THE TEMPORAL DIMENSION IN A 4D ARCHAEOLOGICAL DATA MODEL: APPLICABILITY OF THE GEOINFORMATION STANDARD

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KEY WORDS: ISO 19108, Temporal Information, Archaeological Data, 4D, Time scale, Topology

ABSTRACT:

In recent years, the interest of many researchers in various domains is triggered to move beyond the traditional border of two-dimensionality and explore the possibilities of the third and even the fourth, temporal, dimension. The emerging research interest concerning 3D and 4D and the handling of these additional dimensions can bring many benefits to archaeology as well. A 4D GIS tailored to archaeological data would facilitate better insights and more complex analyses. Its basis must be a conceptual 4D archaeological data model, which pays attention to existing data models and standards. Although in some cases more complex, archaeological data are closely related to geography and geo-information. Since the temporal dimension is a, and possibly the most, substantial element in archaeological research, this paper focusses mainly on this dimension. In this paper, the applicability of the ISO 19108 geo-information standard on temporal information for archaeological data is investigated. For a set of common temporal categories, e.g. the excavation time, the appropriate description according to this standard is determined. This will indicate in which cases the internationally recognized standard is suitable for use in an archaeological data model. Furthermore, three versions of the West European archaeological time scale as temporal ordinal reference system are constructed. For the first version, the ISO 19108 structure is used, whereas the second and third are based on geological variants. The results of the performed analysis are favourable to the usability of the ISO 19108 standard in archaeology; however, other temporal standards or data models may yield up better results.

1. INTRODUCTION

Currently, many researchers have accepted the challenge of moving beyond the traditional border of two-dimensionality (2D). This emerging research interest in 3D (*x*, *y* and *z*) and even 4D (3D + time) is located in various domains, from geography over transport studies to biology (Breunig and Zlatanova, 2011). Handling the additional dimensions (depth and/or time) could facilitate gaining insight and better analyses. Although 3D space and time are both implicitly present in our daily lives, their integration in geo-information science and especially in GIS have seemed slightly problematic (Peuquet, 2001; Breunig and Zlatanova, 2011).

In archaeology as well, geographic information is handled, since archaeological data is mostly located in space and contains a detailed description. Besides an absolute or relative location in 3D space, the temporal dimension is of considerable interest for archaeological research. Current temporal GIS (TGIS) or 3D GIS are locked into modern clock time and are mostly not able to deal with the inherent uncertainty of archaeological (temporal) data. Therefore, a 4D GIS tailored to archaeological data would enable the analysis of more detailed and complex spatial and temporal queries and facilitate gaining better insights (Arroyo-Bishop and Lantada Zarzosa, 1995; Katsianis *et al*., 2008; Green, 2011).

In the developing process of such a 4D archaeological GIS, preference has to be given to the (re)use of existing standards and data models (Breunig and Zlatanova, 2011). In the 1990s, the emerging use of geographic information compelled to standardization (Kresse and Fadaie, 2010). The International Organization of Standardization / Technical Committee 211 (ISO/TC211) was set up in order to establish a set of standards on geographic information (Kresse and Fadaie, 2010, p. 31). In 1994, 20 standardization projects, among which a spatial and temporal schema, formed the agenda for a series of base standards (Kresse and Fadaie, 2010, p. 30).

This paper deals with the applicability of one of these international accepted standards for describing geographic information in the archaeological domain, namely the ISO standard 19108. This standard defines a temporal schema for geographic information (ISO, 2002). The applicability analysis consists of two parts. First, a description for a set of common archaeological temporal indications is attempted to be given in conformity with the ISO 19108 (2002) standard. Second, the archaeological time scale is transformed into a temporal ordinal reference system according to the standard's description and two geological variants of this description. Since, this research is part of a bigger project in which the next steps should result in a formal definition of a 4D conceptual data model tailored to archaeology, the analysis will provide an adequate decision on the usability of this standard for the proposed data model.

The remainder of this paper is organized as follows. Section 2 gives a short discussion of the concept and current research of

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temporal information and temporal data modelling in archaeology. The details of the ISO 19108 standard are outlined in section 3. Section 4 presents the methodology that is used for the applicability analysis. The results of this analysis are presented and discussed in section 5. Finally, section 6 provides the research conclusions and some recommendations for future research.

2. BACKGROUND INFORMATION

2.1 Time concept in archaeology

Although the theoretical discussion about the temporal concepts has only recently arisen in the archaeological domain (Lucas, 2005, p. 28), the number of discussions has multiplied the last three decades (Bailey, 2007). Different directions occur in these discussions, but two main themes can be 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). However, this section does not attempt to contribute to these theoretical discussions, but rather tries 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 such as 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 radio carbon dating (Smedja, 2009; Green, 2011), 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 (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 (2011, 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".

Beside 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; Katsianis *et al*., 2008; Green, 2011). 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. Green (2011) 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 1).

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 temporal paths apply to different excavation objects depending on the interpretive objectives.

Table 1 Temporal categories identified by Katsianis *et al*. (2008)

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; Tsipidis *et al*., 2011). Consequently, archaeological dates are often subjective, uncertain and imprecise (Katsianis *et al*., 2008; de Runz, 2010; Green, 2011). This uncertainty is inherently linked to archaeological data in general (Katsianis *et al*., 2008; Cripps *et al.*, 2012). An anteriority index is proposed by de Runz *et al*. (2010) to indicate the reliability associated to a specific date. Holmen and Ore (2010) present an event-oriented system based on the CIDOC conceptual model (see Crofts *et al*., 2011) which enables the detection of dating conflicts, the improvement of start and end dates and the display of chronologies.

2.2 Current temporal data modelling in archaeology

One 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 (2011, 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, 2011, p. 92-103).

In the remainder of this paragraph, a short overview is given of the Harris matrix, which is a main temporal analysis tool which combines as well the third spatial dimension, and the research of Green, as it is a very recent contribution to archaeological TGIS. For a detailed review of other archaeological efforts in TGIS research, we refer to Green (2011, p. 92 – 103).

