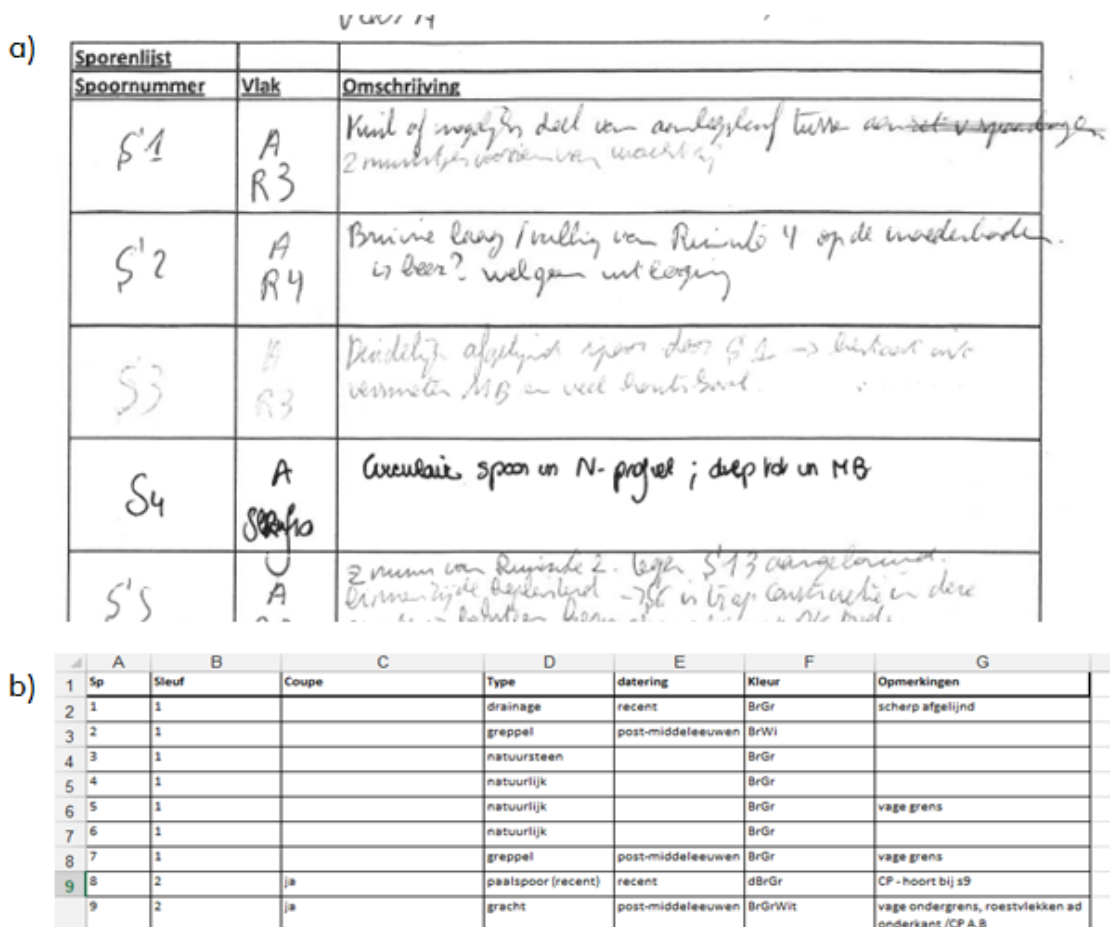


Figure 2-12 Example of a) analogue and b) digital lists used for field registration (a: Ghent Archaeological Service, b: GATE Archaeology)

Furthermore, an excavation journal is kept to describe the daily fieldwork process including the methods followed, the circumstances encountered, the actions taken, finds collected and interpretations done (Figure 2-13). All these data together with the spatial information acquired during the fieldwork form the basis for the final report. However, this also includes results of post-excavation analyses and interpretation. In such a report



not only the results are described, but also the methods used on the field are given and the results and interpretations made are justified and described. An example of such a report is accessible online via the following links: <http://www.solva.be/projectfiles/SOLVAArcheologieRapport20.pdf> for an example in Dutch, <http://www.wessexarch.co.uk/reports> for examples in English.

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▪ Tuesday 19th, July
Very sunny, not much wind

KA-771-016

-drawing of part of the EW-section of stone platform

-deepening of the NW-quadrant of stone platform

!! A pit-like structure appears (which has not been seen in the WS-quadrant)

-sampling for OSL of stones 04 and 05 of str. 016, for details, see field book of OSL-datings

-stone platform: samples 15 and 16 (charcoal)

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Figure 2-13 Extract of an excavation diary (Dept. of Archaeology, Ghent University, Altay Mountains Survey Project)

## 2.5 SPATIAL DATA INFRASTRUCTURES

Spatial Data Infrastructures (SDIs) have been arisen in the 1990s in consequence of the emergence of digital geographic information thanks to the development of information technology (Tóth et al. 2012, Coetzee and Wolff-Piggott 2015). Different definitions for SDI exist in literature, each focusing on another specific aspect. However, Dessers (2013) distinguished two main categories: definitions focusing on the components and definitions centering on the objectives. The Global Spatial Data Infrastructure (GSDI) Association uses the definition given by the Federal Geographic Data Committee in its Executive Order 12906:

“The technology, policies, standards, and human resources necessary to acquire, process, store, distribute, and improve utilization of geospatial data” (Federal Geographic Data Committee 1994, Nebert 2012)

In this definition, both the different components of an SDI and the general objectives are described. The components of an SDI not only include the spatial information or data, but also metadata, services, geodatabases<sup>2</sup> and other technological features, regulations, education and other organizational elements. However, as pointed out by Dessers (2013), more important than giving an exhaustive list of the constituting components, the definitions intend to indicate that “the individual components will not give SDIs their

<sup>2</sup> Although small differences in nuance exist between geodatabase and spatial database, throughout this thesis both terms are used as synonyms for each other.

functionality but some meaningful combination of them” (p. 31). An important component of SDIs, also given in the definition above, is human resources or people. People are key to SDIs as they supply the data but also use these and provide added value in-between (Williamson et al. 2003, p. 27). Therefore, Rajabifard et al. (2002) combined these two SDI components in one of their two categories. The second category included policies, standards and access networks and is summarized as ‘technological components’. By using these two categories, they illustrated that the second category is liable to the rapid technological changes and developments and is thus very dynamic. The relation between both categories and the influence of dynamic behaviour is shown in Figure 2-14.

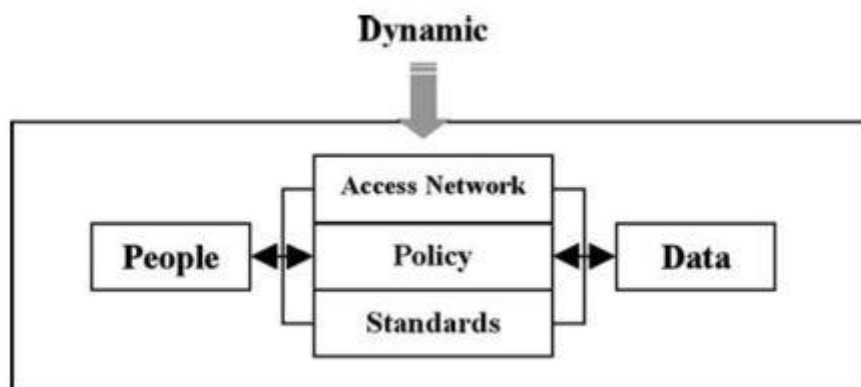


Figure 2-14 Nature and relations between SDI components according to Rajabifard et al. (2002)

In general the objective of an SDI can be summarized to facilitating an efficient and effective use, management and production of spatial data (Rajabifard et al. 2002, Williamson et al. 2003, 2006, Nebert 2012, Tóth et al. 2012). The realization of such frameworks to access and share spatial data are taking place on different levels. Although strictly top-down government-funded initiatives in the beginning, nowadays SDIs are more and more decentralized and considered bottom-up (Coetzee and Wolff-Piggott 2015). Furthermore, SDIs are evolved from the mapping domain towards a much broader scope of underpinning economic, social and environmental decisions (Williamson et al. 2006). However, implementing functional SDIs is not self-evident. The cooperation between different parties (private, public and academic sectors), the statement of a vision and the requirement of capacity building are only a few of the issues that need to be considered and can undermine the SDI’s strengths and success (Williamson et al. 2006).

Another important element to realize the full potential of SDIs is metadata. Forming a component of a SDI, these ‘data about the data’ provide information about the content, extent, quality, creation and administration of a data set (Shaw et al. 2009, ISO 2014). Metadata allow people to search for data and assess their applicability and reliability. There exist multiple standards and guidelines on the elements required for making up metadata. In general, the Dublin Core Metadata Element Set provides a simple set of

fifteen properties needed to describe resources (DCMI 2012). The Dublin Core metadata element set became ISO standard 15836 for cross-domain resource descriptions. With respect to geographical information, the ISO standard 19115 defines more than 400 metadata elements. Because for each geographic data set a minimum amount of metadata is required, the ISO 19115 standard also specifies a set of 22 core metadata elements, of which seven are mandatory, e.g., the title and contact point (ISO 2014). The INSPIRE metadata schema is compliant with ISO 19115. However, full conformance to ISO 19115 requires more metadata elements than needed in the INSPIRE schema and on the other hand, conformance to the ISO 19115 Core elements does require additional elements to be conformant with the INSPIRE metadata schema (Craglia 2013). For an overview of the required elements and the difference between the metadata schemas of ISO 19115 and INSPIRE reference is made to the 'technical guidelines' of the 'INSPIRE metadata implementation rules' (Craglia 2013). With regard to archaeology, the UK's Archaeological Data Service (ADS) makes use of Dublin Core metadata element set to describe the deposited data sets. Furthermore, several thesauri or controlled vocabularies exist to assist in describing the content of the data through keywords (Shaw et al. 2009). The Getty Art & Architecture Thesaurus (The Getty Research Institute 2016), the FISH Archaeological Objects Thesaurus (FISH 2016) and Onroerend Erfgoed Thesaurus of dating (Agentschap Onroerend Erfgoed 2016) are only a few examples. However, creating and using metadata is still challenging. From the data supplier perspective, metadata are often disregarded because at the time of acquiring the data the future reuse is not yet focussed on. Moreover, if metadata are registered, these may often be incomplete or miss necessary elements. From the data consumer point of view, metadata are often not read carefully for instance because of time pressure.

For an overview and discussion of the different definitions of SDI that occur in literature, reference is made to Dessers (2013, p.27-30, 227-235) and Chan et al. (2001). A review of the focal points of SDI research in the last two decades is given by Coetzee and Wolff-Piggott (2015). Finally, the GSDI Spatial Data Infrastructure Cookbook provides extensive and comprehensive background information on how to implement and evaluate existing SDI components (Nebert 2012).

### 2.5.1 Initiatives

The development of a SDI can take place at different scale-levels from the local over regional and national to supranational and global scale. The number of SDI initiatives that are currently operating or under development is estimated by Longley et al. (2011) at more than 150. In what follows, two well-recognized SDI initiatives are briefly introduced which both take place at a large scale: the Global Spatial Data Infrastructure (GSDI) and Infrastructure for Spatial Information in the European Community (INSPIRE). Furthermore, an example of an SDI initiative at the regional level is given, the Geographic Data Infrastructure Flanders (GDI-Vlaanderen).

### *2.5.1.1 GSDI*

At the global level, the Global Spatial Data Infrastructure (GSDI) Association, founded in 2004, does not aim to set up a global data infrastructure. The purpose of the GSDI Association is rather to promote the research on SDIs (Global Spatial Data Infrastructure Association 2015). Furthermore, this organization is participating in and organizing network events and activities concerning capacity building (Global Spatial Data Infrastructure Association 2015). Finally, they have written and are maintaining the 'GSDI Spatial Data Infrastructure Cookbook' to provide background information on SDIs and share examples and implementations of SDI components (Nebert 2012).

### *2.5.1.2 Inspire*

At the European level, i.e. a supranational scale, the European Parliament and the Council enacted Directive 2007/2/EC that establishes an Infrastructure for Spatial Information in the European Community (INSPIRE) in 2007 (European Commission 2016b). This directive is gradually becoming into force and must be fully implemented by 2019 (European Commission 2016c). The aim of the INSPIRE directive is to create a SDI at the level of the European Union that facilitates policy-making by the access to and sharing of spatial information among public parties (European Commission 2016c). The focus is mainly on environmental spatial information and information necessary for environmental applications. This topical focus is specified in 34 spatial data themes, which are classified in three groups, called annexes (European Commission 2016b). The classification is used to represent different actions described in the directive and is linked to different time schedules (European Commission 2016d). Administrative units, land cover and energy resources are examples for Annex I, II and III respectively. A full list of the themes is given in Table 2-6, a detailed description of each theme can be found on the INSPIRE website (<http://inspire.ec.europa.eu/>).

Concerning archaeology, the data theme 'Protected sites' of Annex I is noteworthy. In the context of INSPIRE, a protected site is "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (European Commission 2016d). Although the directive is clear to share information on archaeological and heritage sites that are legally protected, it is unclear if information on sites that are not legally protected also needs to be published. In this regard, McKeague et al. (2012) indicated that the legally protected sites only represent a minor part of the archaeological heritage, which is under pressure in spite of the integrated planning approach. Therefore, a more "holistic" interpretation of the 'Protect sites' data theme should be adopted (McKeague et al. 2012).

Table 2-6 The 34 data themes of the INSPIRE directive (European Commission 2016d)

Annex I	Annex II	Annex III
Addresses	Elevation	Agricultural and aquaculture facilities
Administrative units	Geology	Area management/restriction/regulation zones & reporting
Cadastral parcels	Land cover	Atmospheric conditions
Coordinate reference systems	Orthoimagery	Bio-geographical regions
Geographical grid systems		Buildings
Geographical names		Energy resources
Hydrography		Environmental monitoring facilities
Protected sites		Habitats and biotopes
Transport networks		Human health and safety
		Land use
		Meteorological geographical features
		Mineral resources
		Oceanographic geographical features
		Population distribution and demography
		Production and industrial facilities
		Sea regions
		Soil
		Species distribution
		Statistical units
		Utility and governmental services

### 2.5.1.3 GDI-Vlaanderen

In 2009, the Flemish Government has ratified the decree on the Geographic Data Infrastructure (GDI) Flanders to transpose the European INSPIRE directive. It is the intention of the Flemish Government to provide governmental organizations at different levels (Flemish, Belgian and European) and public with geographic information that is of public interest (Flemish Government 2016). A collaboration agreement is set up in which all Flemish governmental organizations are united. A GDI plan was created which is a strategic policy document for the Flemish Government and acts as a guide for the participants of the collaboration agreement. This plan includes three strategic objects: (i) developing digital services for citizens, companies and organizations, (ii) developing an efficient intragovernmental service, and (iii) developing an efficient intergovernmental service (Flemish Government 2011). Based on the strategic objectives operational objectives are defined in the implementation plans (Flemish Government 2016). The development of a generic platform to share, manage and access information on the public domain and the digitalization of the process to apply for a building permit are only two examples of these operational objectives (Flemish Government 2011). To make the data available 'Geopunt', the Flemish geoportal, has been set up in accordance with the INSPIRE directive (Vlaamse Overheid 2016a).

With regard to archaeological information, three data sets can be accessed on Geopunt: (i) inventory of archaeological heritage, (ii) decreed archaeological zones and (iii) areas where no archaeology is expected (Vlaamse Overheid 2016b). The first data set is situated in the INSPIRE data theme 'land cover', the second in the 'Protected sites' theme and the third in the 'Area management/restriction/regulation zones & reporting' theme.

#### *2.5.1.4 Archaeology*

In addition to the European INSPIRE and national SDI initiatives, several initiatives exist which focus on a SDI specifically designed for archaeological information. Such SDIs can "unlock the rich potential of" archaeological data sets, but their use and development are currently still challenging (McKeague et al. 2012, p. 49). This is because of the technological, organizational and semantical barriers as well as the wide range of parties to be involved in such infrastructures (McKeague et al. 2012). Although it is not the intention to provide an exhaustive list of SDI initiatives that center on archaeological information, some projects are worth mentioning. The 'Spatial Heritage & Archaeological Research Environment I.T.' (SHARE IT) project aimed to develop a strategy for the exchange of landscape archaeology data sets using ICT (Shaw et al. 2009). In the project 'Archaeolandscapes Europe', ArCLand in short, the intention was to create a network to support the use of remote sensing data of the European archaeological heritage via a SDI (Posluschny and Musson 2013). In Australia, the 'Federated Archaeological Information Management Systems' (FAIMS) project aims to create and exchange compatible archaeological data sets via a set of modular tools that focus on data production, archiving and portability (Ross et al. 2013). Furthermore, some online archive and publication initiatives for archaeological data have been developed or are under construction, e.g., Open Context (Alexandria Archive Institute 2016), the Digital Archaeological Record (Digital Antiquity 2016), the UK Archaeology Data Service (ADS) (ADS and University of York 2016), the Dutch e-Deport for Archaeology (EDNA) (DANS 2016), the Swedish Digital Archaeological Workflow (Smith 2015).

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# 3

## A SURVEY ON THE USE OF GIS AND DATA STANDARDS IN ARCHAEOLOGY

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Modified from: DE ROO B., BOURGEOIS J., DE MAEYER P. 2013. A survey on the use of GIS and data standards in archaeology. *International Journal of Heritage in the Digital Era*, 2(4), pp. 491–507.

### ABSTRACT

Geographical Information Systems (GIS) have been used in various archaeological projects. However, the archaeological data particularities (three-dimensionality, temporal dimension, imperfection) hamper the exhaustive application. A 3D or 4D (3D + time) GIS that is specifically tailored to archaeology may accordingly be beneficial. To develop such a system, a human-centred design, which considers the needs and viewpoints of the users in a four stage, iterative design cycle can be used. This chapter focusses on the first two stages, the context of use description and the specification of the user requirements, by means of a user survey and so, does not address the proper design. The survey results clarify the widespread use of GIS in archaeology and the relatively high rate of expertise. Users require storing both raw and interpreted data, handling multiple temporal categories and imperfection. Furthermore, the use of data standards and metadata is limited and has to be encouraged.

## 3.1 INTRODUCTION

The use of Geographical Information Systems (GIS) has been grown in a large number of domains. In various archaeological projects as well GIS have been employed. This is proved by the considerable amount of scientific papers (e.g., Al-Hanbali et al. 2006; Losier et al. 2007; Katsianis et al. 2008) and some basic works on the principles of GIS in archaeology (Wheatley and Gillings 2002; Conolly and Lake 2006). Furthermore, a wide interest is shown in international conferences such as Computer Applications and Quantitative Methods in Archaeology (caaconference.org). However, the use of GIS is hampered by the inability of currently available software packages to handle the complexity of archaeological data, namely three-dimensionality (3D), temporality and uncertainty (Lucas 2005; Losier et al. 2007; Green 2008; McKeague et al. 2012). Therefore, a 4D (i.e. 3D and time) GIS tailored to archaeological data may hold many benefits for archaeological research. Several authors indicate in this context possibilities for new analyses and better interpretations, which arise from the ability to simultaneously handle the three dimensions (Losier et al. 2007; Green 2008; Tsipidis et al. 2011).

Due to economic reasons, the development of GIS specifically designed to the user and data needs of archaeology will never be of major interest of commercial software developers (Green 2008). Scientific research on this topic is for this reason indispensable. This chapter is part of a project, which intends to make a significant contribution towards such a 4D GIS that is specifically designed to suit the needs and particularities of 4D archaeological data. A human-centred design takes into account the needs and points of view of the users during the development of the software (Howard and MacEachren 1996; Maguire 2001; Maguire and Bevan 2002; España et al. 2006) and can therefore be adopted.

Such a human-centred design process consists of four iterative stages, specified in the ISO 9241-210:2010 (former ISO 13407) and graphically depicted in Figure 3-1 (Maguire 2001):

- understand and specify the context of use;
- specify the user requirements;
- produce design solutions to meet user requirements;
- evaluate the design against the requirements.

Due to the initial stage of the overarching project, this chapter does only address the first and second phase. The first stage in the design cycle is the specification and understanding of the context in which the archaeological GIS will be used. Maguire (2001) indicates the need to identify the stakeholders and to meet with them, together with a task analysis and a study of the existing users. The last two tasks are only necessary for more complex systems or more complicated use contexts (Maguire 2001). The next phase then makes up the most crucial part of the design process, namely the specification of the user requirements. Although several subtasks can be delineated, they all constitute



to the clear specification of user, usability and organizational requirements. The first group of requirements, user requirements, concerns the description of the tasks to be performed by the users of the system, the second group deals with the effectiveness, efficiency and satisfaction, the last one concerns the requirements to be met when the system is used in an organizational context (Maguire 2001). The next stages then start with the real designing of the software, followed by an evaluation.

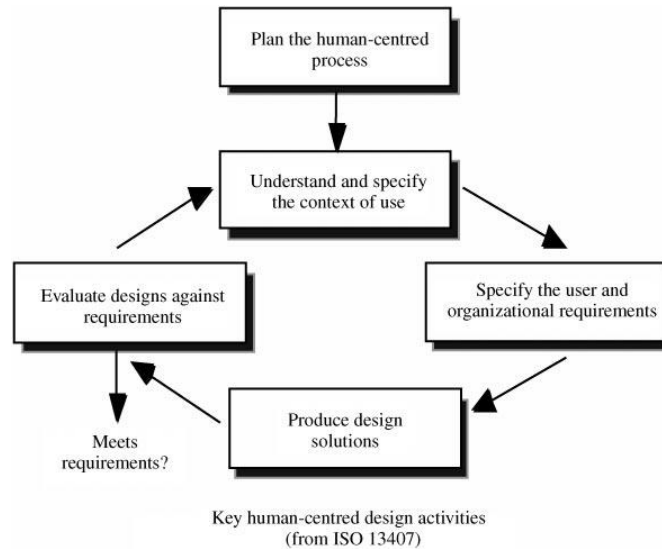


Figure 3-1 Human-centred design cycle (Maguire 2001, p. 589)

To “determine the needs of users, current work practices and attitudes to new system ideas” (Maguire 2001, p. 595) user surveys are indicated as particularly helpful by Maguire (2001) and Maguire and Bevan (2002). However, Maguire and Bevan (2002, p. 10) note that such surveys do not permit in-depth interviews and follow-up. Two elements counterbalance these drawbacks. First, the questionnaire presented in this chapter is a combination of closed, semi-open and open questions, which allows the respondents to go into more detail. Second, the questionnaire will be complemented with interviews and meetings with stakeholders and experts in this field. Next steps in the project are then the third and fourth phase of the human-centred design cycle. The project, this chapter is part of, intends to make a significant step towards a 4D archaeological GIS and hopes to stimulate the scientific (and commercial) interest in the development of such a system.

In this chapter, the results of the online questionnaire are presented. First, the design of the survey and the sample of respondents are outlined. Next, in Section 3.3, the answers on the questions are described and analysed. Subsequently, these results are assembled to give a concluding review of the state of affairs in the use of GIS and data standards and to outline the general user requirements for future developments of 3D and/or 4D GIS.

## 3.2 SURVEY DESIGN AND SAMPLE DESCRIPTION

### 3.2.1 Survey design

In 2004, a similar survey has been set up into the current levels of up-take of GIS and GI standards within the English archaeological community (Bell and Bevan 2004). A widespread use of GIS has been shown; however, the focus was mainly on the GIS use within the organization, rather than on the exchange and interoperability of data. The survey questions of Bell and Bevan (2004) formed the basis for the design of this questionnaire, although the latter is focusing more on 3D and 4D. Some questions of Bell and Bevan's survey (2004) are almost literally copied. This way, it is possible to compare the results without making too many assumptions due to a different expression of the question. The questions concerned are indicated and supplemented with the comparison of their results in the respective discussion sections.

The survey, in total consisting of 45 questions (Appendix, p. 76), was divided into five parts:

- current use and perception of GIS in the archaeological field;
- current archaeological workflow;
- data standards and exchange;
- possibilities of a 3D/4D model or system;
- general questions.

The first three parts mainly contribute to a good understanding of the context of use. The fourth is specifically designed to gather information on the opinions of 3D and 4D systems and analyses, and thus, helps to identify the user requirements. The fifth part is only used to place the other answers in context and comprises general information questions. Different types of questions were used: closed single answer questions; closed, multiple answer questions; semi-open questions and open questions.

The questionnaire was intended to gather information on the existing use of GIS and data standards and the visions on possible 3D and 4D GIS and analyses of archaeologists. Therefore, the archaeologists and people dealing with archaeological data formed the main target group.

In order to try to cater for a broad international public of archaeologists, an online survey was created. However, paper versions were available on request. Cover letters of the survey were e-mailed in English, French and Dutch to a wide range of contact persons, containing both individual archaeologists and organizations and institutions. Although the survey questions were in English, comments and answers on (semi-)open question were allowed in any language. The online survey was available for approximately 2.5 months between January and March 2013.

### 3.2.2 Sample description

Despite the rather large number of questions and the more technical-looking subject, 171 archaeologists took the time to answer the questionnaire, of which 50.3% completed it entirely. Calculating the response rate is next to impossible, since the questionnaire has been redirected and spread amongst colleagues and via archaeological institutions and organizations. However, the confidence interval or margin of error can be calculated for the sample population at a confidence level of 95% and a response distribution of 50% (eqn. 1). This results in a margin of error of 7.5%, which has to be kept in mind for the further interpretation of the results.

$$F \geq \sqrt{\frac{z^2 p(1-p)}{n}} = \sqrt{\frac{1.96^2 0.5^2}{171}} \quad (1)$$

where:

$F$  = margin of error

$z$  = Z-score for the confidence level; here: 1.96 for the 95% level

$p$  = population proportion; here: unknown and thus set to 0.5 to maximize  $F$

$n$  = the sample size; here: 171

The geographical distribution of the respondents is mainly located in Europe and North America. However, only for 89 people the country where they work is indicated. France, the Netherlands and Belgium make up the top three locations with 25, 18 and 13 respondents respectively.

The sample contains an overrepresentation of men (75.6% vs. 24.4%, Figure 3-2a), since we can expect that 55% of the archaeologists are males (Aitchison 2009). The mean age of the respondents is 37 years, which corresponds to the average age found for archaeologists in the European Union in 2007-2008 (Aitchison 2009). Figure 3-2b shows a more detailed age distribution of the respondents. Regarding the highest obtained degree (Figure 3-2c), the largest group (61.8%) comprise people who have obtained a Master's degree, and the second largest group is those who have a PhD degree. We can expect a slight overrepresentation of the latter group (Aitchison 2009). This may be caused by a larger number of academic people this survey was sent to in comparison to private and governmental institutions. This can be seen in Figure 3-2d which illustrates that 46.1% of the respondents work in an academic organization. Furthermore, 33.8% works in a governmental organization, either on national, regional or local level and 20.2% works in private industry. To conclude, 21.6% of the respondents work in another country than where he/she obtained his/her highest degree.

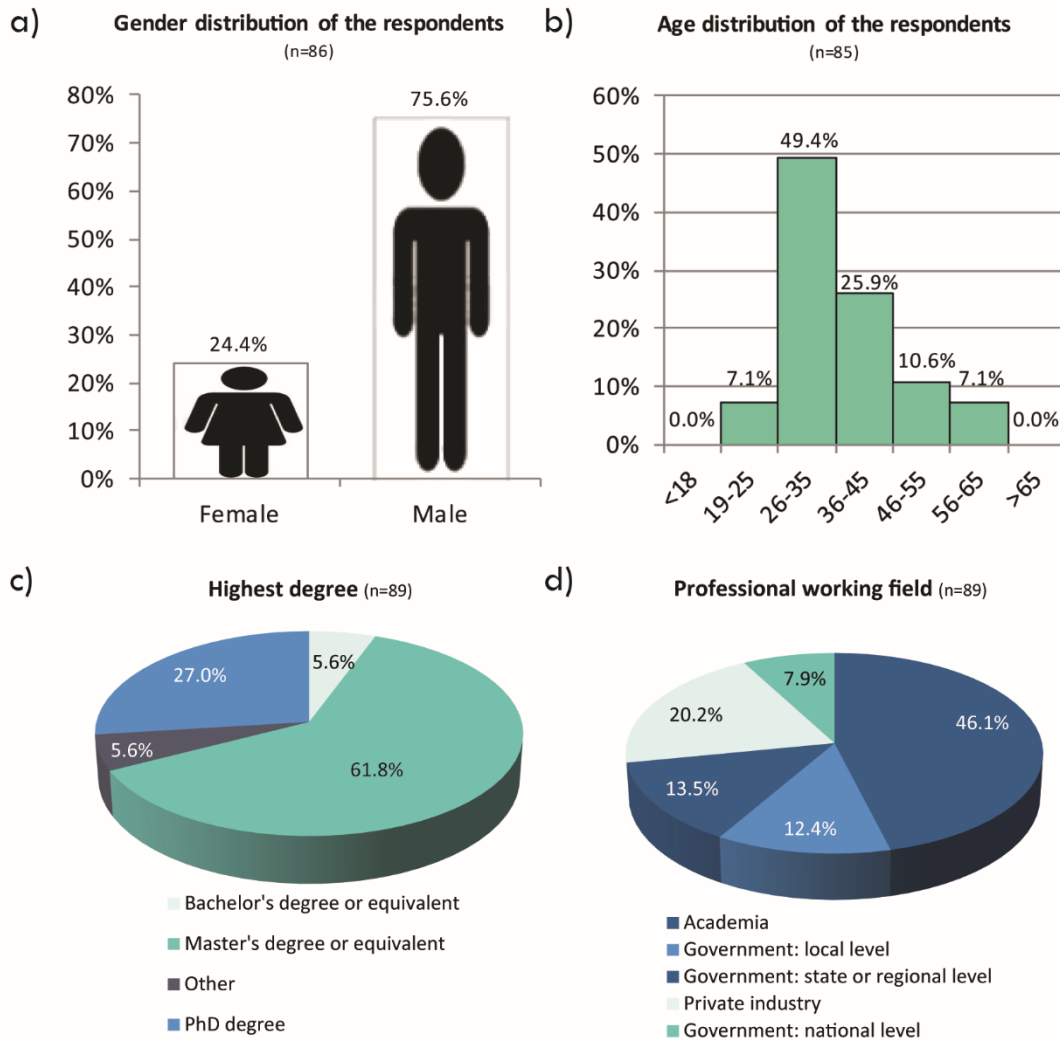


Figure 3-2 Sample description in terms of a) gender, b) age, c) highest obtained degree and d) professional working field

## 3.3 RESULTS AND DISCUSSION

### 3.3.1 Current use of and perception on GIS

As expected from literature and scientific conferences, the results of this part of the survey indicate a widespread use of GIS in the archaeological domain (Figure 3-3). Only 5.2% indicates not to use GIS, mostly because it is not relevant for the work they are doing. Table 3-1 shows how many respondents use GIS frequently until never to perform a set of different activity types. From the 94.6% of GIS users 47% rate their expertise in GIS higher than average (Figure 3-3).

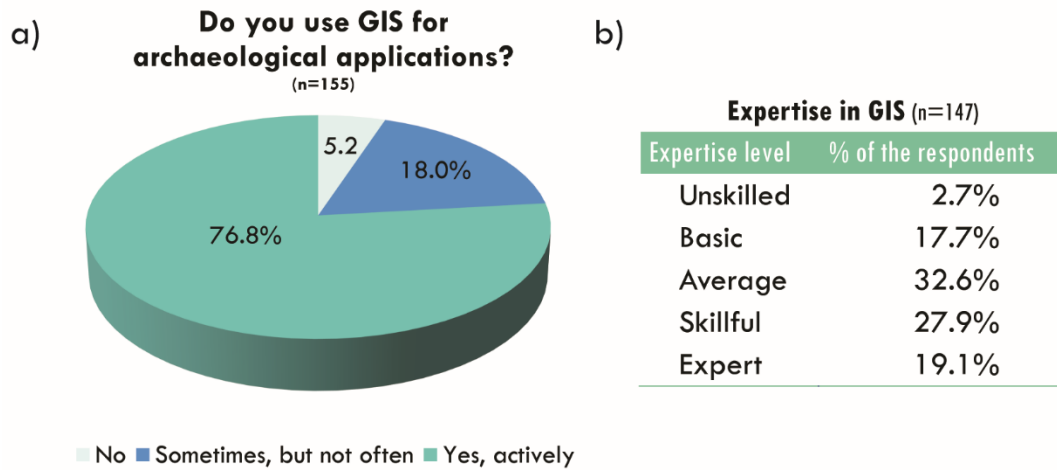


Figure 3-3 a) Use of and b) expertise in GIS in the archaeological domain (n<sub>a</sub>=155; n<sub>b</sub>=147)

Table 3-1 Approximate use of GIS for different activity types (n= 147)

	General Data Management	Research Tool	Spatial Planning and Development Control	Disseminating Information to the Public
<b>Always</b>	47%	30%	17%	23%
<b>Frequently</b>	35%	32%	25%	35%
<b>Sometimes</b>	12%	30%	18%	25%
<b>Seldom</b>	4%	6%	14%	10%
<b>Never</b>	2%	2%	25%	7%
	100%	100%	100%	100%

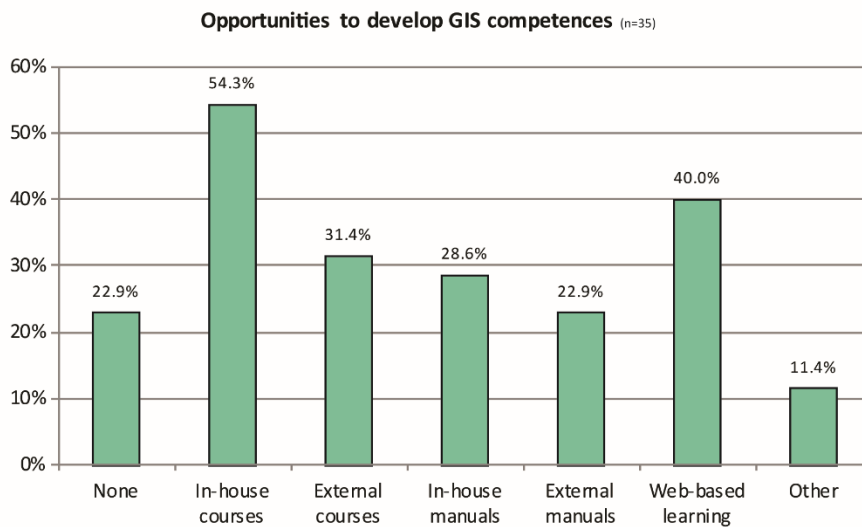


Figure 3-4 Opportunities provided by the organizations to develop GIS competences (n=35) (NB. More than one learning option could be selected)

For the development of this expertise, almost 80% of the respondents are provided with opportunities by their organizations (Figure 3-4). Having used the same categories as Bell and Bevan (2004), a comparison can easily be made. However, only a graph is given by Bell and Bevan (2004), which does not indicate the exact values. The percentage of organizations using in-house courses is approximately the same. However, the use of the external courses, in-house and external manuals have slightly decreased since the survey of Bell and Bevan (2004) ( $\pm 45\%$ ,  $35\%$  &  $47\%$  vs.  $31\%$ ,  $29\%$  &  $23\%$  resp.). The most remarkable difference is the use of web-based learning. In this survey,  $40.0\%$  of the respondents indicated to be provided with this opportunity, while Bell and Bevan (2004) noted only a small percentage of organizations using web-based learning ( $<5\%$ ) and therefore, recommended to encourage this type of cost-effective learning opportunity.

Concerning the software packages used, commercial software has still the largest share ( $51.0\%$ ), while  $19.1\%$  only uses free software. The respondents were also asked to name the software packages they use. The merging of all the answers for the three categories (commercial, free and both) show a leading position for ArcGIS ( $69.6\%$ ), followed with  $40.6\%$  by QGIS. The third place is occupied by MapInfo with  $10.1\%$  and, furthermore, a wide range of commercial and free software is used by only a few respondents. This is a noteworthy result, since Bell and Bevan (2004) found MapInfo the most used software package in English Heritage Environment Records with  $57\%$ , followed by ArcGIS ( $36\%$ ).

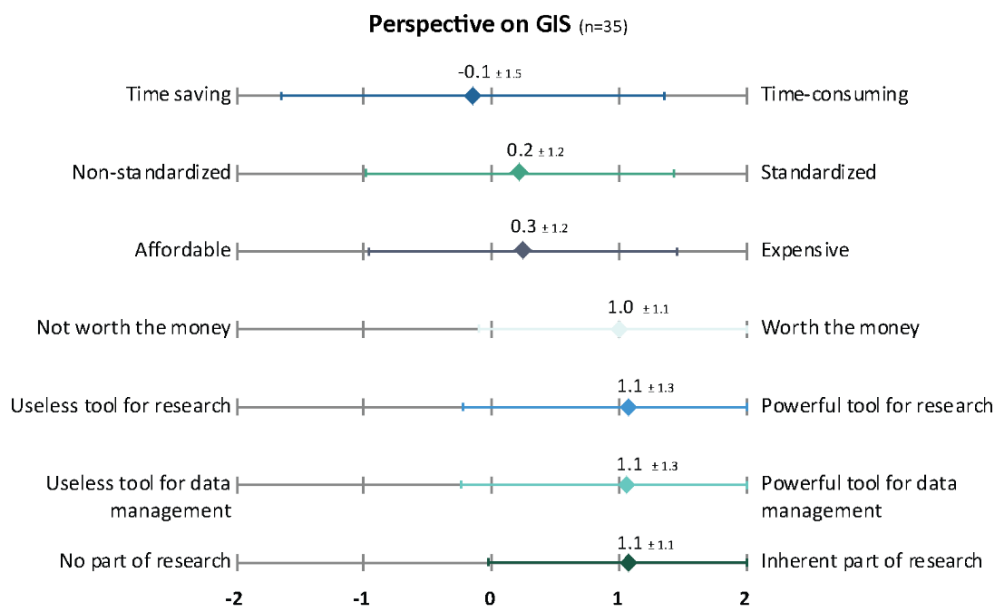


Figure 3-5 The respondents' perspective on GIS (n=35)

Figure 3-5 gives the respondents' perspective on GIS via a number of statements. The respondents were asked to indicate their attitude on a 5-point Likert scale. For each of these five points a percentage was then calculated, which was then further transferred into a general score using -2 over 0 to 2 for the 5 points of the Likert scale. GIS is

conceived as a rather powerful tool for data management and research, as worth the money and as an inherent part of research. However, the attitude is divided on time saving, standardized and the cost of GIS.

### 3.3.2 Current archaeological workflow

To understand the context of use more thoroughly, the second part of the questionnaire started with an open question to describe the general archaeological workflow concerning data acquisition. The answers on this question are very diverse and therefore, they will only be used as background information and will not be described in detail in this chapter. In this section, the focus is on the storage and handling of attributes, temporal information, uncertainty and metadata.

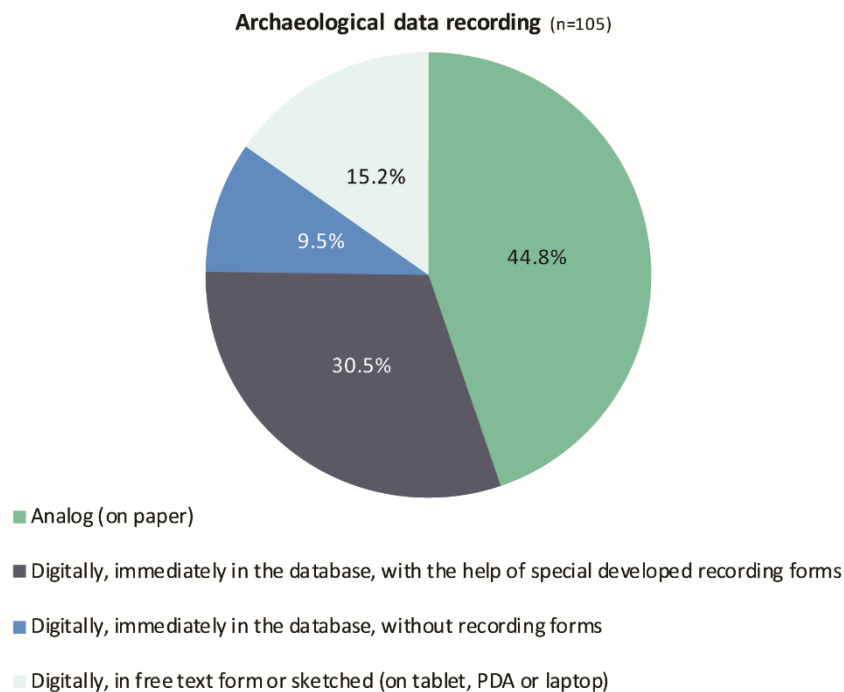


Figure 3-6 The way of recording archaeological data (n=105)

The recording of archaeological data is mainly undertaken digitally (52.2% vs. 44.8%), either immediately in the database or in free text (Figure 3-6). When the data are entered immediately in a database, most respondents use specific developed recording forms (30.5%). The largest part of the respondents (30.9%) wants to store raw data, as well as (semi-) interpreted data and the workflow used (Figure 3-7). Furthermore, 27.3% does not want to store the workflow but did want to store raw and interpreted data. Finally, 30.8% only want to store one of the three types of data (Figure 3-7).

The majority of the respondents (63.6%) stores attributes in GIS as well as in separate databases, while 19.6% and 16.8% store them only in GIS or a separate database respectively. Although 43.3% records metadata, the largest share of the respondents

does not or not consistently record metadata (40.4% and 16.3% resp.). From the 87 respondents who (sometimes) record them, 55 (or 63.2%) use a formal or in-house data standard.

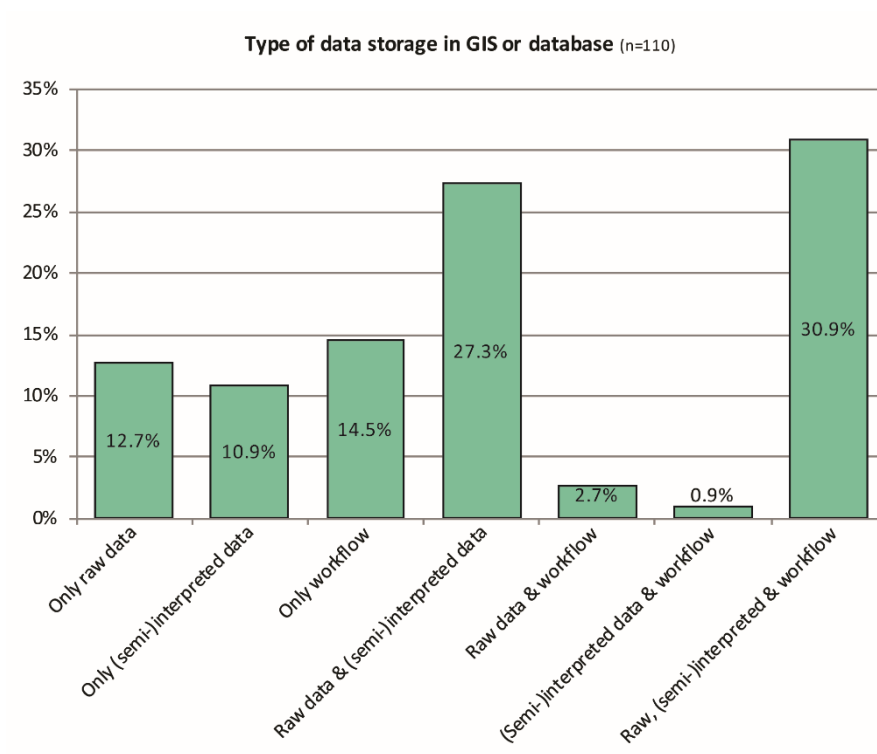


Figure 3-7 Preference for the storage of raw data, (semi-)interpreted data or the workflow (n=110)

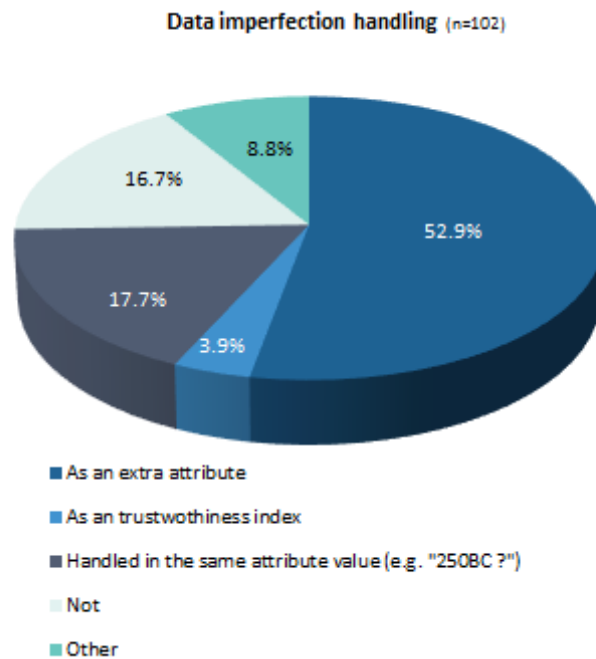


Figure 3-8 Way of data imperfection handling (n=102)



Since archaeology has to deal with imperfect data, it is important to know how this issue is currently dealt with (Figure 3-8). More than half of the respondents (52.9%) handle imperfection by storing it in an extra attribute. A minor part uses a trustworthiness index (3.9%) and 17.6% handles it in the same attribute. The latter may cause problems with regard to data querying or analysis, since for example a numeric temporal attribute will be transformed in a string containing a question mark. Moreover, it is remarkable that a rather large number of respondents (16.7%) do not handle imperfection at all.

Table 3-2 Use of different temporal categories (n=105)

Temporal category	%
Archaeological or Historical time	68.6%
Site phase	61.9%
Absolute date	59.0%
Relative stratigraphic time	42.9%
Relative time relation	39.0%
Excavation time	29.5%
Database time	20.0%
Other	1.9%

Besides the data imperfection, the temporal dimension is vital in archaeological research. This temporal information is usually stored as one or more attributes (86.9%). However, 6.1% of the respondents use a special representation such as the space-time cube. A second element that has been investigated during the survey is the use of different temporal categories. Katsianis et al. (2008) identified six types of temporal information that can be stored in a database system for the recording of excavation data. Those six categories were used in addition to the options 'relative time relation' and 'other' (Table 3-2). All of the categories are quite commonly used, with a minimum usage 20%. The archaeological time, site phase time and absolute time are the three mostly used types.

### 3.3.3 Knowledge and use of data standards

Like the two previous categories, the answers on this survey part contribute to the appropriate description and understanding of the context of use, here of the data standards in archaeology. Almost half of the respondents (47.3%, n=93) use an in-house format or a data standard, although only 17.2% indicates this standard is fully implemented. 54 respondents indicate that they know or often use one of the data standards given in Figure 3-9. XML (extendible mark-up language) is indicated as known or often used by 81.5% of those respondents. VRML (virtual reality mark-up language) holds the second position with 25.9%, which corresponds to the increasing number of researches concerning virtual reality models (Breunig and Zlatanova 2011; Scianna and Villa 2011). CIDOC CRM and Midas Heritage, two standards specifically intended towards cultural heritage and archaeology, are not known ubiquitous and have a share of only 22.2% and 14.8% respectively. In order to be acquainted with the attitude

towards these standards, the respondents who indicated a standard as known, were asked to indicate their experience in three categories: (i) helpful vs. useless, (ii) difficult vs. easy, (iii) not suitable vs. appropriate (Figure 3-10). ConML is found helpful, easy and appropriate by the two respondents. In general, all the data standards except from GeoSciML, are experienced as rather helpful, although a large portion of the respondents indicated them as difficult to use. The data standards are mostly experienced as appropriate, except for CityGML on which opinions differ.

