Each Graffito Deserves Its Polygon—It Is About Time

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Abstract
Time has remained one of the hardest-to-grasp properties of nature despite humans talking about time… all the time. However, even academic fields that are indifferent to the exact physical or philosophical characteristics of time must find ways to engage with the temporal dimension of their data. This applies to all of the Digital Humanities and maybe most to archaeology, a discipline focused on examining space- and time-bound anthropogenic activities. Like archaeological sites and landscapes, graffiti-scapes are spatially and temporally stratified. That is why the academic graffiti project INDIGO uses an archaeological lens to document, disseminate and investigate an urban graffiti-scape in space and time. However, since archaeologists still lack effective practical approaches to manage and visualise the temporal data dimension (besides a handful of data modelling standards and tools, both mainly created by geographers), INDIGO is currently developing graffiti-specific approaches to manage, visualise and analyse the uncertain spatio-temporal boundaries characterising these contemporary artefacts. After a general introduction to time and its relevance for archaeology and the study of graffiti, this paper explains why and how INDIGO uses polygons as digital representations for each real-world graffito. These polygons, stored in a human- and machine-readable file format and annotated with detailed temporal data, aim to provide a nuanced documentation of a graffiti-scape's spatio-temporal dimensions.

Keywords
GeoJSON; Graffito; Graffiti-scape; Polygon; Spatio-Temporal; Time

1. Introduction

1.1. Space, Time, Dimensions, and Spacetime

According to the classical Newtonian view of physics, one needs exactly three mutually perpendicular directions to define any possible position in physical space. The resulting geometrical space is called the three-dimensional (3D) Euclidian space. The adjective "Euclidean" distinguishes this 3D space from other spaces studied in physics and mathematics since the 19th century. However, these non-Euclidian spaces are irrelevant when describing spatial phenomena in the macro world around us; they only become important in certain parts of relativistic physics (Wheeler, 1990). In other words, the universe has three spatial degrees of freedom (Rucker, 2014). That is why an ambient space of three spatial dimensions (like *X*, *Y*, *Z* or latitude, longitude and altitude) will always be considered to define objects or events spatially.

Besides this generally accepted view on the spatial dimensions of the universe, it is possible to impose another mathematical dimension on the three spatial ones: time. Time gives static, rigid bodies a dynamical property. Since time is one-dimensional, the mathematical combination of these elements thus creates, in a technical sense, a geometry of four dimensions: a four-dimensional (4D) 'time plus space' or 'space plus time' reference frame. Therefore, any 'event' in the universe can be uniquely defined by its locational information (*x*, *y*, *z*) and a time of occurrence (*t*). These four numbers make an event a 4D entity (Muller, 2016).

This 4D space + time (or spatio-temporal) system with three dimensions of space and one of time is the accepted norm in almost all mathematical and physical theories. Other space + time systems would be unstable, inconsistent with predictability or too constraining. For instance, if there were a time dimension for every space dimension (i.e., a 3+3 dimensional space + time), it would be unpredictable as no cause-and-effect would exist. This led Tegmark to conclude that a 3+1 dimensional space + time is the only one with decent causal behaviour (Tegmark, 1997).

The well-accepted 4D space + time framework of our universe has led to the general assumption that wherever the abbreviation 3D is used, it invariably and implicitly relates to the three observable spatial/geometrical dimensions instead of, for instance, two spatial dimensions and a temporal dimension. Analogous to 3D, abbreviations such as 4D have come to denote systems or data that feature a temporal dimension in addition to three spatial dimensions. However, this does not mean a fixed numbering system for dimensions exists. Although we live in a universe of one time and three observable space dimensions, there is no inherent order in the space + time dimensional system. Many projected coordinate reference systems have Northing as their first axis, but Easting is also often used (Iliffe & Lott, 2008). Similarly, time can be considered the first or third dimension, like in Hägerstrand's space-time model (Hägerstrand, 1970). Thus, a statement such as 'time is the fourth dimension' is nonsensical "for the sufficient reason that 'the fourth dimension' is a collection of three words without meaning" (Bell, 1937, p. 95). Considering time as the fourth dimension is simply because of convenience, not because there is an inherent and fundamental dimensional order.

In addition, many other dimensions exist. The more general notion of dimension in both physical-mathematical and non-mathematical sense refers to any thinkable property, any measurable variable (Stewart, 1995). Following this logic, good examples of other dimensions are mass, electric potential, saltiness, temperature, humidity, colour or surface roughness.