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 (ii) or double horizontal lines (iii) between their constituting elements, represented as boxes (Harris, 1989, p. 36). Figure 1 shows a simple example of a Harris matrix. 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 (2011) notes the multilinear 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, p. 39-40).

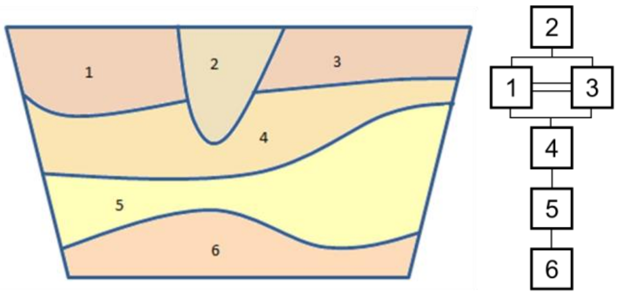

Figure 1 Example of Harris Matrix

One of the most recent studies on archaeological temporal GIS is the research of Green (2011). The aim of his research is the creation of a fuzzy, temporal GIS (TGIS) which is specifically tailored to archaeological data (Green, 2011). Green (2011) made the condition to the system "to be flexible and powerful", and to "remain within the software horizons of GIS-literate archaeologists" (p. 2). The emphasis was laid on handling the temporal uncertainty; input data consists of the minimum and maximum possible time (Green, 2011). Green (2011) uses different methods for the calculation of probabilities 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, 2011). 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, 2011, pp. 142-144).

3. ISO 19108 STANDARD

The ISO 19100 series of standards is developed by the ISO/TC211 and deals with geographic information and geomatics (Kresse and Fadaie, 2010, p.1). ISO 19108 dates back to 2002, with a technical corrigendum of 2008 (ISO, 2008). ISO 19108 "defines concepts needed to describe the temporal characteristics of geographic information" (ISO, 2002, p. vi). However, the standard mentions to be (partly) applicable in other fields (ISO, 2002). The scope of the standard indicates the preference of valid time over transaction time (ISO, 2002).

The ISO 19108 temporal conceptual schema consists of two packages: Temporal Objects and Temporal Reference System (Figure. 1).

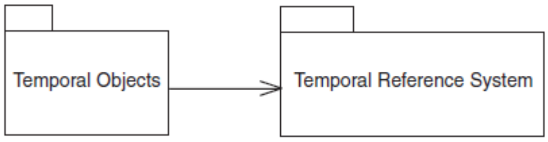

Figure 1 Packages of the ISO 19108 temporal schema

3.1 Temporal Objects

Temporal objects will be used to describe temporal characteristics. A distinction is made between temporal geometric and topological objects, TM_GeometricPrimitve and TM_TopologicalPrimitve respectively (ISO, 2002). The structure of the geometric and topological temporal schemas is analogous to these of the spatial schemas described in ISO 19107 (2003). In the remainder of this paragraph, the similarity with the latter will be emphasized and is summarized in table 2.

	Spatial		Temporal	
	Geometric	**Topological**	**Geometric**	**Topological**
0D	Point	Node	Instant	Node
1D	Curve	Edge	Period	Edge
2D	Surface	Face	-	-

Table 2 Similarity between geometric and topological primitives in ISO 19107 (2003) and ISO 19108 (2002)

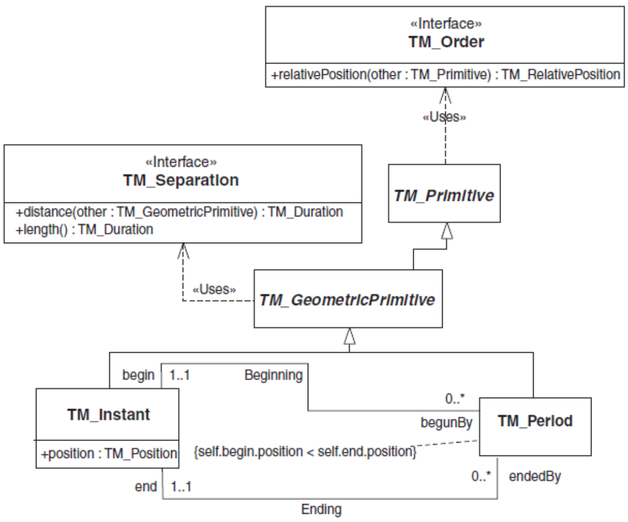

Figure 2 Temporal geometric primitives (ISO, 2002)

The ISO standard describes two geometric primitives, analogous to spatial primitives, who provide information on the position in time measured on an interval scale: TM_Instant and TM_Period (Figure 2). As a point in space, an instant represents a zero-dimensional geometric primitive in time (ISO, 2002). The point that is represented by the instant is specified by the attribute position, which is related to a specific temporal reference system (ISO, 2002). A 1D geometric temporal primitive is represented by a period, which begin and end position are identified by TM_Instants (ISO, 2002) (Figure 2). ISO 19108 (2002) provides an interface TM_Order to determine the relative position of two geometric primitives according to the Allen relations (1983). The relation between two geometric temporal primitives can also be expressed in absolute terms, by the distance-method of the TM_Separation class (Figure 2). This class provides as well an operation to calculate the duration of a period (ISO, 2002). Although the duration of an instant is by default equal to zero, the ISO standard provides a calculation operation for this (ISO, 2002).

The second category of temporal objects described by ISO 19108 (2002) are topological primitives. These objects only provide information about connectivity and ordering in time, not about the temporal position (ISO, 2002). In analogy to spatial topological primitives (ISO, 2003), TM_Node and TM_Edge represent 0D and 1D topological temporal primitives respectively (Figure 3) (ISO, 2002). When the position of a node or edge in time is known, the topological primitive can be associated to its geometric representation (ISO, 2002). In order to represent connectivity between different topological primitives, each primitive should be part of a TM_TopologicalComplex (ISO, 2002). The order of topological primitives belonging to the same complex can be derived through the TM_Order interface and its RelativePosition()-method. This method will return, in this case, one of the temporal Allen relations of which four are excluded: during, contains, overlaps and overlapped by.