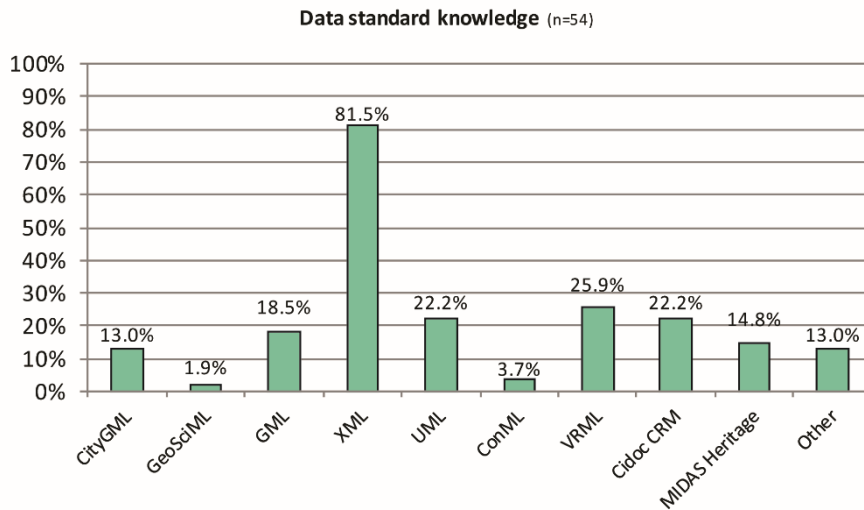


Figure 3-9 Knowledge of data standards (n=54)

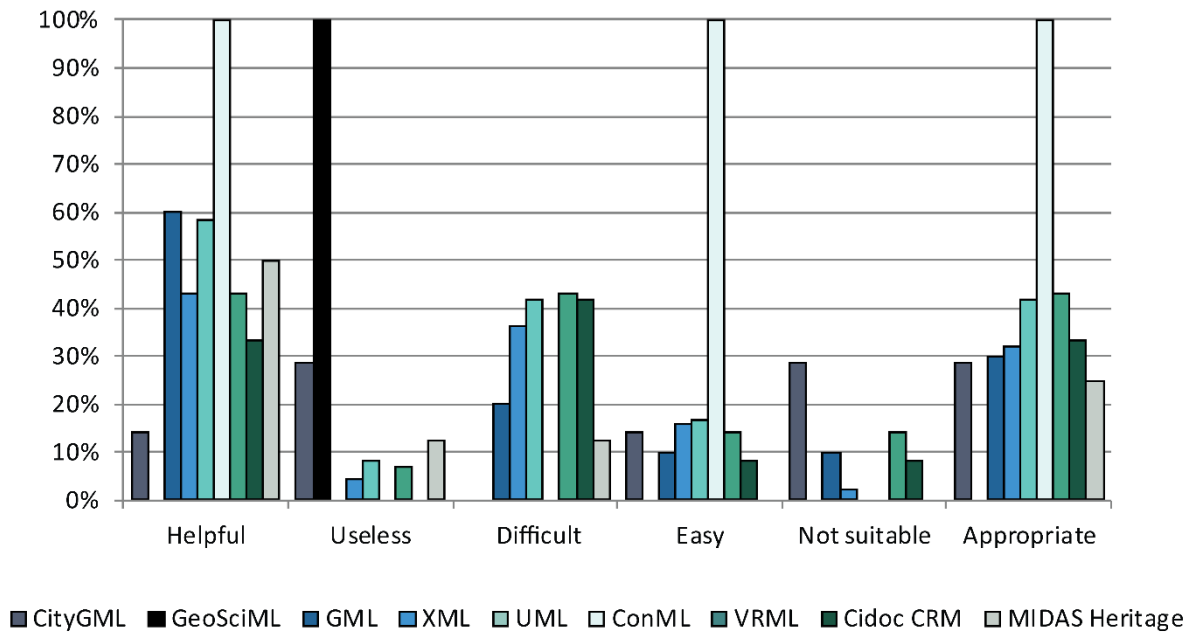


Figure 3-10 Experience in the use of data standards (n=54)

The use of data standards is closely connected to the data interoperability and the exchange of information. In the survey, a distinction was made between data exchange within the organization, towards other organizations and towards the public. The same answer categories as Bell and Bevan (2004) were used for these questions, a comparison can be easily made. Analogous to the findings of Bell and Bevan (2004), for the three exchange groups multiple ways to exchange data are used. Within the organization, the information is generally exchanged via direct access to the system (e.g., server) or via a data dump on a mobile storage device (e.g., USB stick) (41.9% and 34.4% resp.). Bell and Bevan (2004) found the exchange on paper the most commonly used (approx. 50%), followed by a data dump on CD (approx. 45%) and a read-only copy of the system (approx. 30%). Although the practically comparable percentage of the exchange via a mobile storage device, it is remarkable that the paper exchange now only constitutes 12.9%. The top three of ways to exchange data towards other organizations is a data dump on a mobile storage device (35.5%), via a transfer over the network (e.g., ftp or Dropbox) (21.5%) and on paper (17.2%). Exchange of information towards the public is mainly done on paper (43.0%) and via the web (32.3%).

Exchanging data either via direct access to the system, mobile devices or a transfer over the network necessitates a consistent data model or at least metadata. However, the results described above (Section 3.2 & 3.3) show that this is lacking in case of half of the respondents. Bell and Bevan (2004) concluded similarly that this may “increase the risk that they [Heritage Environment Records] maintain multiple, slightly altered copies of the same basic data, and restrict the degree to which data dumps from more than one HER can be integrated” (Bell and Bevan 2004, p. 17).

### 3.3.4 Attitude to 3D or 4D systems

This section of the questionnaire consists of four open questions and two with fixed answer possibilities. For this reason and due to the fact that this was the last technical and maybe the most demanding section, some of the questions have a very low response. Therefore, some of the results will be neglected in this chapter and only be used to get tuned in with the attitude towards 3D systems. From 85 persons 78.8% thinks 3D or 4D queries or analyses could bring benefits to their research, while 7.1% thinks it will totally not. With regard to analyses that are extendable to 3D or 4D, respondent A answered “many of the spatial analysis algorithms used by geographers and others are 2D based and cannot deal with time (e.g., stratigraphic breaks) that result in close spatial proximity but distant real association”. Other respondents share this opinion: respondent X says “determining if a particular trace belongs to a structure could be simplified by also adding the Z-value (e.g., the absolute depth of a trace) to the analysis”, respondent Y answers “spatial relationships based on 3D topologies (eg. What is indised whate)” and respondent Z indicates that “viewsheds could be improved with 3D info, and by extension virtual reality. My own work could benefit from ‘vertical layer structures’ for analysis”. Thus, spatial (geometrical and topological) analyses are mentioned as one of the extendable analyses (e.g., nearest neighbourhood, spatial relationship test). Furthermore,

spatio-temporal analyses, such as the Harris matrix, are another group of potentially extendable functions as already indicated in the answer of respondent A. Respondents K and X also indicate this in their respective answers “phase reconstructions (for excavations and surveys)” and “also temporal analysis may, in my opinion, be simplified, possibly in combination with the creation of a Harris Matrix”. Although it was an open question, some categories of possible disadvantages of 3D or 4D systems could be detected and are describe in Table 3-3. The complexity is indicated as the major possible disadvantage of a 3D/4D system (46.2%, n=26).

Table 3-3 Drawbacks conceived of a 3D of 4D system (n=26)

Drawbacks	%
Complexity	46.2%
Hardware requirements	23.1%
Data management	11.5%
Chance of failure	3.8%
Teaching requirements	3.8%
Costs	3.8%
Time consuming	3.8%
Data requirements	3.8%

### 3.4 CONCLUSION AND RECOMMENDATIONS FOR THE FUTURE

The results of the survey have shown a widespread GIS uptake in the archaeological domain. Although a large share of the respondents work in academia, this corroborates the finding of increasing GIS use and interest in archaeological scientific papers and conferences. Moreover, archaeologists are quite confident on their GIS experience. This is probably due to the high provision of opportunities to develop GIS competence by the organizations. It is remarkable that the web-based learning has increased significantly in comparison to a former study in 2004 by the English Heritage Environment Records (Bell and Bevan 2004). This learning manner is cost-effective and is expected to increase in popularity in the future. The two most commonly used software packages are ArcGIS and QGIS, where the latter reflects the increasing popularity of open-source packages. In general, archaeologists experience GIS as a powerful tool for both research and data management, as worth the money and as an inherent part of their research.

The largest part of the respondents registers archaeological data digitally, although analogue recording has still a very large share. Both raw and (semi-)interpreted data are liked to be kept in a GIS or database. The workflow between both is rather liked to be saved as well. An appropriate way to store this workflow from raw to interpreted data is describing it in the metadata of the interpreted data. However, only less than half of the respondents records metadata. Considering the highly subjective character of

interpreting data, this could be problematic with an eye to data sharing and reusing. It is recommended promoting the metadata registration, preferably using a standard like for instance the Dublin Core Metadata Standard<sup>1</sup>. Another remarkable finding is that almost 17% of the respondents do not deal with imperfection, although this is an inherent part of archaeological data. Approximately half of the respondents store the imperfection in an extra attribute, but another 17% stores it in the same attribute. The latter way of dealing with this issue is rather problematic for further analyses and has therefore to be avoided. Considering the temporal information, a series of temporal categories are used quite commonly.

Unlike the use of GIS, data standards are not widely adopted in the archaeological field. Half of the respondents use a data format or standard, but only a limited number of organizations have fully implemented them. XML is by far the most known standard. Except from GeoSciML, all mentioned data standards are experienced as helpful. Generally, the data standards are experienced as appropriate but difficult to use. A remarkable exception, on which opinions differ, is CityGML, although this standard knows an increasing use in other domains. Data exchange within the organization or towards other organizations is mainly done via a data dump on a mobile device, direct system access or a transfer over the web. To the public, data is distributed via the web or in paper form. The importance of using data standards and metadata relates strongly to data interoperability and data exchange. Therefore, adopting data standards and storing metadata is highly recommended in order to reduce data redundancy and benefit research activities in general.

Due to the late place in the survey (section 4 of 5) of the questions regarding the attitude towards a 3D or 4D GIS, and the more technical character of this section, the response rate was rather low. However, 3D and 4D analyses are generally seen as beneficial for archaeological research. Especially, the extension of currently available 2D spatial analyses and the combination of spatial and temporal elements in analyses are indicated as interesting possibilities. The complexity of a 3D or 4D system is generally acknowledged as the major drawback of such a system.

To conclude, when developing a 3D or 4D system, the current state of affairs in GIS and data standards use has to be taken into account. For example, functionalities for both raw and interpreted data have to be provided as well as the opportunity to store multiple temporal categories and data imperfection in an extra attribute. On the other hand, special attention has to be paid to the current issues that can cause problems in analysing or exchanging data, such as metadata registration, and data imperfection handling in the same attribute. It is recommended to encourage the use of data standards, as well in the current practices as through the development of the new 3D/4D system. Furthermore, it has to be avoided to lapse into complexity. Regular evaluations of the

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<sup>1</sup> <http://dublincore.org/>

design solutions through meetings with experts and potential users are necessary to succeed in this and result in a system that is completely human-centred.

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## APPENDIX

This appendix presents the complete questionnaire, including introduction, questions and closure.

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Dear,

Welcome to the questionnaire 'Archaeology and GIS'. This international survey is intended to determine the current usage of Geographical Information System (GIS) and data standards in archaeology. Therefore, this questionnaire is directed towards archaeologists and people dealing with archaeological data. This survey is part of a research project to **enhance the GIS practice in archaeology and to adapt GIS to archaeological purposes.**

It will take **25 min** to complete the survey. It is possible to **complete the questionnaire in multiple parts**. Therefore, click on 'Resume later', to resume on a later time you click the link again. You can participate till **31/03/2013**. **Your contribution is highly appreciated**, as it will provide insights in the requirements of the archaeological community and since it is necessary to provide tools appropriate for archaeological data and analyses. Your answers will be treated confidentially and with discretion.

The questionnaire consists of 45 questions divided over **5 parts**:

1. Current use and perception of GIS in archaeological field
2. Current archaeological workflow
3. Data standards and exchange
4. Possibilities of a 3D/4D model or system
5. General questions

If you have questions about the survey or the research, you can **contact** Berdien De Roo (Department of Geography, Ghent University, Krijgslaan 281 S8, B-9000 Ghent, Belgium or [berdien.deroo@ugent.be](mailto:berdien.deroo@ugent.be))

Thanks in advance for your cooperation.



## 1 Current use and perception of GIS in the archaeological field

This section assesses your current practice of GIS and your perception of it.

### 1. Do you use GIS in your archaeological research or for archaeological applications?

- Yes, actively       Sometimes, but not often       No (go to question 5.)

### 2. Rate your expertise in GIS. (1 = unskilled; 5 = expert or specialist)

- 1       2       3       4       5

### 3. Do you use commercial or free GIS software?

- Commercial, please specify:       Free, please specify:       Both, please specify:

### 4. What do you use GIS for? Please indicate the approximate GIS use (between always and never) for these tasks.

	Always	Frequently	Sometimes	Seldom	Never
General Data Management	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Research Tool	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Spatial Planning and Development	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Control	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Disseminating Information to the Public	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

### 5. Why don't you use GIS?

- I tried it, but it is too difficult       Not relevant for the goals or objectives       Initial phase of GIS exploration)
- Not involved in archaeological research       No access

### 6. What opportunities are provided by your organization to develop competence in GIS? (Multiple answers possible)

- None       In-house manuals       Web-based learning
- In-house courses       External manuals       Other)
- External courses

### 7. What is your perspective on GIS? (E.g. indicate the fourth button if you find GIS rather time saving than time consuming)

	2	1	0	1	2	
time consuming	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	time saving
standardized	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	non-standardized
expensive	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	affordable
worth the money	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	not worth the money
powerful tool for research	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	helpless tool for research
powerful tool for data management	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	helpless tool for data management
inherent part of research	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	no part of research

**8. What are, from your point of view or from your experience, the shortcomings of current GIS? (Multiple answers possible)**

- |   |  |   |
|---|--|---|
| <input type="checkbox"/> The inability to handle uncertainty                        | <input type="checkbox"/> The 2D approach, the lacking of the third dimension | <input type="checkbox"/> The complexity                   |
| <input type="checkbox"/> The restricted capability to handle the temporal dimension | <input type="checkbox"/> The analyses  | <input type="checkbox"/> The cost of the software license |
|   |  | <input type="checkbox"/> Other:                           |

**9. Additional comments on this section. Feel free to use the language you want.**

.....

## 2 Current archaeological workflow

The questions in this section examine the way you currently work with and analyse archaeological data

**1 Can you describe in general the workflow you follow for archaeological data acquisition (before, during and after excavation)? (Try to use a single word for each step)**

.....

**2 How do you usually record archaeological data?**

- |  |  |
|--|--|
| <input type="radio"/> Analog (on paper)  | <input type="radio"/> Digitally, immediately in the database, without recording forms      |
| <input type="radio"/> Digitally, immediately in the database, with the help of special developed recording forms | <input type="radio"/> Digitally, in free text form or sketched (on tablet, PDA or laptop)) |

**3 What would you like to store in a GIS or database for analysis? (Multiple answers possible)**

- |                                   |   |   |
|-----------------------------------|---|---|
| <input type="checkbox"/> Raw data | <input type="checkbox"/> (Semi-) interpreted data | <input type="checkbox"/> Workflow from raw to interpreted data) |
|-----------------------------------|---|---|

**4 Do you store attribute data in your GIS (e.g. as an attribute table in a .shp-file) or in a separate database?**

- |                                     |                           |  |
|-------------------------------------|---------------------------|--|
| <input type="radio"/> A bit of both | <input type="radio"/> GIS | <input type="radio"/> Separate database) |
|-------------------------------------|---------------------------|--|

**5 Which temporal paths or categories do you often use in your archaeological research? (Multiple answers possible)**

- |  |  |   |
|--|--|---|
| <input type="checkbox"/> Excavation time             | <input type="checkbox"/> Archaeological or Historical time | <input type="checkbox"/> Absolute date          |
| <input type="checkbox"/> Database time               | <input type="checkbox"/> Site phase                        | <input type="checkbox"/> Relative time relation |
| <input type="checkbox"/> Relative stratigraphic time |  | <input type="checkbox"/> Other                  |

**6 Which kind of archaeological or historical time do you use? (i.e. which temporal reference system do you use? e.g. Gregorian calendar, Mayan calendar, Ming dynasty, Western periodization,...)**

.....

**7 How do you currently handle the temporal dimension?**

- As one or more attributes
- With the help of a special representation: the Space Time Cube
- With the help of a special representation: the Triangular Model
- With the help of another special representation
- Other

**8 Do you record metadata for archaeological data? (i.e. how was the data obtained, when, data precision, etc.)**

- No
- Sometimes, but not consistently
- Yes

**9 Do you use a standard or formal data format to record these metadata?**

- No
- Yes, an in-house data format
- Other, specify:

**10 How do you handle data imperfection? (e.g. uncertainty, incompleteness,...)**

- As an extra attribute
- As a trustworthiness index
- Handled in the same attribute value (e.g. "250BC ?")
- Not
- Other, specify:

**11 Additional comments on this section. Feel free to use the language you want.**

.....

### 3 Data standards and exchange

This part of the survey is concerned with the knowledge and use of data standards and the way digital information is shared.

**1 Which standard ontologies for objects, time, metadata,... do you know or often use?**

.....

**2 Do you have any in-house spatial data format(s) and/or standard(s)?**

- No
- Yes, but only partially implemented
- Yes, fully implemented)

**3 Indicate the data models, standards or modelling languages that you know or often use?**

- CityGML
- GeoSciML
- GML
- XML
- UML
- ConML
- VRML
- Cidoc CRM
- MIDAS Heritage
- Other, specify:

**4 How do you experience the known data models, standards or modeling languages that you use?**

	<i>Helpful</i>	<i>Useless</i>	<i>Dificult</i>	<i>Easy</i>	<i>Not suitable</i>	<i>Appropriate</i>
<i>CityGML</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>GeoSciML</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>GML</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>XML</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>UML</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>ConML</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>VRML</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Cidoc CRM</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>MIDAS Heritage</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**5 How do you mainly exchange heritage or archaeological information within your organization?**

- A read only copy of our data
- Data dump on CD, external hard disk, USB, ... as requested
- Direct access to our systems
- I don't
- On paper
- Other, specify:

**6 How do you mainly exchange heritage or archaeological information to other organizations?**

- A read only copy of our data
- Data dump on CD, external hard disk, USB, ... as requested
- Direct access to our systems
- I don't
- On paper
- Over network (e.g. ftp, dropbox, yousendit,...)
- Other, specify

**7 How do you provide information to the public?**

- Data dump in text file
- I don't
- On paper
- Combination web and paper
- Through the web
- Other, specify

**8 Additional comments on this section. Feel free to use the language you want.**

.....

**4 Possibilities of a 3D/4D model/system**

As archaeological data are inherently 3D and time is a main component of archaeological research a 4D (= 3D + time) system could bring many benefits.

**1 Do you have experience with or knowledge of 3D systems? If yes, indicate which ones.**

.....

**2 Do you think a 3D or even a 4D GIS can bring benefits to: (Multiple answers possible)**

- |  |  |
|--|--|
| <input type="checkbox"/> Data management                               | <input type="checkbox"/> Data analysis                         |
| <input type="checkbox"/> Data exploration, structuring or manipulation | <input type="checkbox"/> Data representation and visualization |

**3 Can you imagine some benefits of a 3D or 4D GIS? (e.g. in the context of data exploration, analyses, data interpretation, visualization,...)**

.....

**4 Do you think 3D or even 4D queries or analyses could bring benefits to your research?**

- I have really no idea       No       Yes

**5 Do you have proposals for current 2D analyses that are extendible to 3D or could offer benefits when executed in 3D?**

.....

**6 Can you imagine some drawbacks of using a 3D or 4D approach?**

.....

**7 Additional comments on this section. Feel free to use the language you want.**

.....

## 5 General questions

In this section, you will be asked some general questions to enable us to put your answers in context.

**1 Indicate your professional working field.**

- |   |  |
|---|--|
| <input type="radio"/> Academia                            | <input type="radio"/> Government: national level |
| <input type="radio"/> Government: local level             | <input type="radio"/> Private industry           |
| <input type="radio"/> Government: state or regional level |  |

**2 Please specify your function. (e.g. field archaeologists, policy adviser, PhD student,...)**

.....

**3 What is the highest degree you have achieved?**

- |   |                                      |
|---|--------------------------------------|
| <input type="radio"/> Bachelor's degree or equivalent | <input type="radio"/> PhD degree     |
| <input type="radio"/> Master's degree or equivalent   | <input type="radio"/> Other, specify |

**4 Indicate the country where you obtained your highest degree.**

.....

**5 Indicate the nationality of your organization, i.e. where you work. If you work for an international organization, specify the country where you work (e.g. Indicate 'Italy' when you work for an international company but your office is located in Italy).**

.....

**6 Indicate your sex**

Female

Male

**7 Indicate your age.**

.....

**8 Do you want to be kept informed about the results of this questionnaire and/or the entire project?**

None (go to question 10)

Questionnaire results

Project information

Questionnaire results and project information

**9 You indicated that you want to be kept informed about the questionnaire results and / or the project, please fill in your e-mail address below.**

.....

**10 Do you have additional comments on this survey? Feel free to use the language you want.**

.....

You completed the questionnaire. Thank you for your contribution to this research.

If you have questions, you can contact Berdien De Roo (berdien.deroo@ugent.be or Geography Department, Ghent University, Krijgslaan 281 S8, B-900 Ghent, Belgium)

# 4

## INFORMATION FLOWS AS BASES FOR ARCHAEOLOGY-SPECIFIC GEODATA INFRASTRUCTURES: AN EXPLORATORY STUDY IN FLANDERS

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Modified from: DE ROO B., BOURGEOIS J., DE MAEYER P. 2016. Information flows as bases for archaeology-specific geodata infrastructures : an exploratory study in Flanders. *Journal of the Association for Information Science and Technology*, 67(8), pp. 1928-2942.

### ABSTRACT

Accurate and detailed data recording is indispensable for documenting archaeological projects and for subsequent information exchange. To prevent comprehension and accessibility issues in these cases, data infrastructures can be useful. The establishment of such data infrastructures requires a clear understanding of the business processes and information flows within the archaeological domain. This study attempted to provide insights into how information is managed in Flemish archaeology and how this management process can be enhanced. Therefore, an exploratory study based on an analysis of the new Flemish Immovable Heritage Decree, informal interviews with Flemish archaeological organizations, and the results of an international survey was performed. Three main processes, in which certified archaeologists and the Flemish Heritage agency are key actors, were identified. Multiple types of information, the majority of which contain a geographical component, are recorded, acquired, used and exchanged. GIS and geodatabases therefore appear to be valuable components of an archaeology-specific data infrastructure. This is of interest because GIS are widely adopted in archaeology and multiple Flemish archaeological organizations are in favor of a government-provided exchange standard or database templates for data recording.

## 4.1 INTRODUCTION

Recording and archiving data plays major roles in the detailed and accurate documentation of archaeological projects because of their destructive nature. While total stations and GPS are practically standard equipment, innovative technologies, such as laser scanning and photo modeling, are becoming increasingly prevalent (Stal et al. 2014). Faster and more accurate recording is thus facilitated; furthermore, the acquired data are, by nature, 3D and born digital. During fieldwork, thematic and administrative information, as well as spatial data, is recorded. Many researchers accordingly aim for complete 3D digital documentation to enhance the potential reuse of the information (Katsianis et al. 2008; De Reu et al. 2013).

Because archaeological data can be recorded (mostly) only once, data and information exchange are indispensable. Although the capabilities of Geographical Information Systems (GIS) have been proven to simultaneously analyze thematic and (2D) spatial relationships of integrated archaeological data, little attention has been paid to data integration or the information exchange itself. As noted by Snow et al. (2006, p. 958), most archaeological data are “obscurely archived and difficult to access”. Different elements are responsible for this feature: the data (i) are conceived to be copyrighted, (ii) contain sensitive information or (iii) are stored in a database with a site-specific or organization-specific data model (Snow et al. 2006; McKeague et al. 2012). The first two reasons relate to a change in attitude, whereas the third can be addressed by applying a common data model (Shaw et al. 2009) and developing a cyber-infrastructure (Snow et al. 2006). As a basis for the creation of such data infrastructures, a clear understanding of the business processes and information flows within the archaeological domain is of vital importance. To the best of our knowledge, this has not been explicitly scientifically investigated previously. Although the analysis of information flows may have been done in the context of national archaeological archiving initiatives, such as EDNA (<http://www.edna.nl>) or DAP (<http://raa.se/>), no publication on the results is available. This study thus attempts to answer how information is managed in archaeological processes and how this management process can be enhanced.

Although the general workflow of archaeological projects runs in parallel, differences in applied business flows can occur due to national or regional legislations. Therefore, this study analyzes business processes and information flows in the Flemish context. An exploratory research methodology is used based on (i) an analysis of the new Flemish legislation on cultural heritage, (ii) informal interviews of archaeological organizations and companies active in Flanders and (iii) results of an international questionnaire on data standards in archaeology. In Section 4.2 of this chapter, we present a brief outline of the Flemish archaeological context, including an overview of the content of the new Immovable Heritage Decree and the European Valletta Convention. The details of the method are shown in Section 4.3. Section 4.4 presents the results of this exploratory research. Our findings are then discussed and summarized in Sections 4.5 and 4.6.



## 4.2 FLEMISH ARCHAEOLOGICAL CONTEXT

### 4.2.1 Flemish Immovable Heritage Decree of 12 July 2013

Besides the Federal State, Belgium consists of three Regions (Flemish, Walloon and Brussels-Capital Region) and three Communities (Flemish, French and German-speaking Community), which all act on the same level and all have their own government and parliament. Flanders is the northern of the three Regions in Belgium and forms together with Brussels the Flemish Community (Figure 4-1). As an exception to the other Regions and Communities, the Flemish Parliament and Flemish Government exercise the legislative powers of both the Flemish Community and Flemish Region. Through various state reforms, the fields of power and responsibility have been divided among the Federal State, Regions and Communities. Although it is more complex, Communities have powers in person-related fields, whereas Regions have powers in territory-related fields. For a more complete overview of the Belgian political framework and its federalization process, we refer the reader to Brans et al. (2009); Belgian Federal Government (2016), and Flemish Government (2016).

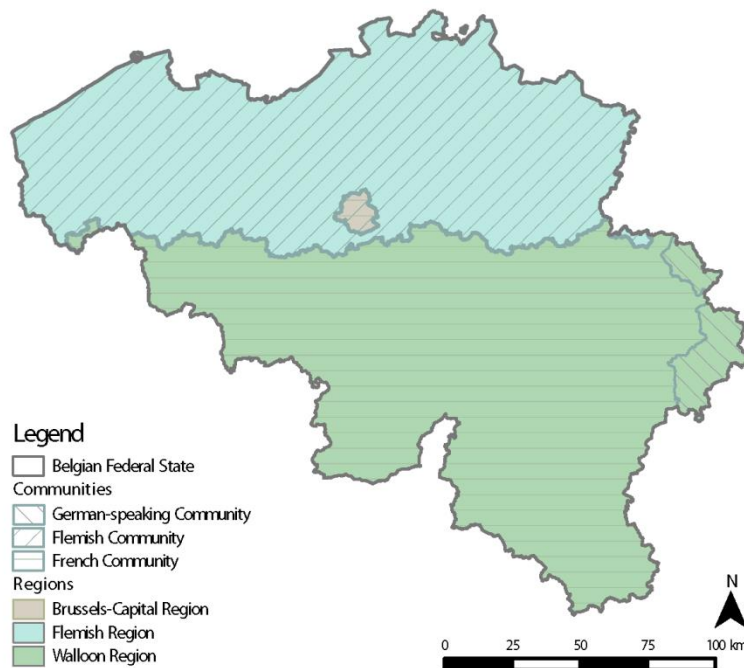


Figure 4-1 Belgian state structure with the Federal State, Regions and Communities

One of the responsibilities that was delegated by the Belgium Federal State to the Regions is immovable heritage, while the jurisdiction on movable heritage is handed over

to the Communities. As a consequence of this rather complex division of powers, a distinction has to be made between archaeological fieldwork and broader archaeological research. Archaeological fieldwork is under the aegis of the Minister of Immovable Heritage, who is in charge of the policy areas of Spatial Planning, Housing Policy and Immovable Heritage. Similar to the other twelve policy areas of the Flemish Government, this policy area consists of one department and multiple agencies. The department prepares the policy and provides support for the Minister, whereas the agency is responsible for implementing the policy. The Flanders Heritage Agency is consequently charged with the implementation of the heritage policy, but nevertheless in 2012 the Flemish Government, added policy support to the agency's responsibilities (Anneels 2014). In contrast, archaeological research is the responsibility of the Ministries of Culture, Scientific Research and Education.

In Flanders, a wide range of conventions and decrees, which were established "organically" (Anneels 2014, p. 17) applies. However, on 12 July 2013, the Flemish parliament adopted a new Decree on Immovable Heritage (called 'Onroerenderfgoeddecreet') that, among other things, endeavored both to assemble the piecemeal legislation and to further implement the European conventions in this domain (Vlaamse Regering 2013). One federal law on monuments and landscapes and three Flemish decrees on monuments, protected villages, archaeology, and landscape conservation were abrogated by this new decree (Vlaamse Parlement 2013). Although the European Conventions of Granada, Firenze and Valletta have already been ratified by Belgium and the ratification of the Convention of Faro is being prepared, this decree strives to implement them more thoroughly (Vlaamse Regering 2013). This decree focuses mainly on archaeological fieldwork. Regarding archaeological heritage, the European Valletta Convention of 1992, which is also called the Malta Convention, is considered the most important. The Convention was ratified by Belgium in 2010. Therefore, an outline of its content is given in Section 4.2.2.

The explanatory memorandum indicates eight basic ideas from which the new Immovable Heritage Decree originated (Vlaamse Regering 2013). In addition to integrating different legislation and further implementing the European conventions, the decree is intended to accomplish the following (Vlaamse Regering 2013, p. 8-12):

- embed the cycle of research – inventory – protect – manage – disseminate – preserve;
- ensure strategic policy planning;
- provide a flexible and simplified financing policy;
- increase involvement of local governments;
- deploy the immovable heritage administration as ambassadors of immovable heritage;
- adopt a new view on preservation.

These six main issues result in a more intensive integration of immovable heritage policy with other policy domains, particularly spatial planning. Inventories will play a substantial

role in this heritage policy because they form the basis for decisions on protection and preservation and for research questions. The decree defines five inventories that provide an overview of immovable heritage in Flanders, including an inventory of known archaeological zones (Vlaams Parlement 2013). This inventory gives an indication of places in Flanders where archaeological heritage that may have scientific or cultural historic value is likely present. The known archaeological zones will be recorded in the inventory with their name, characteristics and location. This last element enables access and management via a GIS. Making these inventories digitally accessible to not only governmental institutions but also the general public will increase public support for immovable heritage and its policy. This support will even be increased by involving local governments and declaring the immovable heritage administration ambassadors of immovable heritage (Vlaamse Regering 2013).

The fifth chapter of the decree is completely dedicated to archaeology and includes the establishment of a good practices guide for archaeological fieldwork. Its precise content needs to be decided by the Flemish Government; however, the order in pursuance (called 'Onroerenderfgoedbesluit') of this part of the decree (i.e., the chapter on archaeology) remains incomplete<sup>1</sup> (Vlaamse Regering 2014). Furthermore, the decree includes the procedures and obligations for archaeological fieldwork preceding a planning permit and archaeological fieldwork resulting from purely scientific interest (Vlaams Parlement 2013). These procedures form the subject of this study's deeper analysis of the decree; we therefore will defer presenting details.

## 4.2.2 European Valletta Convention of 16 January 1992

The European Valletta or Malta Convention dates back to 1992 and focuses on the protection of archaeological heritage (Council of Europe 1992). The convention advocates the preservation of archaeological heritage *in situ* or at its found location whenever possible. Therefore, archaeology should be integrated with spatial planning policy as much as possible. To facilitate this and to stimulate further information and knowledge exchange, inventories and maps of archaeological sites must be created and maintained. The member states of the Council of Europe and the other states party to the European Cultural Convention need to arrange for the total financial costs of archaeological research to be borne. Finally, the convention encourages the awareness of the general public (Council of Europe 1992).

## 4.2.3 The archaeological practice

Although ratified rather recently (in 2010), the concepts and consequences of the Malta Convention started to be adopted in Flanders since the mid-1990s and have been quite

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<sup>1</sup> Since 1 January 2016, the chapter on archaeology of the order in pursuance of the Flemish Immoveable Heritage Decree has gradually come into force. At 1 June 2016, this order in pursuance was completely operative (Vlaamse Regering, 2014). Because this research was conducted in 2014, the chapter on archaeology of the order in pursuance is not considered here.

noticeable since 2004 (De Clercq et al. 2012). As in other European countries, archaeological research has markedly changed due to the Valletta Convention (Kristiansen 2009). The number of archaeological operations, either with or without intervention in the soil, has grown significantly (Kristiansen 2009; De Clercq et al. 2012). Archaeology has changed in Belgium and Flanders from a merely academic activity toward heritage management by governmental institutions, which recently acted in the field, but are now “acting as an intermediary between public and private developers and archaeological operators” (De Clercq et al. 2012, p. 29). In Flanders, private archaeological companies were founded, and a ‘capitalistic’ market has developed (De Clercq et al. 2012). Anneels (2014) identified 23 private archaeological companies in Flanders, of which 19 applied for an excavation permit in 2013. Besides private companies, the archaeological sector in Flanders is made up by seven of the 308 Flemish municipalities, nine intermunicipal archaeological services or associations, four of the five Flemish Provinces, the Flemish Heritage Agency and three universities (Anneels 2014). For a more thorough overview of these different actors and their activities, we would like to refer the reader to Anneels (2014).

De Clercq et al. (2012) noted that, unfortunately, the development of such a capitalistic archaeological market has not resulted in an increased quality of recorded data and has produced only slightly better insights into the history of Flanders. This quality issue is only one disadvantageous aspect for which contract archaeology has been to blame. Development-led archaeology is confronted with great pressure of time, which causes two risks: (i) the use of a standardized methodology, which may be not suitable for the concerned site, and (ii) considering the excavator as a non-thinking technician, who does not make interpretations and only acquires data (Hodder and Berggren 2003, p. 424; De Clercq et al. 2012, p. 52). The latter has been acknowledged as one of the major concerns, as it implies that the interpretation process is more and more separated from the fieldwork (Lucas 2001; Hodder and Berggren 2003; Thomas 2006; Huvila 2014). The separation of data acquisition and analysis and so, the division between excavation and post-excavation activities is in a way logic, e.g., due to the working conditions on the field and the characteristics of the post-excavation tasks (Conolly and Lake 2006, p. 36). However, the complete archaeological workflow including the interpretation process has to be a continuum. Generally, the archaeological workflow starts with the digging, by either machine or hand, to identify deposits, which differ in their composition (Lucas 2001). These deposits are then described on record sheets, drawn to scale and numbered (Lucas 2001), with specific attention to the potential meanings and the relationships. Each artefact found in a deposit is labelled to retain the link with the found deposit (Lucas 2001). Once the excavation is completed, the artefacts are sent to specialists, who analyze them in detail and summarize their results in a report (Lucas 2001). Finally, these specialist reports are combined with the field record sheets to create a narrative about the site (Lucas 2001). It is important to understand that the way data are recorded and catalogued influences the future interpretation and research results (Labrador 2012). In 2006, Thomas (2006) noted that development-led or rescue archaeology has made the

situation in Britain worse in the sense that the excavations are described exhaustively, but mostly in a repetitive way and with “little regard to ‘making sense’ of the evidence that is collected” (p. 30). In the Flemish context, this criticism is shared by De Clercq et al. (2012, p. 52) who understand the justification from a commercial, administrative and even intellectual point of view, but question the focus on the creation of records in the process to understand the past. The nowadays widespread use of digital technologies – both digital recording systems and 3D data acquisition instruments – is contributing to this increasing emphasis on data recording. On the one hand, the use of digital technologies can close the gap between acquisition and analysis by enabling on-site analyses and allowing flexibility and interactivity (Hodder and Berggren 2003, p. 425; Conolly and Lake 2006, p. 37; Huvila 2014). On the other hand, digital technologies can widen this gap, since they encompass “further codification” and “systematization” (Hodder and Berggren 2003, p. 425). The increasing volume of born-digital data (De Roo et al. 2014) entails a “new digital pipeline”, which is characterized by “the flux of data from a digital domain to another” (Forte 2011, p. 8). The necessity of such a digital pipeline also referred to as complete digital documentation workflow has been pointed out, for instance with regard to reusability and accessibility (e.g., Katsianis et al. 2008; De Roo et al. 2014). However, the creation of such a digital archaeological workflow is challenging (De Roo et al. 2014). On the one hand a decent data infrastructure to manage this flux of digital data is required (Snow et al. 2006; Kansa et al. 2011; McKeague et al. 2012), and on the other hand an adequate training in the use of the system is essential (Hodder and Berggren 2003, p. 425). Snow et al. (2006, p. 959) argued that a cyberinfrastructure for archaeology should be conceived as “shared virtual workspaces in which researchers can collaborate virtually on larger tasks” and represented this in diagram form. To the best of our knowledge, in practice, such elaborated archaeological data infrastructures or virtual workspaces are not yet realized. Nevertheless, several initiatives are taken towards such digital infrastructures, even though focusing mostly on the final archiving phase, e.g., EDNA (the e-Depot for the Dutch Archaeology) in The Netherlands, DAP (Digital Archaeological Processes) in Sweden, ADS (Archaeology Data Service) in the United Kingdom and Arches worldwide. In the framework of these projects, business processes and information flows will undoubtedly be analyzed, although the results were not explicitly reported. Furthermore, according to our knowledge, similar analyses have not yet been the subject of scientific research.

## 4.3 METHODS

To study business processes and information flows and to answer the questions of how information is managed in archaeological processes and how this can be enhanced, an exploratory research methodology consisting of two parts was used. First, the research question was approached from a more theoretical viewpoint by deducing and analyzing the business flows included in the new Flemish Immovable Heritage Decree, which was

previously discussed. In this first part, attention was paid to actors and the type of information that is produced, recorded or used in a particular step of the process. In this manner, an understanding of how information should take part in the archaeological process was gained. Second, we moved from theory to practice by involving archaeologists from government, universities and private companies. A combination of informal interviews and an online survey focusing on data recording, registration and information exchange was used. Thus, insights into how information currently takes part in archaeological processes were obtained.

### 4.3.1 Document-analytical approach

For each of the different processes defined in the new decree, a flow chart was constructed. Within the flow chart, conventional shapes were used to distinguish between constituent processes (rectangle), decisions (diamond shape) and products (rectangle with curved base). Furthermore, colors were used to clarify the actors involved in each part of the process. As a result, the responsibilities of the different parties became apparent, and the most influential actor was easily detectable. In addition to the actors responsible for each process part or decision, other parties may be consulted or need to be informed of the outcomes. A responsibility assignment matrix can be deployed to investigate this. In this study, the so-called RACI matrix was used; this matrix refers to the four characters (R, A, C and I) appearing in the matrix of actors (columns) and tasks (rows). For each task, which is a decision or process step in the flow chart, the responsible actor is indicated with an R, the consulted actor is indicated with a C, and the informed actor is indicated with an I. Furthermore, a distinction can be made between responsible (R) and accountable (A), in which the latter owns the final responsibility. Finally, during the processes defined in the new Flemish Immovable Heritage Decree, different types of information, namely administrative or scientific information or a combination of both, are acquired, managed and exchanged. For each of the process parts, the type of involved information was analyzed.

### 4.3.2 Practical approach

Because the decree was recent, the effects on the archaeological practice in Flanders are rather limited to date. Therefore, the document-analytical approach resulted in the business process and information flows desired by the Flemish government. However, analyzing the current practice in the archaeological domain allows the detection of critical issues and points of improvement. Two techniques were used for this purpose: formal online questionnaire and informal interviewing.

An online inquiry into the current use of GIS and data standards in archaeology and the view on 3D GIS was set up from January to March 2013. To target a broad international public of archaeologists and people dealing with archaeological data, the questionnaire was available online. A wide range of individual archaeologists, organizations and institutions were contacted via e-mail to announce the survey and/or redirect this

information to colleagues. Calculating the response rate is therefore rather impossible. The margin of error for the sample population (171 respondents) is 7.5% at a confidence interval of 95% and a response distribution of 50%. The respondents were mainly working in Europe and North-America and had a mean age of 37. An overrepresentation of men (75.6% men vs. 24.4% women) and a slight overrepresentation of people holding a PhD degree as the highest degree can be found in the sample. Divided in five parts, the survey consisted of 45 questions of different types (closed, single answer; closed, multiple answer, semi-open and open questions). The main results of the questionnaire were described in Chapter 3. However, the answers provided by the respondents to the questions regarding data recording, storage, and exchange can aid the understanding of current archaeological practices. Nine of the 45 survey questions were therefore considered for a more elaborated analysis in this research in order to provide more insight in one of these information management actions. Seven survey questions were used as dependent variables (numbers 1-7 below), and two were used as independent variables (numbers 8 and 9 below):

1. Do you use GIS in your archaeological research or for archaeological applications? (*No / Sometimes, but not often / Yes, actively*)
2. How do you usually record archaeological data? (*Analog (on paper) / Digitally, immediately in the database, with the help of special developed recording forms / Digitally, immediately in the database, without recording forms / Digitally, in free text form or sketched (on tablet, PDA or laptop)*)
3. Do you record metadata for archaeological data? (i.e., how were the data obtained, when, data precision, etc.) (*No / Sometimes, but not consistently / Yes*)
4. Do you have any in-house spatial data format(s) and/or standard(s)? (*No / Yes, but only partially implemented / Yes, fully implemented*)
5. How do you mainly exchange heritage or archaeological information within your organization? (*A read only copy of our data / Data dump on CD, external hard disk, USB, ... as requested / Direct access to our systems / I don't / On paper / Other*)
6. How do you mainly exchange heritage or archaeological information with other organizations? (*A read only copy of our data / Data dump on CD, external hard disk, USB, ... as requested / Direct access to our systems / I don't / On paper / Over network (e.g., FTP, Dropbox, YouSendit,...)*)
7. How do you provide information to the public? (*Data dump in text file / I don't / On paper / Combination web and paper / Through the web / Other*)
8. Indicate your professional working field. (*Academia / Government: local level / Government: state or regional level / Government: national level / Private industry*)
9. Please specify your function. (e.g., field archaeologists, policy adviser, PhD student,...)

The open answers from the last question were transformed into eight categories (cultural resource manager, data manager, field archaeologist, field expert, heritage manager,

policy manager, project leader and researcher). The responses were then analyzed in more detail and associated with the role of the respondents, e.g., working as a project leader in a private company, as a researcher for the government, etc. For each dependent question, a Chi-square goodness-of-fit analysis was performed. The associations between the seven dependent and two independent variables were also statistically verified using a bivariate Chi-square analysis. However, the assumption that a maximum of 20% of the expected cell frequencies would be less than 5 was not met; therefore, a Fisher's Exact test was executed. These statistics were further completed with association measures, namely the contingency coefficient and the uncertainty coefficient. Finally, column proportions were compared via a Z-test using Bonferroni corrections. All of these calculations were performed in SPSS.

To complement the results of the questionnaire and to concentrate on the Flemish context, informal interviews were conducted either via personal talks or via e-mail. In a first stage, the Flemish Heritage Agency, the Province of East-Flanders, eight out of the nine intermunicipal archaeological/heritage services or associations, the archaeology department of Ghent University and 17 out of the approximately 23 private archaeological companies were contacted via e-mail (Table 4-1). These seventeen were listed as members of the umbrella organization 'Vlaamse Ondernemers in Archeologie' (VONA – Flemish Entrepreneurs in Archaeology) and indicated on the VONA-website ([www.vona.be](http://www.vona.be)) to perform field prospection and/or excavations. Next, an appointment was made for an informal interview on the techniques and tools used for data recording, storage and analysis. When an appointment was impossible for the respondent, information on rather open questions was requested via telephone or e-mail. As a result, almost 60% of the active archaeological parties in Flanders were contacted between January and April 2014; and an average response rate of 67.9% was achieved.

Table 4-1 Overview of the archaeological actors in Flanders and the number contacted and interviewed

Level	Number*	Contacted	Response	Response rate
Government of Flanders: Flanders Heritage Agency	1	1	1	100%
Provincial authorities	4	1	1	100%
City and municipal authorities	7	0	0	-
Intermunicipal archaeological services and association	9	8	5	62.5%
Private companies	Approx 23	17	11	64.7%
Universities	3	1	1	100%

\*The players and numbers are based on (Anneels 2014)



## 4.4 RESULTS

### 4.4.1 Actors and information in archaeological business processes

Based on the new Flemish Immovable Heritage Decree, two broad archaeological processes can be distinguished: (i) archaeological fieldwork in the case of a planning permit (hereinafter called process A) and (ii) archaeological fieldwork in consideration of a scientific research question (process B) (Vlaams Parlement 2013). In addition, a third process (C) can be deduced from the decree: preserve, conserve, make available for research and disseminate archaeological ensembles. This third process is part of the two previous processes, but because it concerns the storage and dissemination of the data, i.e., the future of the acquired information, it is treated separately in this study. Moreover, it can be conceived as a sequel of the previous processes.

The comparison of the flowcharts of the two main processes (Figure 4-2 and Figure 4-3) revealed that they share multiple steps of the business flow. Before starting the (preliminary) investigation, a permit request has to be submitted. If the permit is denied, an appeal can be lodged with the Flemish Government. The only difference between the two is that, in process A, in addition to the Flanders Heritage Agency, the certified immovable heritage municipality concerned can decide the validity of the permit request. A second common part in both processes is announcing the start of the investigation (excavation in process A and investigation in process B), executing the fieldwork, writing an archaeology and final report and, finally, opening up the final report digitally. It follows from these two common parts that process B is more-or-less a simplified version of process A. The latter includes an additional step between the permit request and the excavation announcement. Due to a preference for in-situ preservation dictated by the European Malta Convention, archaeological investigations involving groundwork and thus possible destruction are avoided as much as possible. Therefore, the first process that is executed once permission is obtained is a preliminary investigation with as little groundwork as possible. The results are then documented in the so-called 'Archaeology note' (*Archeologienota*), which is, in most cases, a necessary document for a building permit request in consequence of the new decree because it provides well-founded advice on the necessity of an archaeological excavation preceding the groundwork for a construction intervention.