Before tackling the relationship between archaeology and time, we must mention again that the above space + time interpretation is only correct for Newtonian physics. Until the 20th century, all significant scientists considered space and time separate and absolute dimensions without any intimate connection. However, Albert Einstein's 1905 special relativity paper (Einstein, 1905) made the world look differently at the concept of time, breaking the notion of an absolute universal time or time as a constant entity. Einstein's former Zürich professor Hermann Minkowski built upon his pupil's special theory of relativity to combine the space and time dimensions in one formulation (Minkowski, 1909), for which he coined the term spacetime or *Raum-Zeit* in German (Minkowski, 1908). In this 4D relativistic spacetime model of Minkowski (also known as Minkowski spacetime), time and space are no longer considered distinct aspects of nature; they are part of a single interwoven continuum and form a 4D union. When formulating his general theory of relativity (Einstein, 1916), this spacetime concept became indispensable to Einstein.

Although relativistic physics packs space and time into the unity of spacetime to deal with length contraction and time dilation, the remainder of this paper relies on the non-relativistic, classical approach to the universe with a 3D Euclidian space and a separate, constantly and universally forward-moving time dimension. This spatio-temporal approach of distinct dimensions is perfectly fine when studying objects that are not moving at speeds close to the vacuum speed of light relative to the observer.

1.2. Archaeology and Time

Archaeology is about space- and time-bound anthropogenic activities. However, whereas spatial dimensions are bidirectional, the temporal dimension is unidirectional. In other words, one can move back and forth along any spatial axis but only forward in time. In addition, an object can be stationary in the three spatial dimensions but never in time coordinates. Even though time always flows (Muller, 2016), archaeology has traditionally dealt with time via discrete temporal blocks. Monolithic temporal units like periods and phases, one followed by the next, thereby ontologising (pre) history "as a series of *replacements*" (Olsen et al., 2012, p. 42) in which time and archaeological materiality unambiguously pass from earlier phases to succeeding ones. However, an increasing number of archaeologists are challenging this oversimplified image of linear, unidirectional successions. In the past decades, the discipline has gradually realised that the temporality of objects can be messy, chaotic and complex. Medieval bridges are still in use, Roman graffiti get photographed two millennia after their production, and highways often deviate from their initial course if they risk crossing an important Celtic burial place. Many things of the past endure; they extend into the present, sometimes even totally forgotten somewhere along the way.

It is thus safe to state that barely anything around us shares the same temporality. Objects and phenomena all have different starting points, unique temporal lifespans, and they transform at different rates (Lucas, 2005). This observation lies at the core of Geoff Bailey's concept of time perspectivism. Formulated in the early 1980s (Bailey, 1981) and more recently summarised (Bailey, 2007, 2008), time perspectivism pivots on two ideas: different processes operate at various time scales, and the archaeological record's temporal resolution is variable but typically coarse. These ideas highlight that different explanatory variables and concepts are needed to understand different aspects of the archaeological record, and how they affect what we can or cannot know about the past.

Bailey attributes much of these issues to the palimpsest nature of the archaeological record (Bailey, 2007). Although there are many different conceptual 'archaeological records' (see Verhoeven (2017) for an overview) and palimpsests are, *stricto sensu*, manuscripts in which the earlier writing is scraped or washed off to make way for new text (Mollett, 1883), the expression 'palimpsest nature of the archaeological record' is often tossed colloquially (e.g., (Lucas, 2008)) when referring to the fact that humans have always reused, adapted and repurposed stuff. That is why archaeological landscapes and sites are such complex, cluttered, diffuse and messy entities (Mlekuž, 2012) in which the meaning and function of their constituents are often hard to separate (Gramsch, 2013). In that vast sense, one can indeed consider any archaeological record a cumulative palimpsest of different intermingling and intersecting temporalities (Mlekuž, 2013).

1.3. Graffiti-scapes and Time

The same temporal messiness holds for a graffiti-scape. They, too, form an archaeological record that is often created via palimpsesting (Myllylä, 2018) (but note again that 'palimpsest' must be understood in its more poetic sense, as the production of a graffito seldom starts with the entire physical or chemical removal of existing graffiti). A graffiti-scape is not just a mere historical layering. Graffitists often patch something new from the old; they modify existing graffiti through overspraying and erasing or even incorporate and reference elements of older works in the new creation. Producing new graffiti is an active, present- and future-orientated engagement with the existing graffiti-scape. And each graffito has its temporality. Some graffiti get covered or destroyed quickly and abruptly; other can live on for centuries. These complex temporalities can apply to the entire graffito or parts of it, thereby adding to the spatial and temporal messiness of graffiti-scapes. Many graffiti pro- and opponents contribute to the formation of graffiti-scapes, each creating and erasing in different rhythms at different locations with various speeds. And those speeds, locations and rhythms interact and combine in countless ways.