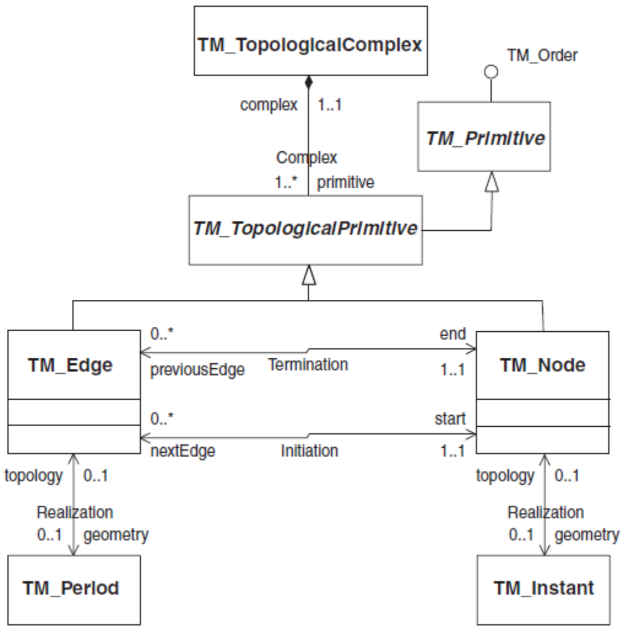

Figure 3 Topology of time (ISO, 2002)

3.2 Temporal reference systems

A temporal position is related to a temporal reference system to which the value is measured. The ISO 19108 standard (2002) specifies four types of temporal reference systems, namely TM_Calendar, TM_Clock, TM_CoordinateSystem and TM_OrdinalReferenceSystem. Table 3 gives an overview of measurement scales of these systems. ISO 19108 (2002, p. 20) explicitly mentions archaeology as one of the application domains which could use ordinal reference systems. This system consists of components, TM_OrdinalEra, which are characterized by a name, begin and end date (Figure 4). The beginning and end of an ordinal era must be specified as a DateTime, which is a combination of the temporal reference systems TM_Calendar and TM_Clock (Figure 5).

Reference System	Scale of measurement
Calendar	Discrete Interval
Clock	Interval
Coordinate system	Continuous Interval
Ordinal reference system	Ordinal

Table 3 Scales of measurement of the ISO 19108 (2002) temporal reference systems

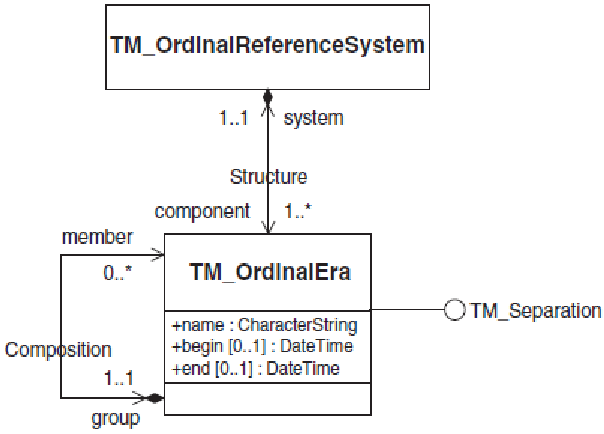

Figure 4 Ordinal temporal reference system (ISO, 2002)

ISO 19108 indicates the preference for the Gregorian Calendar in combination with the Coordinate Universal Time (UTC) as reference system, according to ISO 8601, to describe a temporal position. When another temporal reference system is used, the position in time must be given by a subclass of TM_TemporalPosition (Figure 5) (ISO, 2002). The class TM_TemporalPosition has an optional attribute 'indeterminatePosition' which can be used with or without a value of a TM_TemporalPosition subtype. In the latter case, the attribute is used as a qualifier (ISO, 2002).

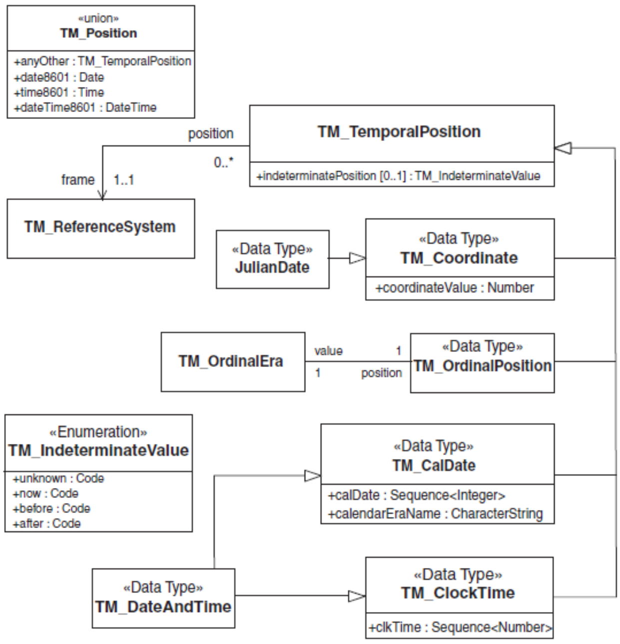

Figure 5 Conceptual schema of temporal position (ISO, 2002)

4. METHODS

The proposed method for the analysis of the ISO 19108 standard's applicability in the domain of archaeology is centred on the six temporal paths identified by Katsianis *et al*. (2008) (Table 1). These temporal categories can be assumed to represent the most common set of time indications, which are applied to 3D archaeological (excavation) objects. Therefore, they are required in a 4D data model for archaeological data which ought to reuse (parts of) existing standards and data models.

For each of the six categories (Table 1) the ISO 19108 standard (2002) is examined in order to assess its suitability. An appropriate standard-conform description of each of these temporal paths is determined. For this purpose, several assessments must be made. First, ISO 19108 (2002) gives the choice between the geometric and the topological temporal representation. Second, irrespective of the preceding choice, the decision between a 0D and 1D representation has to be made. Thus, the temporal value can be geometrically represented by TM_Instant or TM_Period (Figure 2) or topologically by TM_Node or TM_Edge (Figure 3). Finally, an appropriate temporal reference system to which the temporal value is relatively measured has to be chosen (Figure 5).