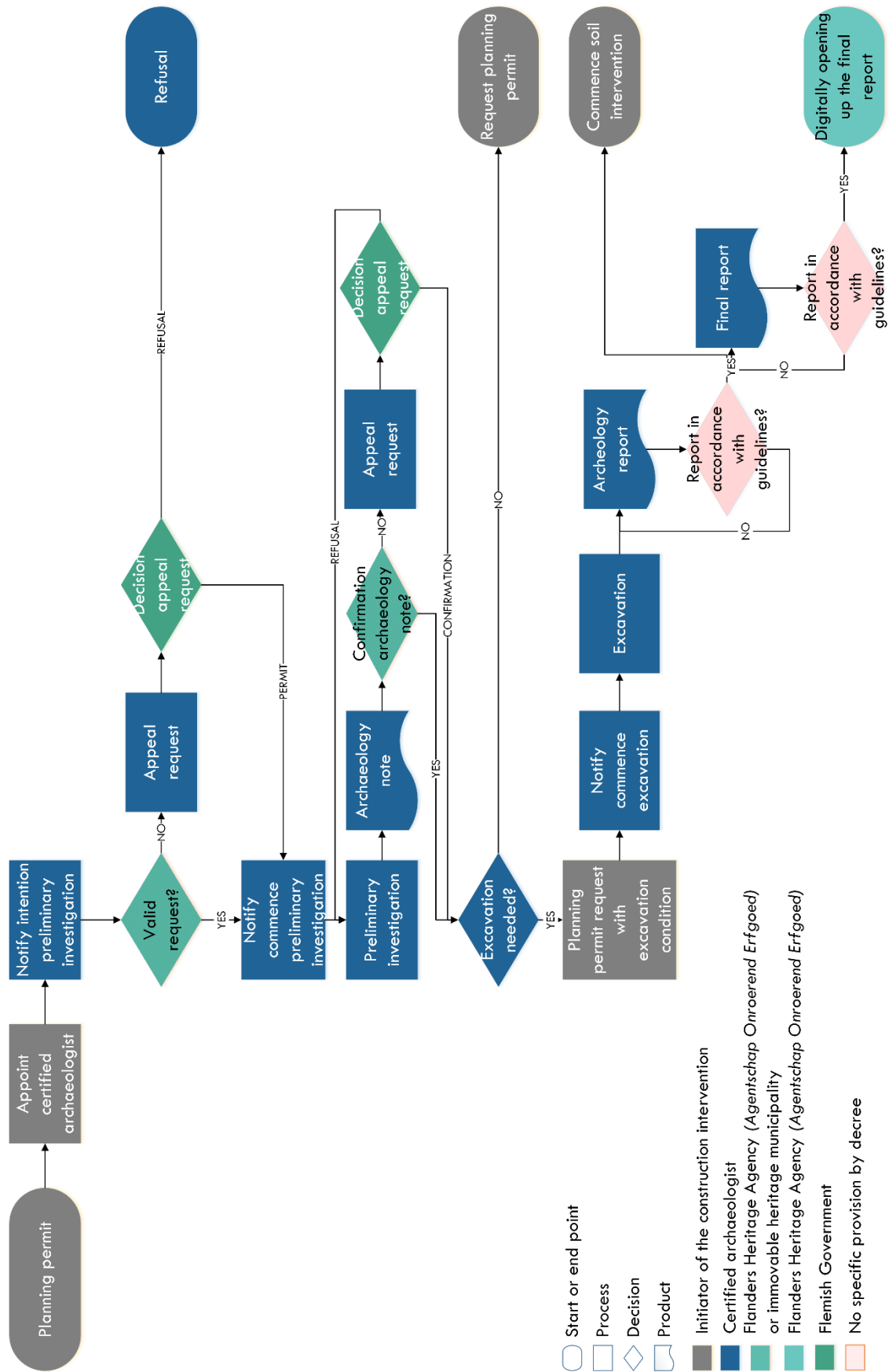


Figure 4-2 Flowchart of the process described in the new Flemish Immovable Heritage Decree for archaeological fieldwork in case of a planning permit (based on Vlaams Parlement 2013)

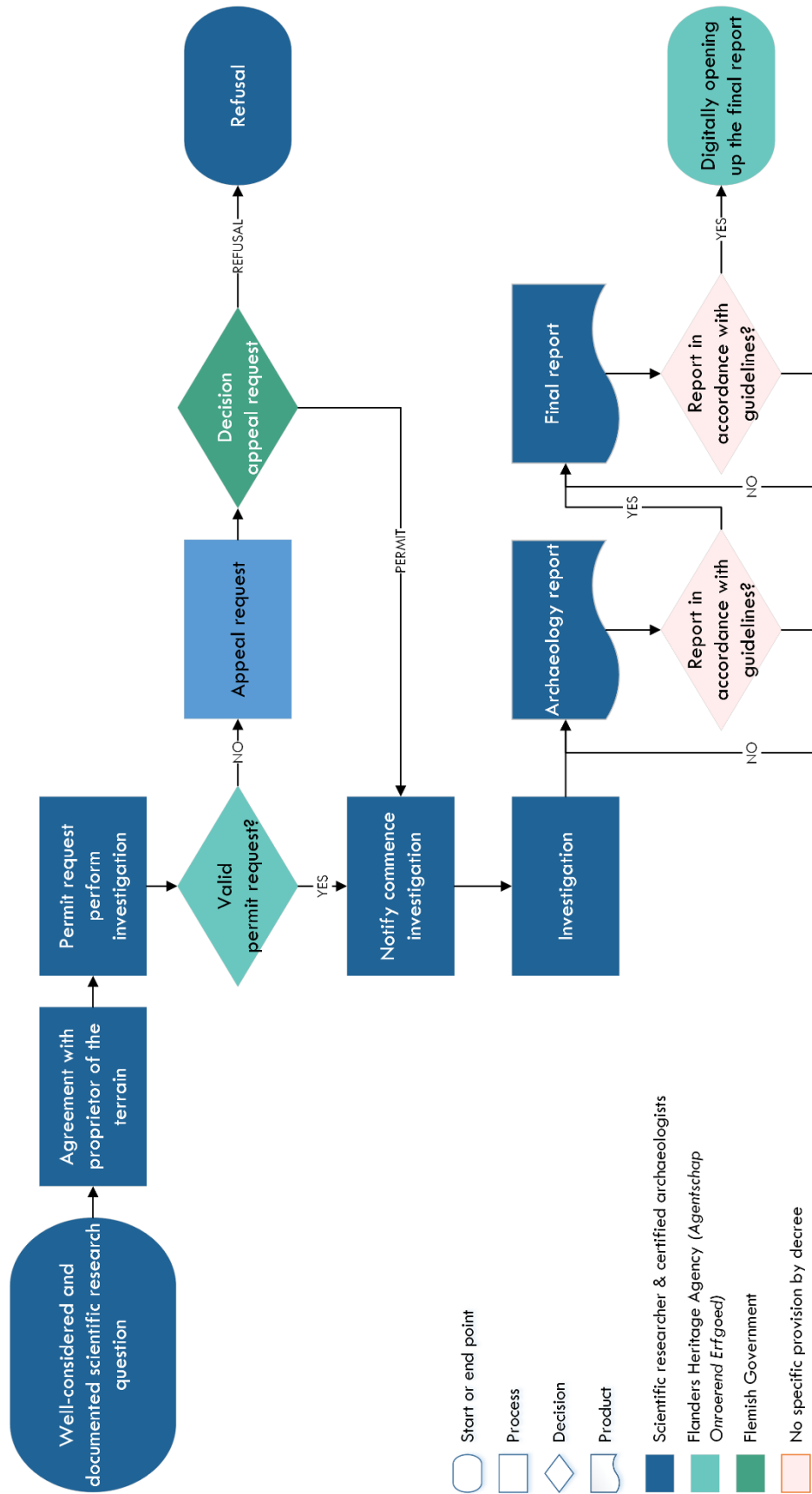


Figure 4-3 Flowchart of the process described in the new Flemish Immovable Heritage Decree for archaeological fieldwork in consideration of a scientific research question (based on Vlaams Parlement 2013)

Table 4-2 RACI matrix for the archaeological fieldwork process in case of a planning permit (R: responsible, A: accountable, I: informed, C: consulted) (based on Vlaams Parlement 2013)

Description	Certified archaeologist	Flanders Heritage Agency	Certified immovable heritage municipality	Initiator of construction intervention	Flemish Government	Flemish Commission on Immovable Heritage
Appoint certified archaeologist	C/I			R/A		
Notify intention for preliminary investigation	A/R	I	I	C/I		
Decision request preliminary investigation	I	A/R	A/R			
Appeal request	A/R	I			I	
Decision appeal request	I	I			A/R	C
Notify commence preliminary investigation	A/R	I	I	C/I		
Preliminary investigation and archaeology note	A/R	I		C/I		
Confirmation archaeology note	I	A/R	A/R	I		
Appeal request decision archaeology note	A/R	I			I	
Decision appeal request	I	I			A/R	C
Notify commence excavation	A/R	I	I	C/I		
Excavation and archaeology report	A/R	I				
Final report	A/R	I				
Digitally opening up of the final report		A/R				

The RACI matrices for processes A and B are provided in Table 4-2 and Table 4-3, respectively. From the RACI matrices and flowcharts (Figure 4-2 and Figure 4-3), it is easily observable that more actors are involved in process A than in B, e.g., the certified immovable heritage municipality<sup>2</sup> and the initiator of the groundwork for the construction. In this regard, more informed and consulted parties can be noticed in process A, as determined through an examination of the two RACI matrices (Table 4-2 and Table 4-3). This is mainly because the initiator of the construction intervention needs to be informed of the progress of the archaeological investigations. In both processes, the certified archaeologist, possibly a scientific researcher, takes most of the responsibility. An almost

<sup>2</sup> The Flemish Immoveable Heritage Decree introduces the concepts of 'certified archaeologist', 'certified immovable heritage municipality' and 'certified immovable heritage depot'. The precise conditions to be certified are established by the Flemish Government in the order in pursuance of the Immoveable Heritage Decree (Vlaamse Regering, 2014).

continuous interaction exists with the Flanders Heritage Agency in which they alternatively have responsibility or are informed. However, the responsibilities of this agency are partly transferred to the certified immovable heritage municipalities in process A. In both matrices, the responsibility (R) and accountability (A) are combined. For the role of certified archaeologist, accountability will lie with the project leader, whereas the responsibility can be split with the archaeologists assisting in the investigation. The same applies for the Flanders Heritage Agency.

Table 4-3 RACI matrix for the archaeological fieldwork process in consideration of a scientific research question (R: responsible, A: accountable, I: informed, C: consulted) (based on Vlaams Parlement 2013)

Description	Scientific researcher & certified archaeologist	Flanders Heritage Agency	Proprietor terrain	Flemish Government	Flemish Commission on Immovable Heritage
Well-considered and documented scientific research question	A/R				
Permit request to perform excavation	A/R	I	C		
Decision on permit request	I	A/R			
Appeal request	A/R	I			
Decision appeal	I	I		A/R	C
Notify commence investigation	A/R	I			
Investigation and archaeology report	A/R	I			
Final report	A/R	I			
Digitally opening up of the final report		A/R			

The third process addresses the actions required with the results of the archaeological investigations once these are completed. The flowchart of this process is given in Figure 4-4, and the RACI matrix is provided in Table 4-4. The two reports created in processes A and B, the archaeology and final report, in combination with the material archaeological finds, constitute the archaeological ensemble (Vlaams Parlement 2013). Because the reports both form the context in which the investigation has taken place and hold a description of the analyses, they have to be maintained together with the remains. Due to the destructive nature of archaeological excavations, this archaeological ensemble is almost the only relic. With regard to further research and thus information exchange, it is important to know where this ensemble is stored. Process C includes the step to inform the Flanders Heritage Agency about a change in the repository location or proprietor of the ensemble (Table 4-4 and Figure 4-4). Consequently, a register of the repositories and proprietors should be maintained by this agency. The decree indicates that the

proprietor of an archaeological ensemble must preserve and conserve the ensemble. The proprietor is either the one who executed the archaeological investigation or a certified immovable heritage depot. Furthermore, the proprietor is also required to make the ensemble available for research and to (partly) disseminate it to the public.

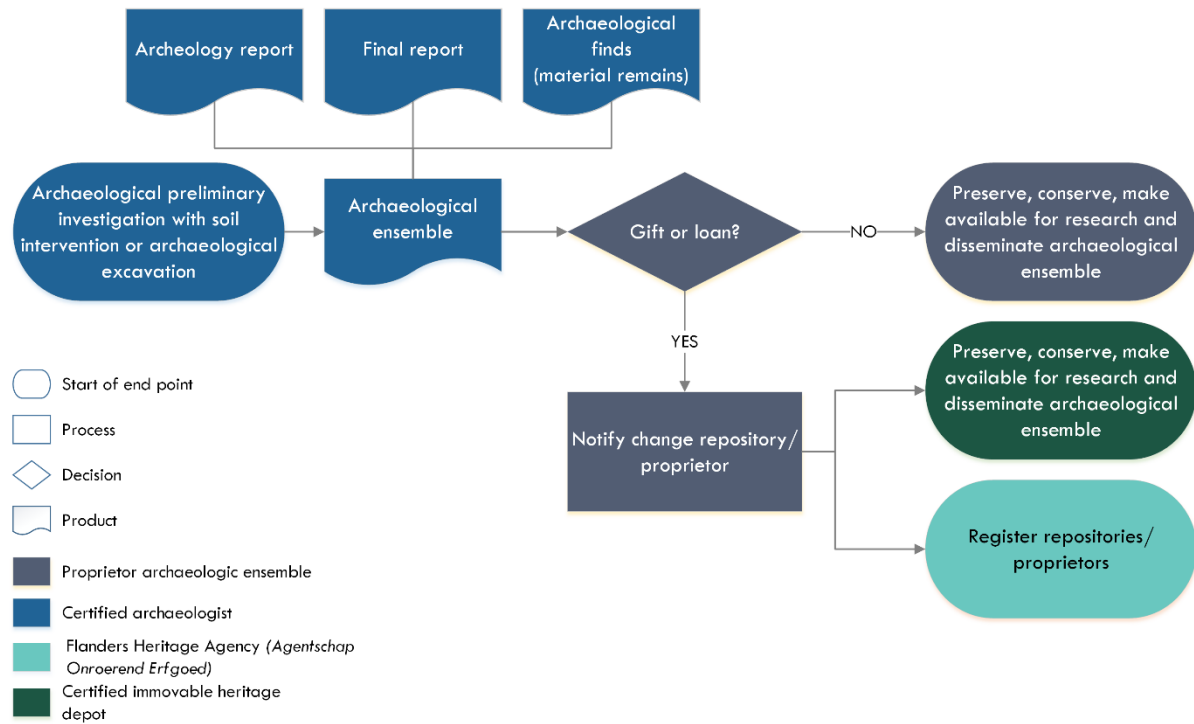


Figure 4-4 Flowchart of the process described in the new Flemish Immoveable Heritage Decree to preserve, conserve, make available for research and disseminate archaeological ensembles (R: responsible, A: accountable, I: informed, C: consulted) (based on Vlaams Parlement 2013)

Table 4-4 RACI matrix for the process to preserve, conserve, make available for research and disseminate archaeological ensembles (R: responsible, A: accountable, I: informed, C: consulted) (based on Vlaams Parlement 2013)

Description	Certified archaeologist	Flanders Heritage agency	Certified immovable heritage depot	Proprietor archaeological ensemble
Create/Compose archaeological ensemble	A/R	I		I
Preserve archaeological ensemble	C	I		A/R
Notify change in repository/proprietor		I	A/R	A/R
Register repositories/proprietors		A/R	C	C

In previous paragraphs, the archaeology note, archaeology report, final report and archaeological ensemble were indicated as products of the processes (Figure 4-2, Figure

4-3 and Figure 4-4). In addition to these, some implicit outcomes are also included in the three processes. With respect to processes A and B, the preliminary investigation archive and excavation archive are two important products that are not referred to in the new decree. These archives include databases or registration forms to use in the field as well as during analyses and the production of the reports. Furthermore, they contain other relevant information, such as topographic, historic and other types of maps, information from or references to historic resources, etc. Assuming that the order in pursuance does not prescribe any regulation on the deposition or preservation of these archives<sup>3</sup> because the decree does not mention these additional details, information on the archaeological heritage may be difficult to access or may even disappear. Another outcome of processes A and B is an inventory of the prospected or excavated zones. Although this inventory corresponds to the inventory of known archaeological zones defined by the decree (Vlaams Parlement 2013), it is not mentioned explicitly in the procedures described in the decree. The third implicit outcome is the range of products created to encourage the consciousness of the general public, including various items such as brochures, websites and information boards.

During the three processes and thus for the creation of the above-mentioned outcomes, a variety of information is acquired, managed, analyzed and exchanged. This information concerns mainly administrative, spatial and thematic or scientific information, although in most process steps, a combination of two or all of these categories is involved. In the first important step in processes A and B, the submission of an investigation request, administrative and scientific information are combined. First, this request should contain administrative details, such as the details of the certified archaeologist (legitimization number and address), and cadastral data (e.g., parcel numbers). It should also contain details of the initiator of the construction intervention in the case of process A and the agreement with the proprietor of the terrain in the case of process B. Second, scientific information on the proposed method should be provided. Furthermore, the request includes the reason for the investigation—the character of the construction works or the reason why excavation is preferred to preserving. During the actual investigation in the field, spatial and thematic data are acquired, and these data are then analyzed and possibly integrated with other spatial and thematic data. These results then become the subject of the archaeology note, archaeology report and final report. The archaeology report leans closely on the permit request and integrates the administrative information with the description of the method used and the first results, which are considered scientific data. Giving advice on the necessity of an archaeological excavation and the required measures, the archaeology note includes the precise location of the concerned zone through plans and maps and the results of the preliminary excavation. Thus, spatial and scientific information are combined, but administrative information, such as details of the responsible certified archaeologist, and cadastral information are also used. Finally, the

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<sup>3</sup> This assumption was confirmed after this research was conducted when the chapter on archaeology of the order in pursuance of the Flemish Immovable Heritage decree was established.

final report has to be published according to the guidelines of good practice defined by the Flemish Government, which so far does not exist<sup>4</sup>. We assume that the final report will include a more detailed description of the spatial and scientific information and will provide the results of the analysis of this information. To conclude, it should be mentioned that the administrative information sometimes comprises spatial data. The location of the investigation specified, for instance, in the permit request is mostly referenced by cadastral parcel numbers; however, cadastral and topographic maps and topographic coordinates will also be included.

#### 4.4.2 Online questionnaire and informal interviews

The use of GIS has become established in archaeology, as shown by Figure 4-5a. Despite the acceptance of this type of digital technology, 45% of the survey respondents still record data on the field analog, i.e., on paper (Figure 4-5c). Most respondents indicate that they have spatial data formats or standards within their organization. For 53%, this standard is, moreover, fully implemented (Figure 4-5d). Although metadata are indispensable information with regard to the future exchange and reuse of archaeological data, recording these metadata is not a common practice. Figure 4-5b indicates that only 43% of the respondents consistently register metadata.

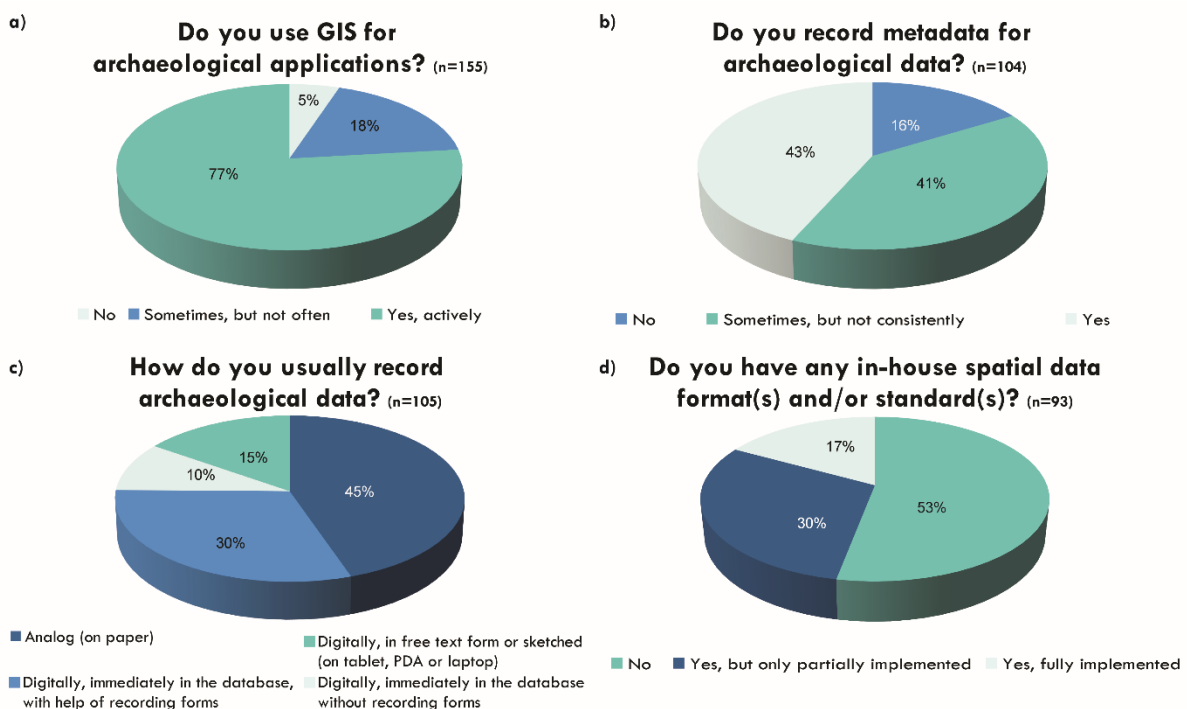


Figure 4-5 Charts displaying the survey results regarding a) the use of GIS, b) metadata and c) data recording, and d) the use of data formats

<sup>4</sup> On 1 January 2016 the competent minister has adopted the 'Code of Good Practice for Archaeology and Metal Detection'.



With respect to data exchange, three questions were selected from the online survey. These probe the medium used for data transfer within the organization (Table 4-5), to other organizations (Table 4-6) and to the public (Figure 4-6). Within the organization, archaeological information is mainly directly accessible thanks to the network structure of the organization (Table 4-5). Next, data dumps on mobile storage devices, such as USB sticks, are the second-most-used method of information exchange and even the first one for information transfer to other organizations. Additionally, in both cases, paper still occupies the third position as a transfer medium, with values of 13% and 17%. Paper dominates even the information exchange to the public, although the share belonging to the Internet is coming close, with 32% compared with 41% (Figure 4-6).

Table 4-5 Archaeological data exchange mediums within the organization

How do you mainly exchange heritage or archaeological information within your organization? (n=93)	
A read only copy of our data	3%
Data dump on CD / external hard disk / USB / ... as requested	34%
Direct access to our systems	42%
I don't	2%
On paper	13%
Other	5%

Table 4-6 Archaeological data exchange mediums with other organization

How do you mainly exchange heritage or archaeological information to other organizations? (n=93)	
A read only copy of our data	6%
Data dump on CD / external hard disk / USB / ... as requested	35%
Direct access to our systems	3%
Over network (e.g. ftp, dropbox, yousendit,...)	22%
I don't	5%
On paper	17%
Other	11%

### How do you provide information to the public? (n=104)

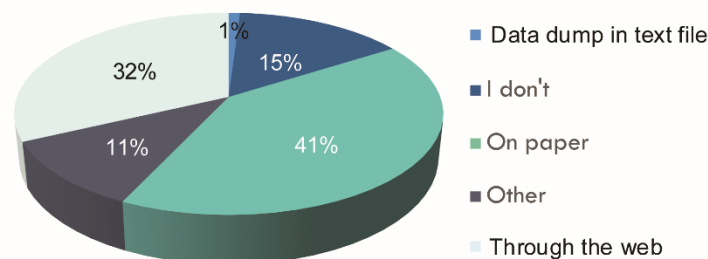


Figure 4-6 Archaeological data exchange mediums to the public

For each of the seven questions, a null hypothesis  $H_0$  of equally spread data among the answer categories is considered. A chi-square goodness-of-fit test evaluates this hypothesis against the alternative. For all of the tests, the assumptions of maximum 20% of the cells having a frequency less than 5, and having a minimum cell frequency of 1 are met. Having a value of less than 0.001 for the asymptotic significance,  $H_0$  can be rejected at the 0.05 significance level in each of the seven cases. Thus, the observed differences and trends in the answers are real and not due to sample errors.

In addition to these observations, crosstabs are created to relate the questions analyzed above with the employer type (i.e., academia, government, private company) and the job title (e.g., researcher, cultural resource manager). The null hypothesis is that the two involved variables are independent; the alternative is that there exists an association between the two variables. Because the assumptions for a chi-square test are not met, Fisher's exact tests were performed for the 7x2 variable combinations. However, no Fisher's exact test statistics could be calculated for the combinations with the variable regarding data exchange to other organizations. Instead, a Monte Carlo algorithm was used in these two cases. The significances for these tests are provided in Table 4-7. For only four of the 14 combinations, which are highlighted in Table 4-7, the null hypothesis can be rejected at the 0.05 significance level. For these, the values and the significance of their contingency coefficients and the uncertainty coefficients are calculated (Table 4-7 and Table 4-8). All four combinations have a medium association strength (contingency coefficient of  $\pm 0.5$ ), which is significant at the 0.05 level (Table 4-8). The uncertainty coefficient varies between 0.122 and 0.187 ( $p < 0.05$ ), indicating that, based on knowledge of the job title or employer type, the error in predicting the values of the other variables can be reduced by 12 to 19% (Table 4-8).

Table 4-7 Fisher’s exact test statistics for the associations

	GIS use	Archaeologic recording	Metadata recording	Spatial data format	Exchange within organization	Exchange to other organizations	Information to public
<b>Job title</b>	0.974	0.26	0.006	0.514	0.085	0.775*	0.682
<b>Employer type</b>	0.736	0.019	0.005	0.343	0.046	0.108*	0.355

\* Monte Carlo test statistic

Table 4-8 Contingency and uncertainty coefficient values and significances

			Archaeologic recording	Metadata recording	Exchange within organization
<b>Job title</b>	Contingency	Value		0.535	
		Exact Sign.		0.029	
	Uncertainty	Value		0.187	
		Exact Sign.		0.007	
<b>Employer type</b>	Contingency	Value	0.483	0.459	0.55
		Exact Sign.	0.041	0.022	0.03
	Uncertainty	Value	0.122	0.141	0.143
		Exact Sign.	0.029	0.006	0.038

From the column proportions comparisons, little information can be deduced regarding the rows and columns responsible for the four relationships described above. With respect to the relationship between metadata recording and job title, the proportion of heritage managers who do not record metadata is greater than the proportion of researchers who do. Furthermore, the proportion of researchers who indicate they record metadata consistently is greater than the proportion of field archaeologists who do. The tests associated with metadata recording and the employer type show that the proportion of people employed in local government and who sometimes record metadata is greater than the corresponding proportion of people working in academia or private industry. National-level governmental employees tend to record archaeological data digitally in a database without recording forms more frequently than academics do. In private industry, direct access to systems to exchange information within the organization has a greater proportion than it has in academia. Finally, no other significant proportion differences at the 0.05 significance level could be detected. One of the reasons for this finding is the rather large number of categories that were not used in the comparisons because their column proportion was either zero or one. This is due to the limited number of respondents who answered the questions regarding job title and employer type and the number of categories available for these two variables.

The interviews with archaeological organizations active in Flanders revealed that the use of GIS is becoming increasingly prevalent, since 14 of the 19 parties indicated to use or plan to use this tool. However, the organizations all indicated that the time available for analysis is limited, and thus, the application of GIS is rather basic, e.g., creating (2D) plans. This is due to the capitalistic market and the fact that government is not explicitly asking for specific analyses, such as a spatial relationship analysis, but only for reports and lists of findings. Similarly, most organizations record spatial archaeological information in 3D but reduce this to 2D outcomes. Further 3D models or analyses are not performed, although these could provide interesting information. Time pressure is also reported to cause the postponing of the reporting of excavations. In this regard, different interviewees noted that the deliverables are of varying quality because no rules are defined for the preservation of recording forms and the governmental quality control appears to be lacking. Another issue raised by several organizations is the lack of supply by the government of a standardized database or exchange format for their data. Currently, three groups of organizations can be distinguished with regard to data recording in the field. The first group contains the organizations that record their data in an analog manner, mainly through the use of paper recording forms. The second group uses digital media, such as tablets and laptops, to register their data but does not use a central database. Thus, new databases are created for each new project. The third group registers data digitally in a central database. This last group has made large investments in the hope that they will prove lucrative. The two first groups share the same reticence to invest and hope that the government promulgates a database template or exchange standard in the near future.

## 4.5 DISCUSSION

In the present study, we show that there exist three business processes and corresponding information flows in the Flemish archaeological context: (i) archaeological fieldwork in the case of a planning permit, (ii) fieldwork resulting from a purely scientific question, and (iii) the preservation, conservation, making available for research and dissemination of archaeological ensembles. It is noteworthy that the second process (scientific questions) is more or less a simplification of the first process (i.e. planning permit). In addition, the third process can be considered a sequel to the other two processes because it concerns the future management and use of archaeological data.

Within these processes, different actors participate, two of whom play a key role: the certified archaeologist and the Flemish Heritage Agency. An almost continuous interaction between these two key actors exists within these processes, either formally via a report or informally via personal communication. What is important to understand is that both are generally organizations rather than single persons. With the increase of the capitalistic market, private archaeological companies were founded (De Clercq et al. 2012; Anneels 2014), and the role of certified archaeologist can thus be divided into the participating field archaeologists and the project leader of the investigation. This

contributes to the separation of fieldwork and interpretation as reported by Hodder and Berggren (2003), Huvila (2014) and Thomas (2006) and is proven during the informal interviews by reporting the postponing of the reporting due to pressure of time. Importantly, the project leader answers to the Flemish Heritage Agency for the interaction. The responsibility of the Agency is delegated to local governments in the process concerning archaeological fieldwork in case of a planning permit. However, we should note that this responsibility is, comparatively speaking, very limited, namely with respect to the decision regarding a preliminary investigation permit and the confirmation of the archaeology note. Furthermore, it is important to understand that other actors, who are not mentioned explicitly in the decree, also participate in the processes. One thinks of the general public, such as tourists and local residents as well as museums, data managers of archaeological companies, etc., as implicit participants.

In the new decree, four outcomes are explicitly mentioned: the archaeology note, the archaeology report, the final report and the archaeological ensemble. For the production of these deliverables as well as for taking decisions during the processes, the information acquired during previous process steps is required and needs often to be integrated. Three categories of information types were detected in this study: administrative, spatial and scientific information. Although treated as a separate category, administrative data often have a spatial nature; for example, a cadastral parcel can be referred to by its administrative number or by its spatial extent. Furthermore, the involved scientific data are mostly linked to a spatial location, either by coordinates or topologically. Note that most of the information in the archaeological processes has a geographical character. In this regard, total station, GPS, laser scanning, etc. have been increasingly used for the recording of spatial data. This 3D-born digital spatial data are, however, reduced to 2D in most cases due to lack of time and money for further analyses. Furthermore, the geographical nature of archaeological information enables the integration in a GIS to determine the spatial relations. In archaeology, GIS are used frequently, although not extensively because of time and money restrictions. The use of GIS and digital spatial data acquisition shows that the influence of increasing computerization and of new technologies (Conolly and Lake 2006; Forte 2011) has also been felt in the Flemish archaeological context.

In contrast, these trends are not strongly affecting how scientific data are recorded in the field. This data recording is still frequently performed either in analog form or digitally without recording forms, which could hamper data consistency for different reasons. First, transcription errors may occur while inputting the data in a database. Second, other types of data and data containing different vocabularies can be acquired by different archaeologists and during different projects. This data inconsistency may grow even worse when metadata are not recorded consistently. From the questionnaire and the interviews, it became clear that metadata registration is a key issue in the Flemish as well as the international archaeological field. In contrast, multiple Flemish archaeological organizations are in favor of a database template or exchange standard for data and metadata recording to be provided by the Flemish government. This could result in a first

part of the new digital pipeline or archaeological data infrastructure (Snow et al. 2006; Forte 2011). Furthermore, this could have the added advantage of increasing quality and providing an easier setup for a quality control system. This lack of quality control is an issue reported by several archaeological organizations and is a consistent result from the work conducted by De Clercq et al. (2012).

Once recorded, data need to be managed and conserved. The new decree does not give any indication regarding the preservation or disposition of the recording forms and investigation databases. Although information exchanges are likely to be done via digital mediums, such as data dumps and direct system access, paper still holds a large share for data exchange in general. This will continue the existing difficulties associated with reusability and even accessibility. This observation is in excellent agreement with previous findings (Snow et al. 2006; McKeague et al. 2012) and constitutes an obstruction for the digital data flux, which has been envisaged by many researchers (Katsianis et al. 2008; Forte 2011). An interesting feature is that the Internet is the second-most frequently used medium for data exchange toward the public, which makes it a point of interest for the future.

From the previous discussion on the way archaeological information is currently managed in Flanders, it appears possible to enhance the information management. The development of an archaeology-specific data infrastructure may mitigate the listed issues and risks, and should take into account the characteristics of the business processes and information flows determined in this study. In particular, the multiplicity of actors and their respective purposes may influence the framework. Due to the geographical nature of the involved information, GIS appear to be able to play an important role throughout the entire lifetime of the described processes. In our opinion, a geodatabase needs to form the basis of an archaeological data infrastructure and can be complemented with a traditional desktop GIS and the development of a web-based GIS. The latter is experiencing tremendous growth in recent years and holds potential for a completely digital archaeological workflow. First, data are available always and everywhere and can be updated continuously, on condition that Internet connection or network access is available. Second, data can be queried and exchanged. Third, basic analyses are immediately possible in the field. Fourth, most geodatabases provide concurrent access and edit possibilities; thus, multiple actors can record, edit, and analyze the data simultaneously. Fifth, thanks to Google Maps and others, web-based mapping applications have reached the general public, making them a promising tool to encourage consciousness in archaeology. An archaeological data infrastructure based on one or more central geodatabases and conceived as a web-based GIS will function as a shared virtual workspace, and agrees with the ideas proposed by Snow et al. (2006) regarding cyber tools for archaeology. Furthermore, the pros and cons of 3D versus 2D data need to be investigated for each process step or (now) infrastructure component. Only if 3D has significant advantages compared to 2D can it be included in the component in question. In general, we suggest the use of 3D for research and analysis purposes or even for tourism, but for most policy decisions, detailed 3D data are not

necessary and would only result in extremely high storage costs. Finally, using free and open-source software (FOSS) is desirable because archaeology is thought by many to be a waste of money and is of only limited interest to large software companies. Due to the availability of FOSS, the design of the infrastructure and applications will be customizable by the users, which may be useful for Flemish organizations that have already implemented their own infrastructures. Thus, a cost- and time-efficient management, research and policy infrastructure can be set up.

## 4.6 CONCLUSION

By means of an exploratory study, consisting of a document-analytical and a practical approach, the business processes and information flows in the Flemish archaeological context were studied and evaluated in the light of potential enhancements. The first part included the study of the new Flemish Immovable Heritage Decree and the according creation of flow diagrams and responsibility assignment matrices. The second part then complemented this by the analysis of both a formal questionnaire and informal interviews. In this manner, three business processes could be detected in the decree: (i) archaeological fieldwork in the case of a planning permit, (ii) fieldwork resulting from a purely scientific question, and (iii) the preservation, conservation, making available for research and dissemination of archaeological ensembles. Although new digital technologies such as total stations and GPS are increasingly used in archaeology, this evolution does not strongly affect the fieldwork, where data is to a large extent still recorded analogously. The capitalistic market causes pressure of time, which has a negative influence on the quality of the research. Interpretation and data acquisition are separated and reporting is postponed, while data analysis is reduced to a minimum. Furthermore, the decree does not define rules for the preservation of recording forms or databases, which hampers data accessibility and reusability. These issues may be restricted or even put right by developing an archaeological data-infrastructure. As the information involved in the business processes has a geographical character, we suggest a geodatabase in combination with web-based GIS tools as basis for a cost and time efficient management, research and policy infrastructure.

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# 5

## SPATIO-TEMPORAL DATA AS THE FOUNDATION OF AN ARCHAEOLOGICAL STRATIGRAPHY EXTRACTION AND MANAGEMENT SYSTEM

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Modified from: DE ROO B., STAL C., LONNEVILLE B., DE WULF A., BOURGEOIS J., DE MAEYER P. 2016. Spatiotemporal data as foundation for archaeological stratigraphy extraction and management system. *Journal of Cultural Heritage*, 19(C), 552-530.

### ABSTRACT

Transforming relationships between stratigraphic units of an archaeological excavation to a formal model like the Harris Matrix is a challenging task. This chapter elaborates on the transformation of 2D polygons of stratigraphic units to a formal representation. An automated procedure for the construction of Harris Matrices serves as a clear overview of an excavation while retaining spatio-temporal complexities of a site. While manually composing Harris Matrices for stratigraphic sequences is common practice, it is a time-consuming and challenging approach. The proposed procedure should overcome this issue through the iterative top-down validation of all possible spatial relationships between each stratigraphic unit. Furthermore, the integration of a formal site model with cartographic, semantic and virtual representations of each stratigraphic unit will facilitate the interpretation of various features and phenomena of excavations as well as generating a stronger understanding of scenes as a whole. In this chapter, a methodology for the automated reconstruction of Harris Matrices based on 2D polygons of stratigraphic units is developed, a set of validation rules for the evaluation of candidate relationships between different stratigraphic units is defined and a user interface is implemented to facilitate interactions with and visualizations of the formal model.

## 5.1 INTRODUCTION

As archaeological excavations are destructive by nature, detailed and accurate documentation involving the use of rapid registration techniques is of paramount importance. An emphasis on data recording has been reinforced on the one hand by the rise of contract archaeology and by its associated time pressures (Berggren and Hodder 2003) and by the widespread use of digital recording and 3D acquisition systems on the other (Dell'Unto et al. 2013; Forte 2014). This form of data recording affects future interpretations of excavations (Berggren et al. 2015), which are mainly designed to reconstruct site formations through the removal of soil components (Traxler and Neubauer 2009; Berggren et al. 2015). These components, which can be identified via observable discontinuities in shapes, colours, textures, etc. (Lucas 2001; Barceló et al. 2003; Traxler and Neubauer 2009), form a “temporal trajectory” (Barceló et al. 2003, p. 86). Such components are recorded not only semantically and topographically but also stratigraphically using spatial relationships (e.g., ‘above’, ‘below’, ‘none’ and ‘equal’) (Harris 1979; Harris 1989; Traxler and Neubauer 2009). These spatial associations are respectively translated into the following temporal topological relations: ‘younger than’, ‘older than’, ‘unknown’ and ‘contemporaneous’. The latter allows for the creation of stratigraphic sequences, which are typically graphically depicted via the Harris Matrix (Harris 1989). This analysis tool first employs information recorded in the field and then removes all superfluous information (e.g., exact locations and redundant relations) to arrive at a directed graph that represents a chronological succession (Harris 1989; Desachy 2012).

In taking into account intensifying time pressures, computer tools can assist in the time-efficient documentation of archaeological stratigraphy (Dell'Unto et al. 2013; Forte 2014; Stal et al. 2014). Tools that document archaeological stratigraphy have been created since the Harris Matrix was first developed in the 1970s (Herzog 1993; Traxler and Neubauer 2009; Desachy 2012; Motz and Carrier 2013). Most tools start from textually recorded stratigraphic relationships between deposits and interfaces. Graph editing techniques in combination with consistency checks form the main features of these applications. Although spatial data on stratigraphic units are recorded during excavation (Berggren et al. 2015) and constitute the primary information source for the creation of the Harris Matrix, it is surprising that they are not used or linked to in any of these tools. As a result, both the automated construction of the Harris Matrix and explicit correlations between the matrix and excavation plans are absent in current practice. An exception is the Harris Matrix Composer developed by Traxler and Neubauer (2009), who created a GIS link to allow for the management of digital archaeological data for analysis. Another link between spatial information and the Harris Matrix can be found in the management system developed by Stal et al. (2014) for the Greek site of Thorikos. In this system, a static Harris Matrix constitutes an interaction link between user and management features including 3D reconstruction models, map interfaces and metadata (Stal et al. 2014). These two studies illustrate the advantages of using a combination of

stratigraphic and spatial information. Furthermore, this integrated approach facilitates the further management and analysis of archaeological information.

This chapter determines how spatial relationships can serve as the basis for the automatic creation of a Harris Matrix and how this automated process can be incorporated into a user-friendly management system. In the remainder of this chapter, the requirements of a stratigraphic management system are outlined. The proposed methodology is presented in Section 5.3, and then the results are presented and discussed in Sections 5.4 and 5.5, respectively. The chapter is concluded in Section 5.6.

## 5.2 REQUIREMENTS OF A USER-FRIENDLY ARCHAEOLOGICAL STRATIGRAPHIC MANAGEMENT SYSTEM

As a variety of Harris Matrix tools have been developed, it is necessary for the management system proposed in this chapter to incorporate all functionalities that have proven to be promising while preventing or even ameliorating drawbacks. Therefore, an outline of the requirements of an archaeological stratigraphic management system is given, partly based on requirements listed by Traxler and Neubauer (2009) and based on parameters of the evaluation of the system developed by Stal et al. (2014).

The composed Harris Matrix must first be pursuant to theory. This has implications on both layout and validity outcomes. In regards to layout configurations, Harris Matrixes depict the archaeological stratigraphy along a vertical axis, where the uppermost and thus newest layer is placed on the top of the diagram directly underneath the upper surface and where the geological interface forms the bottom layer (Traxler and Neubauer 2009). Stratigraphic units that are contemporary are placed on the same vertical level, where equal layers are connected by a double horizontal line. The 'later than' (and equally 'earlier than') stratigraphic relationship is transitive and irreflexive (Herzog 1993), resulting in the need to remove superfluous relationships and to prevent cycles, respectively. The 'contemporary with' relationship is transitive, symmetric and reflexive (Herzog 1993). Properties of these relationships must form the bases for a validity check of the created Harris Matrix in the proposed tool.

To facilitate user interactions with the system, direct diagram manipulation is preferred (Traxler and Neubauer 2009). However, the layout, including validity checks and based on conventional symbology, should be constructed by the system. Furthermore, a user should be able to zoom and pan to navigate the Harris Matrix (Traxler and Neubauer 2009). Due to the geographical nature of archaeological data, a connection with GIS should be made available to support a spatial overview of the matrix while enabling spatio-temporal analyses (Forte 2014; Berggren et al. 2015; Chapter 4). In turn, the system can function as a simplified variant of a 4D archaeological GIS. Furthermore, a dynamic overview map and linkage to an excavation database may facilitate the management of information while improving insights gained (Stal et al. 2014).

A final feature of the tool involves the facility to assign stratigraphic units to phases and periods, which are structural entities and historical epochs, respectively. These manipulations of the initial Harris Matrix, which is only based on topographic and topologic information (Harris 1989, p. 115), are produced from additional information on artefacts or from more detailed structural or temporal analyses (Harris 1989, p. 115; Traxler and Neubauer 2009).

### 5.3 METHODOLOGY

To determine whether spatial relationships can support Harris Matrix creation, four theoretical examples of various complexity are used, as presented by Harris (1989, p. 39) (Figure 5-1) and Bibby (1993, p.106) (Figure 5-2). In this study, it is assumed that every stratigraphic unit is topographically recorded during excavation and that each is given a unique identifier (Traxler and Neubauer 2009). Furthermore, Barceló et al.'s (2003) method is adopted to strictly consider spatial information of the upper plane of the stratigraphic unit, as the stratigraphic unit is at the bottom bounded by another stratigraphic unit. In turn, the four examples are digitalized, where contemporary polygons are stored within the same layer.

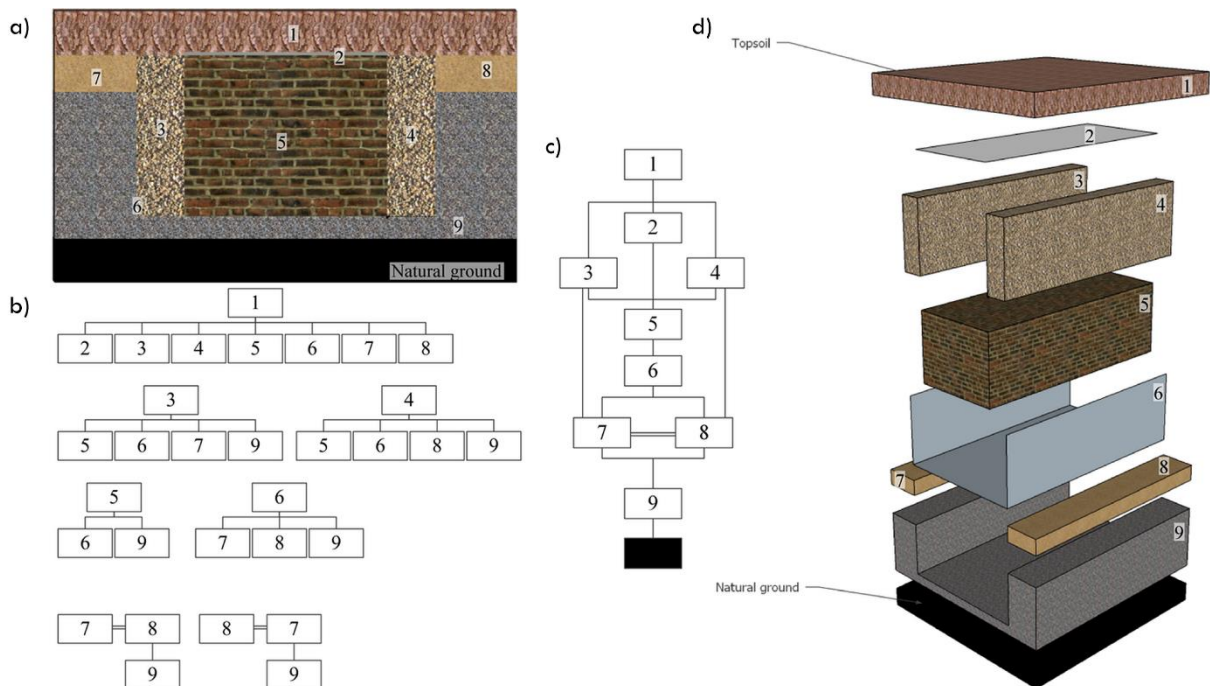


Figure 5-1 Illustrated demonstration of Harris Matrix generation based on Harris (1989, p. 39 fig. 12)

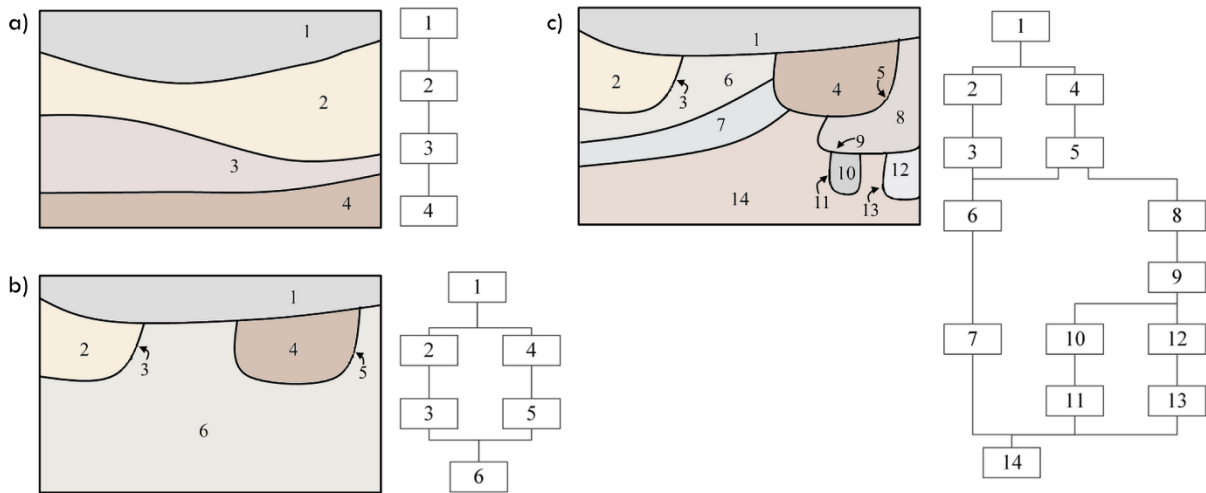










Figure 5-2 Theoretical examples of Harris Matrix creation based on Bibby (1993, p. 106 fig. 7.1)

As this chapter focuses on the use of spatial information in the creation and management of stratigraphy, a geodatabase is used as a central element in the proposed tool. According to Chapter 4, this database allows for extendibility towards a complete archaeological data management, research and policy infrastructure. Given growing demands for cost-efficient recording, free and open-source software (FOSS) in combination with open data standards (e.g., W3C or ISO compliant standards such as HTML or SQL, respectively) are preferred. Data are thus stored in a PostgreSQL database with spatial extension PostGIS (<http://postgis.net>), supporting SQL standards and permitting the addition of custom functions in a spatial context.

Next, spatial information on stratigraphic units and their mutual spatial relationships serve as inputs for the creation of a stratigraphic sequence. PostGIS includes eight basic spatial relationship functions (PostGIS Project 2008), which are based on the 9-intersection model of Egenhofer and Herring (1991) and listed in Table 5-1. Based on projections of these relationships in the data, a custom PostGIS function (`identify_relations()`, see further) is created to identify these relationships in the theoretical examples and to store information needed to create the matrix.

Table 5-1 PostGIS functions for analysing spatial relationships (based on PostGIS Project 2008)

SQL/PostGIS function	Meaning	Example
ST_Equals(A,B)	A and B are identical in shape	
ST_Intersect(A,B)	A and B have no spaces in common	
ST_Overlaps(A,B)	A and B have geometries with the same dimensions and intersects, resulting in geometries of the same dimension	
ST_Crosses(A,B)	A and B intersect, resulting in a geometry of one less dimension	
ST_Disjoint(A,B)	A and B do not intersect	
ST_Touches(A,B)	A and B touch at their boundaries	
ST_Within(A,B)	A is fully situated within B	
ST_Contains(A,B)	B is fully situated within A	

As the Harris Matrix can be treated as a directed graph, an adjacency matrix or adjacency list can be used to store stratigraphic relationships (Herzog 1993; Desachy 2012; Motz and Carrier 2013). In this project, however, a simplified variant of the adjacency list is used: the edge-list (Kolaczyk 2009). As such a list stores start and end nodes for all graph connections, this configuration more closely reflects the way relationships will be retrieved from spatial information. For instance, if the relationship 'A is later than B' is found through a certain spatial relationship test, in the edge-list, this relationship (A-B) can be easily stored in one record without the need to traverse the graph or retrieve extra information. Apart from the resulting table for storing edges, a table containing all graph nodes, i.e., stratigraphic units, is created to store additional information on these stratigraphic units. These two tables are mutually dependent via a cascade-statement, meaning that edges can only be inserted when nodes are already stored in the nodes table, and edges are automatically deleted when one node is removed. Such representation complies with the ISO concept for describing temporal information as assessed by De Roo et al. (2014).



During and after the determination of stratigraphic relations, the topological validity of the stratigraphic sequence must be checked. First, the 'later than' relationship is irreflexive, creating a need to (i) prevent self-loops while (ii) avoiding the 'B later than A' relationship when the 'A later than B' relationship has already been detected. These conditions can be attached to the identification procedure by adding constraints to the edge list. The first one accounts for tests wherein start and end nodes are different and wherein the second determines whether the table already contains a (start,end) or (end,start) row. Second, due to transitive properties of the relationships, superfluous relationships and thus edges must be deleted. This manipulation can only be performed at the end, when all relationships have been determined as a collection of both redundant and unequivocal nodes and edges (Figure 5-1b). A separate SQL function (delete\_dubble\_edges(), see further) is created for this reason. First, this function temporarily stores all possible paths and their distances (i.e., the number of edges) from each start node in the graph. Then, the function removes edges for which a path of higher distance equivalent but equal start and end nodes exists. In Figure 5-3, the proposed procedure is illustrated through a flowchart and pseudocode is given in Figure 5-8 (Appendix, p. 129).