Since the ISO 19108 standard (2002) mentions archaeology explicitly as one of the applications where an ordinal temporal reference system is more appropriate than another temporal reference system (p. 20), this part of the standard is applied to the archaeological time scale. Multiple archaeological time scales exist based on different spatial or cultural regions. In this paper, the archaeological time scale for Western Europe is used. Although different versions occur, the main periods and subperiods are largely accepted. However, begin and end dates vary according to the spatial location and/or are not exactly known. In the example used in this paper, the choice is made to use dates described by the Flemish Heritage Agency (https://inventaris.onroerenderfgoed.be, 16/05/13) and about which general acceptance as rough dates for the Flemish region exists.

Similar research is done for the geological time scale by Michalak (2005) and Cox and Richard (2005). Although both of them presented almost simultaneously a temporal model for the geological time based on ISO 19108, two different results were obtained. Michalak (2005) adapted the structure of the Temporal Ordinal Reference System (ISO, 2002) with topological elements. Cox and Richard (2005), on the other hand, developed the system with geometric elements. In this research, the ISO version of the temporal ordinal reference system as well as the adapted versions of Michalak (2005) and Cox and Richard (2005) will be applied to the West European archaeological time scale. To clarify the differences between the three variants, only a part of the archaeological time scale is used: the Roman time including three subperiods (Early, Mid and Late Roman time) and the Middle Ages. The prefix 'TM_' is used where classes of the original standard are used. After the comparison of the pros and cons of each of the models, a proposal will be given about the most sufficient system for the (West European) archaeological time scale.

5. RESULTS AND DISCUSSION

5.1 Six temporal categories

The first temporal category that can be assigned to an excavation object is the excavation time. This is the date an object is excavated or found. Since this date can be identified to the level of day, month or year or at best to the hour (minute, second) level, for the representation a geometric primitive is selected. It is assumed here and by Katsianis *et al*. (2008) that the value for this date is 0D and thus a TM_Instant. However, a TM_Period is also possible as data type for excavation time when this refers to the complete site or to a 3D excavated layer. The latter is not tackled here, as this paper focusses on temporal attributes of archaeological objects. The position of the instant is provided by 'date8601:Date' for dates down to the level of a day or 'dateTime8601:DateTime' for more specific dates which include hour, minutes and/or seconds. These two options use the default temporal reference system: Gregorian calendar and UTC, as described in ISO 8601 (ISO, 2002, p. 21)

Analogue decisions can be made for the second temporal path, the database time. This can be represented by a TM_Instant, where the temporal position is given as DateTime, thus as the attribute 'dateTime8601'. It can be expected that this time is specified with seconds precision, since it normally is automatically stored by the database or software.

As illustrated in section 2.1 assigning a phase of a site to an excavation object is one of the main tasks in archaeology. Therefore, the third category on which the ISO standard is assessed is the 'site phase time'. This time is typically a topological temporal representation, because a relative ordering is made (Smedja, 2009; Binding, 2010). The word 'phase' indicates that this temporal value is 1D. Thus, a TM_Edge should be used. Different TM_Edges, which all represent a certain site phase, can be aggregated into a TM_TopologicalComplex. Where possible, the edge can geometrically be realized by a TM_Period. In Annex B of the ISO 19108 standard (2002, p. 34) the example of a 'site history' is given. The decisions made above result in the same scheme, although it is linked to the individual objects instead of to the whole site. The topological approach allows to overcome the problems mentioned by Koussoulakou and Stylianidis (1999) (see section 2.1). New phases can be added without causing problems whether it involves phases that fill gaps (3) or appear within other phases (4). The imperfection (1) or changes (2) of begin and end dates do not pose problems, since these are presented by topological nodes. The intended changes of the nodes, does in these cases mostly not affect the structure of the topological complex (cf. spatial topology). Likewise issues (5) and (6) do not set a problem. In both cases only an 'update' of the database or information is needed.

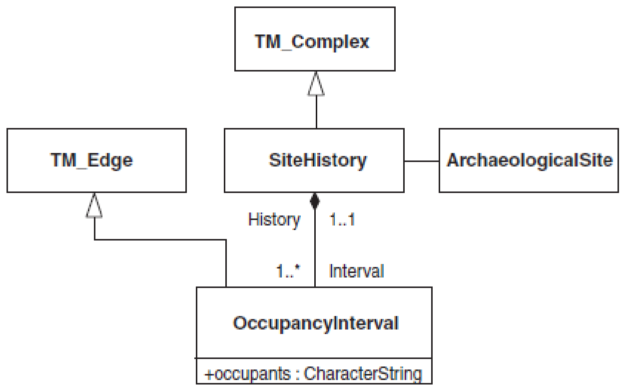

Figure 6 The history of an archaeological site by the use of TM_TopologicalComplex (ISO, 2002)

The topological structure of the site phasing may meet the need pointed out by Green (2011, p. 38) to multiple temporalities and non-linear time representation. This need results from the sceptical points of view on phasing and chronology as reflected by Lucas (2005, pp. 9-10). The multiplicities at the TM_Edge associations Termination and Initiation (Figure 3) allow to have non-linear topology (ISO, 2002, p. 15). This means that different edges could share a node. The ISO 19108 standard (2002) notes that this can occur in two situations: (i) temporal characterisitics of different objects are represented or (ii) different temporal characteristics of the same object are represented (p. 15). This allows, for example, that there are two initial phases (e.g. two cultural groups), but only one continues in the future, while the other tends to extinguish. Furthermore, it is worth mentioning that each site phase may have a 3D spatial extent. This extent could be conceived of as a bounding box of all the excavation objects having a particular value for the site phase time.

The fourth temporal category, the stratigraphic time, is related to the deposition layer in which the object was found. This temporal characteristic bears resemblance to the previous category, the site phase. The same decisions could be made, thus resulting in a TM_Edge representation. The three relationships that can occur in a Harris matrix (section 2.2) are still possible in this topological representation. First, the unlinked relationship is realized by an edge, which didn't share a node with another edge. Second, the later and earlier than relationships are possible by the edge connections. Third, an equivalence should result in two edges with the same begin and end nodes. Moreover, one could argue why not to implement the stratigraphy as a temporal ordinal reference system. This is not a decent option, since the stratigraphy in archaeological context is site-specific and not a general succession or reference frame like the geological time scale. Likewise for the previous category, the stratigraphic time may have a 3D spatial extent as well.

The fifth temporal characteristic that can be assigned to an archaeological object is the archaeological time. This temporal characteristic is described by Katsianis *et al*. (2008) as 'cultural temporal categorization'. This means that you could refer to a certain period of an archaeological time scale. Based on this description, the decision for a geometric representation can be made, because information about the position in time is known. The assessment between 0D and 1D is connected to which this characteristic refers. When it refers to a usage period, the choice for 1D seems obvious. However, the reference is made to an archaeological period, which could be of long duration or even longer duration than the period of usage. In the latter case, you should then refer to the same period for both begin and end node. Therefore, there is opted for a 0D representation. The reference system to which the temporal position is defined is a temporal ordinal reference system. Such a temporal ordinal reference system could be specified in general and then reused in other projects, by other teams, etc. For the application of the ISO 19108 structure of this reference system to the archaeological time scale used in Western Europe reference is made to the section 5.2.

Finally, the sixth category is the absolute time. Absolute dates are mostly the result of scientific analysis, such as radio carbon dating. Although these dates are absolute, they comprise uncertainty, often expressed as probability. The choice for a geometric 0D representation is evident. The temporal reference system to identify the position can be the Gregorian calendar, since absolute dates are usually specified at year level. However, no structure to express the uncertainty or probability of these kinds of dates is available in the ISO 19108 standard. The only possibility is the use of the enumerated data type TM_IndeterminateValue (Figure 5). This data type can be used in combination with a temporal position which uses another temporal reference system than the Gregorian calendar or the UTC. Therefore, a better option could be to create a minimal begin and maximal end value for this temporal category or use a date range. Based on these elements, different probability calculations can be performed analogous to Green (2011).

5.2 Temporal ordinal reference system

For the archaeological time the temporal position is specified relative to a temporal ordinal reference system, namely the archaeological time scale. To clarify the differences between the ISO 19108 structure and structures adapted for the geological time scale (Cox and Richard, 2005; Michalak, 2005), only a part of the archaeological time scale is used (Table 4). The begin and end dates used in table 4 are not fixed, but are rough estimations described by the Flemish Heritage Agency (https://inventaris.onroerenderfgoed.be, 16/05/13).

Period	Subperiod	Date
Roman time	Early	57 BC
	Mid	69
	Late	284
Middle Ages	…	476
	…	
New time	…	1500

Table 4 Part of the archaeological periodization (based on https://inventaris.onroerenderfgoed.be, 16/05/13) used in the temporal ordinal reference system assessment

The structure of a temporal ordinal reference system described in the ISO 19108 standard (2002) is shown in figure 4. The class TM_OrdinalReferenceSystem is a subclass of TM_ReferenceSystem which holds two attributes: 'name' and 'domainOfValidity'. The latter attribute allows defining a time span in which the reference system is valid, or a spatial extent for which the reference system can be used, or a combination of both (ISO, 2002, p. 17).

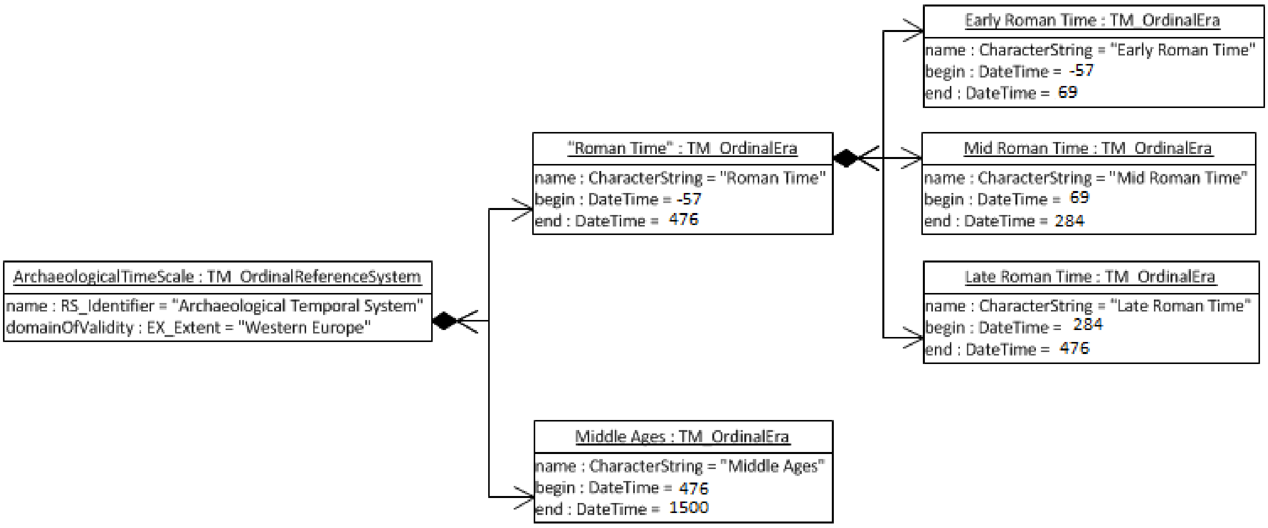

Figure 7 Part of the archaeological time scale as temporal ordinal reference system according to ISO 19108 (2002)

Figure 7 presents the part of the archaeological time scale given in Table 4 in conformity with the ISO 19108 standard. It can immediately be noticed that the same dates are reoccurring. For instance the end time of the Roman time period, 476 AD, appears at three different places in the model (Figure 7). This implies redundancy, which has to be avoided in data modelling to minimise the chance of inconsistency. The model also indicates clearly the begin and end dates of each of the (sub)periods. Although these dates are roughly known, they do not represent precise boundaries of the periods. This remark is also made by Cox and Richard (2005, p. 122): "[…] the limits of TM_OrdinalEra are defined precisely by attributes of type DateTime. However, in historic, archaeological contexts, and certainly in the geological time scale, while the order of eras within a TORS [Temporal Ordinal Reference System] is known, the positions of the boundaries are often not precisely known and can only be estimated". Michalak (2005) passed the same comment and called the choice for the DateTime data type unfortunate (p. 868). Consequently, both researches adapted the ISO model to be tailored to the geologic time scale. However, they both opted for a different variant. Michalak (2005) presents a topological approach, while Cox and Richard (2005) suggest a geometric version. In the remainder of this section, we outline the adaptations made by these two researches and apply the schemes to the archaeological time scale.