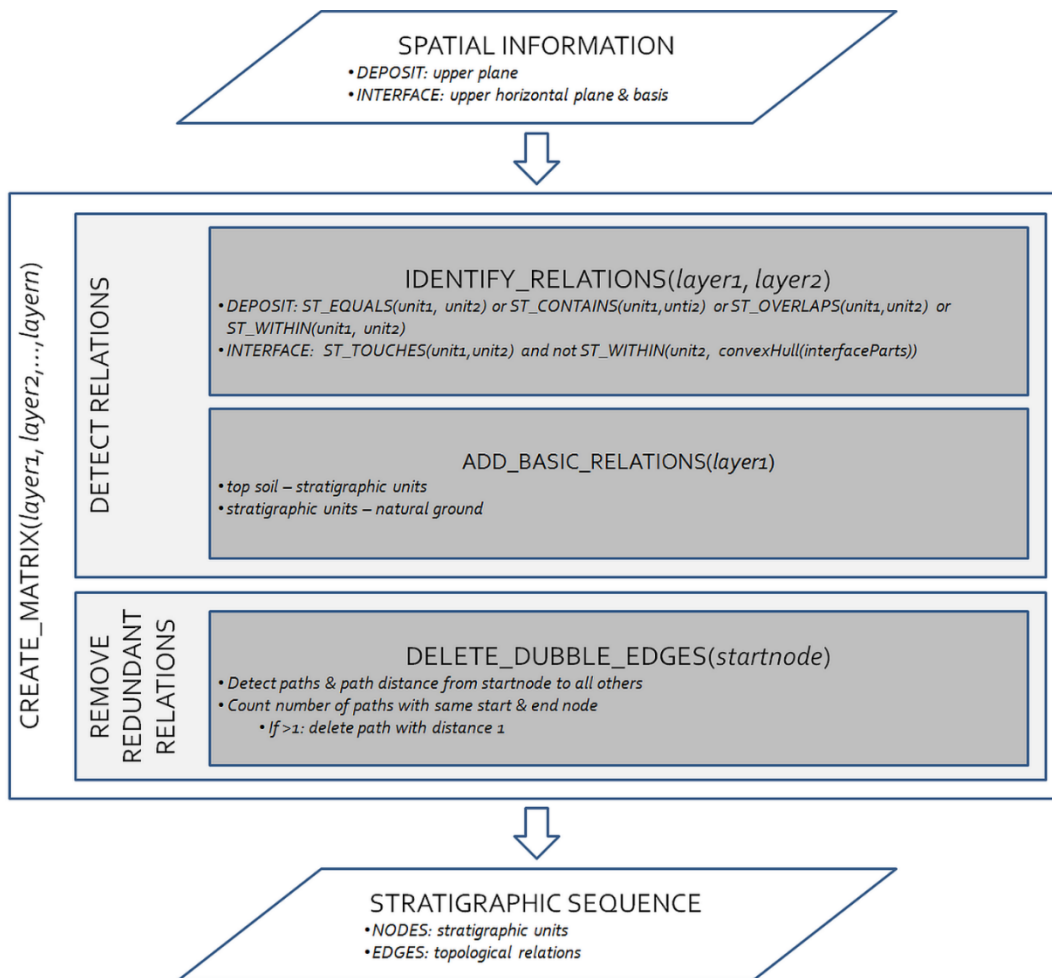


Figure 5-3 Flowchart of the stratigraphy extraction algorithm

Finally, the edge list must be visualized. This may be done by exporting edges into an ASCII-file. With little adaptation, this file can then be used in GraphViz graph visualization software as employed by Costa (2007) and Motz and Carrier (2013). Although this software is free and open-source, it is difficult to integrate with other applications. Therefore, it is preferable to create a prototype web-based platform based on the management system developed by Stal et al. (2014), which includes the Harris Matrix, an overview map, additional information on stratigraphic units, and a 3D representation. To realize this while ensuring interactivity, open-source libraries such as OpenLayers (overview map) and Cesium (3D model) and commonly used scripting languages such as JavaScript and PHP are employed.

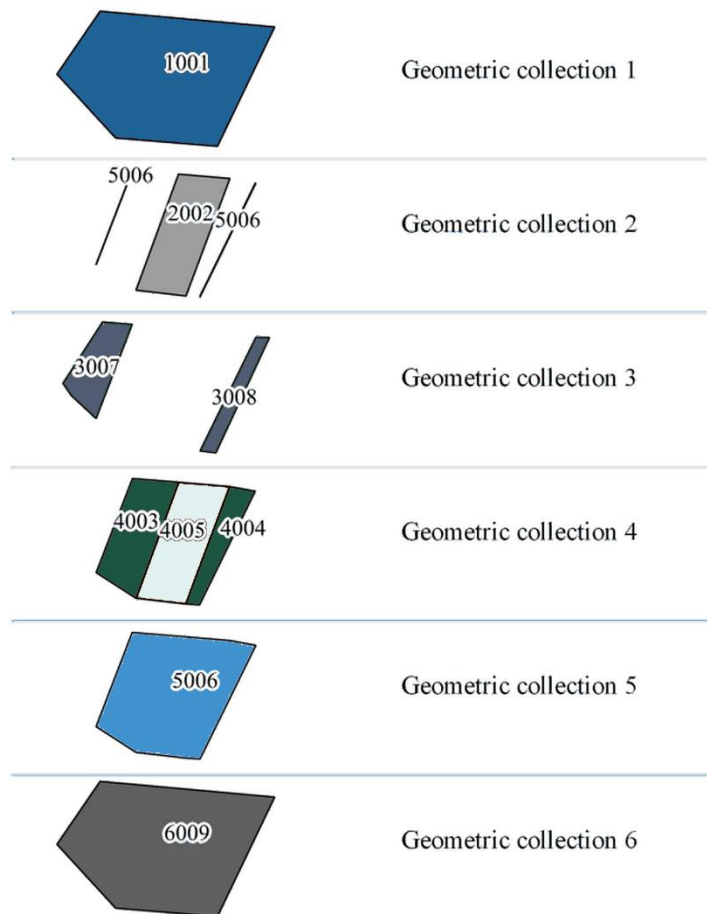


Figure 5-4 Overview of the digitalization of example 1

## 5.4 RESULTS

### 5.4.1 From spatial information to stratigraphic relationships

To evaluate the automated creation of a Harris Matrix, four theoretical examples are digitized to simulate real excavation data. Only upper planes of the stratigraphic units are digitized for the deposits (Figure 5-4), whereas upper horizontal parts and the basis are stored for the interfaces (e.g., 5006 in Figure 5-4). Digitalization is conducted in such a way that contemporary stratigraphic units are stored in the same layer (e.g., 3007 & 3008 in Figure 5-4). In turn, the contemporary relationship can be skipped during identification. As stratigraphic unit equality can only be found by means of additional expert information on artefacts or through analysis, the 'later than' relationship is the only remaining stratigraphic relationship that must be identified.

First, it is necessary to determine which of the nine spatial relationships listed in Table 5-1 are useful for the detection of stratigraphic relationships. This assessment is based on the three theoretical examples presented in Figure 5-2, which uses the eight spatial functions from PostGIS as presented in Table 5-1. The automatic detection of relationships between deposits and interfaces is divided into two phases (Figure 5-3). During the first stage, only deposits are considered, and thus interfaces are disregarded. The basic example shown in Figure 5-2a clearly illustrates that the `ST_Equals()` function can reveal all topological relationships between the four stratigraphic units. Next, as shown in Figure 5-2b, the `ST_Contains()` function is used to identify relationships between 1 and 2 and between 1 and 4. The `ST_Within()` function allows one to detect relationships between 3 and 6 and between 5 and 6. Finally, Figure 5-2c shows that the `ST_Overlaps()` function is also needed to, for instance, detect the relationship between 5 and 8. Interfaces are considered during the second stage. It is evident from Figure 5-2b that the '4 is later than 5' relationship can be detected via `ST_Within()`. If in Figure 5-2c, stratigraphic unit 6 is not digitized as the complete upper plane but only as the part touching stratigraphic unit 1 (thus bounded between stratigraphic units 3 and 5), the '3 is later than 6' and '5 is later than 6' relationships cannot be detected. This implies that the `ST_Touches()` function is also necessary. However, this relationship must only be checked when an interface is being considered and when this relationship is found outside of the interface. The first condition is met when a node identifier is found multiple times in the complete set of tables. The second condition is tested using the convex-hull of these geometries. All of these functions and their respective conditions are combined in a customized PostGIS function `identify_relations()` that uses two table names as an argument (Figure 5-3). As spatial information is spread over multiple tables, we use an additional `create_matrix()` function that uses a character string with all table names as an argument (e.g., '11,12,13,14') and that loops all table combinations that must be tested via the `identify_relations()` function (e.g., 11-12, 11-13, 11-14, 12-13,...). In this function, a `add_basic_relations()` call is created to add relationships between the upper surface with node id 0 (top soil) and the interface to geology with node id 9999 (natural ground) as specified by Traxler and

Neubauer (2009) (Figure 5-3). Applications of the `create_matrix()` function in the three examples given in Figure 5-2 yield the expected results. To validate these results, the function is performed based on the example provided by Harris (1989, p. 39 fig. 12). The resulting relationships of this validation case are given in Table 5-2.

Table 5-2 All superpositional relationships identified by spatial relationships for the validation example given in Figure 5-1

Start node	End node	Start node	End node	Start node	End node
0	1001	1001	4005	4003	6009
0	2002	1001	5006	4003	9999
0	3007	1001	6009	4004	5006
0	3008	1001	9999	4004	6009
0	4003	2002	4005	4004	9999
0	4004	2002	5006	4005	5006
0	4005	2002	6009	4005	6009
0	5006	2002	9999	4005	9999
0	6009	3007	6009	5006	3007
1001	2002	3007	9999	5006	3008
1001	3007	3008	6009	5006	6009
1001	3008	3007	9999	5006	9999
1001	4003	4003	5006	6009	9999
1001	4004	4003	6009		

The next step in determining an archaeological stratigraphic sequence involves the removal of redundant relationships (Figure 5-3). A `delete_dubble_edges()` function, which takes a start node identifier as an argument, is created for this purpose. This function is used at the end of the `create_matrix()` function for each start node in the edge list. To detect redundant relations, all possible paths and their respective distances are first temporarily stored. The number of paths with the same start and end nodes is then determined. If more than one path is possible, the path with a distance of 1 is deleted (Figure 5-3). Tests of this function via the three theoretical examples produce the desired results. Next, a redundancy test is performed for the validation case. Through the 40 stored edges, 403 potential paths can be constructed, with 103 starting from node 1001 (Table 5-3). As shown in Table 5-3, for three nodes, only one path starts from 1001 (towards 2002, 4003 and 4004), whereas for the other nodes, multiple paths are possible. This explains why six (=9-3) edges starting at 1001 and with a distance of 1 must be deleted from the edge list. In total, 390 relationships are deleted and 11 of the resulting edges are consistent with the sequence given in Figure 5-1c. Only edges 4003-

4005 and 4004-4005 are not present and are substituted by 4003-5006 and 4004-5006. In turn, no stratigraphic relationship between 4003 and 4004 on the one hand and 4005 on the other hand can be detected. This is not entirely unexpected, as deposit 4005 is a stone wall, and 4003 and 4004 are foundational trench fill. In this case, it is evident that 4003 and 4004 occur later than 4005. However, such a relationship can only be found through interpretations based on additional information. For the same reason, the 'equal to' relationship between 3007 and 3008 cannot be detected. The obtained edge list is visualized using GraphViz software consistent with Costa's (2007) approach, using the digraph (directed graph) code word, allowing for edge concentrations and setting the node shape to a box (Figure 5-5).

Table 5-3 The number of possible paths before deleting redundant relationships for the validation example

Start node	End node										Total	
	1001	2002	3007	3008	4003	4004	4005	5006	6009	9999		
<b>0</b>												
Number of paths	1	2	14	14	2	2	4	12	52	103	206	
<b>1001</b>												
Number of paths		1	7	7	1	1	2	6	26	52	103	
<b>2002</b>												
Number of paths			2	2			1	2	8	16	31	
<b>3007</b>												
Number of paths									1	2	3	
<b>3008</b>												
Number of paths									1	2	3	
<b>4003</b>												
Number of paths			1	1				1	4	8	15	
<b>4004</b>												
Number of paths			1	1				1	4	8	15	
<b>4005</b>												
Number of paths			1	1				1	4	8	15	
<b>5006</b>												
Number of paths			1	1					3	6	11	
<b>6009</b>												
Number of paths										1	1	

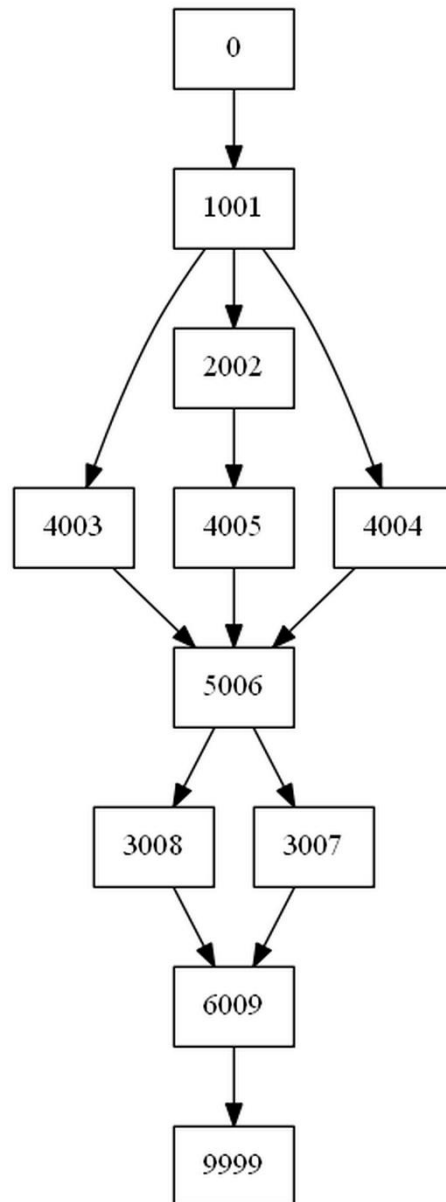


Figure 5-5 GraphViz visualization of the stratigraphic sequence

The satisfying outcome of the procedure described above affirms the capacity for spatial information to serve as a basis for automatic Harris Matrix generation. However, some relationships cannot be detected via geometric analysis and require user interpretation, e.g., equal-to relations. Nevertheless, this issue can be ameliorated rather easily by integrating additional stratigraphic unit information into the developed algorithms. As most archaeological data are managed using pre-defined infrastructures, this integrated approach will comply with geodata infrastructures consisting of central geodatabases in combination with web-based GIS tools, as proposed in Chapter 4 for the management and examination of archaeological data.

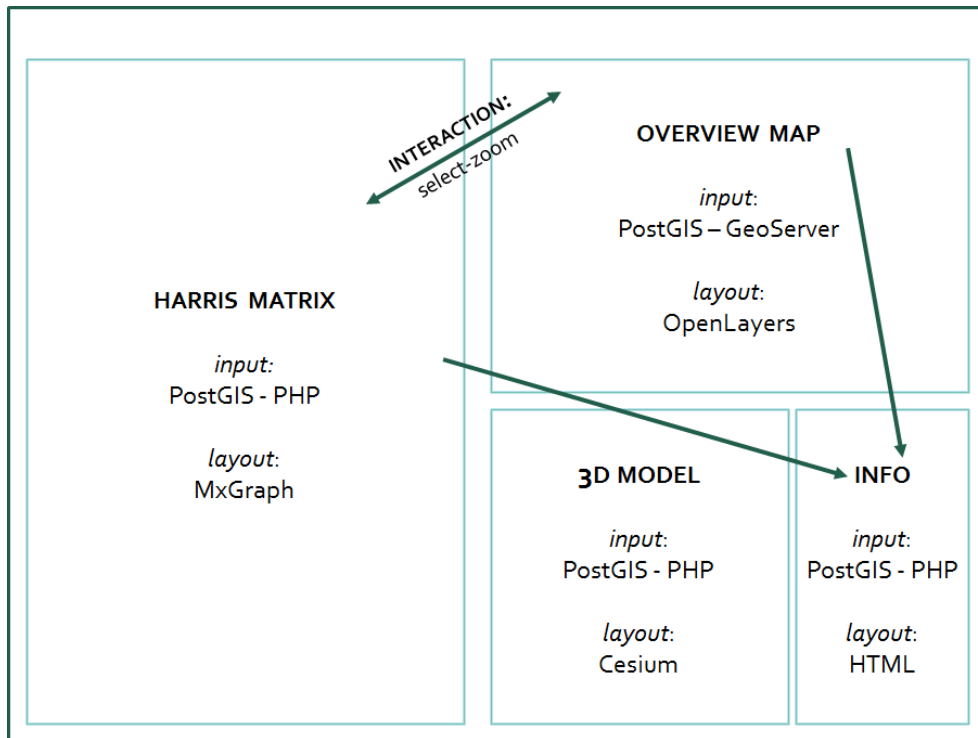


Figure 5-6 Schematic overview and interactions of the web-based management system

### Harris matrix and map

Figure 5-7 Current implementation of the web-based management system

## 5.4.2 From stratigraphic relationships to a prototype web-based management system

It has been stated that spatial information can be used to create a stratigraphic sequence. Therefore, its deployment in a web-based management system may prove even more beneficial. By using the management system developed by Stal et al. (2014) and rearranging the same components, the user interface can be built: the Harris Matrix, overview map, additional information and a 3D model (Figure 5-6). The Harris Matrix is automatically created in this study, PHP is used to access the PostGIS database and JavaScript is used to access the layout (Figure 5-6). Zoom and pan operations allow one to navigate the matrix. As proposed by Stal et al. (2014), a WFS is employed using a combination of GeoServer and OpenLayers. This permits direct access to the data and enables reading and writing capabilities. In turn, interactivity is added to the map and Harris Matrix. Using JavaScript, a connection between these two components is made to allow for simultaneous selection and zooming. When a node is selected in the Harris Matrix, the corresponding feature is selected and zoomed into on the map and vice versa (Figure 5-7). Furthermore, when a node or map feature is selected, additional information on this stratigraphic unit stored in the database is displayed in the information component (Figure 5-7). The last component of the system is a 3D visualization of the model. As theoretical data are used, no 3D models can be reconstructed as was done by Stal et al. (2014). Hence, a 3D overview model that depicts stratigraphic units at their respective depths is created using the Cesium open-source library (Figure 5-7). Nevertheless, future use of and interaction with 3D virtual reconstructions of stratigraphic units originating from laser scan data or photo modelling approaches will be feasible (Figure 5-6). Interactions may be similar to those of the overview map, namely offering zoom-in and select interplays with the Harris Matrix while providing extra information in the info component.

## 5.5 DISCUSSION

A prototype of the design and interactions of the web-based management system are presented based on data generated through the validation case (Figure 5-7). Stal et al.'s (2014) proposal to incorporate more advanced protocols (e.g., PHP and SQL) is accepted and is found to increase the flexibility of the management system, including the automatic creation and validation of stratigraphic sequences based on spatial information. As shown in the previous section, the resulting Harris Matrix is compliant with theory: stretched out along a vertical axis, superfluous relationships were removed, cycles were avoided, and conventional symbology was used (Traxler and Neubauer 2009). Interactions are facilitated in the system among other processes through the allowance of zoom-in, pan and combined feature node selection capabilities. Although nodes and edges of the matrix can be moved, representing a direct form of manipulation that Traxler and Neubauer (2009) ascribed great importance to, these adaptations are not



stored in the database of the existing system. However, the implemented layout algorithm is extendable to automatically outline contemporary relationships on similar levels and to allow for direct manipulation, e.g., by adding additional relationships based on interpretation. Such interpretation is facilitated by the proposed management system, as connections with GIS and 3D models are available. Thanks to the system's modularity, the current version offers opportunities to extend management, interpretation and analysis opportunities. Capabilities using JavaScript that may be supported in the future include:

- the easy insertion, revision and removal of attribute data and metadata;
- combined thematic, spatial and temporal analysis capacities;
- the storage of edited stratigraphic relationships in databases;
- phase and period assignment capacities;
- 3D analysis opportunities.

Extending the system through these features would complement proposals made in Chapter 4 for the use of a combination of geodatabase and web-GIS tools for the development of archaeology-specific geodata infrastructures that can be used for management, research and policymaking purposes.

Considering the widespread use of 3D acquisition systems (Dell'Unto et al. 2013; Berggren et al. 2015), approaches involving the addition of depth information to algorithms will become more reliable. It is currently assumed that spatial information on stratigraphic units must be stored in different layers or tables based on contemporaneity levels. Although this is in line with the process of excavation, storing the third dimension as an attribute of the upper boundary polygon or using 3D representations of deposits will better suit the modern acquisition process. As Forte et al. (2014) have shown, 3D representations of stratigraphic units can successfully augment the interpretation process. However, the use of such data in algorithms requires the application of more advanced data storage and analysis tools such as 3D spatial relationship tests, which remain in their infancy today.

In conclusion, this comparative assessment has described capacities of the proposed web-based management system.

## 5.6 CONCLUSION

In this chapter, capacities to use spatial relationships between stratigraphic features for the automated creation of Harris Matrixes are described. Processes and algorithms used to automatically detect spatial relationships between upper layers of stratigraphic units and to transform these relationships into stratigraphic sequences are described. Such processes are based on the management of spatial data in a free and open-source geodatabase. Although both horizontal and vertical data are considered, data on stratigraphic units comprise only 2D boundaries of the upper planes, as these data are often available. While it is possible to extend such information to the third dimension, this

requires the application of more advanced data recording, storage and analysis techniques (e.g., 3D spatial relationships tests). The proposed procedure is tested on three theoretical data sets and on a validation set. Notwithstanding satisfying outcomes found for all of the data examined, the importance of expert knowledge for validation purposes is not negligible. Such verification is facilitated by the use of a stratigraphic diagram in a user-friendly management system that also contains semantic information and spatial information taking the form of an overview map and 3D model. The current version therefore serves as an optimal trade-off between matrix automation and user expert validation approaches. In the proposed prototype, interactions between these four components (2D and 3D spatial information, stratigraphic relationships and attribute displays; Figure 5-6) are realized to enhance usability levels. As a WFS and central geodatabase are used in the existing system, the Harris Matrix (e.g., relationship revisions and attribute information additions) can be easily manually manipulated, furthering improving expert validation results. In turn, the system can function as a cost- and time-efficient management and research infrastructure wherein 4D (3D + time) information is managed. It is now necessary to determine how algorithms and the system behave when applied to real excavation settings. Although the algorithms are only tested in small test cases, it is evident that the workflow can manage vast quantities of data within a reasonable timespan. Furthermore, we plan to extend the prototype system through direct manipulation (e.g., editing and drawing relationships in the matrix), 3D analysis (e.g., spatial buffers and spatio-temporal queries), etc. Finally, ways that 3D representations originating from, e.g., laser scan data, can be used rather than 2D polygon layers must be examined. Such an investigation should be evaluated by applying adjusted algorithms to case studies and by further elaborating on the user interface through the use of advanced 3D viewers rather than 3D overview maps.

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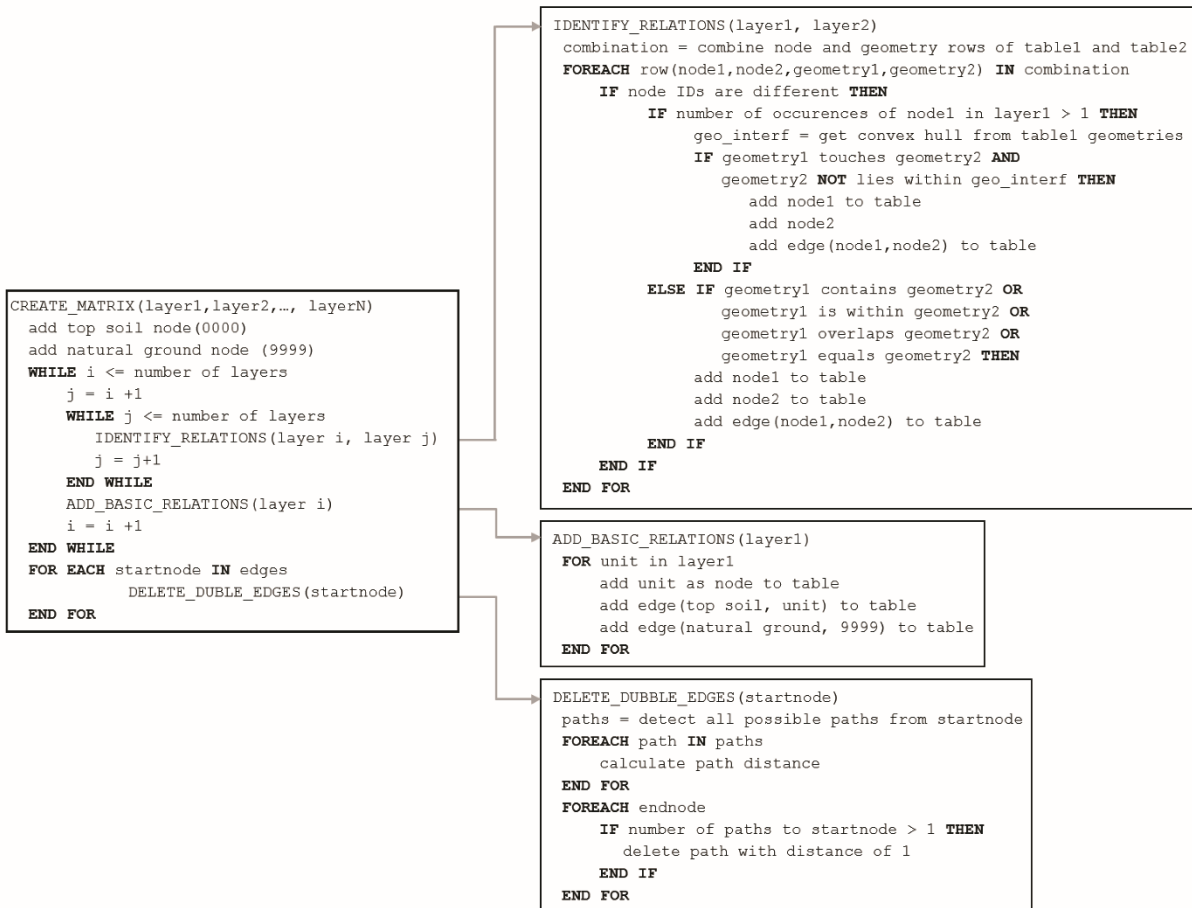
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## APPENDIX

The figure below presents the algorithm in pseudocode.

Figure 5-8 Pseudocode of the stratigraphy extraction algorithm





# 6

## FROM VIRTUAL GLOBES TO ARCHEOGIS: DETERMINING THE TECHNICAL AND PRACTICAL FEASIBILITIES

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Modified from: DE ROO B., LONNEVILLE L., BOURGEOIS J., DE MAEYER P. 2016. From virtual globes to ArcheoGIS: Determining the technical and practical feasibilities. *Photogrammetric Engineering & Remote Sensing*, 82(9), pp. 677-685.

### ABSTRACT

Web mapping and virtual globes are increasingly used to communicate 3D geospatial results to fellow researchers and the public. The lack of analytical functionality nonetheless restricts their utility in research, including archaeology. Integrating both 3D and analytical functionalities should result in a 4D archaeological GIS that can be used throughout the archaeological workflow. This chapter investigates the feasibility of extending a virtual globe to such a user-friendly system. This involves a technical assessment by comparing the characteristics of virtual globes with user, data, functional and organizational requirements. The prototypical implementation consequently uses Cesium® as basis. This prototype served for the practical feasibility evaluation. The usability test with two Flemish archaeological organizations has shown broad support for a low-threshold 4D ArcheoGIS from its potential end-users. Although public activities, analyses and fieldwork preparations were mentioned as application domains, extending the system to fit archaeological workflows or a cyberinfrastructure is necessary.

## 6.1 INTRODUCTION

Thanks to the development of modern technology, geographic information is now no longer spread over the Internet by means of static map images intended for skilled users but through publicly accessible, interactive applications (Brovelli et al. 2013, Minghini 2013, McCool 2014). These web map applications are increasingly taking the form of true web-based Geographic Information Systems (GIS) through which users can integrate, manage, analyse, visualise and communicate their geographic data. The growing creation and use of 3D geographic data, which originate from widespread 3D sensors, in turn ask for efficient ways to distribute 3D geographic information over the Internet. Because virtual globes give 3D representations of the Earth and offer the opportunity to display and investigate geographic data in a realistic environment, they can be considered to be advanced 3D geoviewers or geobrowsers (Brovelli et al. 2013, Minghini 2013, von Schwerin et al. 2013).

Virtual globes' intuitive way of interacting (e.g., zooming and rotating) makes the exploration of complex geospatial data straightforward, even for non-experts or people with limited computer knowledge (Butler 2006, Lonneville et al. 2015). Because of this user-friendliness, virtual globes are used in a multiplicity of disciplines and especially in projects where crowdsourcing or public awareness is involved (Stensgaard et al. 2009, Minghini 2013, Resch et al. 2014, Hunter et al. 2015). The range of potential application domains becomes even larger because some virtual globes enable the integration of subsurface and/or temporal data. Because the emphasis mainly remains visualization, this spectrum of possible applications has yet to narrow. If compared to traditional GIS and other 2D web mapping applications, practically no analytical functionalities are available in virtual globes. The open-source software trend can nevertheless contribute to resolve this omission. Successful extensions of open-source virtual globes in, for example, the domain of geoprocessing and environmental monitoring (GeoJModelBuilder) (Zhang and Yue 2013) and public safety and planning (Gaea+) (XLAB, 2015) support this supposition. These implemented analytical functionalities can perform even better by using virtual globes that are based on the Web Graphic Library (WebGL) (Resch et al. 2014). This increasingly popular group of globes does not need additional plugins and takes advantage of hardware-accelerated graphics functionalities (Jackson 2014).

Similarly, in archaeology, the geographical character of the data makes web mapping and virtual globes increasingly used media to communicate archaeological research results for both fellow researchers and the public (Wagtendonk et al. 2009, Kansa et al. 2011, McCool 2014, Lonneville et al. 2015, Chapter 4). The use of Google Earth™ and other virtual globes is promising because they are easily understandable, low-cost and allow the integration of both the third and fourth—temporal—dimension (Lonneville et al. 2015). Although a number of those applications include splendid visualizations (McCool 2014), the lack of analytical functionalities makes them unsuitable for



professional use throughout the entire archaeological workflow. On the other hand, when analytical capabilities are provided, the consideration of the third dimension, which is inextricable from archaeological data, is often restricted or even ignored (Wheatley and Gillings 2002, Breunig and Zlatanova 2011, von Schwerin et al. 2013).

The current chapter attempts to integrate both 3D data and analytical functionalities in a 4D archaeological GIS. Such a 4D GIS, in which 3D and temporal data can be simultaneously handled, will contribute to archaeological research by facilitating the gathering of new insights and the building of well-founded interpretations. Taking into account previously gathered user and organizational requirements (Chapter 3 and 4), a virtual globe is considered as the basis for such an application. In addition to their strength in visualizing spatial data, virtual globes have proven their intuitive nature and capabilities in both professional applications for non-GIS experts and public participatory GIS projects (Butler 2006, Minghini 2013). However, their use in archaeology as 4D GIS has not yet been investigated. Therefore, the purpose of this chapter is to probe the potential feasibility of extending a virtual globe towards a 4D archaeological GIS while centring on the end-users, both technically and practically.

First, to evaluate the technical feasibility, the following two research questions are considered.

- Which virtual globe is most appropriate to match the requirements of an archaeological GIS?
- Which GIS functionalities does the virtual globe already have and how can the missing functionalities be developed?

Second, the practical feasibility evaluation is probed by answering the following research question.

- How is the system assessed by the archaeological community?

Once the most appropriate globe was determined (i.e., the result of question 1.1), it was used as the basis of a prototypical implementation (question 1.2). To answer question 2.1 and gain insights into the assessment of both the concept and implementation, two archaeological organizations took part in a user test of the developed prototype.

The remainder of this chapter is organized as follows. Before answering the first and second research questions in Section 6.3, an outline of the requirements for a 4D archaeological GIS is given in Section 6.2. Next, the methodology and results of the practical feasibility assessment of the prototypical application are described in Section 6.4. The chapter concludes with a discussion of the results and outlines avenues for further research.

## 6.2 REQUIREMENTS FOR 4D ARCHAEOLOGICAL GIS

Given the geographical character of archaeological data, GIS have been proven to serve archaeology well. The applications for which GIS are used vary from basic data management and map-making to complex network analyses and predictive modelling (Wheatley and Gillings 2002, Scianna and Villa 2011). Although the 3D spatial character of archaeological data is captured using land survey equipment such as laser scanners and total stations, the vertical dimension in those applications is either ignored or only handled as an attribute. This is primarily caused by the high level of complexity that these systems have to address in three dimensions. A reduction to a 2D abstraction of reality thus takes place. The need consequently arises for a user-friendly 3D GIS that integrates both the analytical competencies of traditional 2D GIS with the attractiveness and strengths of 3D representations (von Schwerin et al. 2013, Lonneville et al. 2014).

In addition to their three-dimensionality, archaeological data are characterized by four other particularities: (i) temporal information, (ii) data imperfection, (iii) multiple scale levels, and (iv) various object types. Dealing with the temporal—4<sup>th</sup>—dimension is even more complex in archaeological applications compared to other geospatial domains, because not only valid and database time should be handled (Katsianis et al. 2008, Section 2.3.3). At least six temporal categories are commonly used in archaeology to express the temporal information of an excavation object, e.g., absolute time and relative chronology (Katsianis et al. 2008, Chapter 3). Because they are the result of analysis and interpretation, those temporal values are also often subjective and imperfect (i.e., uncertain and imprecise) (Katsianis et al. 2008, Smedja 2009, de Runz et al. 2010). In fact, such data imperfections are inherently linked to archaeological data in general (Katsianis et al. 2008, Cripps 2012). For example, an object's function can be unknown or a building's shape can only be assumed based on postholes that have been found. The latter example demonstrates another aspect of the multiplicity of scale levels in archaeology; found objects (postholes) are used to reconstruct higher-level objects (buildings). Another aspect of the use of multiple scales in archaeology is the level of analysis, which can differ from 'intra structure' (objects) to 'inter site' (landscapes) (Deweirdt 2010, Forte 2014). This scale multiplicity links to the object variation. Studying life in the past, all real world objects can basically be the subjects of archaeological research. Taking these four extra data particularities into account, the need for 3D GIS expressed above should be refined to the demand for a 4D GIS tailored to archaeological data and allow attractive visualizations as well as elaborate analyses and orderly data management.

This GIS should ideally be part of a cyberinfrastructure that can be used throughout the entire archaeological workflow (Snow et al. 2006, Chapter 4). Hence, not only the data and functionality requirements but also the user and organizational requisites should be taken into account. Those requirements were earlier identified as part of this research project by means of a user survey, scientific literature review, legislation analysis and

interviews with experts and non-experts (Chapters 3 and 4). Regarding the user, the system's intuitiveness and ease of use are central. Due to the increasing capitalistic organization of the archaeological market, cost and hardware requirements must be kept to a minimum, and customizability is preferred. The multiplicity of actors and the respective purposes for which the system will be used further supplement the organizational requirements. To conclude, Figure 6-1 summarizes the main requirements for a 4D archaeological GIS.



Figure 6-1 Requirements for a 4D archaeological GIS

## 6.3 TECHNICAL FEASIBILITY OF EXTENDING A VIRTUAL GLOBE TO ARCHEOGIS

The first step in the evaluation of the technical feasibility consists in the choice of an appropriate virtual globe based on the requirements outlined in Section 6.2. The second step includes listing the available and missing GIS functionalities and developing the latter ones.

### 6.3.1 Matching virtual globes against 4D ArcheoGIS requirements

Given the wide range of available virtual globes, five technical criteria can support the selection of a particular virtual globe: (i) license type, (ii) platform, (iii) application type, (iv) provided data and (v) customizability (Brovelli et al. 2013). Based on those criteria, Table 6-1 summarizes and compares the properties of six virtual globes: (i) Google Earth™, the market leading globe; (ii) NASA World Wind™, which is scientifically purposed; (iii) ArcGlobe™, which is from the leading traditional GIS provider ESRI®; and the three most common WebGL globes (iv) WebGL Earth™, (v) OpenWebGlobe™ and (vi) Cesium®. In addition to ArcGlobe™, ESRI® also offers ArcGIS Earth™ as a free, desktop-based interactive globe for more professional usage. However, because this software was launched after this research was concluded, it is not considered here.

Table 6-1 Properties of six virtual globes according to five technical criteria

GLOBE	LICENSE		PLATFORM			APPLICATION			EXTERNAL DATA		CUSTOMIZE		
	FOSS	Closed, free	Closed, Pay	Operating system	Multiple releases	independent	Desktop	Pure Web	Plugin	Proprietary data server	Standards (WMS, KML)	API (black-box)	Open-source
<b>Google Earth</b>		X	*		X		X		X		X	X	
<b>ArcGlobe</b>			X	X			X				X	X	
<b>World Wind</b>	X					X	X	X			X		X
<b>WebGL Earth</b>	X					X		X			X		X
<b>OpenWebGlobe</b>	X					X		X					X
<b>Cesium</b>	X					X		X			X		X

\*Google Earth Pro and Google Earth Enterprise

Considering the previously outlined data, functionality, user and organizational requirements (Figure 6-1), the number of eligible virtual globes can gradually be narrowed.

Given the capitalistic market, the software and hardware costs should be kept as low as possible, and customizability should be supplied for organizations, which already have their own data infrastructures (Chapter 4). The last in particular calls for a Free and Open-Source Software (FOSS) virtual globe because the software code is open for adaptation. As seen in Table 6-1, Google Earth™ and ArcGlobe™ can be eliminated. Choosing a WebGL-based globe can reduce hardware costs because this is a pure web application and is platform-independent. Consequently, NASA World Wind™ also can be excluded.

Within the group of WebGL-based virtual globes, a particular globe should be picked that suits the other two elements: 3D subsurface and temporal data. Although all virtual globes natively support 3D data, only a limited number allow subsurface data. Of the WebGL virtual globes in Table 6-1, only Cesium® supports subterranean data (Analytical Graphics Inc. 2015, Hunter et al. 2015, Klokan Technologies 2015, OpenWebGlobe 2015). Furthermore, that virtual globe also includes timeline and animation widgets for exploring time-dynamic data (Analytical Graphics Inc. 2015). If also addressing the other requirements outlined in the previous section, Cesium® is apparently the best suitable virtual globe for this research.

Given the wide range of zoom levels from the entire globe to a particular place and the ability to handle a variety of geometry types (e.g., polygons, polylines and volumes) and data formats (e.g., GeoJSON, COLLADA), Cesium® allows the study of diverse

archaeological data at multiple scale levels. The final requirement in the data group, namely handling data imperfection, is not foreseen in the application. Therefore, that omission should be tackled during system implementation.

Because the functionality requirements will be addressed in the next section, the user needs and multiplicity of actors and purposes are the only remaining requirements to be evaluated here. The two widely reported advantages of all virtual globes, namely the intuitiveness of the system and ease of use (Butler 2006, Brovelli et al. 2013, Lonneville et al. 2015), automatically comply with the user requisites. In addition, this parallels the need to suit a multiplicity of actors because persons with varying IT skills and GIS expertise can use the system without problem. Together with its user-friendliness, Cesium®'s open-source JavaScript code advantageously allows the system to be tailored to a variety of purposes.

## 6.3.2 Extending the virtual globe to 4D ArcheoGIS

### *6.3.2.1 Available and missing functionalities*

For a 4D GIS to be successful, in addition to providing 3D spatial, 3D topological and temporal analysis capabilities, the functionalities of a 2D GIS should at least be sufficiently available (Zlatanova et al. 2002). This implies that the system should enable the integration, management, visualization, analysis and communication of geographical data (Maguire 1991). According to those five purposes, the available and missing functionalities of Cesium® are summarized on the left side of Table 6-2.

First considering data integration, Cesium® provides a range of default background imagery such as OpenStreetMap and Bing Maps Aerial. Regarding vector data, the GeoJSON and TopoJSON formats are supported. For raster data, images can be loaded via WMS or TMS. Furthermore, 3D models stored in COLLADA files can be integrated, although they must be converted to glTF format. Finally, KML-files can be integrated. The ability to load vector data via WFS is currently unavailable.

Second, to manage data, Cesium®'s functions for spatially and semantically exploring data were considered. The standard Graphical User Interface (GUI) allows direct navigation via the mouse or via the geolocator using an address or world coordinates. Zoom, pan and rotate actions are obviously also available by default. The only possibility for exploring data semantics is via an information box that appears when a feature is clicked. Currently, attribute tables comparable to those in all main desktop GIS cannot be opened. Consequently, no edit functionalities for the semantics are provided. An overview of the imported data (or layers) and their styling (or legend) are not available.

Third, for data visualization, Cesium® facilitates switching between the 3D virtual globe, a 2D map and a 2D tilted map. Although switching the view from 3D to 2D also reduces the data to 2D, it is not possible to display 3D data as 2D when in 3D view. Furthermore, Cesium® is capable of handling subterraneous data; however, a view from the bottom

upwards is not yet available. In addition to static data display, an animation widget for visualizing dynamic geographic data is provided by default.

Table 6-2 Available, missing and developed functionalities of Cesium®

Purpose	Available	Missing	Developed
<b>Data integration</b>	Background layers Vector (GeoJSON) COLLADA WMS KML	WFS	Connection PostGIS
<b>Data management</b>	Geolocator Zoom, pan, rotate Info on display	Custom info Layer overview Legend Table view Metadata	Custom info Layer overview Legend Table with edit functions
<b>Data visualization</b>	2D, tilted 2D view 3D view Temporal animation	3D subsurface view Switch 2D – 3D data	Excavate Extrude Zoom to data
<b>Data analysis</b>	Temporal filtering	Limited time-span (dates AC) - Temporal function Spatial function Geometric function Semantic function	Temporal filtering - timeline BC 3D buffer Distance Thematic filtering
<b>Data communication</b>	GUI Web application	Export data	Data export

The animation widget and accompanying timeline feature allow for the only analysis function available in Cesium®: temporal filtering. On clicking a specific point on the timeline, a filter is executed to display only valid data. Especially noteworthy is the restricted temporal range of the timeline because it does not accept dates before Christ. The timeline further only functions with modern clock-time, whereas archaeology is less precise and instead uses periods or relative temporal indications (Green 2008). Furthermore, no spatial, geometric or semantic operations are available by default.

Data communication and dissemination, the fifth purpose set of the system, is an important aspect for archaeology; public interest needs to be aroused, and research results should be shared with fellow researchers and government. The web nature of the application serves this purpose inherently. For exchanging information, access to the entire data set, provided either as a download or as a data service, is necessary.

### 6.3.2.2 Developing missing functionalities

Based on the overview of the available and missing functions discussed in the previous section, the features necessary for a high-fidelity vertical prototype were determined. During the practical assessment, users will thus be able to interact fully with a system that

includes a limited number of functions that represent the intended set (Nielsen 1993, Rudd et al. 1996). The right side of Table 6-2 lists those developed functions.



Figure 6-2 a) User interface of the prototype application, with b) zoom on top toolbar

The design and implementation of the prototypical ArcheoGIS was realized by the use of modern web technologies such as HTML, CSS, JavaScript, PHP and AJAX. The setup and testing of the system was performed locally in a WampServer Environment on a Dell Windows 8.1 laptop (16GB RAM, Intel® Core™ i7 CPU 2.1GHz 2.7GHz, NVIDIA GeForce GT 720M). Figure 6-2 shows the interface of the prototype at initialization, with the standard Cesium® buttons (e.g., geolocator) and the implemented functionalities (e.g., filter button, layers panel), which are made accessible to the user via additional buttons and dialog boxes.

Regarding the data integration, connections are realized with a PostGIS database. A PHP-script is used to allow the data transfer from the database to the Cesium® viewer in the GeoJSON format.

To facilitate data management, the 'Attribute info' button in the toolbar (Figure 6-2b) enables the display of a customized information box when the user clicks a feature. On the left hand side of the user interface, a layers and legend panel is integrated that is comparable with those in traditional GIS applications, allowing toggling the layers' visibility, viewing the legend and changing the active layer. For the active layer, the 'show table' button gives access to the entire attribute table. In addition to providing a tabular overview of the visualized data, each row contains an 'edit' and 'delete' option. Therefore, data can be managed entirely inside the application.

For visualization, three functions were developed that are accessible via the following buttons: ‘Fly to data’, ‘(Un)excavated’ and ‘Extrude’. Using the first button, users can zoom to the data integrated in the application. The excavate capability pushes down part of the earth’s surface to allow a better visualization of subterranean data. For this, the Ground Push plugin from National ICT Australia (NICTA) was used (NICTA 2015). Due to the monthly release of Cesium®, the plug-in is not always available for the most recent Cesium® version. Therefore, the prototype application was built using Cesium® version 1.6. Finally, the extrude function allows the transformation of 2D polygons to 2.5D by extruding them based on attribute values, e.g., depth or height, and vice versa.

The analytical functionalities currently implemented in the prototypical application are

- thematic filtering;
- distance calculation;
- 3D buffer around a point; and
- extended temporal filtering.

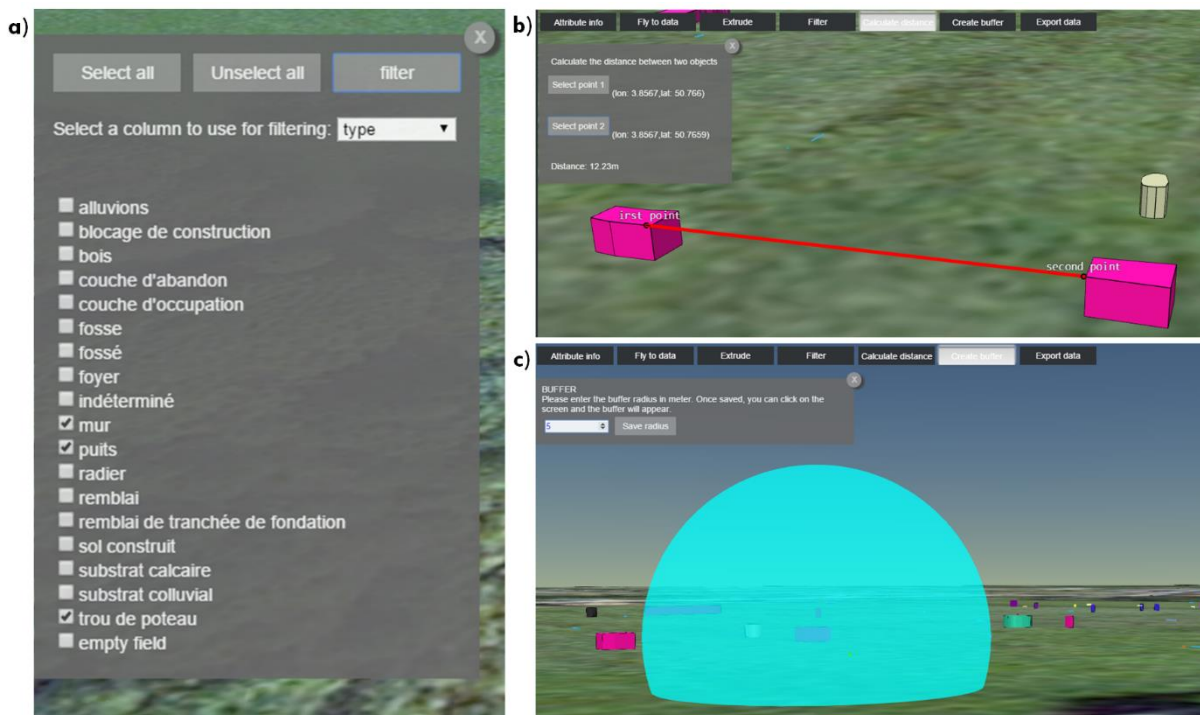


Figure 6-3 Implemented analytical functions: a) thematic filtering, b) distance calculation, c) 3D buffer computation

Selecting the ‘Filter’ button opens a new modal window in which the user can select the attribute field and the corresponding filter values (Figure 6-3a). Representing potential geometric functions, the ‘calculate distance’ function gives the coordinates of and distance between selected points (Figure 6-3b). To limit the programming workload of this prototypical application, only one spatial function, a 3D buffer calculation, was developed (Figure 6-3c). So that the temporal filtering could better meet the needs of archaeology, the timeline feature was extended to address dates before Christ. Because



the source code (JulianDate.js and Timeline.js) uses an algorithm to convert Gregorian to Julian Dates, the earliest date useable after the adaptation is 4800 BC (Fliegel and Van Flandern 1968). Thus, the data can be temporally filtered for dates from 4800 BC onwards by clicking a point on the timeline.