Cox and Richard (2005) introduce a variant on the model described in ISO 19108 in which the boundary between two temporal ordinal (geologic) eras is present. This boundary is represented by the class TimeOrdinalEraBoundary which is associated with TM_Instant (Figure 8). A TimeOrdinalEraBoundary can exist either with or without a geometric representation. Although the possibility to have TemporalOrdinalEraBoundaries without known position exists, this model leans on closely to a geometric variant of the ISO model. Cox and Richard (2005) refute the opportunity to express the geological time scale as a topological complex (Figure 3). They indicate two concerns for this. First, multiple inheritance would be required in that case, which causes practical problems. Second, some constraints should be enforced: (i) boundaries and eras should be connected and (ii) an era can only be divided once (Cox and Richard, 2005, p. 136).

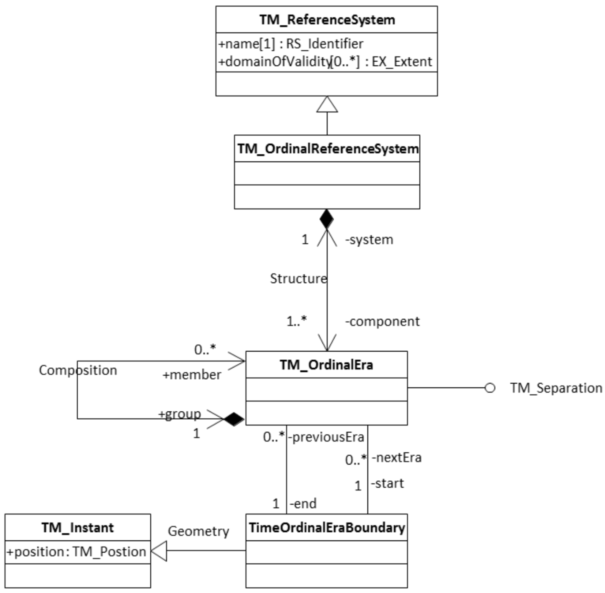

Figure 8 Model for temporal reference systems adapted from ISO 19108 by Cox and Richard (2005)

In figure 9, the model presented by Cox and Richard (2005) is applied to part of the archaeological time scale. Five instances of the class TM_OrdinalEra are given with their start and end relationships to five TimeOrdinalEraBoundaries (Figure 9). For each of these TimeOrdinalEraBoundaries the geometric realization is performed by defining a value for the temporal position. In this case, there is simply opted to use the Date data type and specify this until the year level. Other possible data types for specifying the position of a TimeOrdinalEraBoundary are Time, DateTime, TM_Coordinate, TM_CalDate, TM_ClockTime or TM_OrdinalPosition. The first five possibilities are strongly related to the Date data type, since they all consider the temporal position as fixed. The use of TM_OrdinalPosition to specify the boundary of a temporal era in a temporal ordinal reference system could lead to confusion.

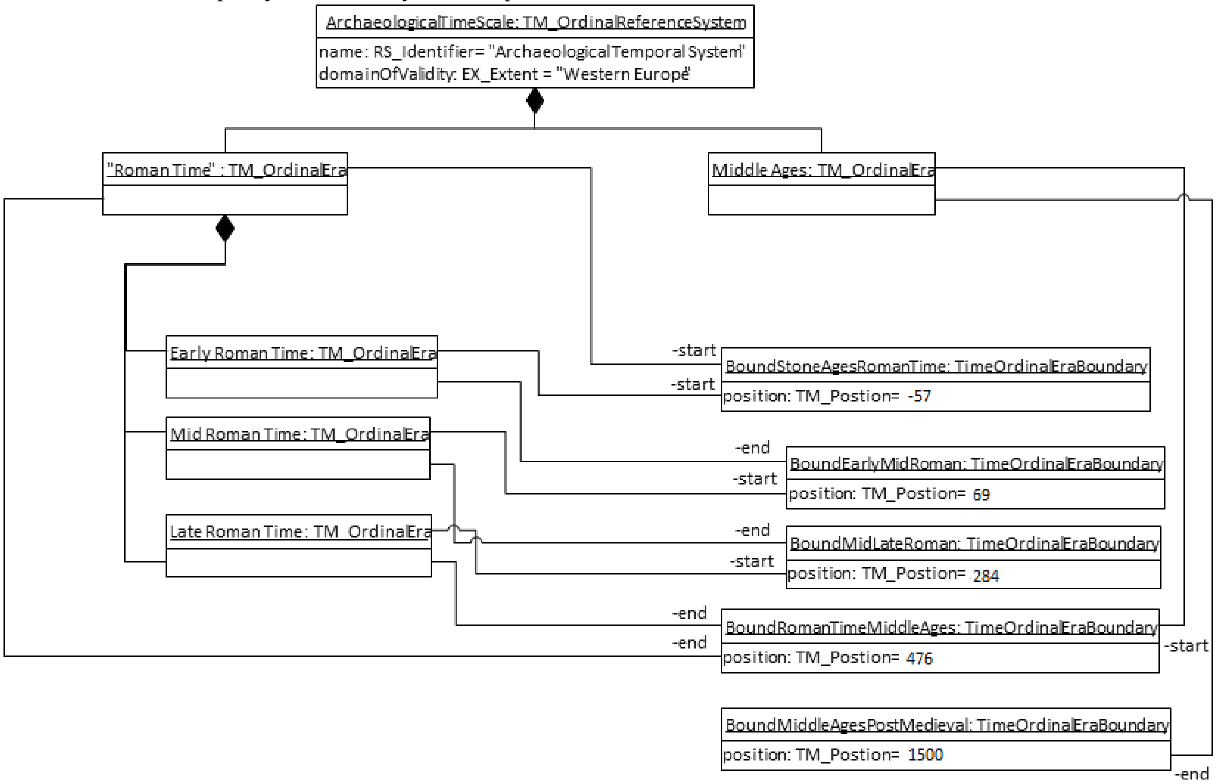

Figure 9 Archaeological time scale as temporal ordinal reference system according to the model of Cox and Richard (2005)

Michalak (2005) introduced around the same time another variant of the ISO 19108 temporal ordinal reference system, shown in figure 10. Before presenting his adapted version of the model, Michalak (2005) first outlined the shortcomings of the model presented in the ISO standard (Figure 4). In the standard, no indication is made about the inheritance of the class TM_OrdinalEra (Michalak, 2005, p. 868). However, Michalak (2005, p. 868) found some arguments demonstrating that TM_OrdinalEra implicitly inherits from TM_GeometricPrimitve:

- The relationship with TM_Separation. This interface has operations for the calculation of distance and length and can, therefore, only handle geometric temporal objects.
- The begin and end attributes belong to the geometric domain, since they represent temporal positions.

Another issue is reported by Michalak (2005). The multiplicity '0..1' for the attributes 'begin' and 'end' can cause problems for the performance of the TM_Separation interface. It is impossible to use the operations length() or duration() when no values are given for the attributes.

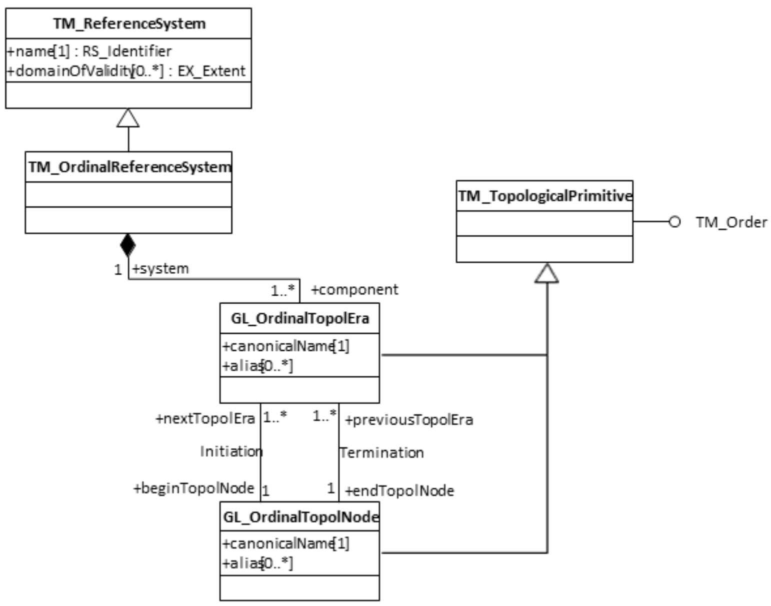

Figure 10 Conceptual model of topological ordinal reference system for geological application based on elements defined in conformity with ISO 19108 standard by Michalak (2005)

For geologic applications the assumption of TM_OrdinalEras being GeometricPrimitives "is not the best solution" (Michalak, 2005, p. 867). Geologists mainly want to explain topological relations between findings or layers and thus, do not desire to calculate lengths or distances (Michalak, 2005). Rather they want to indicate temporal relative positions by Allen relations (1983). Therefore, Michalak (2005) argued that topological elements should be used for the temporal ordinal reference system for geology. Using the topological model of time described by the ISO 19108 standard (2002), a link can be made from topological temporal objects to geometric objects via a realization association (Michalak, 2005). The model proposed by Michalak (2005) is shown in figure 10. The boundaries of an ordinal era are in this variant as well explicitly realized by adding the class GL_OrdinalTopolNode (Figure 10). Both GL_OrdinalTopolEra and GL_OrdinalTopolNode are subclasses of TM_TopologicalPrimitive and inherit from this class the interface TM_Order, which allows returning relative temporal positions. The optional attribute 'alias' enables the use of different names for the same era or boundary, comparable to linking to a thesaurus.

The application of Michalak's (2005) model on the archaeological time scale is depicted in figure 11 and 12. According to an example given by Michalak for the geologic time scale, part of the archaeological time scale is first schematically drawn in figure 11, which shows the temporal edges and (shared) nodes. This figure graphically depicts the structure of the model described in figure 12. In figure 12, five temporal ordinal eras and their initiation and termination associations to five ordinal topological nodes are given. Geometric realizations are not included in this example. This model allows defining a temporal ordinal reference system when the positions of the temporal boundaries are not known (exactly). At the other hand, specifying the temporal position of (one of the) boundaries remains possible by the geometric realization association from the topological to the geometric primitives.

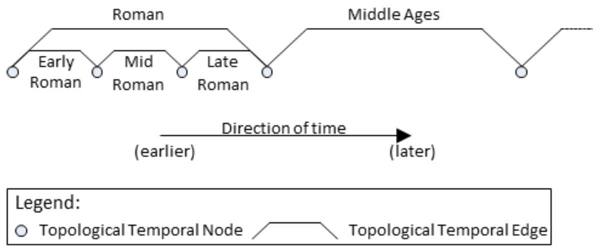

Figure 11 Topological structure of archaeological time scale after Michalak (2005)