Finally, the use of the application as a channel for data communication and dissemination was extended by providing a data export function. The prototypical application can export the active layer's data or the current filtered part of it in either CSV or GeoJSON formats.

## 6.4 PRACTICAL FEASIBILITY ASSESSMENT

To practically extend a virtual globe to a 4D ArcheoGIS, the attitudes of end-users towards the concept of the current prototype were investigated via a usability test. In the remainder of this section, the test design is described, and the test results are then presented.

### 6.4.1 Test setup

Two Flemish archaeological organizations (GATE and SOLVA) were contacted to participate in the project by providing data and allowing some employees to take part in the usability test. Although only eight test persons were reached that way, according to Nielsen (1993), that rather small number was sufficient in the early development stage to uncover the general attitude towards the system and potential usability problems. The test was conducted at the (on-site) offices of the organizations and during the participants' working hours and was limited to approximately 30 minutes per test user. The experimenter's laptop was used because it was running the prototypical application locally (see Section 6.3.2.2 for the specifications). To facilitate easier navigation, mice were provided to the users. An internet connection was required to load the virtual globe's background images, and Google Chrome was used to load the application.

The user test, which was designed according to Nielsen's usability engineering principles (Nielsen 1993) was comprised of three parts: an introduction, the actual usability test and a final questionnaire. The first part was used to explain the broader research context, system design and test goal and, thus, to put the participants at their ease. Furthermore, some questions on the user's background such as age and experience with GIS were asked in that part.

In the second part, the users were asked to perform test tasks with two variants of the prototype. The first prototype (A) used data provided by the organization, whereas the second prototype (B) used data that were unknown to the participants. The unknown data and the data that were received from GATE were 2D polygons with separately stored depth information. The data from SOLVA were 2D but could be draped over a terrain model based on height points. For the presentation, the data were visualized at their

found depth in one version (Figure 6-4b) and extruded based on the depth information in the other version (Figure 6-4a). Furthermore, unlike that in prototype A, the timeline widget in prototype B was incorporated, and the data were only visualized during the period they actually dated to. After becoming acquainted with prototype A, the users were asked to perform a series of GIS-related tasks using prototype A; this exercise was followed by an exploration of prototype B and the performance of comparable tasks (Table 6-3). For each of the tasks, the following usability measures were used: (i) time to complete a task, (ii) type of commands used, and (iii) number of errors. Indications of satisfaction and confusion or frustration were also collected per task. Additionally, the users were asked to think aloud and to indicate when they completed the tasks.

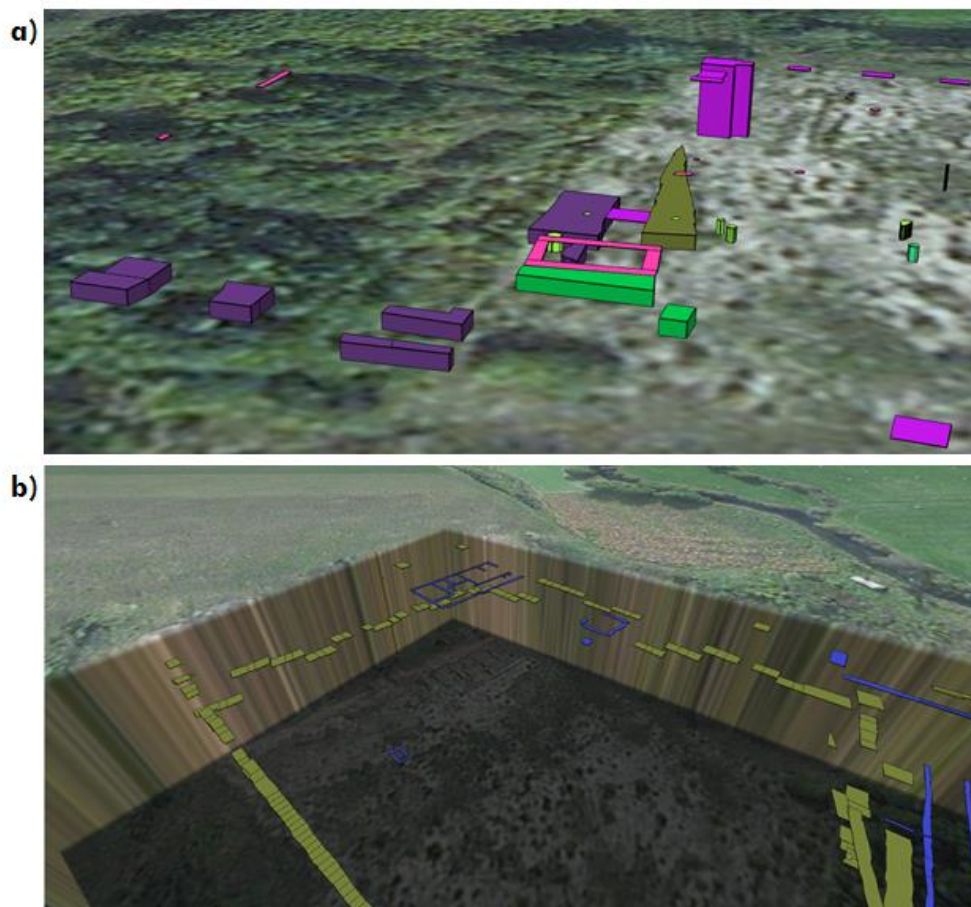


Figure 6-4 Visualization of the data: a) extruded based on height information and b) on their depth level

Table 6-3 Overview of the test tasks and their objectives

Prototype	Task	Short description	Objective
A	A1	Explore the application; navigate to complete globe and change background map.	Getting acquainted with the application
	A2	Change visibility and get attribute information	Using data management functions
	A3	Filter on attribute	Using query functions
	A4	Change extruded to flat polygons	Using visualization function
B	B1	Explore the timeline and time animation	Familiarizing with the temporal functions
	B2	Filter on attribute and time	Using query function and timeline

The final part of the test served as a debriefing. A questionnaire was given to the participants to probe their opinions on both versions of the application.

### 6.4.2 Test results

All of the test users (six male, two female), who had an average age of 33, had at least a Master's degree in archaeology. Although all of the participants used Windows PCs, iOS was most commonly used on the on-site tablets. The test users who assessed their computer knowledge as experienced (three out of eight) used GIS daily, whereas the persons with average computer experience (five of eight) only sporadically or never used GIS. Six of the eight participants indicated that they used Google Earth, primarily to gather impressions of future site locations. Half of the participants had experience with 3D applications or reconstructions.

The usability measures could not reveal differences between the participants with regard to their previous experience with GIS, virtual globes or 3D applications. Although the participants took approximately five minutes to discover prototype A (task A1), they only needed 1.5 to 2 minutes to become accustomed to prototype B (task B1). No relationships were found between the number of commands used or errors and the time needed to complete a task. The most confusing tasks seemed to be the filtering tasks. Most users expected real-time filtering once an option was selected, but the application instead required the 'filter' button to be explicitly clicked. Furthermore, task A4, in which the participants should have switched the extruded polygons to flat 2D shapes, was not correctly understood by most of the participants, who changed the globe view to a 2D map view. The most satisfactory task was apparently A2 because the semantic information was shown by clicking a feature, and, thus, the map-database connection became visible.

Thanks to the encouragement to think aloud, additional usability problems became apparent during the tests. Multiple participants at first encountered problems changing

the view angle. Although common in 3D applications, pushing down the scroll wheel while dragging the mouse is an uncommon operation in other computer programs. As noted by several participants, the zoom operations should be extended. In the current prototype, Cesium®'s standard navigation operations are maintained, which implies using the scroll wheel to zoom. Unfortunately, dragging a rectangle with the mouse from the top left to bottom right to zoom to that region is not supported by the default Cesium® Viewer. Furthermore, a participant noticed that the application zoomed to the middle of the screen and not to the position to which the mouse was pointing. Another related remark made by two participants was that the zoom level was not maintained when changing views (e.g., from a 3D globe to a 2D map). A second issue that became clear regarded the filter functionality. Although the filter box contained controls to (un)select all of the options, no participant noticed them at first. Because only two options should have been checked for the given tasks (A3 and B2), the participants clicked multiple times to uncheck all of the other options. Some of the users, however, found the 'unselect all' button at the end of the task. Furthermore, as mentioned above, real-time filtering was preferred by the test users. A third issue concerned the timeline. Several participants indicated that the labelling on the timeline was unclear; it was too long, too specific and vaguely positioned. In addition, task B1 demonstrated that the navigation operations for the timeline, i.e., zooming and scrolling, were not intuitively found.

The final questionnaire showed further suggestions for improvements. Regarding the design, the current text in the toolbar buttons should be replaced with icons. Furthermore, the 'filter' button should be moved to the bottom of the modal box. To support the interpretation of excavation results and the creation of reports, the prototype should be expanded to allow

- connecting spatial features with drawings and photographs;
- exporting reports;
- integrating other data, e.g., environmental data;
- viewing the data from below; and
- performing spatial analyses, e.g., density analyses.

In general, the concept of a 4D archaeological GIS that has a low threshold was received rather positively (one neutral, three rather positive, four positive). From the final questionnaire, it became apparent that visualization was the most interesting feature of the system. The visualization of the data at their found depth was preferred above the extruded polygons. The participants' opinions on the extrude function differed. Some found that the function was useless for the current data but thought it could be beneficial for more complex excavations. The timeline feature was enthusiastically entertained because it has many advantages for both analysis and communication. The last was one of the reasons why accessing the application via an internet browser was experienced as an advantage. In addition to the visualization, the query functionalities and database connection were the most liked features. Those three elements also accounted for the considered future purposes, namely analysis, public activities and fieldwork preparation.

## 6.5 DISCUSSION

For the feasibility study of extending a virtual globe to a 4D archaeological GIS, the end user requirements were first matched to the characteristics of virtual globes. Four elements were decisive when selecting the most appropriate virtual globe: cost savings, customizability, 3D data and the temporal dimension of the data. Choosing a FOSS virtual globe that was also based on WebGL allowed the first two elements to be tackled. The open-source character also allowed the globe's functionalities to be extended and imperfections and multiple purposes to be addressed. Subsequently, Cesium® was chosen because of the combination of three spatial dimensions and one (or more) temporal dimension(s) in archaeological data. Cesium® can handle subterraneous data and allows time-dynamic data to be explored via its timeline widget.

In the second part of the technical feasibility evaluation, a prototype 4D ArcheoGIS was implemented to allow end-user participation early in the design. Taking advantage of Cesium®'s open-source JavaScript code, the basic functionalities of the globe were extended to represent the five common groups of GIS tasks. Regarding data integration and management, the main development was the realization of a connection between the application and a geodatabase, namely PostGIS. This allowed thematic information on a specific feature or on the entire data set to be accessed via a table view. The table includes editing and deleting capabilities that are immediately carried through the database. This calls for an elaborated authorization control and history tracking when the system becomes operational. In the initial development phase, only a limited set of spatial, thematic and temporal analyses were implemented in the prototype: thematic and temporal filtering, distance measuring, 3D buffer creation and temporal animation. Nevertheless, it is believed that those analyses constitute a representative set of potential functions, and the development of more complex analyses should be achievable. The most significant features to be extended in the future are temporal representation and analysis and spatio-temporal analyses. Currently, the representation of temporal information is limited to 4800 BC, and only modern clock times and dates are covered. Archaeological periods, fuzzy dates and other temporal characteristics of archaeological data are currently not dealt with. This constitutes a major deficiency of the system and thus forms an important subject for future research. This is consistent with the conclusions of Resch et al. (2014) that handling time-varying geo-information on the web still holds methodological and technological challenges.

In addition to technical feasibility, it is important to gain insights into the attitudes of archaeologists towards the new concept and the implementation. The usability test with two Flemish archaeological organizations demonstrated a positive approach toward the concept. This may be explained by the current absence of tools that integrate both 3D and analytical functions (von Schwerin et al. 2013). During the test and the subsequent questionnaire, the user-friendliness and good learnability factor generally attributed to virtual globes in the literature (Butler 2006, Brovelli et al. 2013, Resch et al. 2014,

Lonneville et al. 2015) were confirmed. Those benefits make them especially valuable tools for disseminating information to the public and to non-experienced computer users. Notably, public activities were indicated as a major application of the prototype. The web-based nature, therefore, was seen as an advantage rather than as a system bottleneck. This is in contrast to the argument sometimes put forward that archaeological data can be sensitive and contain copyright and, thus, should not be shared on the web (McKeague et al. 2012). On the other hand, this finding agrees with suggestions for a web-based geodata infrastructure for archaeological research reported by several authors (Snow et al. 2006, von Schwerin et al. 2013, Chapter 4). Apart from the geodatabase connection, additional actions should be undertaken to develop a true cyberinfrastructure in which researchers can collaborate, share and transfer information. The implementation of an authorization system and history tracking for the information are two of those actions. Exchange and integration functionalities (e.g., WFS) should be elaborated. A common agreed-on data structure or exchange structure could facilitate that data integration, although it will also require a change in the current line of thought. Moreover, existing geo-collaborative initiatives and the opportunities semantic web-technologies could offer in this context should be studied more thoroughly.

During the usability test, the database connection and query functionalities were assessed as the most interesting features, in addition to visualization. Those capabilities suit the two other major application domains of the system: analysis and fieldwork preparation. The current usability problems such as zoom issues, replacing button texts by icons and redesign of the timeline are easily implementable and should be tackled first. However, as mentioned previously, to support the entire archaeological workflow and to function as a fully fledged 4D archaeological GIS, the current prototype needs to be substantially expanded. This involves elaborating current spatial and spatio-temporal functions. Those could range from a combined spatial and temporal query to temporally extended geostatistical analyses or even spatio-temporal simulations (e.g., site evolution in both time and space). Before arriving at such an advanced stage, the application will have passed through several development cycles in which the user requirements will be refined and rematched each time.

## 6.6 CONCLUSIONS

In this chapter, the technical and practical feasibility of extending a virtual globe towards a 4D archaeological GIS was proven. The technical evaluation demonstrated the ability to match the requirements on an archaeological GIS against the Cesium® virtual globe. Its open-source JavaScript code was advantageously used to implement a prototypical application. The prototypical application not only served to evaluate the technical feasibility but also formed the basis for a practical feasibility study. In that assessment, a usability test with two Flemish archaeological organizations, which are potential end-users, proved that the usability of virtual globes is good; in addition, public activities, analyses and fieldwork preparations were indicated as future applications domains for

the system. However, to be used throughout the entire archaeological workflow and to ideally be part of an archaeological cyberinfrastructure, the system needs to be further elaborated. The next step will be to extend the system's temporal and spatial functionalities and to increase its data integration capabilities. In addition, further study needs to be undertaken on existing geo-collaborative initiatives, opportunities offered by semantic web-technologies and data exchange standards.

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# 7

## ADAM: A CONCEPTUAL DATA MODEL TO IMPLEMENT FLEXIBILITY IN ARCHAEOLOGICAL DATA MANAGEMENT AND RESEARCH

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### ABSTRACT

Archaeological data, which are detailedly acquired today, are mostly left unused after the final excavation report is written. To enable the reuse of these data and to contribute to a complete digital documentation of excavations, an integrated archaeological data infrastructure can be set up. At the basis of such a collaborative management and research infrastructure is a conceptual data model. This chapter suggests a novel conceptual data model: Archaeological DATA Model (ADAM). ADAM consists of nodes, properties and relations and allows for an uncomplicated description of the wide array of archaeological objects for use in diverse domains in a cost and time efficient manner. This flexible data model therefore addresses the challenges archaeology faces regarding data diversity, multiplicity of actors with varying IT skills, varying purposes in different domains and increasing time pressure and cost constraints. As the description of the data model may be viewed as overly abstract, a potential database implementation and web application are presented in this chapter to illustrate the potential of ADAM. This web application sows the seeds of an integrated archaeological data infrastructure. Employing ADAM as the basis in such a framework will enable the dissemination and integration of data, as well as collaboration and discussion with respect to their interpretation. This approach can ensure the data and information continue to flow even after the excavation and report writing have been finished.

## 7.1 INTRODUCTION

During archaeological excavations, increasingly large amounts of spatial and semantic data are acquired. Three main causes for this emphasis on data recording can be mentioned: (i) the growing awareness of the destructive nature of excavations, (ii) the widespread use of digital - especially spatial - recording technologies (Forte 2014; Stal et al. 2014) and (iii) the increasing time pressure due to the capitalistic market (Berggren and Hodder 2003). These data are later used to compose the final excavation report, which is generally considered the final deliverable of an archaeological investigation (McKeague et al. 2012). In the best case, the 'raw' data are stored in a central database by the organization. The use of these data, however, remains restricted given the limited time available for extensive analysis and interpretation in contemporary, capitalistic archaeology (Chapter 4). Furthermore, these data are mostly inaccessible for future research due to the organization-specific database structure and varying data use policies (Snow et al. 2006; McKeague et al. 2012). Nevertheless, the dispersed databases contain useful information for archaeological research, conservation management and other domains (e.g., spatial planning) (Snow et al. 2006; Forte 2011; Chapter 4). An integrated data infrastructure has therefore been proposed by several authors (Snow et al. 2006; Huvila 2008, 2011; McKeague et al. 2012).

Such a data infrastructure can contribute to a complete digital documentation by providing the framework to manage the increasing flux of digital data. Ensuring that the data and information flow continues even after the excavation and report writing have been completed is possible by conceiving the infrastructure as a platform for collaboration and discussion. For the data infrastructure to be seen as a collaborative management and research infrastructure for archaeological data, several issues should be considered during the design (Snow et al. 2006; Kansa et al. 2010; McKeague et al. 2012). Handling the diversity of the archaeological data is the first challenge (Schloen 2001; Huvila 2011; Labrador 2012). This relates not only to the wide range of archaeological objects (e.g., building vs. bone fragment), but also to two other unique characteristics of archaeological information, namely the geographical character of most data involved in archaeological information flows (Chapter 4) and the temporal sequence that they encompass. The second challenge originates primarily from the current economic situation. As most current excavations are classified under the heading 'rescue archaeology', archaeological organizations are faced with increasing time pressure and cost constraints (Kristiansen 2009; Wendrich 2011, p. 228). When designing the data infrastructure, attention should be paid to not reinforcing these pressures. The third and fourth challenge both relate to the multiplicity of actors who are either involved in the archaeological research process (e.g., field archaeologist, heritage agency, and project leader) or use archaeological research outcomes (e.g., museums, tourists, spatial planners, etc.). Being large and diverse, this group of actors will have different levels of computer skills. The third challenge consequently concerns the usability of the intended infrastructure and the avoidance of complexity. Furthermore, these actors will use the infrastructure for

different purposes depending on their domain, requiring actions from simple consultation to detailed analysis. Hence, the fourth challenge is the wide deployment that has to be kept in mind during the design of the infrastructure. Addressing these challenges should already be taken into consideration during the development of the conceptual data model that lies at the basis of an integrated archaeological infrastructure.

The general purpose of this research project is to develop a conceptual data model specifically designed to suit an integrated archaeological geodata infrastructure. This chapter determines how such a data model and infrastructure should be developed to address the aforementioned challenges. Section 7.2 gives an overview of the current practice of archaeological data organization and existing initiatives for archaeological data infrastructures. The proposed concept is introduced in Section 7.3. In Section 7.4, the suggested implementation of the concept in a database is presented together with an application that illustrates the potential of an archaeological geodata infrastructure. Finally, a discussion and the chapter's conclusions are presented in Section 7.5.

## 7.2 ARCHAEOLOGICAL DATA ORGANIZATION

Archaeological data are recorded and catalogued in a very exhaustive manner, as future interpretation and research results are influenced by how the data are organized. Many authors question whether the current stress on data acquisition enhances the quality of archaeological research outputs and thus archaeological knowledge production (Berggren and Hodder 2003; Thomas 2006; De Clercq et al. 2012). This criticism is even shared by archaeological organizations themselves, who blame government for the absence of quality control in the delivered archaeological outputs (Chapter 4). In this regard, many of these organizations favour a standard database template or exchange format (Chapter 4). This mainly originates from the varying practices in recording and storing data within and between archaeological organizations. Although digital technologies are gaining ground in archaeological recording, a large share of data is still acquired on paper forms (Forte 2011; Chapter 3). Similarly, large differences exist in storage practices, which range from using simple Excel files that vary for every project to employing a central database with the same predefined fields for every project (Chapter 4). What these diverse storage practices have mostly in common is a class-based, tabular data organization system (Schloen 2001; Bruschke and Wacker 2014). These are mostly implemented in relational database systems by a fixed set of tables with predefined columns in which many empty cells occur and even redundant information can be found if these tables are not optimized (McKeague et al. 2012; Schloen and Schloen 2012; Bruschke and Wacker 2014).

These differing organization practices have led to numerous projects and initiatives on both the national and international levels. Several projects intend to enhance data exchange and integration, facilitate the sustainable preservation of research outcomes,

or aim to accomplish both. Next, an outline is given of the most relevant projects and initiatives within the context of this research.

On the one hand, different national governments have formulated or have even enforced guidelines or data standards for recording archaeological research data. Apart from provisions in national or regional legislation, examples of such guidelines and standards are the Archaeological Data eXport standard (ADeX) in Germany (Verband der Landesarchäologen 2016), the Dutch Archaeology Quality Standard (KNA) in the Netherlands (Willems and Brandt 2004) and MIDAS Heritage in the United Kingdom (English Heritage 2007). The latter adapts the terminology of CIDOC CRM for indicating what to record during archaeological research for preservation (English Heritage 2007). The international ISO standard CIDOC CRM is a standardized ontology to represent information on cultural heritage (Crofts et al. 2011). However, this standard focuses on museums and archives in particular (Crofts et al. 2011) and is rather complex due to the considerable number of concepts and relationships covered by the standard (Schloen and Schloen 2012; De Roo et al. 2014).

On the other hand, several initiatives to set up an archaeological data archive are being taken at the national level. One of the first and most well-known is the UK's Archaeology Data Service (ADS), supported by the University of York (ADS and University of York 2016). The ADS aggregates information, provides online access to digital archaeological resources, such as reports, photographs and databases, and ensures digital sustainability of these sources (Wagtendonk et al. 2009; Richards et al. 2011). Similarly, the Netherlands has set up the e-Depot for the Dutch Archaeology (EDNA) and in Sweden, the Digital Archaeological Workflow (DAP) programme is being carried out to address the lack of such a central digital archive (Smith 2015). As in Sweden, a digital archaeological archive is not available for actors in the archaeological process in many other countries, for example, in Belgium. From this lack of national initiative, several projects aim to develop an international digital archaeological archive or integration platform, regardless of whether it is based on a common data standard. In the United States, two such international data repositories exist. The multi-institutional organization Digital Antiquity has developed the international repository tDAR (the Digital Archaeological Record) (Digital Antiquity 2016), while the Alexandria Archive Institute (AAI) has established Open Context (Alexandria Archive Institute 2016). According to Sheehan (2015), who made an extensive comparison between both repositories, differences occur in the licencing of data, availability of data sets and search retrieval designs. Open Context claims to be flexible in scale and description because it is founded on the Archaeological Markup Language (ArchaeoML) that is specified by Schloen (2001). This abstract model, which is implemented in XML, consists of five schemas (locations or objects, people or organizations, properties, resources and relationships) (Kansa 2005). Furthermore, it is an item-based data model that hierarchically represents spatial containment relationships (Schloen 2001). However, further documentation on the data model is no longer available, most likely because ArchaeoML evolved into the OCHRE ontology which consists of eighteen XML document schemas (Schloen and Schloen

2012, p. 372). The schemas, together the OCHRE ontology, include fourteen basic concepts (e.g., project item, spatial item, temporal item, etc.) and four concepts for grouping purposes (e.g., hierarchy and set) (Schloen and Schloen 2012). These eighteen concepts make up the semi-structured data model of OCHRE that “occupies the middle ground between the strongly structured relational model and the weakly structured graph (or network) data model” (Schloen and Schloen 2012, p. 364). This OCHRE ontology is not only used in the Open Context project, but also in the broader OCHRE (Online Cultural and Historical Research Environment) project. This project aims to provide a database system in which multiple users can record, integrate, analyse, publish and preserve data from various projects at varying research stages (Schloen and Schloen 2012, p. 1). A Java user interface can be downloaded from the website to view the data in the database (Schloen and Schloen 2012), but no open-source application is available for adaptation to specific needs. Finally, it is worth mentioning the Arches project, which intends to provide inventory and management solutions for immovable heritage at different scales (Carlisle et al. 2014). Within this project, the Arches open-source web-based information system is being developed thanks to collaboration between the Getty Conservation Institute and the World Monuments Fund (Myers et al. 2012). Based on international standards, among others, CIDOC CRM, the core data standard package consists of four categories of resources, each of which is further subdivided into types that are presented completely in extensive graphs (Carlisle et al. 2014).

Apart from these national or international projects, many researchers are determined to use alternative data models or a different research infrastructure for archaeology either through local implementation or on a higher level of abstraction. Although the list is not exhaustive, the following research projects all have contributed to database and data infrastructure research in archaeology: Katsianis et al. (2008), Stal et al. (2014), the MayaArch3D project (von Schwerin et al. 2013) and the Catalhöyük project (Forte 2014) on the integration of 3D data in a digital workflow; McKeague et al. (2012) on the potential reuse of archaeological data; Labrador (2012) on trends in archaeological database design; Cripps (2012) on event-based modelling in archaeology; Huvila (2011), Forte (2011) and Snow et al. (2006) on collaborative cyberinfrastructures for archaeology. However, all of these projects focus on either a very specific situation or a nonconcrete idea and are therefore difficult to deploy in other projects that focus on different data and purposes.

## 7.3 ADAM: ARCHAEOLOGICAL DATA MODEL

Conceiving a novel conceptual data model that functions as a basis for an archaeological data management and research infrastructure requires that several challenges be addressed. As outlined in the introduction to this chapter, four main characteristics of archaeological information flows constitute these challenges:

- the diversity of archaeological data, including spatial and temporal variation
- the multiplicity of actors with varying IT skills

- the varying purposes in different domains
- the time pressure and cost constraints of archaeological organizations

The first three challenges or requirements can be summarized as the need for the data model, and by extension the data infrastructure, to be flexible, broadly deployable and easily understandable. As noted in the previous section, a class-based organization of archaeological data is currently the most commonly used. This implies a set of predefined tables that represent the archaeological object categories, with a number of predetermined columns that are the properties of the objects. The diversity of archaeological data results in countless different tables and columns. Of course, archaeological objects can be grouped together in more abstract tables, such as ‘finds’ or ‘traces’. However, such a generalization implies more predetermined columns to facilitate the thorough description of the different objects. A large number of empty cells will occur using this approach because some columns refer to properties that are only identifiable for a small number of objects (e.g., weight). To avoid a data model with a pre-set number of objects and properties in which it is hard to handle exceptional objects, a flexible and extendible data model is proposed here.



Figure 7-1 Components of ADAM in abstract form

The proposed data model, called ADAM (Archaeological DAta Model), consists of three main concepts: (i) nodes, (ii) properties and (iii) relations (Figure 7-1). Nodes form the fundamental elements of the data model as they correspond to the archaeological objects. However, the concept of nodes must be interpreted broadly here. Nodes not only represent finds and traces, as well as other tangible archaeological objects, but also conceptual items such as sites and projects. Each node has a name and a description (Figure 7-1). Figure 7-2a exemplifies the abstract node concept: a particular site is conceived as a node with the name ‘site a’ and description ‘archaeological site located in city A’. Each node, which is either a tangible archaeological object or a conceptual item, can be described more elaborately by its characteristics (e.g., is a site) or by its connections to other nodes (e.g., is part of a site). To allow this further specification of a node, the concept of ‘relations’ is used. A relation connects a node with a value, which can be either a general value (i.e. characteristic) or another node (i.e. connection) (Figure 7-1). The relation type is defined using the property concept, which gives the relation type a name, a broader description and a data type for the expected value (Figure 7-1). Figure 7-2a illustrates how the property and relation concepts should be comprehended. For example, the node ‘site a’ can be specified further by indicating that



its type is 'site'. For this specification, a new relation is created with start node 'site a', a property and value 'site'. The property needed for this has the name 'is of type' and specifies that the value must be of type 'text' (Figure 7-2a). This property can be reused by other relations. As shown in Figure 7-2a, the relation between two nodes, e.g., to indicate that a particular zone is part of a site, can be realized via a property with data type 'node'. Figure 7-2b summarizes the previous examples graphically. The relation concept can furthermore be used to give more information on another relation. This possibility, hereafter called secondary relation, is not included in Figure 7-1 and Figure 7-2, as this is strictly speaking only an extension of the basic relation concept. In this case, the relation has a start relation instead of a start node, in addition to a property and a value. To illustrate this extended concept: a relation 'has date 1000/1500', which is assigned to a node, can be further specified by the (secondary) relation 'is determined by C14', which indicates the method used to determine this period. Secondary relations can thus also be used to incorporate some metadata elements, e.g., the methods used to determine the value of the parent relation.

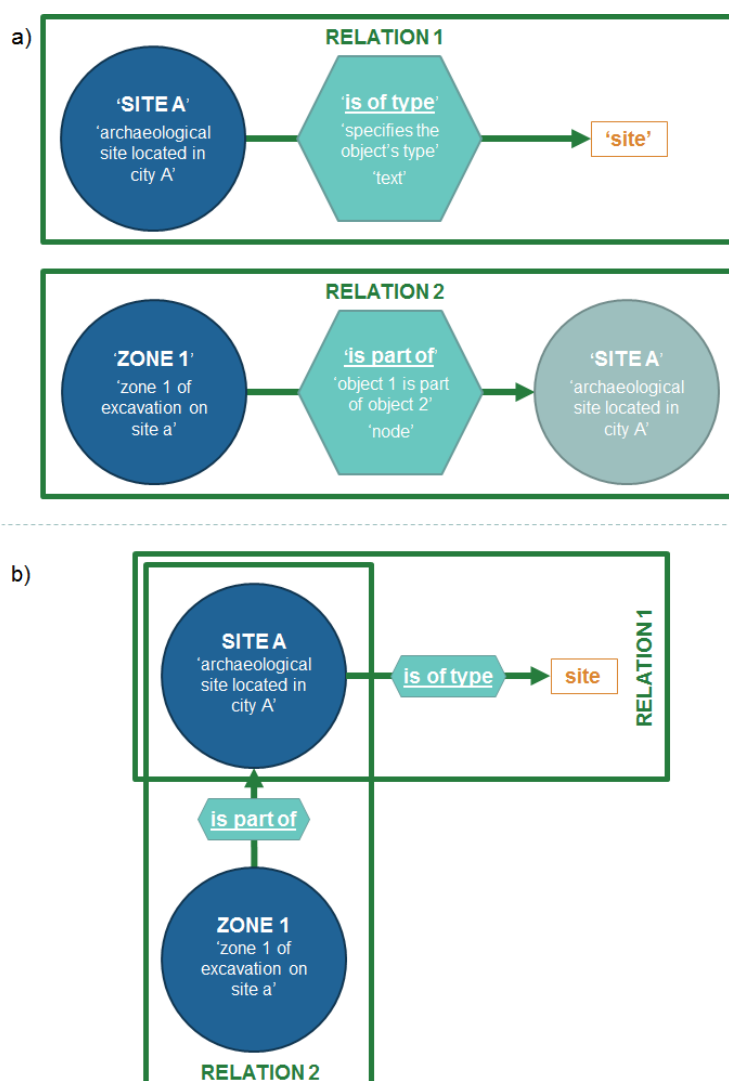


Figure 7-2 Use of ADAM's node, property and relation as a) atomic and b) integrated example

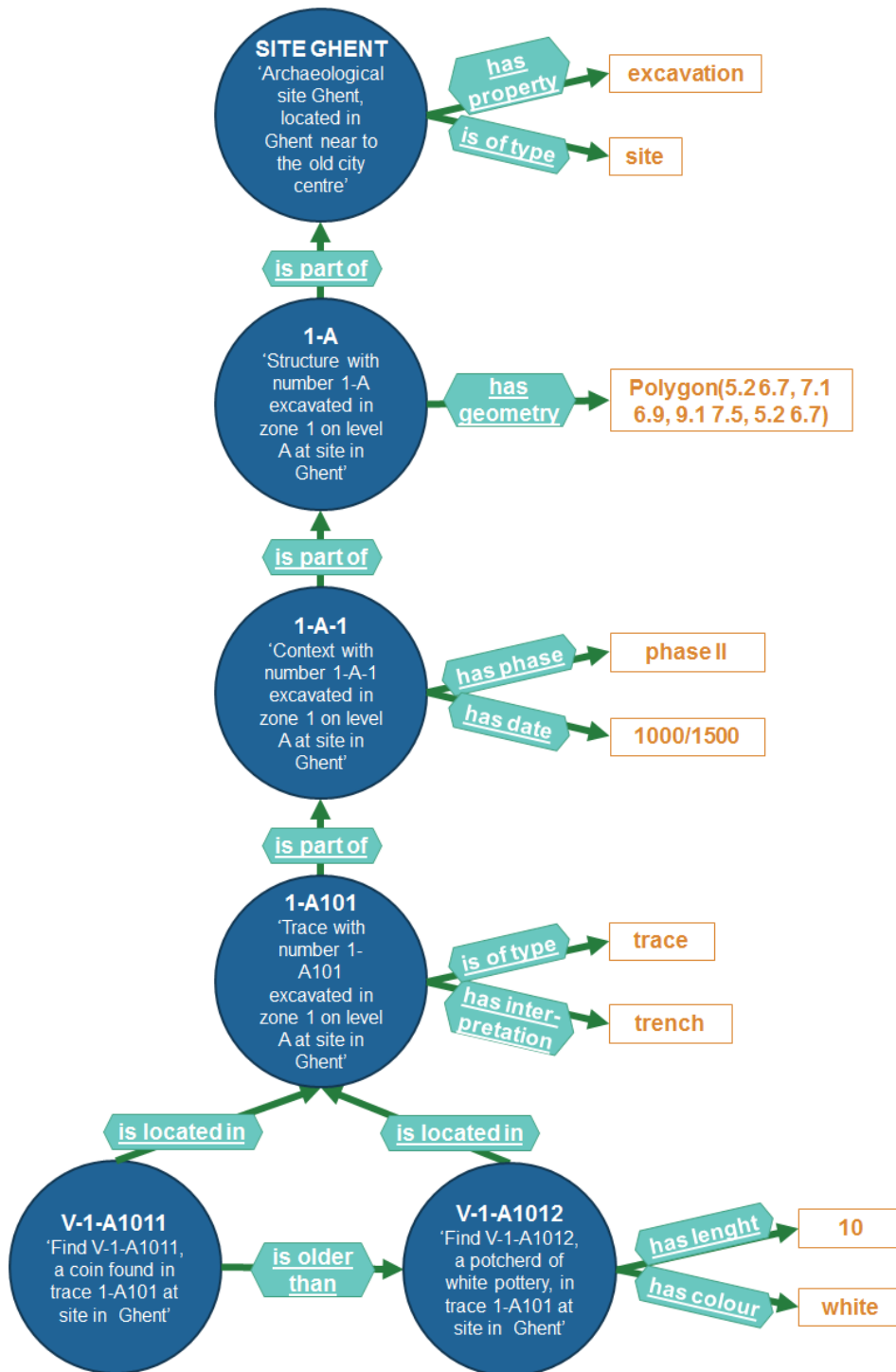


Figure 7-3 Example of using ADAM consisting of nodes, properties and relations

A more extensive example of using ADAM is presented in Figure 7-3. This figure clearly illustrates that the relation concept can be used to build a hierarchical structure: a context is part of a structure, which is part of a site. Apart from this hierarchy and the variety of archaeological objects, a spatial and temporal description characterizes archaeological data. These characteristics are also admitted in the proposed structure. First, the spatial nature of archaeological objects is approachable from two viewpoints: absolute and

relative. On the one hand, the spatial location of an object can be specified via geographical coordinates. For this, either a point can indicate the finding place or the topographic measurements of the object's shape can be used. As indicated in Figure 7-3, structure '1-A' has a polygon geometry that describes both its shape and location in an absolute way. On the other hand, the location of an object can be described in relation to another object. For instance, finding 'V-1-A1011' is located within trace '1-A101' (Figure 7-3). Second, multiple categories are used to describe the temporal character of an archaeological object, like the site phase, the absolute date, etc. As multiple relations can be assigned to a node, multiple temporal categories can be added and even temporal relations between objects are possible. In Figure 7-3, context '1-A-1' has been dated between 1000 and 1500 AD, but has been assigned at the same time phase II. An example of a temporal relation between two nodes is given in Figure 7-3 where find 'V-1-A1011' is indicated to be older than 'V-1-A1012'. This way a temporal hierarchy can also be described using ADAM.

## 7.4 PROPOSED DATABASE AND APPLICATION IMPLEMENTATION

ADAM, proposed in the previous section, may be seen as too abstract, so a database implementation and a potential application are presented here. The combination of the database implementation and test application will allow ADAM's abstract concept to be tested by practical experience and examining the implementation against the requirements. Furthermore, the test application will clearly illustrate the concept used in ADAM, show the potential of the idea as a basis for an archaeological data infrastructure, and stimulate discussion on the further development of such an infrastructure.

### 7.4.1 Basic database structure

The concepts used in ADAM can be easily transformed into a database model. The three basic elements (node, relation and property) accord with three tables (nodes, relations and properties). These tables have similar columns as specified in the previous section (Figure 7-1 & Figure 7-4). For the secondary relations, one could opt to use the same table as for the relations. However, as a normal relation requires the ID of a node while a secondary relation requires the ID of the relation it further specifies, in the proposed database structure a separate table is used for safety and simplicity reasons (Figure 7-4). For similar reasons, a separate table (geometries) is proposed to store spatial information (Figure 7-4). To this end, a geodatabase system is suggested to store the data and information. A geodatabase not only allows geometries to be stored, but also facilitates spatial analyses. The latter holds potential for future investigation of the data.

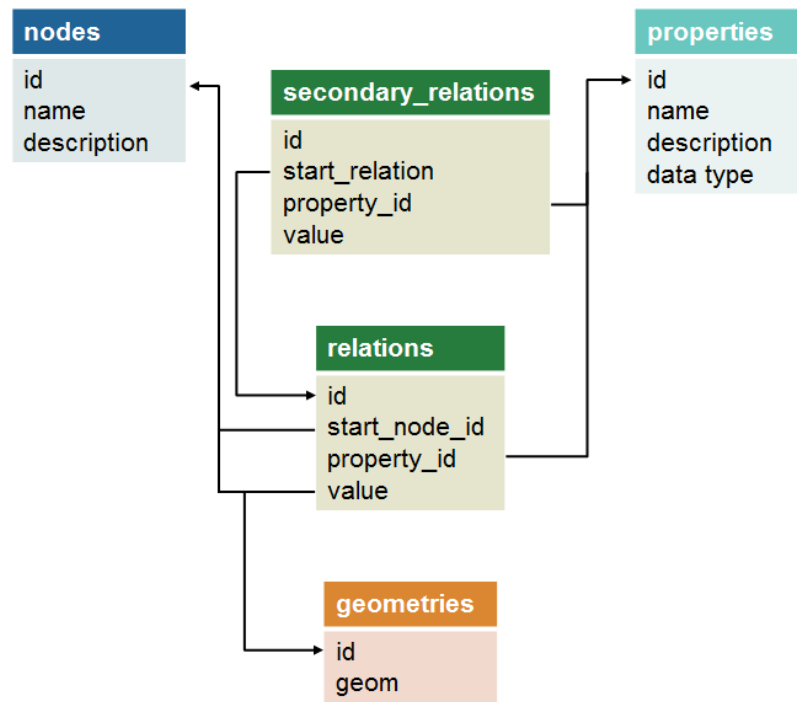


Figure 7-4 Proposed database structure based on ADAM's node, relation and property

## 7.4.2 Design of the test application

The examples given in Section 7.3 (Figure 7-2 & Figure 7-3) and the database implementation explained in Section 7.4.1 show that the proposed data model is easy to learn, flexible and linkable. However, the use of this database throughout the archaeological workflow, the display of information, the query opportunities and the potential functionalities realizable through this data model are best expounded by means of a test application. Such a test application should therefore incorporate a set of functions as diverse as possible: from data management over analysis to visualization.

Taking the challenge of cost efficiency into consideration, the use of Free and Open-Source Software (FOSS) is encouraged for the design of the application. Hence, for the central database system PostgreSQL with its spatial extension PostGIS (PostGIS Project Steering Committee 2015) is chosen in this research project. The ability of PostGIS to handle 3D and even 4D geometries and the wide variety of linkable applications (e.g., QGIS) lend support to this choice. FOSS is also chosen in other parts of the application. For the presentation of the data, for instance, OpenLayers (OpenLayers Contributors 2015), Cesium (Analytical Graphics Inc. 2015) and D3.js (Bostock 2015) are used. Some spatial analyses are made possible via the open-source library Turf.js (Herlocker 2014).

The test application is developed using the PHP framework Silex, template engine Twig, object-relational mapper Doctrine and the JavaScript libraries JQuery, OpenLayers, Cesium, OL3-Cesium, Turf and D3. For developing and testing purposes, a local WampServer Environment on a Dell Windows 10 laptop (16GB RAM, Intel® Core™ i7

CPU 2.1GHz 2.7GHz) was utilized. During the development and testing of the application, both fictive data and data from Flemish archaeological organizations were used. To illustrate the working of the application with regard to ADAM, in this chapter, the fictive data from the example given in Figure 7-3 is incorporated.

As the developed application also intends to be usable by multiple actors, a user management system is implemented first. This requires a minor extension of the database model proposed in the previous section, but has no influence on the concepts of ADAM itself. Figure 7-5 indicates where these changes intervene in the database structure; apart from a table to store the users of the application, some logging tables are also envisaged to allow for history tracking (Figure 7-5). This implicitly provides a small part of the metadata, since for each insert, delete or update action the time is registered as well as the name of the person who executed the action. Different roles can be assigned to the users, e.g., giving them only the permission to view the data in the database or permitting them to both read and write the data. Even more complex access rules can be implemented.

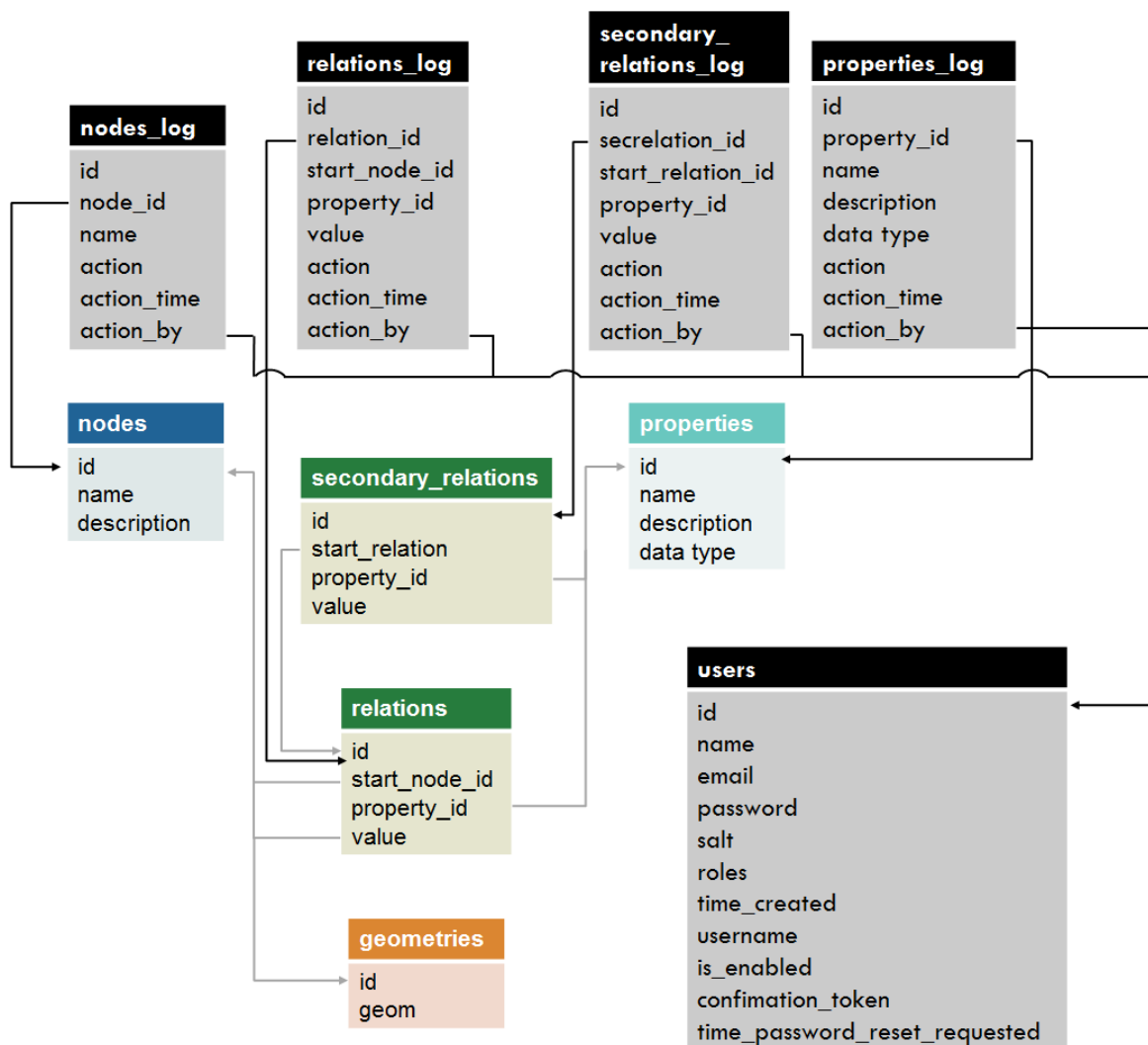


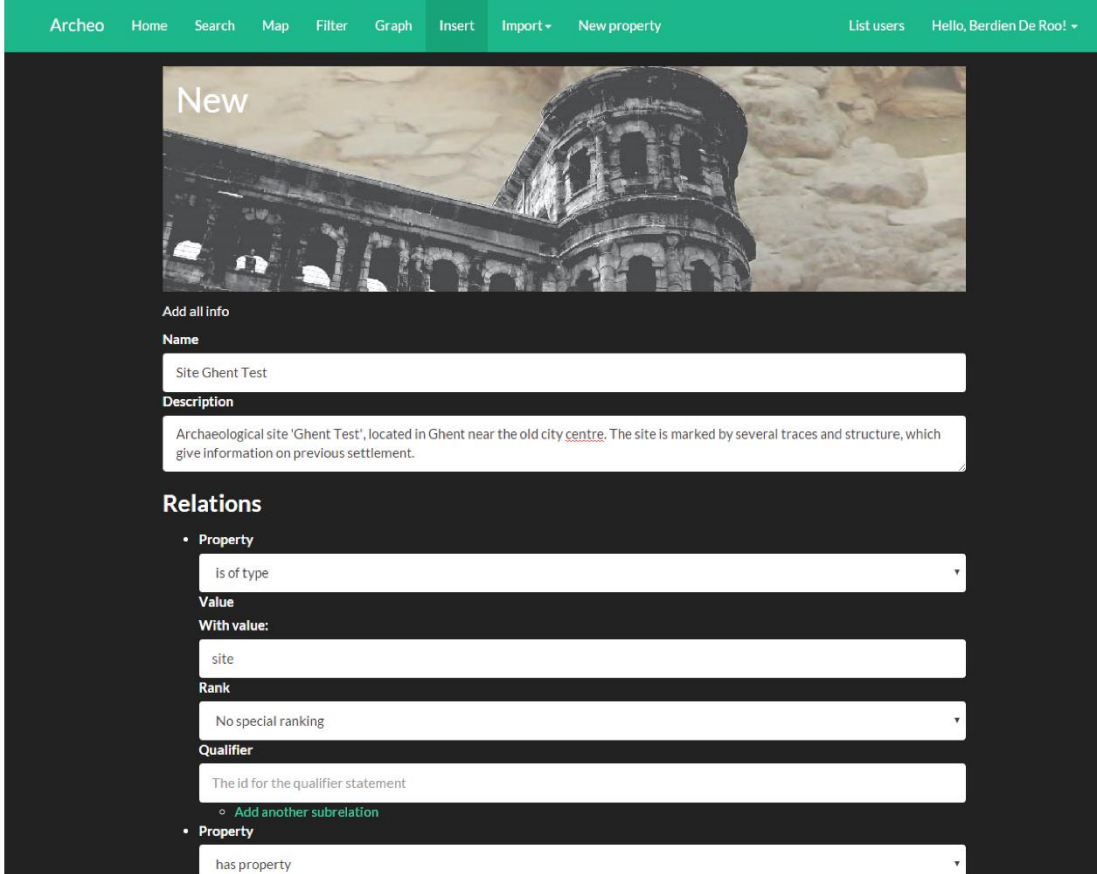
Figure 7-5 Proposed database structure extended for user management and history logging

In the current test application, the implemented functions can be categorized in three groups: data management, data display and data analysis. These groups constitute actions to be undertaken throughout the archaeological workflow by different actors (Chapter 4). Although in some cases they are rather basic, these functions will show the potential of ADAM and illustrate how the test application can function as an archaeological data infrastructure in which different actors can work alongside or together with one another.

In the data management group, functions to insert, update, and search data and track the data history are developed. For inserting data, the user has two options: inserting individual data or importing files. Individual data can be inserted via a form in which the name and description of the new node can be completed (Figure 7-6a). Next, the form offers the opportunity to specify this node further by adding relations and secondary relations. This insert option could be used during fieldwork. The user can also insert multiple data at once by importing either an Excel file or shapefile. Once the file is selected, an overview of all columns in the file is given. Next, the user is asked to indicate the column that represents the node name and indicate the properties that define the relations of the other columns. For example in Figure 7-6b, for the column 'spoorinterpretatie 1', the property 'has interpretation' is indicated for use. Using a shapefile to import data, even 3D spatial information can be stored and linked to the nodes. After data are inserted and thus stored in the database, users are able to change the relation or add additional relations via the update function. For this, a similar form is shown as for inserting data, but it is populated with the data stored in the database. This feature could be useful when reviewing the data during interpretation report writing. Since the editing history of a node and its relations is stored in the log tables as described above, for each node a history overview can be shown. This overview indicates the type (insert, delete or update), the user and the time for each action.

To visualize the data, a list, map and graph display are implemented in the current test application. All of these three presentation options are available on both a general and individual level. The general list overview shows the name and description of the nodes stored in the database (Figure 7-7a). On the individual level, the relations (and secondary relations) starting from and ending in this node are shown (Figure 7-7b). This information is displayed on the node's individual page. On this page, a map indicates all geometries that are related to the node (e.g., has geometry), while the graph visualizes all relations of the node (Figure 7-7b). On a general level, a map displays all nodes that have a geometry and the graph shows the nodes that are connected to each other via relations (Figure 7-8). In both displays, individual node info is shown when clicking either a geometry or a graph point (Figure 7-8). As the majority of archaeological data contain a geographic component, this map visualization is beneficial for the archaeological infrastructure. Therefore, not only a 2D map is included, but also a 3D virtual globe and split view, which shows both 2D and 3D side by side (Figure 7-8a), are integrated in the test application. The open-source JavaScript library Cesium is used for the 3D virtual globe implementation.

a)



Archeo Home Search Map Filter Graph Insert Import New property List users Hello, Berdien De Roo!

## New

Add all info

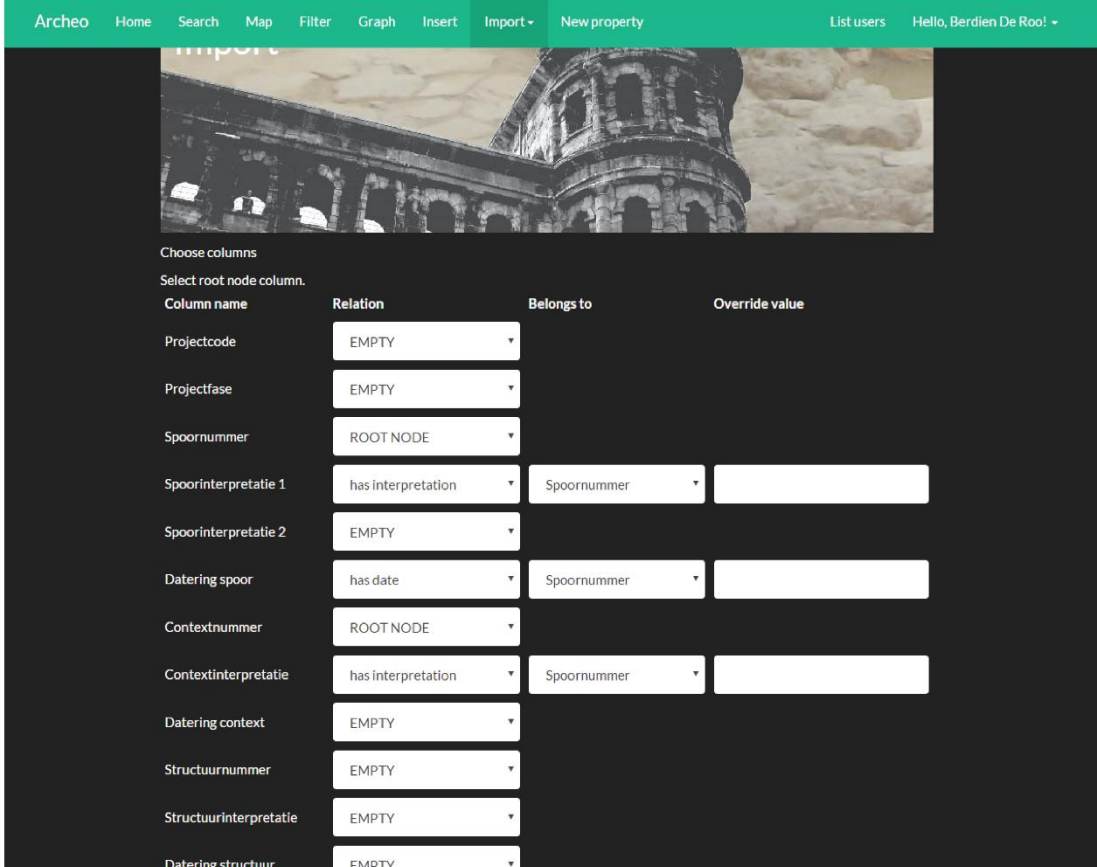
**Name**

**Description**

**Relations**

- Property
  - is of type
  - Value
  - With value:
  - Rank
  - Qualifier 
    - Add another subrelation
- Property
  - has property

b)



Archeo Home Search Map Filter Graph Insert Import New property List users Hello, Berdien De Roo!

## Import

Choose columns

Select root node column.

Column name	Relation	Belongs to	Override value
Projectcode	EMPTY		
Projectfase	EMPTY		
Spoornummer	ROOT NODE		
Spoorinterpretatie 1	has interpretation	Spoornummer	<input type="text"/>
Spoorinterpretatie 2	EMPTY		
Datering spoor	has date	Spoornummer	<input type="text"/>
Contextnummer	ROOT NODE		
Contextinterpretatie	has interpretation	Spoornummer	<input type="text"/>
Datering context	EMPTY		
Structuurnummer	EMPTY		
Structuurinterpretatie	EMPTY		
Datering structuur	EMPTY		

Figure 7-6 Inserting data in the database via the test application: a) individually, b) file import

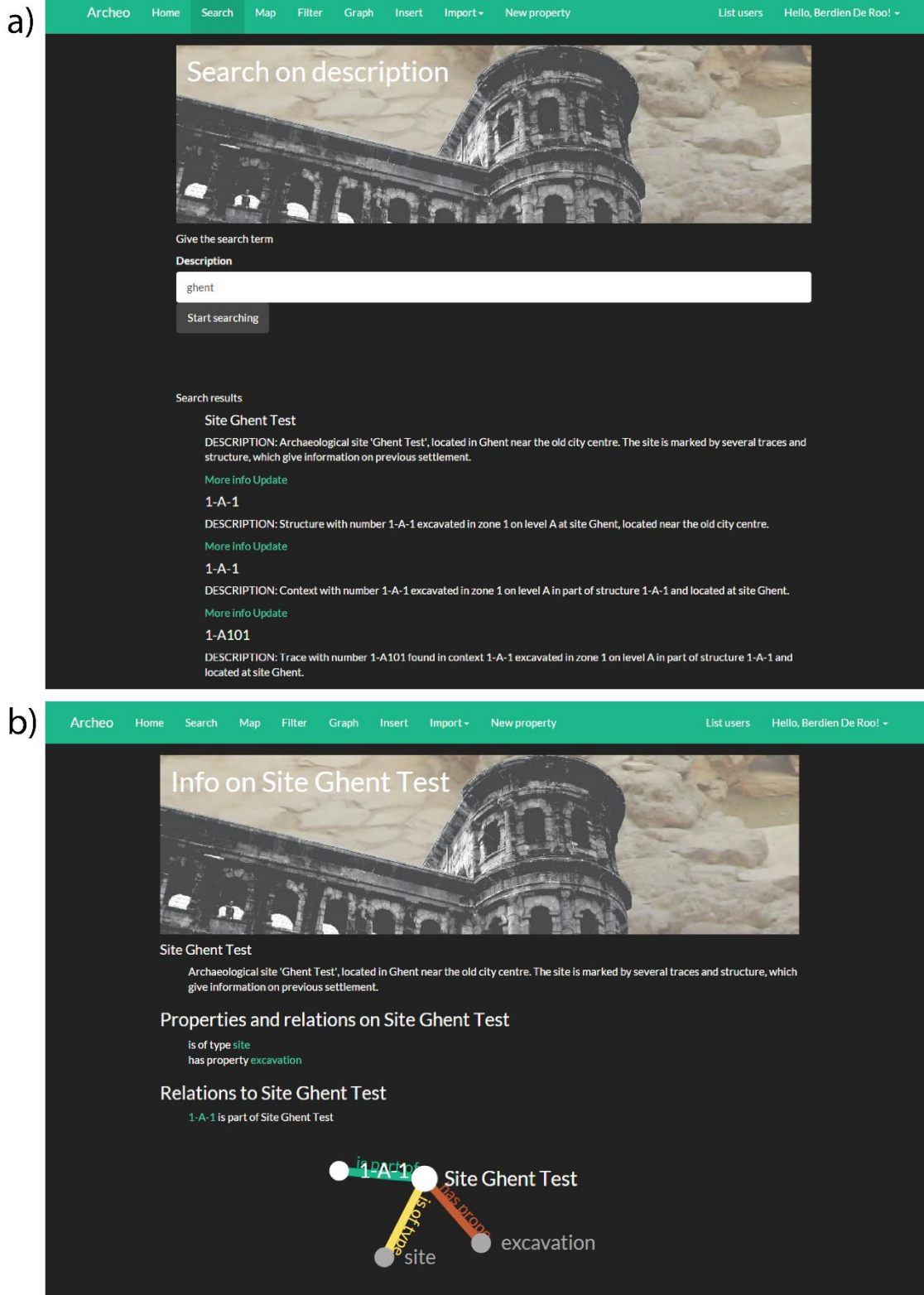


Figure 7-7 Data display in the test application: a) general list view and b) individual node page



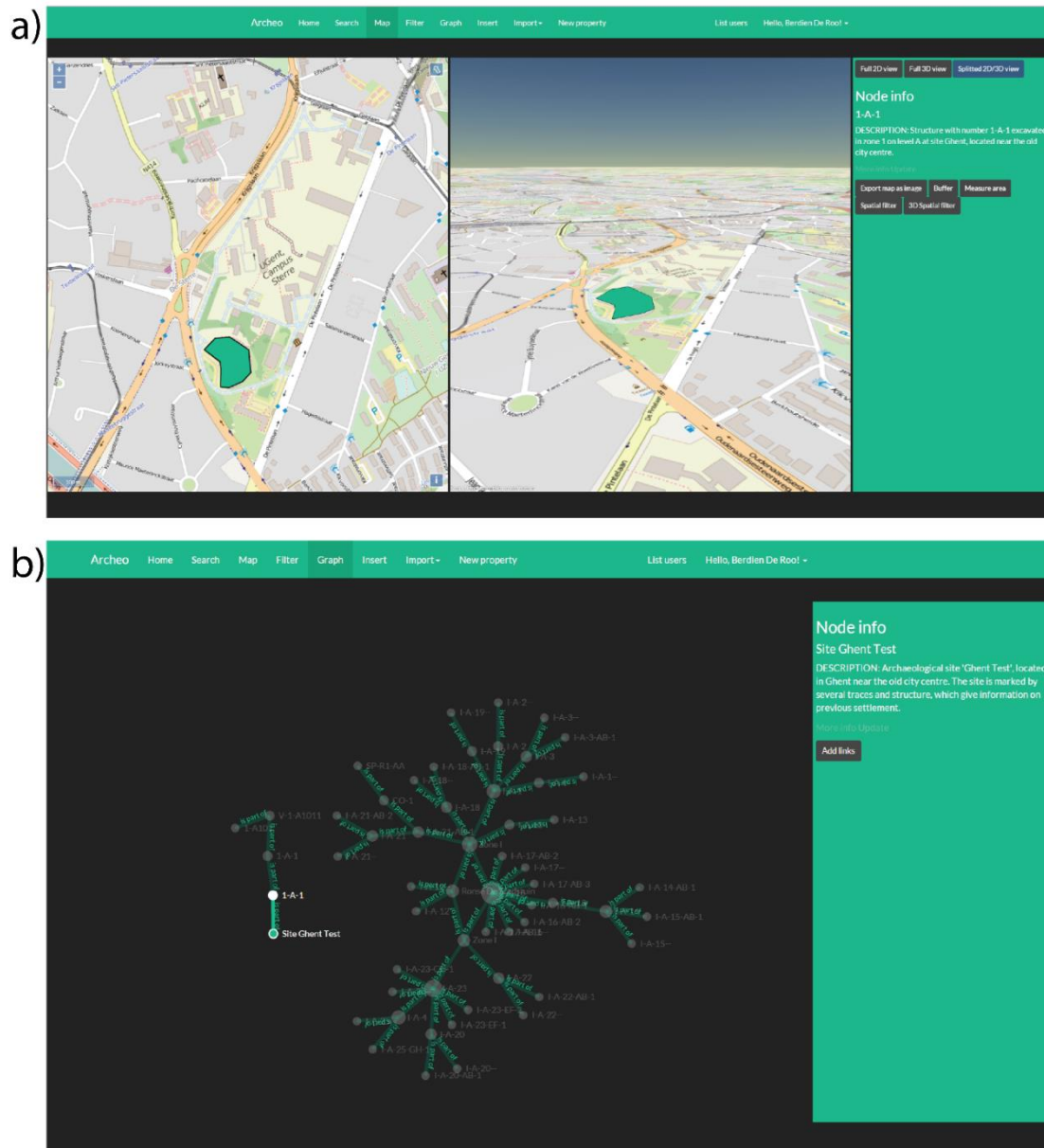


Figure 7-8 Graphical data display in the test application: a) map view and b) graph view

The data analysis group is represented in the test application by a search function, thematic and spatial filter functions and geometric functions. Searching a specific node is possible either by name or by description. The usability of these search functions is enhanced by enabling auto completion in the search boxes and making use of full text search algorithms. The search results are displayed as a list (Figure 7-7a). Besides searching name or description, nodes can also be filtered based on their relations. On the one hand, users can use the filter form to search all nodes with specific relations by indicating both the property and value (Figure 7-9a). On the other hand, on the node page, users can click on a particular relation value and then they are given an overview of all nodes that have a relation with this value. For instance, clicking on 'site' in the relation 'is of type site' from the node 'Site Ghent Test' (Figure 7-7b) will show all nodes

that have a relation with a value equal to 'site'. This can be useful during the planning of new excavations. The two filter options thus differ in whether a specific property is required. For filtering on spatial properties, the query 'select all geometries within X meter around selected geometry' is developed in both 2D and 3D. This filtering first requires selecting a particular geometry on the map, and then indicating the radius of the buffer circle (2D) or buffer sphere (3D). Next, all geometries that are located inside this buffer are highlighted in red (Figure 7-9b). Related to this, a function is included to draw a 2D buffer around a chosen point. Finally, a geometric function is implemented to allow users to measure an area on the map. All of these features can be useful during the analysis of an archaeological research project, but also in the case of evaluating a building permit. In the latter case, one can determine whether archaeological features are (probably) available within X metres of the location that is the subject of the planning permit request.

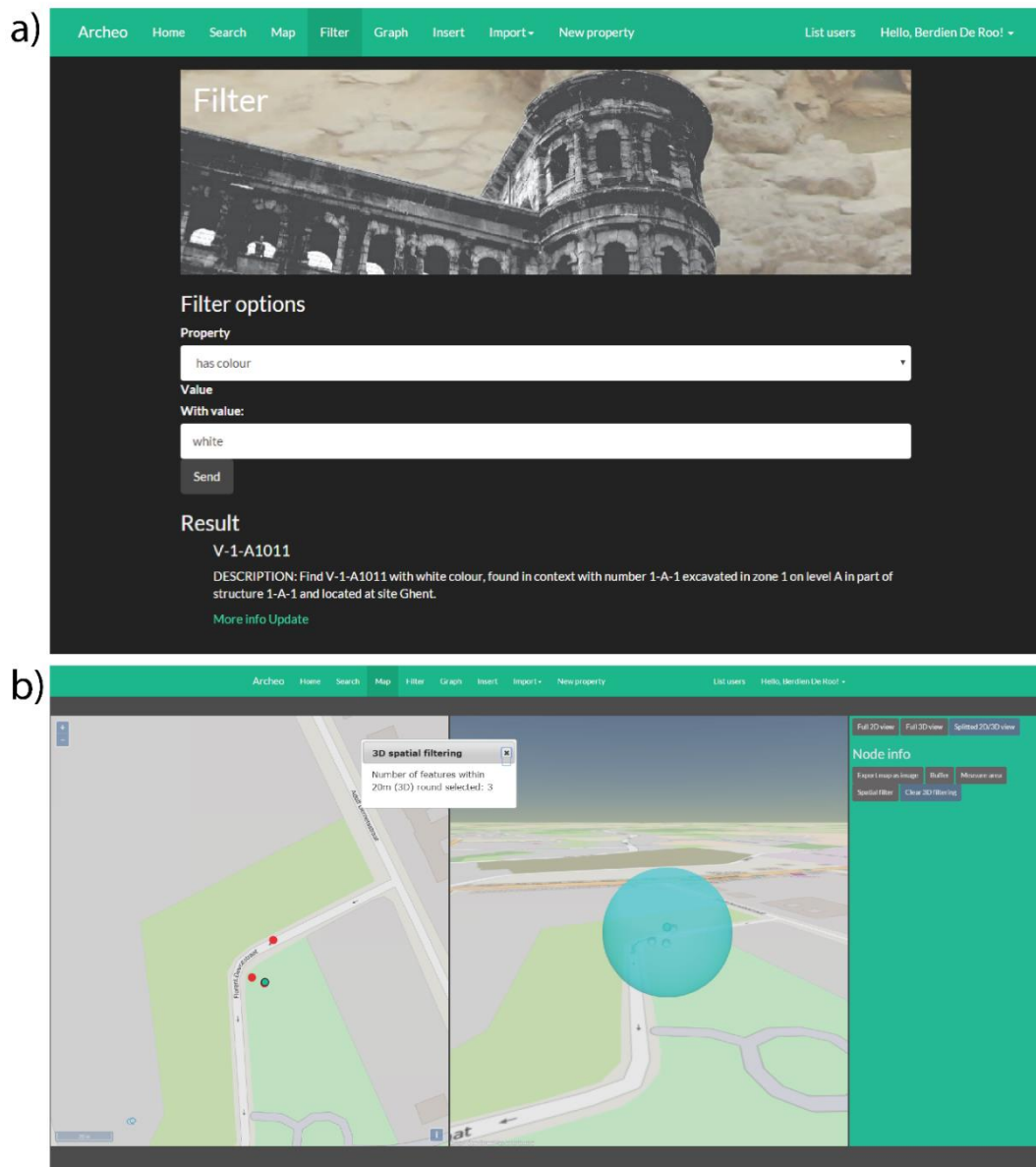


Figure 7-9 a) Thematic and b) 3D spatial filter functionality in the test application

## 7.5 DISCUSSION AND CONCLUSIONS

A conceptual data model to suit the needs of an integrated archaeological data infrastructure is presented in this chapter: ADAM (Archaeological DATA Model). This data model consists of three basic elements: nodes, properties and relations. A node has to be conceived broadly, as it can represent either a tangible archaeological find or a more abstract concept such as a project. The characteristics of a node and its linkages to other nodes can be specified through relationships, which are in turn defined by a property. Using ADAM and its concepts of nodes, properties and relations thus allows archaeologists to describe a huge variety of objects in an uncomplicated way for (re)use in various domains. During the development of this data model, several challenges were taken into account to allow the data model to function as a basis for an archaeological data management and research infrastructure.

The first challenge relates to the diversity of archaeological objects, which also includes their spatial and temporal variation. Avoiding a rigid, fixed data structure has the advantage that even uncommon finds can be stored without the necessity to create additional tables or columns. In comparison with a tabular data structure, empty cells will be avoided as only relevant relations will be added to the node. Furthermore, relations that are very specific for a particular node can be added, as users are not restricted to predefined relations (columns). This finding is consistent with the work of Schloen and Schloen (2012) who indicate that predefined ontologies hamper the representation of archaeology's variability and suggest a more item-based ontology. However, the OCHRE ontology is less radically item-based, as outlined by Schloen in 2001, because it still consists of 18 different XML documents or schemas (Schloen and Schloen 2012). This is in contrast to ADAM, where only the concept nodes, relations and properties are fixed. This way, ADAM allows different types of data to be described and integrated, ranging from archaeological objects over administrative data to methodological data in the same structure. This agrees with the way an object, or in this case a wiki page, is considered by Huvila (2011) in his abstract framework for documenting archaeology. Furthermore, the proposed data model allows adding to a single node multiple relationships that consist of the same property. This way, both multivocality (Section 2.3.4) and multitemporality (Section 2.3.3) can be handled, which fulfils the predictions of Labrador (2012, p. 237) that "archaeological databases may better put into practice certain theoretical developments in the field".

The second challenge that the data model intends to take up is providing usability and avoiding of complexity. This challenge originates from the varying IT skills that potential users of the data model or research infrastructure have. Using ADAM, actors who are not familiar with a particular data set are not required to study the database structure in detail before they start using it. They only need to comprehend the concepts of node, property and relation.

The third challenge is also related to the diversity of actors in the archaeological process, i.e. making it usable for different purposes. Since practically all objects can be described by ADAM, the data model is widely deployable from fieldwork to archaeological depots, conservation management and policymaking.

The fourth challenge concerns the increasing time pressure and cost constraints archaeological organizations are facing. As no pre-set structure needs to be known by field archaeologists or other staff members, no additional time is spent on this. On the other hand, some archaeological organizations have already invested considerable time and money in a decent database structure (Chapter 4). For these organizations, ADAM holds the advantage that it is linkable. These organizations can thus continue using their database structure, while a mapping can be constructed between both structures to allow for reuse and integration of their data by other persons and for other purposes.

Having accepted the four challenges, the proposed data model is used as a basis for a test application that could function in the future as an integrated archaeological data infrastructure as proposed by many researchers (Snow et al. 2006; Huvila 2011; McKeague et al. 2012). Such data infrastructure will enable the dissemination of information, collaboration and discussion of the data and their interpretation, including quickly acquiring, editing, analysing and presenting information. Using a geodatabase as a foundation for this application agrees well with the proposal in Chapter 4 for the design of an archaeology-specific geodata infrastructure. Furthermore, the test application is developed using FOSS to further address the increasing cost-pressure archaeological organizations face today and at the same time enable customization (Wagtendonk et al. 2009; Minghini 2013). Due to the simplicity of the data model, the workload on the application side will be higher than when using a more rigid database structure. However, this does not imply complexity for the use of the application. In the current test application, functions for data management, display and analysis were integrated to show the potential of the data model. Although the test application appears to be useful and advantageous, additional tests and case studies should be performed to verify its value as a collaborative management and research infrastructure. Therefore, technical and practical assessments of the system are planned with urban and marine archaeological data sets (Chapter 8). Moreover, several more elaborated capabilities may be supported in the future. First, to act as a fully-fledged collaborative infrastructure, features to discuss and collaborate should be developed to realize “shared virtual workspaces” as argued by Snow et al. (2006, p. 959). Second, more advanced search functions are needed, e.g., complex multi-criteria filters. Third, the spatial aspect of the infrastructure has to be expanded as most archaeological data contain a spatial component and GIS are ubiquitously used in archaeology. This is in agreement with the importance many researchers attach to archaeology’s spatial components and their suggestions for spatial-enabled data management (Katsianis et al. 2008; Shaw et al. 2009; Forte 2011; McKeague et al. 2012; Stal et al. 2014; Chapter 4). Its current implementation with 2D and 3D visualizations and analyses is already more extensive than in most other archaeological integration platforms such as OCHRE, OpenContext,

Arches, which mostly include only a 2D map. Nevertheless, both the visualization and the analyses of spatial data should be extended in the current test application while paying special attention to the third dimension. The integration of a 3D and even 4D (including time) visualization and analysis platform in an archaeological cyberinfrastructure agrees with the results of Chapter 6, in which Cesium was used to develop a low-threshold 4D ArcheoGIS. The 3D webGIS and analytical tools developed in the MayaArch3D by von Schwerin et al. (von Schwerin et al. 2013) also form a splendid example of how to extend the infrastructure's spatial component. Furthermore, algorithms to generate Harris Matrices automatically from spatial information incorporated in the infrastructure, like presented in Chapter 5, can be considered a benefit. To realize these and other capabilities, we suggest developing small packages of functions. These can then be combined in a custom-build application similar to plug-ins in current software packages.

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# 8

## A GEODATA INFRASTRUCTURE FOR ARCHAEOLOGY: FLEXIBILITY IN MANAGEMENT AND ANALYSIS

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### ABSTRACT

To come to well-grounded conclusions, spatial, semantic and administrative data need to be handled simultaneously in archaeology. This data integration is still not fully accomplished today due to the increasing time-pressure imposed by the capitalistic market and the maladjustment of GIS to archaeological data. Furthermore, exchanging and integrating archaeological data is hampered by the diverse organization- or project-specific databases. The reuse of archaeological data is consequently very limited, although valuable information is likely to result from it. Therefore, an archaeological geodata infrastructure that allows for the integration of spatial, semantic and administrative data will contribute to the data management, analysis and exchange. This chapter demonstrates that the flexible Archaeological DATA Model (ADAM) can form the basis for an archaeology-specific geodata infrastructure by means of two case studies. The first case, SeArch project, focusses on the integration of different data sources and a user-friendly WebGIS and management tool for marine archaeological heritage. The second case concerns the design of an archaeological infrastructure useful for registration, management and analysis of urban excavations. By implementing the points for improvement and ideas for extension indicated by the potential end-users, the value of the application for both management and research will even increase.

## 8.1 INTRODUCTION

The records of archaeological data acquired during fieldwork constitute mostly the only raw residuals of archaeological investigation along with the found material remains. The way these records are created influences the future interpretation, the resulting reports and ensuing policy decisions (Labrador 2012). This increasing consciousness of excavations' destructive nature combined with the current development-led archaeology has resulted in on the one hand an increasing emphasis on data recording and on the other hand a growing gap between fieldwork and interpretation (De Clercq et al. 2012; Forte 2014). The first is even strengthened by the widespread use of spatial recording techniques, such as GPS, total station and laser scanning (Forte 2014; Stal et al. 2014). These fast and accurate topographic measurements result in born-digital spatial data that can be used in Geographical Information Systems (GIS). Notwithstanding the geographic component in the majority of archaeological data and its importance in research, integrating spatial, thematic and administrative data during management and analysis is not fully exploited in contemporary archaeological research (Green 2008). Two main reasons can be found for this: (i) the increasing time pressure due to a capitalistic environment and (ii) the maladjustment of GIS to the archaeological data particularities.

Apart from their important geographic component, archaeological data are characterized by four other particularities. A first aspect is the three-dimensionality of archaeological data since the depth (or height) an object is found on plays an essential role in archaeology, e.g., for deriving temporal information (Katsianis et al. 2008; Forte 2014). This temporal information is a second important characteristic of archaeological data. Multiple temporal values can be assigned to an archaeological object, including an absolute date, a relative date and a phase from the site evolution (Green 2008; Katsianis et al. 2008). Furthermore, these temporal categories can be uncertain or imperfect. Such imperfection also occurs for geometric and semantic properties, making imperfection the third particularity of archaeological data (Katsianis et al. 2008). Finally, the variety of objects archaeology is dealing with makes up the fourth aspect (Labrador 2012). As archaeology studies the activities of societies in the past through the remains found today, basically each everyday object (e.g., coin or house) or its trace (e.g., posthole) can be the subject of an archaeological investigation.

These aspects hamper not only the simultaneous handling of thematic and spatial archaeological data, but also the archaeological data exchange and integration between different projects and organizations (Snow et al. 2006; McKeague et al. 2012). This is due to the organization- or even project-specific database structures used to store the fieldwork data (Snow et al. 2006). These database models are often organically grown to fit the expected findings and tailored towards a specific research method. Although performing well for one project or within the organization, these database structures, diverse and specific, hide useful information for further archaeological

research, conservation management and other domains. A spatial data infrastructure that facilitates data creation, exchange and use will prevent these exchange and integration issues (Snow et al. 2006; Huvila 2011; Chapter 4). Managing semantic, spatial and temporal characteristics simultaneously will be facilitated which is necessary to reach well-grounded conclusions (Arroyo-Bishop and Lantada Zarzosa 1995). Such an infrastructure should be conceived also as a management and research infrastructure in which fellow researchers can collaborate and discuss (Snow et al. 2006). At the basis of this infrastructure lies a conceptual data model that takes into account the specificities of archaeological data described above as well as additional challenges. These challenges include the varying IT skills and application domains of the actors involved in the archaeological process (Chapter 4) and the pressure to minimize costs and enhance time-efficiency (De Clercq et al. 2012).

In the course of this research project, a conceptual data model is designed to suit an integrated archaeological geodata infrastructure: Archaeological DATA Model (ADAM) (Chapter 7). This chapter assesses how this flexible data model can form the basis of an archaeological geodata infrastructure by implementing specific management and research applications for two case studies. The first case study concerns the ongoing research project SeArch ([www.sea-arch.be](http://www.sea-arch.be)) in which marine archaeological data from the Belgian North Sea will be made available to both researchers and the public via a geo-application based on ADAM. The second case study focusses on how ADAM and a joint management and research application could offer advantages for an ongoing urban excavation project in which data are registered in an analogue way. The applications implemented in the case studies start from the same test application, developed in Chapter 7.

In the remainder of this chapter, the data model proposed in this research project and the architecture of the initial test application are outlined. Next, the method for testing the model and its consistency through two case studies is presented in Section 8.3. Section 8.4 outlines the implementation of the data infrastructure application and describes the test results for two cases. The results of the case studies are discussed in Section 8.5. The chapter concludes in Section 8.6.

## 8.2 ADAM AND THE TEST APPLICATION

To describe the high diversity of archaeological objects including their 3D spatial characteristics (i.e. location and shape) and temporal categories the flexible and linkable ADAM is proposed. This data model consists of only three concepts: nodes, properties and relations. The fundamental elements are the nodes as they correspond to archaeological objects, but they can also be used to describe more conceptual elements (e.g., project or site). Each node has a name and a description, and a unique identifier for database purposes. In Figure 8-1, two nodes, one named 'Site Ghent' with description 'archaeological site located in Ghent' and another named 'V-1-A1011' with description

'find V-1-A1011, a coin found in trace 1-A101 at site in Ghent', are represented as circles. The further description of a node can be realized by using relations. A relation, represented as box in Figure 8-1, connects a node to either a value to indicate an attribute (e.g., colour) or another node via a particular property. These properties, hexagons in Figure 8-1, define the type of the relation and consist of a name, a description and a data type for the expected value (e.g., text or node). Figure 8-1b combines the two elementary examples into a simple integrated model to illustrate the three concepts. Properties that have a node as data type allow for the reconstruction of hierarchical structures, either functional, spatial or temporal. In Figure 8-1b, for instance, a spatial hierarchy can be found between 'Site Ghent' and 'V-1-A1011'. For a more detailed explanation of the data model reference is made to Chapter 7.

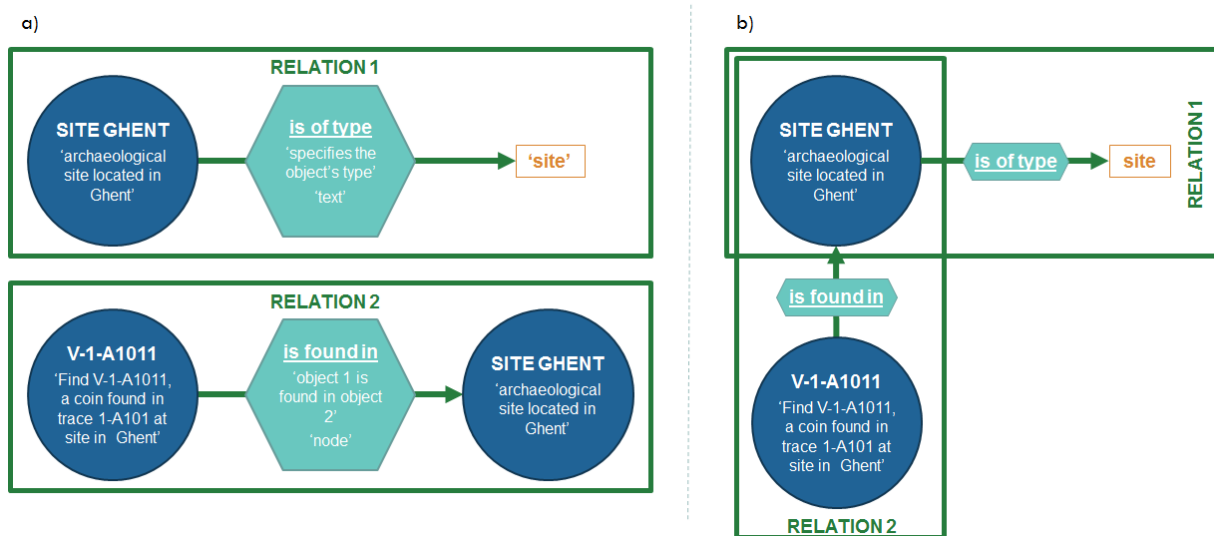


Figure 8-1 Illustration of ADAM's concepts node (circle), properties (hexagon) and relations (box) as a) two elementary examples and b) an integrated scheme

While traditional tabular data structures are mostly specific for one type or a set of comparable objects, ADAM accepts practically all archaeological objects. Attributes or links between objects that are specific for a particular object, can simply be added exclusively to this node via a relation. Empty cells, which occur in tabular views when a specific column is added for describing uncommon finds, are thus avoided. Consequently, ADAM is widely deployable from fieldwork to conservation management and spatial planning. Avoiding a rigid and fixed data structure holds the advantage that no pre-set structure needs to be studied before the data model can be used. This allows the data model to be used by persons with varying IT-skill levels and increases time-efficiency, even for them with lower-level IT-skills. Furthermore, the linkable character of ADAM allows for the integration of existing data sets in a straightforward way, namely by mapping the columns to properties and translating the row values into relations.

To illustrate the potentials of ADAM, an initial test application (Figure 8-2) was developed earlier in this research project (Chapter 7). This test application intends to give an idea of how ADAM could function as basis for an integrated archaeological data infrastructure, which is proposed by many researchers (Snow et al. 2006; Katsianis et al. 2008; Huvila 2011; McKeague et al. 2012). To represent data management, analysis and visualization capabilities a varied set of functions is incorporated in the test application:

- data insert, update and deletion;
- data import from Excel files or Shapefiles;
- general data display: in list, 2D and 3D map and graph form;
- individual data display: in list, 3D map and graph form;
- thematic and spatial filtering;
- history logging

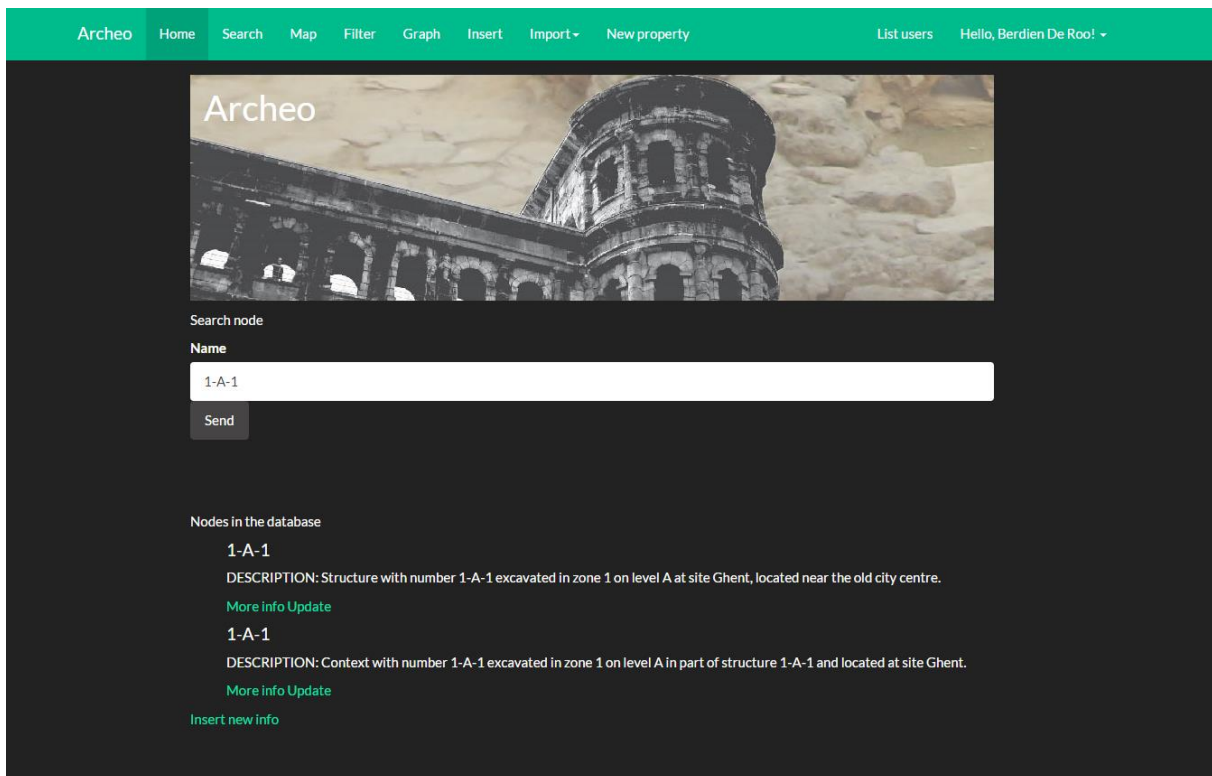


Figure 8-2 Home page of the initial test application

The application makes use of Free and Open-Source Software (FOSS) to result in a cost-efficient and customizable infrastructure. As the spatial component is an important characteristic of archaeology, ADAM is implemented in a PostGIS geodatabase. The database, forming the basis of the application, consist of three tables equivalent to the node, property and relation concept, complemented by tables for the geometry values, secondary relations, history logging and the user authentication (Chapter 7) . Furthermore, to act as a cyberinfrastructure for archaeological (geo)data, the application

is web-based and built using PHP, JavaScript and several open-source libraries. Figure 8-2 shows the home page of the test application. A more detailed description of the database implementation and initial test application is given in Chapter 7.

## 8.3 METHODS

To study whether ADAM, presented in the previous section, can form the basis of an archaeological geodata infrastructure two cases are considered. The two selected case studies are projects situated in Belgium, which has the advantage that involved parties can be approached more quickly and easily. Furthermore, in the course of this project the information flows and business processes in Flanders have been analysed (Chapter 4) and provide a solid backing for the development of a management and research infrastructure. The first case study is the SeArch project in which marine archaeological data from the Belgian North Sea will be made accessible to both researchers and the public. The second selected project concerns an ongoing urban archaeological research project called ‘Vogelmarkt’ that is executed by ‘De Zwarte Doos’, the Ghent Archaeological Service. These two projects are selected because they differ in terms of the archaeological subdiscipline or study context, type of research, status of the project, registration method and number of sources. Table 8-1 summarizes these aspects for the two projects. Because the SeArch project deals with marine data and the second project with urban excavation data, the combination of the two case studies will assess the deployment of ADAM for a wide variety of objects in different domains. Considering the different project statuses, the case studies will also provide insight in how ADAM and the developed infrastructure can be used during the archaeological workflow and which advantages these can hold. Furthermore, the case studies will also show the usefulness of ADAM against data registered in analogue way or the advantages for integrating digital data from different sources. Apart from these general objectives, each of the case studies has a specific purpose within the scope of this chapter. The first case study, SeArch, focusses on the one hand on the integration of data from different parties and on the other hand on the user-friendly geo-application to visualize the data for both researchers and the public. Furthermore, the attitude of archaeologists and others dealing with archaeological data towards the infrastructure as a management and research tool is probed. The second case study will be used to simulate the use of ADAM and the implemented infrastructure on the field. Moreover, the case study intends to show the attitude of archaeologists towards the infrastructure as a management and research tool for ongoing projects.

Table 8-1 Characteristics of the selected projects

N°	Project	Subdiscipline	Research	Status	Registration	Source
1	SeArch	Marine archaeology	Finds	Ongoing	Digital	multiple
2	Gent Vogelmarkt	Urban archaeology	Excavation	Ongoing	Analogue	1

To answer the questions that are specific for each case study and to achieve the general research objective of this chapter, a three-phase method is used. The first phase consists of determining the specificities of the involved data and studying the structure of these data. Next, also the properties and needs of the project are examined. Both the data and project characteristics form the input for the second phase, in which is analysed whether the initial test application (Section 8.2) needs extension. Finally, a demonstration of the application is organised with the parties providing the case study data, i.e. SeArch project partners and De Zwarte Doos. Combined with an interview, this will disclose additional issues in the conception and design of the application.

## 8.4 CASE STUDIES

### 8.4.1 SeArch: marine archaeology for researchers and public

#### *8.4.1.1 Project and data details*

As sea level has risen after the last ice age with about hundred meters, remains of former societies and civilisations became submerged. Now, a rich collection of cultural heritage lies on or beneath the seafloor. Considering the increasing pressure on the North Sea from an infrastructural and commercial viewpoint, a structured data management and research infrastructure is necessary to avoid ad hoc judgements on the importance of the underwater heritage. The SeArch project<sup>1</sup> ([www.sea-arch.be](http://www.sea-arch.be)) brings together different partners (Ghent University, Flemish Heritage Agency, Flanders Marine Institute and Deltares) to develop an efficient evaluation methodology and proposal for sustainable management in Belgium. Furthermore, during the project a close collaboration exists with the stakeholders: government, marine industry (e.g., dredging), harbour management and museums. One of the main project objectives is to set up a Spatial Data Infrastructure (SDI) including a web-based GIS to allow for user-friendly integration and visualization of archaeological and environmental data. This SDI and especially the WebGIS will be a valuable tool for research and marine spatial planning as well as for raising public awareness on underwater heritage.

The SeArch project not only involves archaeological data but also geological and geophysical data. The project has started from the integration and visualization of existing data sets, but has also the intention to allow the future incorporation of other data set in the WebGIS. The archaeological data used in this project originates from the Marine Archaeology cell, which is part of the Flemish Heritage Agency ([www.maritieme-archeologie.be](http://www.maritieme-archeologie.be)). This research cell maintains a database concerning marine heritage in Flanders, which consists of wrecks, marine sites, finds, events, etc. coming from diverse

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<sup>1</sup> The SeArch project (Archaeological heritage in the North Sea) is funded by the Flemish Agency for Innovation and Entrepreneurship (VLAIO)

sources. Besides textual information, the database includes photographs, pictures, reports, and links to relevant references. This database consists of predefined categories, e.g., shipwreck or artefact from aircrafts, each with specific columns (i.e. characteristics). Although very exhaustive, this manner of data structuring is very rigid, asking for a new category each time a new type of find is encountered and resulting in numerous uncompleted fields when not enough information is available on a specific object. Therefore, using ADAM as basis in the SDI of the SeArch project will be advantageous to describe the wide diversity of marine heritage in a flexible and uncomplicated way. Besides archaeological data, the WebGIS should incorporate data on the geology and geophysics of the Belgian part of the North Sea. This includes bathymetric data originating from the Flanders Marine Institute, both gathered prior and during the project, and data on historic landscapes delivered by the Research Centre for Marine Geology (UGent). Furthermore, the WebGIS should also incorporate some administrative data layers, e.g., borders of the Belgian continental shelf.

#### *8.4.1.2 The application*

Considering the objective of the project to develop a user-friendly WebGIS and provide a SDI that enables the effective management and protection of underwater cultural heritage resources, an extension of the initial test application (Chapter 7) is necessary. The most important operations take place in the current map visualization that needs extension towards a full WebGIS. Nevertheless, the currently available archaeological data have to be translated into the ADAM-based data structure first.

As the database of the Marine Archaeology cell does not provide web-based data access services, automatically mapping the data to the new database is impossible and thus exporting the data was necessary. This export has resulted in one Excel file containing all information required for the SeArch project. This file thus includes all types of objects with their respective characteristics; that means 44 columns in total. Next, these data are translated into the ADAM-based database via SQL-statements directly in PgAdmin, the management system for PostgreSQL.

Since the WebGIS intends to function as data access point for both experts and non-experts, it is conceived as an individual application and thus built as a separate webpage (Figure 8-3, <http://cartogis.ugent.be/Search/>). However, the newly built WebGIS is not unlinked from the initial test application that still functions as the administrative side of the project's application. For the development of the WebGIS, GeoServer is used as web map server and OpenLayers forms the basis for the map design. As the geological data to be included in the WebGIS are static, these raster data are loaded directly to GeoServer, while for the archaeological data PostGIS is connected to GeoServer to allow for automatic updating the map layers. To allow data display in separate layers based on the object type (e.g., ship wreck, aircraft wreck, artefact), a filtering is performed using PHP and JavaScript. For this, the layers to be used in the WebGIS are defined as an additional PostgreSQL table, which includes the layer name and



corresponding object types. Changes in the visualized categories can thus be adjusted directly in the database without the need to structurally adapt the source code of the application.

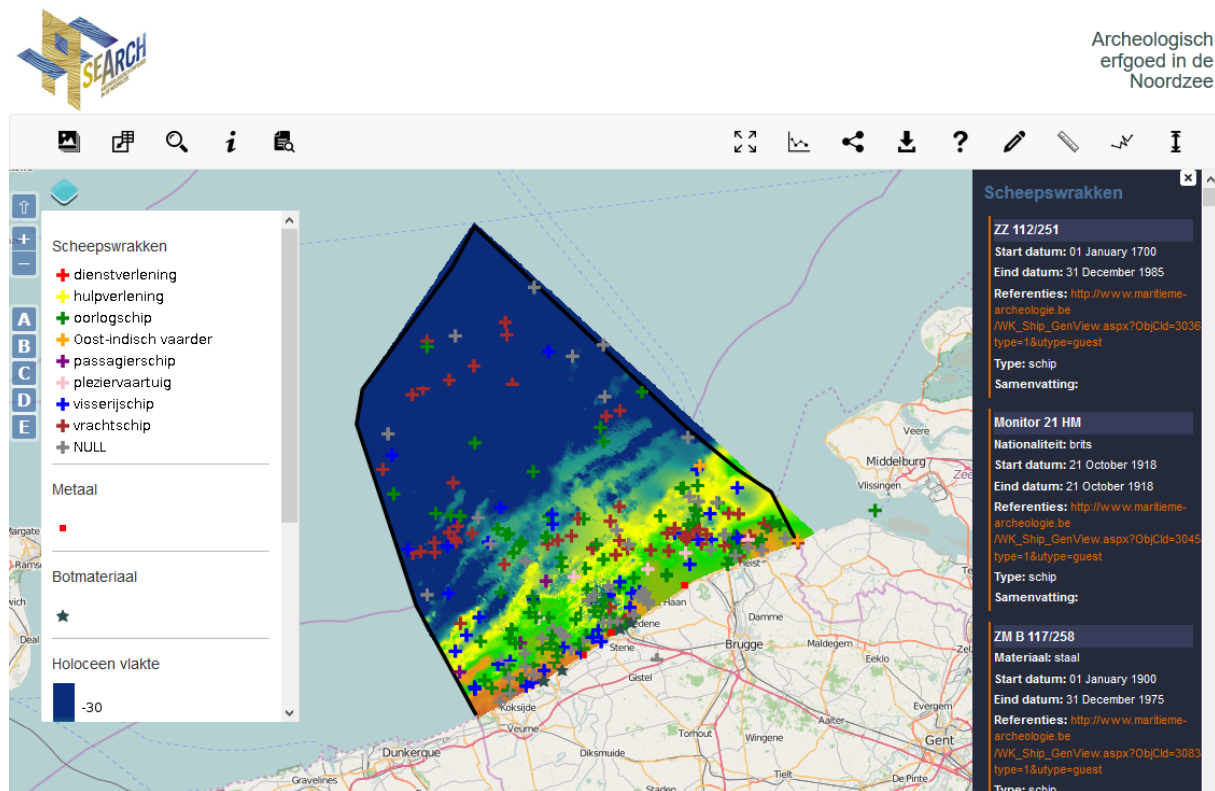


Figure 8-3 Screenshot of the SeArch WebGIS

The main objective of the WebGIS is to provide an efficient and user-friendly integration and visualization of archaeological and environmental data. Therefore, the developed functionalities are kept rather basic in this pilot project. Apart from zoom and pan operations, the application enables users to switch the layers' visibility, access attribute and metadata information of a selected feature, select features located in a drawn polygon, get depth information for a picked point, create a depth profile along a specified line and measure a distance. Furthermore, fitting the purpose of increasing the public awareness on marine heritage the application allows exporting the map as an image and sharing the map via social media. In a later stage, when the WebGIS and SDI have proven their usefulness in providing a better understanding and monitoring of the underwater cultural heritage, additional functionalities such as predictive modelling and simulation analyses, can be added.