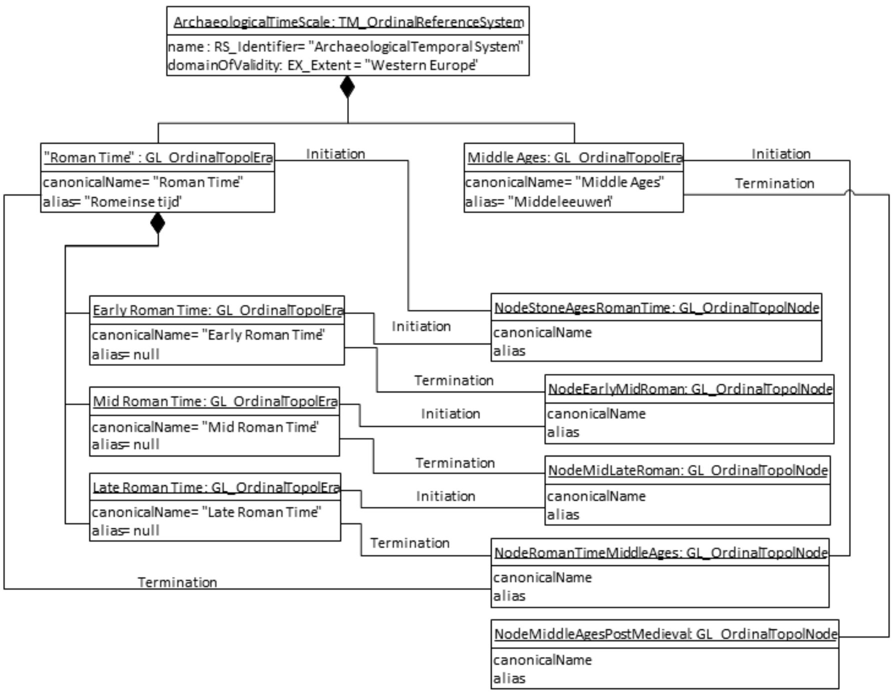

Figure 12 Archaeological time scale as temporal ordinal reference system according to the model of Michalak (2005)

The three applied temporal ordinal schema variants all have pros and cons, which are summarized in Table 5. The first part of this table shows the complexity of each of the models quantitatively. The number of classes indicates clearly that the model proposed by Michalak which includes both topology and geometry, is more complicated (5 vs. 3/2). However, this disadvantage is counterbalanced by the advantages. The latter model enables the use of both, eras with and without precisely known boundaries. The model proposed by Cox and Richard (2005) can be placed in between the ISO (2002) version and the variant of Michalak (2005). This model allows distinguishing boundaries from their eras, but at the other hand, the temporal position of these boundaries still requires a precisely known date. This induces that the ISO model for the temporal ordinal reference system is not complete enough to be suitable for the definition of the archaeological time scale. The variant of Cox and Richard (2005) is more extensive, but does still need precisely known dates. The variant of Michalak (2005) is basically topological, and thus, focusses on ordering rather than on the exact dates. However, the model permits the geometric positioning of the temporal era boundaries. These advantages lead to the conclusion that Michalak's model (2005) which combines topology and geometry is the most sufficient one for use in archaeology.

	ISO (2002)	**Cox & Richard (2005)**	**Michalak (2005)**	
Adaptation		Geometric	Topological	Topol + geom
# classes	2	3	3	5
# compositions	2	2	1	1
# associations		2	2	4
# inheritance		1	2	4
# interfaces	1	1	1	2
+	+Simple	+Division between era and boundary +Order explicitly defined by associations	+Completely topological +Division between era and boundary +Order explicitly defined by associations +No explicit temporal position required	+Extendable by geometry
-	-DateTime requires precisely known date	-More complex -Use of 'Position', implicitly only fixed dates possible	-No geometric information -More complex	-Multiple inheritance -Multiple associations

Table 5 Pros and cons for the application of the ISO 19108 model for temporal ordinal reference systems, the variants of Cox and Richard (2005) and Michalak (2005) to the archaeological time scale

6. CONCLUSIONS

The suitability of the ISO 19108 (2002) standard on temporal information for archaeological data is assessed in this paper. The first part of the applicability analysis focussed on six temporal categories, which are frequently assigned to archaeological objects. As discussed above, most of these categories can be given a formal description conform to the standard. Excavation and database times can be specified as TM_Instant with the temporal position given as Date or DateTime. Both, the site phase time and stratigraphic time, can be described as TM_Edge and grouped into a TM_TopologicalComplex. The structuring of stratigraphic times into topological complexes allows identifying the (spatio-temporal) relationships used in the Harris matrix, which is a main and one of the first temporal analysis tools. Both the site phase and stratigraphic time can have 3D spatial extents which bound the objects with different values. The archaeological time can be specified as a TM_Instant which temporal position is referenced to a temporal ordinal reference system. For the sixth category, the absolute time, the description as a TM_Instant with data type Date is chosen, but a small remark has to be made. Absolute dates are not that fixed as the name leads one to suspect. Absolute dates coming from scientific methods like C14-dating are mostly characterized as a date range or by probabilities. Therefore, the suggestion is made to split the category into a minimal begin and a maximal end date. These two elements allow the calculation of probabilities, for instance according to methods described by Green (2011). The second analysis part examined three variants of the temporal ordinal reference system structure. The ISO 19108 (2002) version and the variant of Cox and Richard (2005) are not sufficient to be applied to the archaeological time scale. Both models require precisely known dates for the beginning and end of a certain period. Michalak (2005) overcame this problem by centring the model topologically. However, the geometric representation remains possible. Therefore, the suggestion is made to use the last variant to describe an archaeological time scale as a temporal ordinal reference system.

In conclusion, we can conceive the ISO 19108 standard as applicable for archaeological purposes. However, some adaptations should be made, e.g. to the temporal ordinal reference system and to the way of incorporating probabilities. Furthermore, it must be kept in mind that this conclusion is only based on the assessment of this standard. Therefore, analyses of other temporal standards or data models could shed another light on the analysis results presented here. Other temporal standards may exist which are more suitable to archaeological data. Consequently, future research is needed to review and analyse currently available (spatio-)temporal data models from an archaeological data perspective. In the broader context of this project, similar analyses are required concerning other key aspects of archaeological data in the process of developing a 4D conceptual archaeological data model.

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ACKNOWLEDGEMENTS

Financial support from the Special Research Fund (BOF) from Ghent University is gratefully acknowledged