For the feature identification tool, the link with the initial test application comes to the fore. When clicking on a particular feature a new window pops up which contains the information from the node info page of the initial test application. Apart from the name and description of the selected feature, the relations linked to this object (i.e. node) are given in both textual and graphical form (Figure 8-4). Similar to the functionality of this

page in the initial test application, one can click on a particular text value to list objects that have relations with the same value. For instance, when clicking 'brits' (i.e. British) on the info screen shown in Figure 8-4, all objects which have a relation with value 'brits' will be listed. This enables the explorative investigation of the data and allows for detecting previously unknown relations. Furthermore, the functionalities that are available in the initial test application (e.g., importing, searching and filtering data) remain accessible via a separate link. This second application (next to the WebGIS) is especially intended for the project partners for administrative reasons and is seen as a part of the SeArch SDI.

## Info on Bristol Blenheim MK IV

### Bristol Blenheim MK IV

- Britse bommenwerper, vermoedelijk van type Bristol Blenheim. Obstructie ontdekt door visser L.Louwagie. mogelijk bommenwerper type Bristol Blenheim. Verschillende vliegtuigen van dit type werden neergehaald door de Duitse Luftwaffe tussen Westhinder en Thorntonbank tijdens operatie Cerberus (12/02/1942)

### Eigenschappen en relaties van 'Bristol Blenheim MK IV'

- Nationaliteit [brits](#)
- Materiaal [aluminium](#)
- Start datum 12 February 1942
- Eind datum 12 February 1942
- Referenties [http://www.maritieme-archeologie.be/WK\\_Ship\\_GenView.aspx?ObjCId=3105&type=2&utype=guest](http://www.maritieme-archeologie.be/WK_Ship_GenView.aspx?ObjCId=3105&type=2&utype=guest)
- Type [vliegtuig](#)

### Relaties van 'Bristol Blenheim MK IV'



Figure 8-4 Info screen containing specific data on an object (node) in the SeArch WebGIS

### 8.4.1.3 Evaluation of the application

The SeArch WebGIS and administrative application have been presented to the project partners throughout the development cycle during the regular project meetings. Hereby, the attitude of the project partners towards the newly developed WebGIS could be recovered early in the development phase. Adaptations to the design and usability of

the application could therefore be carried out promptly. Furthermore, additional requirements or desired adjustments became clear and could quickly be considered. Such method corresponds to the user-centred design cycle (Maguire 2001). These frequent meetings have resulted in a higher level of involvement of the potential end users, which can consequently result in a higher acceptancy rate of the final product (Maguire 2001). In general, the project partners were positive on the design and functionalities of the WebGIS.

Recently, the application is transferred to a public webserver to make the WebGIS available for both experts and non-experts (<http://cartogis.ugent.be/Search/>). Additional meetings are planned in the course of the project to gather additional requirements and issues on the WebGIS. At the end of the project term (December 2016), a conference is planned to demonstrate the achieved results. This conference will also include a workshop to illustrate the potentials of the WebGIS for research, industry and public.

## 8.4.2 Gent Vogelmarkt: ongoing urban excavation project

### *8.4.2.1 Project and data details*

In the city centre of Ghent, BRAVOKO is a major infrastructure project to renew roads and sewers along the axis Brabandam-Vogelmarkt-Kouter. As the project concerns radical soil interventions in the medieval city centre, precautions need to be taken to preserve archaeological heritage that is conceivably present in this zone. Therefore, archaeological investigations took place in two zones. This case study concerns the investigation situated in the second zone (Vogelmarkt) executed between 16 November and 4 December 2015. The Ghent Archaeological Service cooperated with archaeological organization Studiebureau Archeologie and building contractor COLAS. Based on historical source research, the small Butcher's Hall was located in this zone in 1595 (Vermeiren et al. 2016). Furthermore, the current street 'Vogelmarkt' seemed to have formerly been a narrow alley that has been broadened multiple times since the Middle Ages (Vermeiren et al. 2016). The archaeological excavation was meant to prove these findings.

During the archaeological excavation, data were registered in an analogue way, except for the spatial demarcation of the traces, which were measured in 3D using total station by a land surveyor. All details of the 39 traces, the 80 finds they contain and the 23 sieve samples taken from them were noted on lists. Next, these lists were scanned in anticipation of future transcription in Excel files. Furthermore, 87 photos were taken and a list was maintained to describe their place and subject. Profiles (36 in total) were drawn and described and sketches were made of the trace locations including their identification numbers. Because the spatial data were delivered in AutoCAD DWG format and only contained the geometries, the sketches were necessary to combine the spatial information with the lists of archaeological information.

### *8.4.2.2 The application*

This case study intends to simulate the use of the initial test application during the fieldwork. As the application already includes an insert module for individual objects (i.e. nodes), no major extensions are necessary for this part. Next, these semantic data should be linked to the spatial data, which are stored in the AutoCAD file. In the initial test application, spatial data can be imported directly from Shapefiles. However, a similar import function for AutoCAD files (.dwg or .dxf) is not yet available. To allow this, the import module should be extended with a DWG or DXF parser written in PHP. Such parsers are, to the best of our knowledge, unfortunately not available as open-source code. Since writing such parsers from scratch is not as straightforward as for Shapefiles given that multiple geometry types are stored in the same file, these geometries are stored in different layers and the numerous sections of which a DXF file is composed. Due to the considerable time needed for analysing the file structure and the significant amount of coding, the AutoCAD file importer is not written as an extension in this case study. As a workaround, the available DWG file was converted in DXF format and then imported in ArcGIS where the polygons representing the traces are linked to their identifiers.

Seventeen traces and their information available on the lists are inserted in the database via the application. This means that each trace corresponds to a node with the name and description copied from the written lists. The written descriptions are also transferred into relations, e.g., 'trace s1 has interpretation hole' (Figure 8-5). Generic relations to indicate the source of the data (Ghent Archaeological Service) and the type of the object (e.g., trace) are added to the nodes too. Furthermore, the finds and sieve samples belonging to these traces are also inserted as separate nodes with corresponding relations. These finds and sieve samples are connected to the trace by adding a node-to-node relation (e.g., with property 'is found in'). Adding such relations is possible since traces will be inserted in the database before their corresponding finds are added following the fieldwork chronology. After the fieldwork, the spatial information needs to be added to the traces using the Shapefile importer. Assuming that the identifier of the traces used in the Shapefile corresponds to the name of the nodes inserted in the database, the connection is made automatically via a relation (Figure 8-5). According to the 3D registration on the field, the shapes stored in the database are also 3D. Apart from the 3D shapes, the drawn profiles also provide 3D information on the excavation that is useful to reconstruct the site evolution. The exact position of these profiles is however not known. Although drawn on scale, integrating these profiles in the 3D map either as vertical image or as digitalised vector shapes is thus impossible. Therefore, the drawings were added to the nodes as pictures (Figure 8-5).

Archeo List Map Graph Search Filter Insert Import+ New property List users Hello, Berdien De Rooi

## Info on Spoor S1

Spoor S1  
Kuil of mogelijk deel van aanlegseuf tussen twee muurtjes

Relations on Spoor S1

has photo [http://users.usgent.be/~bedroo/Profielen/Sleuf1\\_Z.png](http://users.usgent.be/~bedroo/Profielen/Sleuf1_Z.png)

is of type [spoor](#)

is part of [Site: Vogelmarkt](#)

originates from [de zwerle doos](#)

has Interpretation [kuil](#)

has geometry POLYGON Z ((104926.24737033 193571.79464378 10.039946278219,104927.68835674 193572.59839384 10.121476599576,104927.90934216 193572.04928141 9.6933247534688,104926.57513449 193571.42983935 10.24048461152,104926.49595797 193571.50477374 10.25759060206,104926.44478566 193571.52392452 10.111660940943,104926.24737033 193571.79464378 10.039946278219))

Relations to Spoor S1

Vondst: Vogelmarkt 6 is found in Spoor S1

Location

Show history  
Update  
Back to overview

Figure 8-5 Info page showing the description and relations of node 'Trace S1' of site Vogelmarkt (data from Archaeological Service Ghent)

### 8.4.2.3 Evaluation of the application

The user takes a central position in this case study as well, as multiple contacts were organised. First, the idea of ADAM and the initial test application were presented to staff members of the Ghent Archaeological Service. This meeting took place during the development of the initial test application. The main questions focussed on the concepts of ADAM and the application, e.g., how a hierarchy could be found in the data, how the temporal dimension would be integrated. Furthermore, some remarks were made regarding the ownership of the data and the access restrictions when multiple organizations store their data in the same, shared database. These remarks and questions

were taken into consideration during the further development of the initial test application. Next, the test data used in this case study were provided and discussed at length. During the familiarization of the data in view of the use in the application, the Ghent Archaeological Service was contacted multiple times to clarify some issues, e.g., the exact location of a particular trace. Once a part of the data was inserted in the database using the application, a new meeting was scheduled. First, the application was shown again. During this demonstration, special attention was paid to the way the data were inserted while referring back to the use of this application on the field. In addition, the ways to explore the data were demonstrated and feedback was given with regard to questions from the start meeting (e.g., how can you retrieve a hierarchy?). Second, the staff members were given the possibility to explore the application and to insert data by themselves. Throughout the demonstration and testing, a positive attitude became clear. The staff members also realized the advantage of using a digital field recording system over analogue recording and indicated the timesaving and the decreasing of errors as advantages. The concepts of ADAM, i.e. node, relation and property, became clear for the staff members on the info pages and were assessed positively and comprehensible. Third, the staff members were explicitly asked to provide their opinion on the application both through a short discussion and via an inquiry form. This phase confirmed the positive attitude towards the system, although some points for improvement were formulated. A multi-criteria filtering should be incorporated in the application to enable more extensive querying. Having the possibility to query on multiple relations will also allow restricting the results within the context of one site. Furthermore, this multi-criteria querying should also incorporate a full-text search. This will make it possible to search for instance a node based on its name that lies in a particular site, which will be particularly helpful when multiple nodes with the same name, but differing description and relations, occur in the database. From the inquiry form, it became apparent that the linkage between the application and the database and the combined semantic and spatial information are found especially interesting. The staff members have indicated that they would use the application throughout the archaeological workflow from data management over analysis to public activities. Both the 3D visualization of the data and the graph display of the relations were appreciated.

## 8.5 DISCUSSION

In this chapter, the flexible and linkable ADAM was successfully used as basis for two archaeological management and analysis applications. Through these two case studies, the hypothesis that ADAM can form a solid foundation for an archaeology-specific geodata infrastructure was tested. This hypothesis was supported because both applications were developed to allow data creation, exchange and use and could be used throughout the complete archaeological workflow. Moreover, interviews with the potential end-users of such an infrastructure have shown a favourable attitude towards the applications.

The first case study fits in with the SeArch project, which intends to develop an SDI and WebGIS for the underwater heritage in the Belgian part of the North Sea. Such WebGIS should enable the sustainable management of heritage data and support research, marine spatial planning and public activities. The developed application for this project mainly focusses on the user-friendly visualization of archaeological and geological data. The data available from Marine Archaeology were integrated in the application and thus converted to ADAM. To familiarize with the data and its characteristics of this case study, the data were imported directly in the database via SQL statements. For future data sets, however, the available import and insert functions of the application can be used. These functions are part of the administrative part of the application. The WebGIS and administrative part seem two separate applications for the users, but actually, they are linked. This connection facilitates the inspection of both semantic and administrative data when clicking on a map feature and to continue this exploratory research by clicking through and searching for nodes and values. Although rather basic, the functionalities of the WebGIS have proven to be sufficient as access point to marine heritage data. In a later stage, the WebGIS can be extended to enlarge its value as research tool by implementing analyses that are more complex. This application addresses the limited combination of spatial, semantic and administrative data in contemporary archaeological management and analysis (Green 2008). Another opportunity for improving the WebGIS and adding value to the research and management tool is by integrating the 3D component. This could be done by using a virtual globe visualization as illustrated by Resch et al. (2014) for 4D marine geodata. Extending the web-based GIS component of the archaeological management and research infrastructure to 3D is in excellent agreement with the recommendations given in Chapter 4 and 7. On the other hand, the questions formulated by Resch et al. (2014) concerning graphical variables for web-based 3D/4D visualizations and guidelines for enhanced user experience in these applications still remain open. Therefore, additional user tests should be undertaken to gain insight in these impediments and to enhance the usability. Notwithstanding these potential points for improvement, the case study has shown that data from different sources can be integrated in an ADAM-based structure, visualized in a user-friendly way in combination with geological data and investigated in a convenient and exploratory way. Furthermore, the project partners have taken a positive view on this. During scheduled meetings and workshops with the broader stakeholders group, additional opinions will be gathered through which further developments can be planned. This repetitive development method including multiple user meetings is consistent with the User-Centred Design method (Maguire 2001).

The second case study focusses on urban archaeological excavation data that were registered in analogue way. By inserting the data in the same order as would be done on the field, a simulation of on-field registration was conducted. Data regarding traces, finds, sieve samples and photos were added for the site 'Vogelmarkt' located in the city of Ghent. Apart from this semantic information, 3D information was available for the shape and location of the traces. These spatial data were stored in AutoCAD-format for

which currently no import function is available in the application. Therefore, the DXF file was transformed to a Shapefile in which the trace identifiers were added to the geometries. Next, this file was successfully imported in the application, resulting in an automatic linkage between the polygons and the respective trace nodes. This workaround, however, demands the use of multiple software tools that are not integrated in the infrastructure, in this case AutoCAD and ArcGIS. The idea of an integrated management and research infrastructure for archaeological data is consequently invalidated. A parser for either DXF files or file formats that are used for storing raw spatial data (e.g., .raw) is thus necessary. In this regard, it is important to consider how the connection between the geometries and the stored nodes can be realized, as for instance, in DXF files no custom identifier can be linked to the shapes. Besides this shortcoming, the workflow for registering archaeological data is maintained in this simulation. The staff members of the Ghent Archaeological Service showed a positive attitude towards the application. They realized the advantage of using this application during field registration, in particular, with regard to saving time and limiting errors. Saving time and allowing for on-site analysis and interpretations, the application can contribute to decrease the growing time-pressure imposed by the profit-driven environment (De Clercq et al. 2012; Forte 2014). Leaving the missing functions aside, the staff members would use the application for data management, analysis and public activities.

The results of these two case studies have shown that both ADAM and the proposed application can be used for a wide variety of data and disciplines. In this study, data ranging from shipwrecks over sieve samples and urban traces are all described using only three simple concepts: nodes, properties and relations. Having considered an ongoing project and a project in which data from different sources is integrated, we can conclude that the application is versatile and allows for the integration of diverse sources. Finally, simulating the on-field use of the application has demonstrated its advantage over analogue recording. This way, the developed application fits in the idea of an archaeological digital pipeline or data infrastructure suggested by many researchers (Snow et al. 2006; McKeague et al. 2012; Chapter 4). However, to be implemented as a fully-fledged archaeological geodata infrastructure for management and research, the application needs some improvements, extensions and user tests. Thanks to the use of modern web technologies and open-source software and libraries, the application can be used in modular way. This means that parts of the application can be selected for re-use while others are disregarded for custom purposes. Furthermore, additional small task-specific packages can be developed for integration in the application. Custom-built applications can thus be realized by combining small packages of functions. This way, the risk of failure of 'a single complex (and expansive) system' pointed out by Snow et al. (2006) will be reduced.



## 8.6 CONCLUSION

The feasibility of using the flexible Archaeological DATA Model as basis for an archaeological geodata infrastructure was studied in this research by means of two case studies. These two case studies differed in terms of subdiscipline, project status, registration method and number of sources. In both case studies, a custom application was developed and assessed by the potential end-users. This has shown the successful implementation of ADAM and an application based on this model. The wide deployment of the data model has been proven by the difference between the case study contexts. Furthermore, the usefulness of the developed application in different parts of the archaeological workflow from registration over analysis to public interest raising has been illustrated. Fitting in the user-centred development method, the applications were tested and discussed with potential end-users. During these interviews, points for improvement (e.g., spatial data import) and ideas for additional developments (e.g., multi-criteria query) became clear. Implementing these adjustments and ideas will improve the value of the presented infrastructure with regard to data management, analysis, exchange and integration.

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# 9

## GENERAL DISCUSSION

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### 9.1 INTRODUCTION

This thesis has the goal of contributing to the research on archaeological data modelling and 3D archaeology. Because a data model that is tailored to archaeological data and purposes may form the basis of an archaeological data infrastructure, complete digital documentation and the subsequent open use of data may be facilitated. Given the essential character of the spatial and temporal dimensions for archaeological research, a 4D archaeological GIS can be part of such an infrastructure to facilitate taking well-grounded conclusions. As such, this thesis has the following general objective:

**DEVELOP A CONCEPTUAL DATA MODEL FOR ARCHAEOLOGICAL PURPOSES, IN WHICH THE PARTICULARITIES OF 4D ARCHAEOLOGICAL DATA AND THE REQUIREMENTS OF ARCHAEOLOGISTS TAKE A CENTRAL POSITION.**

This general research objective was refined into four specific research questions:

- RQ 1a. What are the current procedures for archaeological data storage, analysis and exchange?**
- RQ 1b. Which newly proposed 4D analyses are feasible and suitable for archaeology?**
- RQ 2a. How can the requirements be translated in an archaeological data model?**
- RQ 2b. How can this data model be integrated in a broader context, i.e., the archaeological workflow?**

These four research questions were addressed in Chapters 3 to 8 of this thesis. The remainder of this chapter continues with a summary and discussion of the main research outcomes in the context of these research questions (Section 9.2). Next, a critical reflection

on the methodology and the results is presented in Section 9.3, giving rise to future research avenues, which are described in Section 9.4.

## 9.2 SYNOPSIS AND DISCUSSION OF THE MAIN RESEARCH OUTCOMES

### 9.2.1 Current procedures for archaeological data storage, analysis and exchange

The first question in this study sought to determine the current practices regarding archaeological data. In particular, three aspects were focused on: data storage, data analysis and data exchange. Hence, Chapters 3 and 4 concentrated on acquiring the requirements of the archaeological world. By designing an online survey, it was possible to address this first research question on a global scale. The survey, described in Chapter 3, was available online for 2.5 months in 2013 and reached 171 participants, either archaeologists or others dealing with archaeological data. According to the recommendation of Maguire and Bevan (2002), this questionnaire was combined with interviews of the stakeholders and a document analysis of the Flemish Immovable Heritage Decree of 2013 (Chapter 4). The interviews, performed via personal contact, telephone or e-mail between January and April 2014, reached 41% of the archaeological parties active in Flanders. Chapter 4 further refined and contextualized the findings of Chapter 3 by shifting from the global to the local level, namely, Flanders.

Common to the three focus points of this research question is the nature of the archaeological data and the archaeological workflow in which they play a role. During the analysis of the Flemish Immovable Heritage Decree of 12 July 2013, it was found that three types of information are used in the archaeological workflow: administrative, spatial and scientific. In accordance with the present results, previous studies have demonstrated the importance of the spatial component in archaeological data (Katsianis et al. 2008, McKeague et al. 2012) and the necessity to handle thematic, spatial and temporal information simultaneously (Arroyo-Bishop and Lantada Zarzosa 1995, Katsianis et al. 2008). In line with the increasing number of archaeological investigations due to spatial development (De Clercq et al. 2012), two main business processes were found in Chapter 4: investigation in case of a building permit and fieldwork resulting from a purely scientific question. This division is reminiscent of the existing tension between private archaeological organizations and academia (Chapter 1). Preserving, conserving, making available and disseminating archaeological ensembles is the third business process, although constituting a sequel to the first two processes.

Because data storage, the first focus point, is strongly connected to data recording, an important finding across both chapters was that archaeological data are still frequently recorded on paper. This result agrees with observations from other studies, which reported the large component of paper-based recording in the data collection practice. Although considerably lower than the 84% found by Ross et al. (2013), the 45% of the survey respondents indicating the practice of written recording is somewhat surprising

given the increasing use of digital media in archaeology (Forte 2011, Jensen 2012). A possible explanation is that a digital database that synchronizes among the various mobile devices of the excavators is necessary (Wagtendonk et al. 2009). As shown in both Chapters 3 and 4, a central database in which the archaeological data recorded in the field are immediately stored is not a common practice. Although registering data digitally, some archaeologists (or organizations) do not use a central database either within one project or across their projects. Site- and organization-specific database structures are thus common in Flemish archaeology (Chapter 4). On the international level, this lack of data standardization was also demonstrated by the limited number of respondents indicating a full implementation of a particular standard within their organization (Chapter 3). Moreover, data standards that are specifically intended for cultural heritage or archaeology, such as MIDAS or CIDOC CRM, are little known or used by the survey respondents (Chapter 3). However, they are reported to be helpful but difficult to use. These findings corroborate with previous studies that revealed a lack of standardization and a large variety of archaeological database structures (Schloen 2001, Snow et al. 2006, McKeague et al. 2012). Another major finding concerning the storage of archaeological data is the inadequacy of metadata registration. More than half of the survey respondents do not (consistently) register metadata, although governmental employees tend to register more metadata than people working in academia or at private companies. At the Flemish archaeological organizations, metadata registration likewise appeared to be lacking. This result corroborates the statement of Wagtendonk et al. (2009) that metadata are not common in archaeology to complement research results. This finding has important implications for the reusability of the data. As explained by Dunn (2011), metadata are needed both for the data and their creation process to provide the users with information on “how that data has been created, including all processes associated with its recording, context, and current status.” (2011, p. 106). In this regard, it is interesting to note that the survey reveals a large willingness (49% in total) to include the archaeological workflow in a database. Hence, by storing the methods for passing from raw to interpreted data, future users can assess the value of the interpreted data. Furthermore, by storing both raw and interpreted data, as 58% of the respondents prefer, the interpretations can later be verified or reinterpreted. The latter may occur when a clearer insight into particular subjects is gained thanks to new investigations, analyses and research results. It is encouraging to compare these findings with the thoughts of Hodder on reflexivity, which is “the recognition and incorporation of multiple stakeholder groups, and the self-critical awareness of one’s archaeological truth claims as historical and contingent” (2003, p. 56). Hodder (2003) argues that not only should the data be opened up for future reinterpretations but also the way the data were gathered and how the current interpretations were generated. Furthermore, he argues for increasing and ameliorating the interpretation process both in the fieldwork phase and other phases of the archaeological workflow to narrow the gap between data acquisition and interpretation (Hodder 2003).

Two final important findings on data storage detected in the questionnaire results (Chapter 3) concern data imperfection and temporal information. While 53% handle data imperfection in an extra attribute, 18% include it in the same attribute and 17% completely ignore it. Handling imperfection in the same attribute as the value it concerns (e.g., 250 BC?) may cause severe problems for querying the data because the extra information (e.g., a question mark) obscures the actual value. Often involving data imperfection, temporal information is expressed as multiple types in archaeology. Although all six temporal categories identified by Katsianis et al. (2008) (Table 2-4) are frequently used by the survey respondents, archaeological time (e.g., Middle Ages), site phase time (e.g., phase I) and absolute time (e.g., 500 BC) are most often used (Chapter 3). This makes clear the necessity for both relative and absolute date storage possibilities. This also accords with the findings of Green (2008, p. 9), who noted that archaeological time is less precise and fuzzier than normal clock time and consequently expressed the need for a temporal GIS.

GIS is a part of the second focus point of the first research question, namely analysis. Both the questionnaire (Chapter 3) and interviews with Flemish archaeological organizations (Chapter 4) have shown the widespread use of GIS in archaeology. More than 70% of the respondents and interviewees indicated a regular use of GIS during their work. These findings match those of earlier studies, which demonstrated the prevalent use of GIS in general (e.g., Green 2008, Carlisle et al. 2014), and in particular at national and local cultural heritage authorities (Petrescu 2007) and in the English archaeological record-keeping community (Bell and Bevan 2004). Furthermore, Chapter 3 demonstrated that most archaeologists are confident of their GIS-expertise level. In accordance with Bell and Bevan (2004), who found that a quarter to half of the GIS users termed themselves as 'expert', in the current survey, 19% named himself/herself 'expert' and 28% 'skilful' (Figure 3-3). To know how these skills can be developed, the questionnaire probed the learning opportunities provided by the respondent's organization. At 54% and 40%, respectively, in-house courses and web-based learning were the most available resources (Figure 3-4). This result differs from Bell and Bevan's (2004) study, which found almost no evidence for web-based learning. They found that result surprising because web-based learning can be a cost-effective learning tool independent of the budget available for IT or training. Ten years later, the potential of the Internet as a media for training has been revealed by the questionnaire results. Although the finding that in-house courses occupy first place and a large percentage matches the findings of Bell and Bevan (2004), the percentage is thought to be slightly too high. This can be explained by the expected overrepresentation of survey respondents working in academia, where academic GIS courses are organized. This represents an opportunity for future generations of archaeologists, who will be trained in the basics of GIS during their university education. However, GIS and ICT courses still have to compete with other subjects to be part of the archaeological curriculum (Wagtendonk et al. 2009). Furthermore, these courses mostly show only the basics and

disregard how GIS and ICT can be effectively used within, or even provide enhancements to, the archaeological research process (Llobera 2011).

The lack of specialized and practically oriented GIS courses may be one possible explanation for the basic usage of GIS in archaeology. During the interviews described in Chapter 4, it became clear that the use of GIS by most Flemish archaeological organizations is limited; for instance, to make 2D plans or thematic maps. Another explanation for this restricted application originates from the capitalistic market organization implemented in Flanders: limited time and budgets. Because the government does not explicitly oblige (advanced) spatial analyses, archaeological organizations do not include these in their bids, in order to avoid overpricing. Consequently, the archaeological data are left until assimilated into research concerning a broader scientific question (Ford 2010). Given the large share of participants working in academia, this outcome may be further strengthened by the questionnaire result that 62% use GIS frequently or always as a research tool. In addition, the basic use of GIS is demonstrated with 82% always or frequently using it as general data management tool. Another important finding of the interviews is that the spatial data that are acquired in 3D from the field are mostly, if not always, reduced to 2D (Chapter 4). Again, this is due to the limited budgets available to further process, explore and interpret 3D data. Accordingly, 3D models originating from laser scanning or photo modelling are not commonly found within Flemish archaeology, except at universities. However, Chapter 3 reveals a high confidence of the respondents in the usefulness of 3D or 4D analyses. Extended 2D spatial (e.g., contains A element B?) and combined spatio-temporal analyses (e.g., Harris Matrix) are seen as possible new analyses. Other important results described in Chapter 3 regarding the development of a new 3D or 4D system are the potential drawbacks of such a system. Complexity is the most mentioned disadvantage (46%), followed by hardware requirements (23%). Furthermore, cost, time and additional training needs may limit the use of and even interest in a new 3D (4D) system. These drawbacks are similar to those mentioned in earlier studies on the use of digital technologies in archaeology, such as laser scanning, UAVs and geo-ICT (Lonneville et al. 2009, Wagtendonk et al. 2009, Plets et al. 2012, Forte 2014, Stal et al. 2014, Berggren et al. 2015).

Finally, the results described in Chapters 3 and 4 provided insight in the current practices regarding data exchange, the third focus point of the first research question. The document analysis of the Flemish Immoveable Heritage Decree showed that four explicit outcomes are dealt with in the archaeological business processes: archaeology note, archaeological report, final report and archaeological ensemble. These outcomes are intended to either inform other actors or to be consulted by other parties in the process (Huvila and Uotila 2012). Although multiple other explicit and implicit actors are concerned with data exchange, from the RACI matrices (Table 4-2, Table 4-3 and Table 4-4) it became clear that the certified archaeologist mainly exchanges these outcomes with the Flanders Heritage Agency. Nevertheless, implicit outcomes of the business flows were detected in Chapter 4, namely the preliminary investigation and excavation

archives, an inventory of prospected or excavated zones and products created for raising public awareness. These products will also be subject to exchange, the last with the public and the others within the organization and with other organizations (e.g., academia, local government). In general, the results of the survey revealed the media used for data exchange (Chapter 3). First, within the organization, direct system access and data dumps to mobile storage devices were the most used data exchange methods (Section 3.3.3). Second, towards other organizations, the results of the questionnaire indicated that data are provided mostly via a mobile storage device over the network (e.g., via FTP or Dropbox). The third place is taken by paper exchange, both within the organization or with other parties (13% and 17%, respectively). Compared to the survey of Bell and Bevan (2004), the share of paper-based data exchange within the organization has considerably decreased (from 50% to 13%). However, their recommendation to adopt metadata and geospatial mark-up standards in order to facilitate data integration and mitigate the risks of multiple local copies still applies to today's archaeology, given the metadata and data standards issues outlined above. This also agrees with the finding that several interviewed organizations were in favour of an exchange or database template provided by the government (Chapter 4). Together with a predefined set of quality control rules for the products, this could ensure the quality of the deliverables and even the archaeological research. Third, providing the public with archaeological data or information primarily occurs via paper (43%) or the Internet (32%). This finding is in agreement with the observation of earlier studies, that the internet is increasingly used to disseminate archaeological data towards a wider audience (Berggren and Hodder 2003, Ford 2010, Boast and Biehl 2011). The rapidity, ease and inexpensiveness of using the Internet makes it perhaps the most important way to publish and communicate archaeological information and for wider public involvement (Boast and Biehl 2011, p. 126).

Forming part of the user-oriented pillar, the combined findings of Chapters 3 and 4 provide information to answer the four questions formulated by Howard and MacEachren (1996) and to specify the context of use and organizational requirements. However, the findings of Chapters 5 and 6, in which potential new 4D analyses are proposed and evaluated, will further complement these requirements.

#### 1) Who is the system intended for?

The archaeological data infrastructure, of which the intended conceptual data model will be the basis, is directed at the actors involved in the archaeological business processes. In Chapter 4, two main actors were identified: certified archaeologists and the Flanders Heritage Agency. Furthermore, a whole series of actors, either explicitly or implicitly mentioned in the Decree, are potential users of the system: initiator of construction work, local government, researchers, public, museums, and data managers of archaeological companies, for example.



## 2) What requirements must be fulfilled by the system?

From the preceding information, four categories of requirements for the data model (and subsequent data infrastructure) can be deduced: user, organizational, data and functional requirements. Regarding the user, avoiding complexity is the main requisite. This can be broken up into the need for the system to be easy to use on the one hand and easy to learn on the other hand. The paragraph below describes the organizational requirements in more detail. The data requirements determined in Chapters 3 and 4 are consistent with the data particularities outlined in Chapter 2. In the archaeological workflow, data have an administrative, a spatial or a scientific character. The spatial data are three-dimensional. Dealing with the variety of objects and scales is also an important data requirement, just as the multi-temporality and data-imperfection. Finally, metadata are crucial to allow future understanding of the data. For the functional requirements, spatial analyses that are extended to 3D and analyses that combine both spatial and temporal dimensions are preferred.

## 3) What should be the result of working with the system?

As mentioned in the introduction to this thesis and this chapter, the intended archaeological data model and consequent data infrastructure is aimed at facilitating a complete digital documentation and open use of data. Thus, the system should result in making data available for reuse once they are recorded instead of leaving them in organization- or site-specific databases, which are either inaccessible or do not provide metadata.

## 4) How can this objective be reached?

Developing such a data model and infrastructure occurs by taking into account the previously mentioned requirements and the particularities of archaeological data outlined in Chapter 2. As mentioned in the introduction to this thesis (Section 1.1.2.3), the user needs to be placed in a central position during the development to ensure a broader acceptance (Nielsen 1993, p. 7). In addition to improving the system's acceptance, applying a user-centred design may also result in increased productivity, reduced errors, decreasing training needs and better reputation (Maguire 2001).

## 5) Organizational requirements

From the organizational perspective, capitalist market settings primarily determine the requirements. First, the system should be cost-efficient both in hardware and software requirements. Furthermore, training costs need to be taken into account, including time for the employees to conduct the training and become acquainted with the new system. This time constraint also needs to be considered so that working with the system does not increase the already high time pressure. Another organizational requirement includes the preference for a customizable data model and infrastructure; some organizations have already invested in implementing a specialized database or technologies. Finally, because multiple employees with various backgrounds work within an archaeological

organization and interaction occurs with other parties, the multiplicity of actors and purposes are also an important requirement.

#### 6) Context of use

The archaeological data infrastructure of which the intended conceptual data model may be the backbone targets the complete archaeological workflow as an application domain. Thus, the infrastructure will be used in the three business processes determined in Chapter 4: (i) investigation in case of a planning permit, (ii) investigation from a scientific question and (iii) dissemination and preservation. Given the rules enforced by the Malta Convention (Section 2.2 and 4.2.2) to establish and strengthen the relationship between spatial planning and archaeology, the applicability of the data model and infrastructure may be extended to other (policy) domains such as spatial planning and tourism. Multiple actors may thus take advantage of the data infrastructure to acquire, manage, analyse and/or exchange archaeological data. Furthermore, the use context of the conceptual data model and data infrastructure is influenced by the capitalist market organization. This mainly encompasses the issue of time and cost restrictions. Thus, during the development of the data model and subsequent data infrastructure, time and cost efficiency of the resulting product must be kept in mind.

### 9.2.2 New feasible and suitable 4D archaeological analyses

The second research question concerned the feasibility and suitability of possible new 4D analyses for archaeological purposes. As mentioned above, proposals for new analyses became clear as result of the survey (Chapter 3). Analyses that combine both the spatial and the temporal aspect of archaeological data or that are intended to explore 3D spatial questions either geometrically or topologically seemed the most preferred. Through the creation of two prototypical applications (Chapters 5 and 6), it was possible to further specify user needs and to obtain feedback on the potential implementations of these types of analyses. While Chapter 5 focussed on spatio-temporal analyses, Chapter 6 concerned the extension of basic traditional GIS functionalities to 3D. As the user requirements gathered in Chapters 3 and 4 not only have formed the basis for the two applications, but are also used to evaluate the applications, a bidirectional relationship thus exists between Chapters 3 and 4 on the one hand and Chapters 5 and 6 on the other.

Chapter 5 was designed to determine if spatial relationships could form the basis for the automatic construction of a Harris Matrix. This graphical model depicts sequences between the stratigraphic units of an archaeological excavation according to the rules defined by Harris (Harris 1979, 1989). For the creation of such a Harris Matrix, spatial relationships between the stratigraphic units (e.g., above, below, equal) are translated into temporal topologic relationships (e.g., younger than, older than, contemporary). Although thus constituting the basis of a Harris Matrix, surprisingly, spatial information is not used or linked to in most of the existing Harris Matrix tools. Using three theoretical data sets, an algorithm for the automatic creation of a stratigraphic sequence from

topographically recorded spatial data was formulated in Section 5.3. Next, this sequence was visualized in accordance with the theoretical rules. Testing the algorithm with a fourth validation data set has proven successful. However, validating the outcome of the algorithm by an expert remains indispensable. To facilitate the expert validation, the resulting Harris Matrix has been integrated in a web-based platform, which may serve as a management and research system because it also incorporates a 2D overview map, 3D representation and additional information on the stratigraphic units. Providing flexibility and user-friendliness, the developed digital tool may contribute to narrowing the gap between fieldwork and analysis (Berggren and Hodder 2003, Huvila 2014). Furthermore, this research supports the findings of Forte et al. (2014) that digital technologies and tools can facilitate the interpretation process of stratigraphic units.

The prototypical application developed in Chapter 5 meets the requirements outlined in the previous section. Regarding the user requirements, the system is easy to use and learn because the Harris Matrix is automatically created and is visualized in combination with a 2D and 3D overview of the involved spatial data and an attribute table containing additional data for the stratigraphic units. Second, the system is evaluated positively against the organizational requirements. By using Free and Open-Source Software (FOSS) for both the database and the management system, the cost of the system is very limited. Furthermore, it has the advantage of being customizable and extendable. The application can, for instance, be extended to allow phase and period assignment. Because the Harris Matrix is created automatically, time is saved for the interpretation process. Third, the functional requirement is fulfilled by the spatio-temporal nature of stratigraphic sequence creation. Fourth, incorporating spatial information in 2D and 3D overview maps, scientific and administrative information in an attribute table and temporal information in the Harris Matrix realizes the data requirements.

Chapter 6 sought to determine if a virtual globe could be extended towards a 4D archaeological GIS. Given their intuitive character and realistic 3D overview, virtual globes have already proven successful in crowdsourcing and public awareness projects (Minghini 2013, Hunter et al. 2015). Although acknowledged as promising tools to manage and disseminate 3D and 4D archaeological data, virtual globes have been restricted in professional use due to the absence of analytical functionalities. By matching the user, data, and organizational requirements gathered in Chapters 3 and 4 against a set of virtual globes, the FOSS and WebGL-based Cesium® was chosen as most appropriate for archaeological purposes. The development of a prototypical application based on Cesium® has proven the technical feasibility of extending a virtual globe to a GIS. Although only a limited number of functions were developed, these gave the test participants the opportunity to interact fully with the system as a real application. During the user test, the practical feasibility was apparent. The test users had a positive attitude towards the concept and indicated public activities, fieldwork preparation and analysis as the three activities for which they would consider using the application. However, to integrate the prototype in the archaeological workflow extensions need to be made to allow more advance analyses, history tracking, authorization, and WFS, for example.

The user requirements outlined in the previous section formed the criteria to select Cesium® as the basis for the prototype. The organizational requirements, 3D nature and temporal aspect of the data formed the decisive elements for this selection. However, the other requirements are also fulfilled by this prototype, as illustrated in Section 6.3.1. Furthermore, the intuitiveness of learning to use the virtual globe has been proven during the user tests, making the application suitable for a wide range of users regardless of their technical background. As FOSS, Cesium® facilitates the development of customizable and cost-efficient applications.

Both chapters have shown that advanced spatio-temporal or extended 3D spatial analyses are suitable for archaeology and feasible to develop and implement in user-friendly applications. Both applications combined spatial information with scientific and administrative information, which was indicated by the test users as one of the most interesting capabilities. The spatial overview, either a map or 3D globe, and its connection to scientific information via a database connection can thus be considered essential parts of an archaeological data infrastructure. This result can be considered part of the data-oriented pillar (Section 1.1.2.3) because it delineated which data and operations the data model should enable. Furthermore, both chapters (5 and 6) fit in the analysis-oriented pillar (Section 1.1.2.3) by proposing potential analyses and their implementation. Finally, the set-up and performance of a usability test with two Flemish archaeological organizations in Chapter 6 has allowed the assessment of the functionalities by its potential end-users and so completed both the UCD cycle of the chapter and a first UCD cycle in this doctoral research.

### 9.2.3 From requirements to an archaeological data model

The third research question of this thesis was to identify how the identified requirements could be translated into an archaeological data model. From the four categories of requirements, gathered in Chapters 3 to 6 and outlined in the previous sections (9.2.1 and 9.2.2), three major elements could be inferred which are crucial for the development of an archaeological conceptual data model. The first element originates from the data requirements and the diversity archaeology is confronted with. This includes not only the variety of objects but also the multi-temporality and three-dimensional geographical character. The second element stems from the organizational and functional requirements, namely the need for the data model to be applicable for different purposes in different domains and thus to allow diverse functions. The third element corresponds to the user requirements: avoiding complexity and providing usability for a diverse group of actors.

In Chapter 7, a conceptual data model that attempts to fit these three elements is suggested: the Archaeological DATA Model or ADAM. Consisting of nodes, properties and relations, ADAM is flexible, linkable and easily understandable. In contrast with tabular data organizations, which are today predominant in archaeology (Schloen 2001, Brusckke and Wacker 2014, Ross et al. 2015), a predefined structure of the data is not necessary when using ADAM. Furthermore, the storage of empty cells is avoided, as only

the known or relevant data for a particular object are stored as relations to the specific node. This makes it possible to describe the wide diversity of archaeological objects (e.g., a bone fragment and a Roman villa) in the same way. When using ADAM, the aspect of multi-temporality can be tackled by adding multiple relations to a specific node; e.g., 'trace A has phase Phase II' and 'trace A is older than find B'. Similarly, multiple spatial characteristics of an object can be described; e.g., geometry or a spatial relation. Storing relative relationships, either temporal or spatial, implies that two nodes become linked. In this way, ADAM allows for the easy creation of temporal and spatial hierarchies. Similarly, other types of hierarchies (e.g., structural or functional) could be constructed by using ADAM's linking ability (Figure 7-3). This capability fulfils the suggestion of Limp (2011) that a data model for archaeology should match the data and in particular its complexities, such as diverse hierarchies. ADAM thus allows integrating scientific, spatial and administrative data. Lacking a fixed structure that is drawn up for a particular purpose allows the data to be re-used afterwards for other objectives. This finding supports the conclusions of previous research that archaeological data are currently stored for a specific purpose while a general data model may facilitate the repurposing of the data (Kansa and Kansa 2011, p. 168, Ross et al. 2015, p. 118). Avoiding a purpose-specific data structure holds opportunities to reuse the data later to answer broader scientific research and contribute to creating new knowledge of our past but also to create symbiosis between archaeology, economics and society (Ford 2010, De Baerdemaeker et al. 2011). Because the data model only consists of three elements, future users of the data do not need to study the used structure in-depth (Snow et al. 2006). This makes the data model usable for people with various technical backgrounds.

To clarify the potential use of ADAM in archaeological practice, a possible database implementation and test application were introduced in Chapter 7. The database implementation is proposed for a relational geodatabase management system, the most common database type (Bruschke and Wacker 2014). This corroborates the idea of Ross et al. (2015) that relational data avoids such issues as data redundancy and integrity. However, setting up a relational database "requires time, resources, and expertise" (Ross et al. 2015, p. 118), in particular if adaptations are necessary for every new project or unexpected find (Limp 2011, p. 268, Huvila and Uotila 2012, p. 214). The latter counts if the relational database attempts to highly structure the archaeological data, creating separate tables for every type of object. Consisting of three basic elements (node, property and relation), ADAM in fact only asks for three database tables and thus avoids this difficulty. Additional tables are suggested for secondary relations and geometries. For the latter, the suggestion given in Chapter 4 to use a geodatabase as the basis for an archaeological information infrastructure is followed. Although the proposed implementation of ADAM in a relational database is uncomplicated, other database models such as graph databases may be even more suitable. Graph data models and databases arose in the late 1980s and early 1990s (Angles and Gutierrez 2008). In contrast to traditional database models, such as relational ones, graph database models allow capturing information on the connectivity of the data (Bruschke and Walker 2014).

Although other database models took over the lead for several years, graph databases are again gaining in importance the last decade (Angles and Gutierrez 2008). Their relevance is reconfirmed by the big data realm (Angles and Gutierrez 2008, Brusckke and Walker 2014, Robinson et al. 2015). In the context of geographical information, graph databases are commonly used to store and analyse network information, e.g., road, river and railway networks, and the spatial component in social networks (Angles and Gutierrez 2008, Cattuto et al. 2013). Brusckke and Walker (2014) indicated that archaeology could benefit from graph databases because it deals with large amounts of connected data. However, implementing ADAM in a graph database will lead to additional training needs in the use of these databases, which are not commonly used in archaeology.

The flexibility of ADAM, which does not impose a very detailed and specific data structure, accords with the issue of top-down enforced data standards. Such imposed standards or database formats in which archaeologists are “forced to squeeze their data” (Limp 2011, p. 268) are commonly lacking adoption and are not favoured (Limp 2011, Ross et al. 2015). However, these highly standardized formats have the advantage of sharing common vocabularies and ontologies<sup>1</sup>, making data integration easier. Nevertheless, the use of ADAM does not impede the adoption of a common ontology (Cripps et al. 2004). For instance, CIDOC CRM or an organization-specific ontology can be used as the basis for the possible properties. This example makes it clear that ADAM per se is not sufficient to accomplish the open use and reuse of data in archaeology. Therefore, ADAM should be considered in a broader context (i.e., the complete archaeological workflow) and to a larger extent (i.e., the national or even international level). This result supports the suggestion of Dunn (Dunn 2011, p. 100) that cyberinfrastructures can assist in supporting and realizing standard archaeological procedures, both in the field and afterwards. A test application that can function as an elementary cyberinfrastructure is described in the second part of Chapter 7. Because the discussion of this application fits in with the fourth research question, we do not consider this here and refer to Section 9.2.4.

## 9.2.4 The data model in a broader context

The fourth research question attempted to ascertain if the data model proposed in Chapter 7 as a result of the third research question could be integrated in the archaeological workflow. To allow the study of ADAM in a broader context, an initial test application was developed in Chapter 7. Next, this prototype was analysed, extended and evaluated by means of two case studies in Chapter 8. By focussing on the capabilities of the data model, the fourth research question matches the analysis-oriented

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<sup>1</sup> Providing the connection between used vocabularies, dictionaries and taxonomies, “in such an ontology, definitions associate the names of entities in the universe of discourse (e.g., classes, relations, functions, or other objects) with human readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of these terms” (Gruber 1993, pp. 908–909).

pillar of the methodological framework (Section 1.1.2.3). Furthermore, the evaluation of the case study applications by the stakeholders fulfils the UCD cycle of this project, which consisted of understanding the use context and specifying requirements, producing design solutions and evaluating them against the requirements.

The test application developed in Chapter 7 intended to illustrate the potential of ADAM as the basis of an archaeological data infrastructure. Such an infrastructure corresponds to the recommendation of several researchers to create a complete digital documentation process in archaeology (Katsianis et al. 2008, Forte 2011, Ross et al. 2013, Smith 2015). The importance of the spatial aspect in archaeology makes it recommended to found this archaeological data infrastructure on a geodatabase and complement it with GIS tools, as suggested in Chapter 4. This idea corroborates with those of other studies, which suggest the construction of a Spatial Data Infrastructure (SDI) for archaeology (Wagtendonk et al. 2009, McKeague et al. 2012, Billen et al. 2013, von Schwerin et al. 2016). Allowing for the creation, use and exchange of archaeological data, this archaeological geodata infrastructure should moreover be conceived as a cyberinfrastructure that allows for collaboration and interactivity (Snow et al. 2006, Kansa 2011, Billen et al. 2013). To illustrate that ADAM, the data model proposed in Chapter 7, holds the potential to frame an integrated archaeological geodata infrastructure, the prototypical test application was developed with as diverse a set of functions as possible. These include management (e.g., insert, update, history logging), display (e.g., list, graph, 2D and 3D map) and analysis functions (e.g., thematic filter, 3D buffer). For the development of the application and its capabilities, FOSS was chosen: PostGreSQL with its spatial extension PostGIS as the database; OpenLayers, Cesium® and D3.js for presentation purposes; and Turf.js for analysis. Furthermore, for the actual development of the application, FOSS was also used (e.g., the PHP framework Silex). Using open-source software has the advantage of reducing costs, although maintenance and hardware make it not 'free' as in 'free beer' (Dunn 2011, Ross et al. 2015, Stallman 2016). However, the application makes use of FOSS as 'free speech' (Stallman 2016). This allows customizing the used software code to fit the specific purposes of the different actors in the archaeological workflow. Furthermore, according to Kintigh (2006), sharing parts of the cyberinfrastructure as open-source components may advance interoperability between different disciplines. In this way, the intended archaeological cyberinfrastructure will be developed by multiple parties. This differs from the vision of Dunn (2011) that a cyberinfrastructure originates from only few collaborators while Web 2.0 initiatives are developed and maintained by a complete user community. However, the approaches of Web 2.0 and cyberinfrastructure, bottom-up and top-down, respectively, are not incompatible in the sense that Web 2.0 applications and tools can assist in the evaluation of the data created, used and exchanged in a cyberinfrastructure (Dunn 2011). By incorporating web map applications such as the Cesium® virtual globe, the test application matches the last concept. Furthermore, being web-based and focussing on more than data collection, the test application is in agreement with the finding of Wendrich (2011, p. 211) that research is more focussing on "data selection,

data reduction, and data interpretation” because of Internet availability. This argument supports ideas of previous researchers who argued that digital technologies could contribute to narrow the gap between fieldwork and interpretation (Berggren and Hodder 2003, Huvila 2014).

To determine how the initial test application will behave in practice with real archaeological data, two case studies are elaborated in Chapter 8. The first focussed on maritime heritage in the Belgian part of the North Sea. Forming part of the SeArch project, a web-based GIS was set up to allow integrating and visualizing archaeological and environmental data in a user-friendly way. The second case study intended to simulate the in-field use of the application and made use of analogue urban excavation data from the Ghent Archaeological Service. The data of the SeArch project were delivered in one Excel file including all the different objects and their characteristics. This supports previous observations that spreadsheets are frequently used in archaeology making efficient data integration difficult (Ross et al. 2015). However, importing Excel files and Shapefiles is possible in the test application. Importing the spatial data from AutoCAD files was more complicated as no open-source DXF or DWG are available for PHP. Therefore, the spatial data from the second case study had first to be converted to Shapefile. Once acquainted with the data, the test application was assessed to determine necessary adaptations to fit the purposes of the case study. For the SeArch project, the application was extended with an extra component: the WebGIS. This web application seems to stand alone, but is actually linked to the initial test application. In the WebGIS, non-archaeological data were also integrated, such as bathymetric measurement results. Although the developed functionalities of the SeArch web application are basic (e.g., obtain attribute information, obtain depth information), these will be extended in the future; e.g., temporal analyses. Furthermore, the link with the initial test application, which functions more as a management application, allows one to explore the data more thoroughly, for instance via the node’s relations. For the second case study, no specific adaptations of the application were needed, except for the DXF parser. The third step consisted of the evaluation of the application by the end-users. During regular project meetings, new versions of the WebGIS were presented to the stakeholders of the SeArch project allowing rapid intervention in the development. In general, the WebGIS and the management system were deemed positive. Future incorporation of bathymetric data in 3D, and thus realizing a fully fledged 3D or even 4D WebGIS, would enable more advanced analyses and facilitate even better marine spatial planning. The idea of integrating 3D data from laser scanning or other sensors in an archaeological infrastructure corresponds to the idea of von Schwerin et al. (von Schwerin et al. 2016). Testing and assessing the second application with employees of the Ghent Archaeological Service has shown positive results. They acknowledged the advantages of digital registration over analogue recording, both in error avoidance and time efficiency. These results match the concept of Dunn (2011, p. 100) that cyberinfrastructures can play an important role during fieldwork as well as post-excavation. The positive attitude of the employees to use the application in the field also supports previous research that digital



tools can narrow the gap between fieldwork and interpretation. Furthermore, they were in favour of the connection between thematic, spatial and administrative information. This finding supports previous research, which stresses that thematic archaeological data should be handled simultaneously with their spatial and temporal aspects (Arroyo-Bishop and Lantada Zarzosa 1995, Wagtendonk et al. 2009).

The two case studies have shown that ADAM performs well to form the basis of an archaeological geodata infrastructure. Although Chapter 8 found that the proposed test application holds potential to behave as such an infrastructure, improvements and adaptations should be made before being implemented in practice. As illustrated above, taking advantage of open-source software is preferred for future development. Chapter 8 concluded that the test application should be conceived in a modular way allowing custom selection and combination of separate small parts of the application. This makes it possible to realize custom-build applications that are tailored for specific purposes or actors, without losing the common backbone; i.e., the conceptual model ADAM. Furthermore, as proposed in the methodological framework (Section 1.1.2.3), additional user-tests to evaluate these improvements and adaptations are then needed.

## 9.3 CRITICAL REFLECTIONS

While a discussion of the specific research results was given in the respective chapters and the outcomes were summarized and discussed in light of the research questions in the previous section, this section aims to reflect critically upon some general and overarching aspects of this thesis. These aspects will also provide avenues for future research, discussed in Section 9.4.

### 9.3.1 The central place of the user

Emanating from the used methodological framework (Section 1.1.2.3), the user is centrally placed in the presented research. The term 'user' is understood to mean archaeologists, but others dealing with archaeological data can be included under this term. The last thus includes the actors involved in the archaeological business processes, as described in Section 9.2.1.

The involvement of the user during the research was especially notable in Chapters 3 and 4, which corresponded to the user-oriented pillar of the methodological framework. By setting up the questionnaire online, it was hoped to reach a diverse archaeological public representing the actual statistical population. However, as noted in Chapter 3, we expected that men, holders of a PhD degree and academics would be (slightly) overrepresented in the respondents group. The last two aspects may be caused by the method of distributing the survey: mainly via e-mail to colleagues, contact persons within the networks of my supervisor, archaeological (academic) institutions and some archaeological organizations. Thus, the survey invitation was sent to a larger number of people working in academia than working in private companies or government. Although

some archaeological organizations were contacted (e.g., CAA-Computer Applications and Quantitative Methods in Archaeology), more actively distributing the survey invitation among the members of other organizations (e.g., European Association of Archaeologists (EAA), Society for American Archaeology (SAA)) could have increased the number of respondents and consequently reduced the margin of error. Furthermore, to avoid the overrepresentation of academics and PhDs, the invitation could have been extended to archaeological interest groups and professional associations. In this regard, Flemish archaeological organizations, the Flemish archaeological professional association VONA and interest groups VLAC (Vlaams Archeologen Collectief) and Forum Vlaamse Archeologie could have been approached more actively to create a structural link between the survey (Chapter 3) and the interviews (Chapter 4). Allowing the separation of the answers of the Flemish archaeological actors from those of the other respondents could have provided an additional backbone during the development of the prototypical implementations and their respective user tests completed in this research.

Setting up a representative user group in the beginning of the project could also have strengthened the central role of the user in the research. Such a user group or focus group should be composed to correspond to the actual diversity of the intended users and stakeholders in terms of age, sex, nationality, education, employer type and IT skills. This would have allowed discussing as a group the requirements for an archaeological conceptual model and the evaluation of the idea and design of the prototypes. Similarly, focus groups have provided better insights into data management, living doubts, risks and opportunities in the FAIMS project (Ross et al. 2013). However, a focus group cannot replace the questionnaire and interviews, but should complement them. This way, a combination of sectional interests and individual requirements and ideas may be expressed (Maguire and Bevan 2002, Yovcheva et al. 2013). If the members of the focus group took part in every user test of the different prototypes (Chapters 6 and 8), an evolution of the perceptions, ideas and experiences could be constructed. Furthermore, a focus group can form a solid basis to communicate the ideas and advantages of the research to the archaeological community. This way, the support from the archaeological field may be reinforced, potentially enabling a higher level of acceptance of the data model and infrastructure in the future.

Although these two points of improvement—the survey distribution and a focus group—would have strengthened the central place of the user in this research, the methodology clearly focussed on the archaeologist and his needs. Having contacted Flemish archaeological companies had the advantage of easy approachability. Furthermore, this allowed rapid feedback during and after the user tests. These elements are advantages of the small test group and fit in the bottom-up approach as proposed in the methodological framework (Section 1.1.2.3). To conclude, having placed the user in a central position is expected to result in “increased productivity, enhanced quality of work, reductions in support and training costs, and improved user satisfaction” (Maguire and Bevan 2002, p. 133).

### 9.3.2 The 3D spatial nature of archaeological data

In addition to the user, the archaeological data characteristics have also been focussed on in this project. In particular, the spatial aspect and 3D nature play an important role in archaeological research. The focus on the 3D spatial nature of archaeological data is particularly featured in Chapters 5 and 6.

Spatial information from archaeological stratigraphic units formed the basis to extract spatial relationships between them and consequently build a Harris Matrix in Chapter 5. In this chapter, theoretical data were used in the form of 2D polygons stored in different groups according to their depth and thus contemporaneity. Extending these 2D polygons to 2.5D by including a general depth attribute only requires a minor adaptation of the suggested algorithm. The polygons are then sorted on this depth attribute and the spatial relationships determined between the units directly instead of between the units of the different layers. 3D polygons reflecting the actual 3D boundaries of the stratigraphic units would even increase the accuracy of the Harris Matrix generation. However, extracting the spatial, and the ensuing stratigraphic, relationships between these units is not straightforward. This is mainly because of the complexity of the computation, resulting in limited support for the full 3D spatial relationship tests in current geodatabases and GIS. Even the 'OpenGIS® Implementation Standard for Geographic information' does not describe these 3D operations and suggests projecting the 3D geometries to a 2D horizontal plane (Open Geospatial Consortium 2011). Differences and thus errors in topology may be introduced, resulting in inaccurate or unreliable results for the Harris Matrix generation. The implementation of 3D spatial relationship tests is an important issue for further research. Nevertheless, using 3D data in the algorithms and/or web-based management system would correspond to the increasing use of 3D topographic measurement techniques, such as total station and GPS. In this regard, laser scanning and photo modelling are increasingly used in archaeology, mostly in archaeological research starting from a purely scientific research question (Dell'Unto et al. 2013, Stal et al. 2014, von Schwerin et al. 2016). The latter techniques result in full 3D models. These have shown their advantages during the registration and interpretation of archaeological stratigraphic units (Forte 2014, Stal et al. 2014). Similar to 3D polygon data, detecting spatial relationships between these 3D models of the stratigraphic units requires complex analyses and topology tests. This makes the incorporation of 3D models in the suggested algorithm to identify stratigraphic relationships currently next to impossible. However, integrating 3D models in the prototypical web-based management system is already foreseen. In the present implementation, the virtual globe Cesium has been included to allow for a 3D overview map. The 3D models can thus be shown in this overview map, or this component can be replaced by a 3D viewer. Both options enable the user to interact with the 3D representation of the stratigraphic units.

Although spatial archaeological data are increasingly acquired in 3D and there is a proliferation of 3D models because of their splendid visualizations, time and budget restrict the use of 3D in the capitalist archaeological market (De Reu et al. 2013). The

acquired data are consequently mostly converted to 2D (Chapter 4). Therefore, basing the algorithm of Chapter 5 on 2D polygons grouped in contemporary sets corresponds to the practices of most private archaeological companies. Likewise, in the user tests of Chapter 6 and 8, no 3D models were used. All the data provided by the archaeological organizations were 2D, except for the data from the 'Vogelmarkt' project used in Chapter 8 that consisted of 3D geometries. However, the 2D data in Chapter 6 either were complemented by a depth attribute for each geometry or could be draped over a digital terrain model that was based on GPS height points. Although Cesium is capable of integrating 3D models, future studies are nevertheless recommended to investigate the visualization behaviour, analysis opportunities, and connection with the database. The last aspect merits particular attention, as the connection of spatial data with thematic and administrative data was appreciated by the test participants.

In addition to the data, the analyses implemented in the prototypical applications also focused on the spatial and 3D aspect of archaeology. These spatial analyses were kept to a basic level for two reasons. First, as mentioned earlier, in a capitalistic market, the time and budget to execute analyses and interpretations are limited. Therefore, the prototypes only implemented some basic spatial analyses that may be performed within these confined resources. Second, it was not the intention of this research to deliver a finished product, but rather to demonstrate and prove capabilities and feasibilities regarding the 4D aspect of archaeological research. Therefore, the prototypes developed in this research attempted to implement a representative set of functions that could be useful in the framework of an archaeological geodata infrastructure. Thus, there is abundant room for further progress in determining potential 4D archaeological analyses. Special attention should be paid to the multi-temporality and imperfection of archaeological data.

### **9.3.3 Archaeological data infrastructure, more than a data model**

The aim of this research was to develop a conceptual data model that may serve for a variety of archaeological data and purposes. By considering such a data model in a broader context, thus integrating it in an archaeological data infrastructure, it is hoped that the increasing flux of data continues even after the stage of writing the final report. This way, a complete digital documentation, as proposed by several researchers (Tsipidis et al. 2005, Al-Hanbali et al. 2006, Forte 2011), may be facilitated. Through calling particular attention to the spatial aspect of archaeological data, more thoroughly integrated analyses may become possible, in which spatial data are simultaneously handled with temporal and thematic data following proposals of previous research (Arroyo-Bishop and Lantada Zarzosa 1995, Wagtendonk et al. 2009). Such an archaeological data infrastructure, which is based on the proposed data model ADAM, can be set up at different levels and consequently can offer respective advantages at these levels.

First, the archaeological geodata infrastructure can be implemented within an archaeological company. For this purpose, the prototypical application of Chapters 7 and 8 can be used. Although not yet thoroughly tested in practice, it is conceivable that employing the application during the complete archaeological workflow has several advantages. The test participants also expressed these advantages (Chapter 8). When using the application as a digital registration tool in the field, the efficiency is expected to increase, the risk of errors will be drastically reduced and transcription errors may disappear. Furthermore, the combined visualization of thematic, administrative and spatial data and their simultaneous analysis are likely to result in better insights and interpretations. Having this integrated view of the data already available in the field contributes to lessen the currently existing gap between data acquisition and post-processing or fieldwork and interpretation. This hypothesis corresponds to those from other studies (Stal et al. 2014, Berggren et al. 2015). In the presented test application, as described in Section 8.4.2, the spatial data are linked only after the thematic and administrative data were inserted in the application. However, integrating map editing functionalities that allow the identification of object locations directly in the application's map or making use of location-based services would prevent this drawback of the current design. Furthermore, it should be possible to link the application with the topographic devices used for the spatial registration, such as total station and GPS. The advantages will become especially noticeable if the archaeological company was previously not digitally registering data in the field or was not using GIS or other geospatial tools.

Second, the archaeological geodata infrastructure can be used between different archaeological companies at a regional or even at a national or international level. At these levels, overarching multiple companies, data, information and knowledge exchange is attempted by the infrastructure. The currently implemented authorization system and history tracking is one of the tools necessary for this purpose. Furthermore, PostGIS allows for concurrent access to the database. In addition, tools to discuss the findings and collaborate on the research are needed to arrive at a shared virtual workspace as proposed by Snow et al. (2006). Further work is thus required to establish the infrastructure application as collaborative research infrastructure.

Third, the archaeological geodata infrastructure can also be used to increase public awareness of archaeology. This potential is illustrated in the SeArch project, in which a special WebGIS was built to make people aware of the marine heritage in the North Sea. In addition to increasing public interest in archaeological research, such applications can also encourage the involvement of the public in the research (Kansa et al. 2010).

However, setting up such an archaeological data infrastructure based on a central data model in an organization, between different organizations or in a country will not completely tackle the issues of data accessibility and reuse in archaeology. Therefore, implementing an archaeological geodata infrastructure consists of more than solely using ADAM and the prototypical management and research application proposed in Chapters 7 and 8. The following aspects need to be considered: regulation and legislation,

financing, training and education, licensing and lines of thought. The first aspect concerns establishing the necessity to make archaeological data sets accessible by regulation or legislation. In most cases, the digital publishing of archaeological data is not legally required. However, exceptions exist; e.g., in The Netherlands, digital deposition and detailed metadata are obligatory (Wagtendonk et al. 2009). Establishing these legal requirements are also in conformity with the Convention of Malta that states in article 8 that member states should attempt “to promote the pooling of information on archaeological research and excavations in progress and to contribute to the organization of international research programme” (Council of Europe 1992). Furthermore, quality control of the deposited archaeological reports and potentially the data sets could also be embedded in existing laws. Currently, such governmental quality control is lacking in Flanders, as noted by the Flemish archaeological companies interviewed in Chapter 4. While regulating the archaeological data publishing and quality control, it has to be kept in mind not to block new research avenues and flexibility (Wendrich 2011, p. 226). Second, digitally preserving data involves costs, even if open-source software is used (Shaw et al. 2009). The costs vary from hardware costs for storing the data and running applications, and education costs for training employees in using the new technologies to efficiency costs because changing workflows and customs will initially cause a slight loss in efficiency (Wagtendonk et al. 2009). Further research should be conducted to investigate the financial implications and how these can best be counterbalanced. The third aspect that is necessary for an archaeological geodata infrastructure to succeed concerns training and education. Although ADAM and the test application were developed to be usable by actors with varying IT skills, integrating computer, information and geo-ICT skills in the current academic curricula may be advantageous (Wagtendonk et al. 2009, Llobera 2011). Furthermore, providing opportunities for improving technical and information skills outside of academic training should be provided (Huvila and Uotila 2012, Ross et al. 2013). This is especially necessary as long as geo-ICT and computer courses have to compete to be a substantial part of the curriculum because of the fear that those will weaken basic archaeological skills. This initiative could be taken by the organization but also by governments, commercial companies or the open-source and Web 2.0 community. Increasing in popularity, as described in Chapter 3, web-based learning reaches a wide audience and contains costs. The fourth aspect concerns the licensing of the provided or deposited archaeological data. Making archaeological data sets accessible and open for reuse evokes issues such as intellectual property and privacy rights and citation requirements. As Kansa (2010, p. 319) has noted, “in order to encourage the legal use and reuse of this content, intellectual property issues need to be addressed”. This can be done by complementing the data sets with a license. Although Creative Commons licenses, which are well known in the open-source field, provide the necessary means to manage copyright (Creative Commons 2016), Kansa and Kansa (2011) argued that political and cultural aspects might complicate their adoption. Furthermore, archaeological data, in particular location, are kept inaccessible for a wider audience due to sensitivity reasons and as a precaution against robbery (Schlanger and Aitchison 2010, McCool 2014,

Sheehan 2015). Although a user management system including the possibility to define different access roles is implemented in the test application, further research needs to be undertaken on the necessary licenses, sensitivity of information and ways to cite the data sets. The fifth element that needs to be considered when establishing an archaeological geodata infrastructure is the lines of thought of archaeologists. It has been noted by several researchers that the archaeological community needs to change their mind on the way (geo-)ICT can advance archaeology (Llobera 2011, Jensen 2012). The increasing use of GIS (Chapter 3) in recent years may be an indication that this mind shift is already occurring. In addition, the manners and methods to document an archaeological excavation may need to be rethought if new digital technologies are or become available (Jensen 2012). However, the introduction of new tools to the archaeological workflow needs to be “a process of evolution, not revolution”, as noted by Dunn (2011, p. 101). This research has fulfilled this need by placing the user in a central position. Using a methodological framework to develop the conceptual data model and infrastructure that is based on the user-centred design cycle, the potential acceptance rate may be increased.

## 9.4 RECOMMENDATIONS FOR FUTURE RESEARCH

Although showing promising results, the current research project has limitations due to the decisions taken. Therefore, “one person’s completed research project is another person’s point of origin” (Linn et al. 2004, p. 377). Avenues for future research were outlined in the discussion and conclusion sections of each research chapter in this thesis. Furthermore, some more overarching recommendations have been mentioned in Section 9.3 when discussing the limitations of the current research. A general overview of potential future research actions follows.

A first research line that needs further investigation is how ADAM, the suggested prototypical infrastructure (Chapter 7 and 8), and the test applications of Chapters 5 and 6 would behave in practice. It is recommended to test their suitability and feasibility through a series of case studies representing different fields of study and diverse parts of the archaeological workflow. However, in a later stage, ADAM and the integrated management and research infrastructure should be tested throughout the complete workflow, from fieldwork preparation to publication of the results. Before arriving at such advanced testing, some additional features need to be implemented in the prototypical application currently proposed in Chapters 7 and 8. These features include the ability to efficiently combine spatial and thematic registration in the field, capabilities to discuss and collaborate during research and more extensive (spatio-temporal) analysis facilities. All of these are discussed in more detail in the previous section. For the implementation of these capabilities, a continuation of the methodological framework used in this research is advisable. In doing so, potential end-users should stay involved in the development process, providing an advantage for the final acceptance rate of the new system. Moreover, considerably more work needs to be conducted on how 3D models

can be fully integrated in the application, focussing on both their visualization and analysis.

A second line of research relates to the broader framework in which the archaeological geodata infrastructure is found. As discussed above, implementing ADAM and the suggested infrastructure application will not completely resolve the issues of data accessibility and reuse. Therefore, it is recommended to undertake further research in the following areas: cost management, licensing opportunities, privacy issues, regulation and legislation. During these investigations, consulting the actors involved in the archaeological workflow, which form the potential users of the system, is advisable. Furthermore, to tackle the issues of mentality and training and education it might be valuable to explore the opportunities of setting up an archaeological community around the infrastructure developments. To successfully represent the actors in the archaeological process, this community should consist of people working in academia, the government and the private sector and represent the archaeological community at minimum in age and gender. Such community could assist not only in expressing additional needs and building new tools but also in improving the quality of the archaeological research. Creating a system of peer-review for the disseminated data can form a potential investigation area to explore how a better quality control system can be achieved.

Finally, some minor future research possibilities can also be mentioned. Setting up a new online survey on the use of GIS and data standards in archaeology at regular points in time (e.g., each 5 years) would allow a better monitoring of and insight into the influences of new developments in the field. However, when distributing the survey, it is recommended to strive for a representable sample. As mentioned in the previous section, archaeological organizations and interest groups could be approached in addition to academia and private archaeological companies. Another potential area of future research would be to investigate if ADAM could also be applied in other related domains, such as built heritage or museums. To conclude, it could be interesting to analyse the impact of the market organization (socialist vs. capitalist) on the use and benefits of ADAM and the archaeological geodata infrastructure.

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## GENERAL CONCLUSIONS

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The main goal of the current research was to develop a conceptual data model in which the 4D archaeological data specificities and the requirements of the archaeologists take a central position. Such a data model could form the basis of an archaeological data infrastructure, which may contribute to the accessibility and reuse of the increasing amount of archaeological data. Because of the importance of the spatial aspect for archaeological research, a 4D GIS could be a very valuable part of this archaeological data infrastructure. By thoroughly investigating the user's needs and then translating these requirements in a conceptual data model, the goal of this study was to contribute to the development of a complete digital archaeological documentation.

In the first part of this thesis, the general requirements for analysis and structuring of archaeological data were determined through an online survey, document analysis of the Flemish Immovable Heritage Decree, interviews with Flemish archaeological companies and user tests of two prototypical applications. The combination of the questionnaire results, document analyses and interviews (Chapters 3 and 4) identified four categories of requirements for the data model and data infrastructure: user, organizational, data and functional requirements. First, from the perspective of the user, the data model should avoid complexity and thus should be easy to learn and use. Second, from the viewpoint of the organization, the following elements should be considered: limiting costs for hardware, software and training; not increasing the time pressure; allowing customizability; and supporting multi-actors and multi-purposes. Third, the data requirements corroborate with the particularities of the archaeological data: 3D spatial, multi-temporality, data imperfection, multiple scales and diverse objects. Fourth, the functional requirements constitute combined spatial and temporal analyses and 3D extended analyses. The potential feasibility and suitability of new 4D archaeological analyses were tested by the development of two test applications. Chapter 5 showed that the algorithm proposed to automatically detect stratigraphic relationships from spatial archaeological data and to transforming these relationships into a Harris Matrix was successful. Chapter 6 revealed that it is both technically and practically feasible to extend a virtual globe to a 4D archaeological GIS. The combination of a spatial overview

with the scientific and administrative information stored in the database was indicated as very valuable by the test users of the second application.

The second part of this thesis attempted to translate the requirements found in the first part into an archaeological data model and place its applicability in a broader context; i.e., the archaeological workflow. The flexible, linkable and easily understandable Archaeological DATA Model (ADAM) is described in Chapter 7. ADAM consists of nodes, properties and relations and allows for describing the wide diversity of 4D archaeological data in an uncomplicated way for later reuse. Testing the data model with theoretical data has shown that spatial and temporal hierarchies can be described by using the linking capacities of ADAM. Furthermore, adding multiple relations with a temporal property to a specific node tackles the aspect of multi-temporality. However, the data model by itself cannot accomplish open use or reuse of archaeological data. Therefore, a test application was developed which was based on ADAM and could function as an elementary archaeological geodata infrastructure. Testing this application through two case studies has shown promising results (Chapter 8). Via the user test of the first case study it became clear that the test application based on ADAM has the potential to be used directly in the field for registering excavation data. The advantages of ADAM and the application for integrating and disseminating data emerged from the second case study, in which the application was extended with a user-friendly WebGIS. However, improvements and adaptations should be made for the application to be applicable in practice. Therefore, it is proposed to take advantage of the open-source code of the test application and to conceive the archaeological geodata infrastructure in a modular way.

In general, the results of this study indicate that for the development of an archaeological data model and geodata infrastructure, the data but also the user, the organizational context, and the desired functionalities, need to be considered. Notwithstanding the necessary improvements on the application and the requisite of practical tests, the study suggests that the flexible and linkable ADAM can contribute to the issues of data integration, exchange and reuse in archaeology. It is believed that ADAM could assist in the efficient registration, analysis and exchange of 4D archaeological data while respecting future scientific and socio-economic value. In this regard, the presented prototypical application provides a framework for the development of an archaeological geodata infrastructure. The methodological framework that focuses on the user may hereby serve as a base for future user studies on the suitability of the application.



# NEDERLANDSE SAMENVATTING — DUTCH SUMMARY

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Archeologische erfgoed is een belangrijke en vaak ook de enige bron die informatie verschaft over ons verleden. Het vormt een herinnering aan eeuwen economische, sociale en culturele activiteit. Door de toenemende bebouwing sinds de Tweede Wereldoorlog is dit erfgoed sterk onder druk komen te staan. Het bewustzijn omtrent archeologie is vanaf de jaren zestig op Europees vlak op de agenda komen te staan. Na het Verdrag van Londen uit 1969, is het uiteindelijk het Verdrag van Malta uit 1992 dat de interactie tussen archeologie en ruimtelijke planning vooropstelt en aanstuurt op een meer geïntegreerd behoud en bescherming van het archeologische erfgoed (Council of Europe 1992). Sinds de late jaren negentig en begin jaren tweeduizend is de invloed van dit verdrag in de praktijk merkbaar. Niet alleen is het aantal en de grootte van de archeologische onderzoeken sindsdien toegenomen, ook is er een archeologische markt ontstaan die plaats biedt aan (semi)private archeologische bedrijven (De Clercq et al. 2012). Aangezien bouw- en ontwikkelingsprojecten het archeologisch onderzoek sturen, wordt dikwijls de term *development-led* archeologie of contractarcheologie gehanteerd. Het principe ‘de verstoorder betaalt’ – een vertaling van het ecologische ‘de vervuiler betaalt’ – zorgt er echter voor dat deze archeologische bedrijven geconfronteerd worden met een grote druk om kosten te besparen. Daarnaast betekent een archeologisch onderzoek ook een vertraging voor het bouw- of infrastructuurproject wat zorgt voor een enorme tijdsdruk op de archeologische bedrijven. Deze heersende druk om kosten- en tijdsbeparend te werken heeft ertoe geleid dat geen uitvoerige analyses en interpretaties worden uitgevoerd in de contractarcheologie. Een basisrapport vormt dan ook vaak het enige resultaat van een archeologisch onderzoek.

Aangezien een archeologische opgraving een éénmalige actie is en bijgevolg niet kan worden herhaald, is het van belang om archeologische data zo gedetailleerd en correct mogelijk te registreren en documenteren. Door de toenemende tijdsdruk worden meer en meer digitale technologieën ingezet om de efficiëntie en snelheid van de registratie te verhogen. Dit is voornamelijk het geval voor de opname van 3D ruimtelijke gegevens, alhoewel ook steeds vaker thematische gegevens digitaal worden geregistreerd. Hierdoor kunnen en worden momenteel grote hoeveelheden archeologische data opgenomen. Hoewel deze gegevens zowel uit wetenschappelijk als socio-economisch oogpunt zeer waardevol kunnen zijn, is hun hergebruik, na het voltooien van het basisrapport, zeer beperkt. Dit is te wijten aan twee factoren. Enerzijds worden de ruwe gegevens bijgehouden door het archeologisch bedrijf dat het onderzoek uitvoerde, waardoor deze vaak ontoegankelijk of moeilijk opspoorbaar zijn. Anderzijds worden deze gegevens dikwijls opgeslagen in een databank die specifiek is opgesteld voor een bepaalde site of bedrijf. Bovendien worden de ruimtelijke en thematische gegevens vaak onafhankelijk van elkaar opgeslagen en behandeld. De integratie en uitwisseling van gegevens moet daarom beschouwd worden vanuit een bredere context, nl. de complete

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archeologische workflow. In dit opzicht werd door meerdere onderzoekers reeds het voorstel gedaan om een compleet digitaal documentatieproces op te stellen. Om dergelijke stroom van digitale data te realiseren, is een archeologische data-infrastructuur die gebaseerd is op een conceptueel datamodel noodzakelijk.

Dergelijk datamodel zal moeten beantwoorden aan de eigenschappen van archeologische data om de diverse archeologische doelstellingen te kunnen bereiken. In het algemeen kan worden gesteld dat archeologische gegevens worden gekenmerkt door vijf elementen: 1) 3D, ruimtelijke aspect, 2) meerdere temporele categorieën, 3) grote variëteit aan objecten, 4) meerdere schaalniveaus en 5) data-imperfectie. Aangezien het ruimtelijke karakter van de gegevens van groot belang is voor archeologisch onderzoek, zullen ruimtelijke data-infrastructuren (SDI) en hun onderdelen (bv. technische infrastructuur, datamodel, etc.) een bron van inspiratie vormen voor een archeologische data-infrastructuur. Geografische toepassingen zoals GIS zullen er dan ook noodzakelijker wijs deel van uitmaken. Hoewel GIS zijn voordelen al heeft bewezen voor archeologie, wordt het gebruik ervan beperkt door de moeilijkheid om met 3D en de tijdsdimensie om te gaan. Omdat het ruimtelijke karakter nauw samen hangt met de temporele dimensie van archeologie, is het van belang bij de ontwikkeling van een archeologisch datamodel de aandacht te vestigen op dit 4D-aspect.

Momenteel beschouwen softwareontwikkelaars de archeologische sector echter als een nichemarkt en laten deze daardoor links liggen. Daarom is een eerste stap in de richting van een 4D archeologische data-infrastructuur vanuit de onderzoekswereld noodzakelijk. Hieruit zal moeten blijken op welke manier archeologische data geregistreerd, beheerd, geanalyseerd en uitgewisseld kunnen worden zonder hun potentiële wetenschappelijke en socio-economische waarde te verliezen. Er wordt daarbij gehoopt dat deze onderzoeksresultaten op hun beurt de ontwikkeling van kosten- en tijdsefficiënte tools voor de registratie, analyse en uitwisseling zullen stimuleren.

## ONDERZOEKSDOELSTELLING

Dit doctoraatsonderzoek tracht een bijdrage te leveren aan het huidige onderzoek omtrent archeologische datamodellering en 3D-archeologie. Hierdoor beoogt dit proefschrift ook onderdeel uit te maken van het onderzoek dat een aanzet poogt te vormen voor de ontwikkeling van een 4D archeologische data-infrastructuur.

Het voorgaande heeft geleid tot volgende algemene onderzoeksdoelstelling:

**HET ONTWIKKELEN VAN EEN CONCEPTUEEL DATAMODEL VOOR ARCHEOLOGISCHE DOELEINDEN WAARIN DE BIJZONDERE EIGENSCHAPPEN VAN 4D ARCHEOLOGISCHE DATA EN DE VEREISTEN VAN DE ARCHEOLOGEN EEN CENTRALE PLAATS INNEMEN.**

Uit deze onderzoeksdoelstelling kunnen vier meer specifieke onderzoeksvragen (OV) worden afgeleid:

- OV 1a. Wat zijn de huidige manieren voor het opslaan, analyseren en uitwisselen van archeologische data?**
- OV 1b. Welke nieuwe 4D-analyses zijn mogelijk en geschikt voor archeologie?**
- OV 2a. Hoe kunnen de vereisten vertaald worden naar een archeologisch datamodel?**
- OV 2b. Hoe kan dit datamodel geïntegreerd worden in een bredere context, nl. de archeologische workflow?**

## ONDERZOEKSBENADERING

Voor het beantwoorden van deze onderzoeksvragen wordt gebruik gemaakt van een methodologisch kader dat bestaat uit drie pijlers: gebruiker-georiënteerde, data-georiënteerde en analyse-georiënteerde pijler. Het voorgestelde kader is opgesteld op basis van twee bestaande methodologieën, namelijk deze over geovisualisatie van Howard en MacEachren (1996) en deze van *user-centred design (UCD)* of gebruikersgericht ontwerpen (Maguire 2001). In beide methodes wordt de gebruiker en gebruikservaring centraal geplaatst. In de gebruikersgerichte pijler wordt getracht de gebruikersvereisten te verzamelen en een beter inzicht te krijgen in de gebruikcontext van het beoogde datamodel en de data-infrastructuur. De data-georiënteerde pijler probeert een eerste datamodel of infrastructuur uit te bouwen en focust voornamelijk op de data, daarvoor gebruikmakend van case studies. Ten slotte wordt in de analyse-georiënteerde pijler gefocust op de functionaliteiten van het datamodel of de infrastructuur. Telkens de drie pijlers doorlopen zijn, wordt het model of de infrastructuur geëvalueerd op basis van de vereisten.

Hoewel de volgorde gebruiker-data-analyse aangehouden wordt, zijn de drie pijlers met elkaar verweven in dit onderzoek. Terwijl onderzoeksvragen 1a en 1b overeenkomen met de gebruiker-georiënteerde pijler, maakt OV1b ook deel uit van de data- en analyse-georiënteerde pijlers. Daarnaast maakt OV2a deel uit van de data-georiënteerde en OV2b van de analyse-georiënteerde pijler. Dit proefschrift is opgebouwd uit zes artikelen die zijn gepubliceerd in of ingediend bij internationale peerreviewtijdschriften of –boeken. Deze artikelen vormen Hoofdstukken 3 tot en met 8 van dit proefschrift en worden aangevuld met een korte onderzoeksachtergrond in Hoofdstuk 2 en een discussie en conclusie (Hoofdstuk 9 & 10).

## VOORNAAMSTE BEVINDINGEN

Hoofdstuk 3 heeft getracht de huidige gebruiken in verband met het opslaan, analyseren en uitwisselen van archeologische gegevens op een globale schaal in kaart te brengen (OV1a). Hiervoor werd een online enquête ingesteld. Deze was in 2013 gedurende drie

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maand beschikbaar en heeft in totaal 171 archeologen of personen die omgaan met archeologische gegevens bereikt. De enquêteresultaten bevestigen dat nog steeds frequent op analoge wijze data wordt geregistreerd. Bovendien blijkt ook dat er een gebrek aan standaardisatie is en dat datastandaarden die specifiek voor archeologie werden ontwikkeld maar weinig bekendheid genieten. Hoewel meer dan de helft van de respondenten niet consistent metadata bijhoudt, is er wel een grote wil om de workflow van ruwe naar geïnterpreteerd gegevens op te slaan. Het wijdverspreid en regelmatig gebruik van GIS wordt bevestigd door meer dan 70% van de respondenten. Er blijkt ook dat de meeste respondenten een groot vertrouwen hebben in hun GIS-kennis; 19% noemt zichzelf expert, 28% ervaren. Hoewel 3D- en 4D-analyses algemeen als nuttig worden aanzien, worden complexiteit en hardwarevereisten genoemd als mogelijke nadelen van een 3D/4D-analyse of –systeem. Ten slotte heeft de enquête ook de meest gebruikte manieren van data-uitwisseling aan het licht gebracht. Binnen een organisatie gebeurt de uitwisseling via directe toegang tot de documenten of via een mobiel opslagsysteem (bv. USB-stick). Tussen organisaties onderling wordt meestal gebruik gemaakt van een mobiel opslagmedium of een transfer over het internet (bv. FTP of Dropbox). Naar het publiek, ten slotte, wordt informatie meestal op papier en meer en meer via internet verspreid.

Aan de hand van interviews met actoren uit de Vlaamse archeologie en een analyse van het Vlaamse Onroerenderfgoeddecreet is getracht de bevindingen uit Hoofdstuk 3 verder te verfijnen en te contextualiseren. Hierbij vindt ook een verschuiving plaats van de globale naar lokale schaal. Hoofdstuk 4 heeft op die manier drie processen onderscheiden: archeologisch onderzoek voorafgaand aan een stedenbouwkundige vergunning, archeologisch onderzoek vanuit een pure wetenschappelijke vraagstelling en het bewaren, behouden en beschikbaar maken voor onderzoek en ontsluiting van archeologische ensembles. Dit laatste proces kan dan ook als vervolg van de eerste twee worden beschouwd. Aangezien verschillende types informatie worden uitgewisseld in deze processen, kunnen deze ook worden beschouwd als informatiestromen. Het merendeel van de beschouwde gegevens heeft ook een geografische component. Hoewel vaak geregistreerd in 3D, blijkt dat deze ruimtelijke data vaak herleid worden naar 2D. Uit de interviews is ook duidelijk geworden dat enkel de basisfunctionaliteiten van GIS worden gebruikt. Dit blijkt voornamelijk te wijten te zijn aan de tijdsdruk en de beperkte beschikbare middelen. Ondanks de vele site- en organisatie-specifieke databankstructuren, zijn de meeste Vlaamse organisaties voorstander van een uitwisselingsstandaard of standaard databankmodel.

Uit de enquêteresultaten van Hoofdstuk 3 is gebleken dat voornamelijk 2D ruimtelijke analyses die naar de derde dimensie worden uitgebreid en analyses die tijd en ruimte combineren de voorkeur verdienen. Om een antwoord te bieden op OV1b werden daarom twee prototypes ontwikkeld die elk focussen op één van beide analysegroepen. De vereisten verzameld in Hoofdstukken 3 en 4 hebben de basis gevormd voor deze ontwikkelingen.

Hoofdstuk 5 heeft zich toegelegd op de combinatie van het temporele en ruimtelijke aspect. Hiervoor is een toepassing voorgesteld die op automatische wijze een Harrismatrix, een voorstelling van de stratigrafie bedoeld voor temporele interpretatie, opstelt. Het voorgestelde algoritme vertrekt vanuit de ruimtelijke informatie, in dit geval 2D-polygonen, over de stratigrafische eenheden. Op basis hiervan worden alle mogelijke ruimtelijke relaties tussen deze eenheden bepaald, waarna deze worden vertaald in temporele topologische relaties door de overtollige relaties te verwijderen uit de data set. Het resultaat van dit algoritme wordt daarna voorgesteld in een eenvoudige webtoepassing die de Harrismatrix integreert met een 2D- en 3D-overzichtkaart en attribuut informatie over de stratigrafische eenheden. Zo ontstaat als het ware een beheers- en onderzoekstoepassing die bovendien de validatie van de gegenereerde Harrismatrix door experts zal bevorderen. Dergelijke expertvalidatie blijft noodzakelijk, niettegenstaande de positieve resultaten die bekomen werden met vier theoretische data sets, waarvan er drie gebruikt werden om de procedure te testen en één om deze te valideren.

Een tweede prototype is ontwikkeld in Hoofdstuk 6 waarbij de uitbreiding van bestaande 2D-GIS functionaliteiten naar de vierde dimensie wordt bestudeerd. In het bijzonder werd nagegaan of *virtual globes* hiervoor geschikt zijn, zowel op technisch als praktisch vlak. Omwille van hun intuïtieve karakter en hun realistische voorstellingswijze worden dergelijke 3D-webtoepassingen reeds vaak gebruikt in crowdsourcingprojecten en projecten met publieke deelname. Nochtans is hun professionele gebruik beperkt door het ontbreken van analysefuncties. Uit een technische vergelijking van verschillende *virtual globes* en een toetsing aan de eerder verzamelde vereisten (Hoofdstuk 3 & 4), blijkt dat Cesium® het meest geschikt is om te worden uitgebreid naar een 4D archeologisch GIS. Gebruikmakend van de opensourcecode werden een aantal functies ontwikkeld die de verschillende taken categorieën van een GIS weerspiegelen, bv. een attribuentabel met editeeropties, 3D-buffer en temporele filtering. Vervolgens is de praktische haalbaarheid van de toepassing bestudeerd door middel van een gebruikerstest bij twee Vlaamse archeologische bedrijven. Hieruit is een positieve houding ten opzicht van het concept – een laagdrempelig 4D archeologisch GIS – gebleken. Hoewel de testpersonen hebben aangegeven de toepassing te willen gebruiken voor publiekswerking, analyse en voorbereidende studies, zijn uitbreidingen van de voorziene functionaliteiten noodzakelijk.

De vertaling van de verzamelde vereisten voor het opslaan, analyseren en uitwisselen van archeologische gegevens in een conceptueel datamodel (OV 2b) vormt de focus van Hoofdstuk 7. De diversiteit aan objecten, inclusief hun ruimtelijke en temporele karakter, de veelheid aan doelstellingen en het vermijden van complexiteit kunnen als de drie belangrijkste vereisten worden beschouwd. ADAM, het Archeologisch DATaModel dat wordt voorgesteld in dit hoofdstuk tracht aan deze vereisten te beantwoorden. Enkel bestaand uit knopen (*nodes*), eigenschappen (*properties*) en relaties (*relations*) laat ADAM toe op een eenvoudige en flexibele manier de grote variëteit aan archeologische data te beschrijven zonder de toekomstige wetenschappelijke of socio-economische waarde

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in te perken. Verschillende soorten hiërarchieën (bv. ruimtelijke of temporele) kunnen worden opgebouwd door een relatie tussen twee knopen toe te voegen. Bovendien kan het aspect van multitemporaliteit worden aangepakt door verschillende relaties met een temporele eigenschap toe te voegen aan eenzelfde knoop. Ondanks de positieve verwachtingen, is het gebruik van ADAM op zichzelf niet voldoende om een open gebruik en hergebruik van data binnen de archeologie te bereiken. Om dit te verwezenlijken moet het datamodel vanuit een bredere context worden bekeken.

Deze bredere kijk op ADAM, namelijk vanuit de volledige archeologische workflow, vormt het onderwerp van Hoofdstuk 8. Om een antwoord te geven op de vierde onderzoeksvraag (OV2b) wordt gebruik gemaakt van twee casestudy's. Op basis van de suggesties voor een archeologische geodata-infrastructuur uit Hoofdstuk 7, worden twee aparte toepassingen ontwikkeld. De eerste casestudy, Search, focust op het integreren van verschillende databronnen en het eenvoudig voorstellen en beheren van mariene erfgoeddata in een gebruiksvriendelijk WebGIS. De tweede casestudy, Gent Vogelmarkt, richt zich op het opstellen van een archeologische infrastructuur die nuttig is voor de registratie, het beheer en de analyse van stedelijke opgravingsgegevens. Beide toepassingen bevestigen de bruikbaarheid en het nut van ADAM in een bredere context. Gedurende de evaluatie (via vergaderingen en gebruikerstesten) werden beide toepassingen door de mogelijke eindgebruikers op positieve reacties onthaald. Niettemin zijn verbeteringen in het design, uitbreidingen van de functionaliteiten en uitgebreide praktijktesten noodzakelijk. In dit opzicht kunnen de toepassingen ontwikkeld in Hoofdstukken 5 en 6, Harrismatrix en 4D GIS, ingepast worden in de huidige infrastructuur. Gebruikmakend van een ruimtelijke databank aangevuld met geografische tools (bv. WebGIS en ruimtelijke analyses in 3D) wordt met deze twee testtoepassingen de kiem gelegd voor de ontwikkeling van een (4D) archeologische geodata-infrastructuur die ervoor zorgt dat de data- en informatiestroom zich doorzet nadat het finale opgravingsrapport werd voltooid.

## **BEPERKINGEN VAN HET ONDERZOEK EN MOGELIJKHEDEN TOT VERDER ONDERZOEK**

Hoewel dit onderzoek positieve resultaten heeft opgeleverd, zijn er ook een aantal beperkingen aan verbonden door de keuzes die gemaakt werden. Deze beperkingen kunnen bijgevolg het startpunt vormen voor nieuw onderzoek. Gedurende het volledige onderzoek is de gebruiker centraal gesteld om zo een hoger slaagpercentage van de uiteindelijke toepassing te bekomen. Hoewel een gemakkelijke benadering en het snel verkrijgen van feedback sterke argumenten zijn om de gebruikersgroep op te bouwen uit lokale, in dit geval Vlaamse, organisaties, verdient het de aanbeveling in de toekomst archeologische organisatie uit verschillende landen in het onderzoek te betrekken. Hierbij moet worden opgemerkt dat ook een representatief beeld nagestreefd moet worden inzake leeftijd, geslacht en opleiding. Niettegenstaande een internationaal publiek werd bereikt met de online enquête (Hoofdstuk 3), is een overrepresentatie van mannen, houders van een doctoraatsdiploma en personen werkzaam bij universiteiten

waargenomen. Naast aan de gebruiker, werd ook aan het ruimtelijke karakter van archeologische data bijzonder aandacht geschonken. Hoewel 3D-modellen meer en meer gebruikt worden in de archeologie, werden deze in dit onderzoek niet behandeld. In Hoofdstukken 5, 6 en 8 werd gewerkt met gegevens die de huidige gebruiken in de Vlaamse context weerspiegelen. Er werd dan ook enkel met 2D-, 2.5D- en 3D-vectordata gewerkt. Terwijl de inpassing van 3D-modellen in de toepassingen uit Hoofdstuk 6 en 8 relatief eenvoudig kunnen gebeuren, is dit veel minder voor de hand liggend voor Hoofdstuk 5. Verder onderzoek is dan ook aangewezen om de mogelijkheden van 3D-modellen in het kader van een archeologische data-infrastructuur te evalueren. Tot slot, komt er bij het implementeren van een archeologische data-infrastructuur meer kijken dan enkel een datamodel. Ook wet- en regelgeving, financiering, opleiding, licenties en het wijzigen van de gedachtegang zijn belangrijke aspecten die moeten worden beschouwd. In dit onderzoek zijn deze zaken niet of weinig aan bod gekomen waardoor toekomstig onderzoek vereist is. De impact van deze elementen kan eventueel gekoppeld worden aan doorgedreven praktijktesten. Dergelijke testen zijn noodzakelijk om het gebruik van ADAM en de voorgestelde infrastructuur in verschillende delen van de archeologische workflow en in verschillende subdisciplines van de archeologie te kunnen evalueren en later te implementeren.

Samengevat kan worden gesteld dat uit de resultaten van dit onderzoek is gebleken dat voor de ontwikkeling van een archeologisch datamodel of een archeologische geodata-infrastructuur niet enkel met de gegevens, maar ook met de gebruiker, organisatiecontext en de gewenste functionaliteiten rekening moet worden gehouden. Hoewel verbeteringen en uitvoerige praktijktesten noodzakelijk zijn, stelt dit onderzoek dat ADAM kan bijdragen in de efficiënte registratie, analyse en uitwisseling van 4D archeologische gegevens. De voorgestelde prototypes kunnen dan ook het kader vormen voor de ontwikkeling van een archeologische geodata-infrastructuur die zal bijdragen aan de problemen omtrent data-integratie, -uitwisseling en -hergebruik.

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# CURRICULUM VITAE

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Berdien De Roo (°1989) was born in Aalst (Belgium) on 17 June 1989. In 2007, she finished high school at Onze-Lieve-Vrouwcollege Zottegem campus Bevegem and started her education in geography and geomatics at Ghent University. She graduated as Master of Science in Geomatics and Surveying (summa cum laude) in 2012. In the same year, she received a grant from the Ghent University Special Research Fund and started as a PhD fellow at the Department of Geography, CartoGIS research unit. As employee of the Department of Geography, she was involved in the supervision of the practical classes on programming. During her research, Berdien gained experience in acquiring user requirements and has gathered knowledge on spatial databases, database models, GIS (desktop & GIS) and web applications. In the course of the past four years, she participated in several international conferences on geomatics and archaeology (e.g., 3DGeoInfo and CAA) and performed a research stay at the Universidad de Concepcion (Chile) in 2013. The results of her PhD research have furthermore been published in or are submitted to leading international journals in the field of geography, information science and archaeology.



# PUTTING THE PAST IN PLACE

A CONCEPTUAL DATA MODEL FOR A 4D ARCHAEOLOGICAL GIS

BERDIEN DE ROO

The archaeological heritage buried in our ground bears testimony to economic, cultural and social habits of past societies. In recent years, a more integrated approach of spatial planning and archaeology is adopted to preserve our heritage. Increasing amounts of archaeological data are this way acquired. However, their reuse afterwards is fairly limited because of accessibility and data structuring issues.

This thesis examines the requirements for archaeological data storage, analysis and exchange and determines how these can be translated into an archaeological data model. An online survey and interviews with archaeologists working in Flemish commercial and governmental organizations were conducted to get insights in current practices. An algorithm for automatic Harris matrix creation and a prototype 4D (3D + time) archaeological GIS were developed to test the suitability and feasibility of spatio-temporal archaeological analyses. Next, a flexible and linkable archaeological data model is proposed in this thesis: ADAM. Based on ADAM, a user-friendly web-based management and research application, which could function as an elementary archaeology-specific geodata infrastructure was developed and tested. The results of two case studies have shown positive results for the management and research of 4D archaeological data. Focussing on the spatial aspect of archaeology, with this thesis a first step was taken to put the past in place.