Similar to how landscapes are arrays of related features, so are graffiti-scapes. They are socially constructed spaces of human activity; like landscapes, they only possess spatial and temporal boundaries when imposed by analytical procedures and intellectual traditions. Graffiti-scapes are also more than a material backdrop to social life. They are a temporal phenomenon intertwined with the occupation of its (non-)human inhabitants. In that sense, a graffiti-scape is a 'taskscape': "an array of related activities" (Ingold, 1993, p. 158). Social anthropologist Tim Ingold coined this term to express that landscapes develop through processes of temporality, and their study needs to go beyond purely symbolic or contemplative approaches.

Documenting and analysing such a diffuse and complex environment in a simple way typically only adds to the mess because plain and uncomplicated approaches break down if what they describe is messy. So, the only helpful way out of this seems to be the creation of descriptions that mirror the nature of graffiti-scapes: not a series of spatially discrete features in clear and distinct chronological succession, but a spatial continuum of multi-layered traces characterised by a mess of temporalities.

For this reason, one of project INDIGO's primary goals was to develop (meta)data structures and tools to capture and analyse a graffiti-scape's spatio-temporality. This paper presents the authors' initial thought exercises, considerations, challenges and implementations towards these goals.

2. Moments of Creation

Before tackling the development of concepts and tools to document, analyse and understand the spatio-temporal complexity of an individual graffito, it is helpful to consider the temporal meaning of a graffito's primary documentation step: capturing a digital photograph.

Consider Figure 1. Imagine a scholar of the Ancient Graffiti Project (http://ancientgraffiti.org/Graffiti) photographing a Roman wall painting with inscribed text in Pompeii, Italy (Figure 1, left). At the same time, someone from project INDIGO photographs a contemporary bird graffito in Vienna, Austria (see Figure 1, right). Both digital photographs feature the same creation date: 16th of June 2023, 10:25 Central European Time (CET). Whereas scholars of Roman graffiti would never consider this date and time a close proxy for the graffito's production, this would be standard practice in most contemporary graffiti research (with only a few scholars, like Levin (2019, p. 93), explicitly noting their potential separation). In both cases, the date and time mark a creation event: not of the graffito, but of the digital photograph. The following paragraphs will delve deeper into the consequences of this time lag between an artefact's production and its documentation.

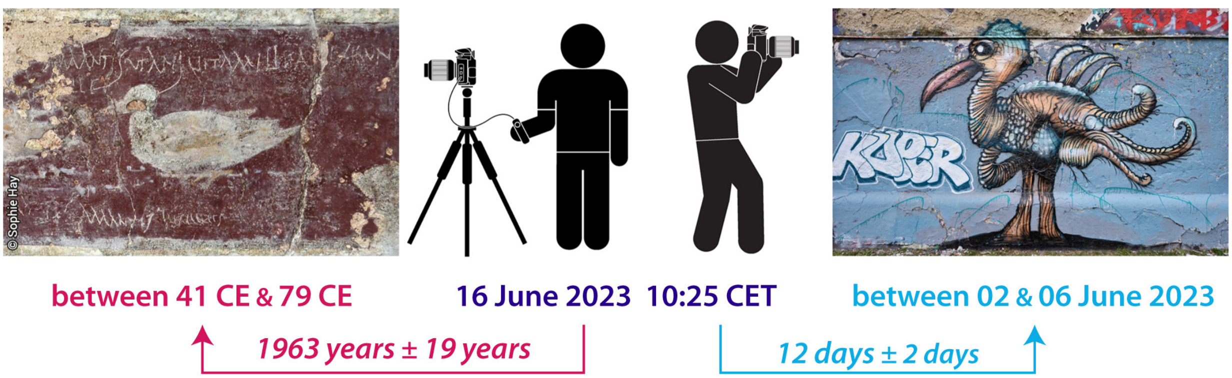

Figure 1. Simultaneously photographing a Roman graffito (left) and a contemporary graffito (right) leads to different temporal distances and uncertainties between the photo and graffito productions. The Roman graffito photograph is by Dr. Sophie Hay.

Imagine that KUPER posted a video of his/her bird graffito on Instagram on the 6th of June 2023. The date of this Instagram post provides a *terminus ante quem* (Eng., a limit before which) for creating that graffito. In other words: KUPER must have created this graffito before the Instagram post. If somebody from project INDIGO was scouting new graffiti on the 2nd of June 2023 and KUPER's graffito was not visible on that wall at that time, the 2nd of June 2023 would be a *terminus post quem* (Eng., a limit after which) for the creation of KUPER's bird graffito. Ignoring hours and just focusing on the day, the production of the graffito must thus have happened 12 days ± 2 days before the digital photo.

The same reasoning can be applied to the left side of Figure 1. Pompeii, a thriving city south of ancient Rome, was covered by volcanic ash and pyroclastic surge deposits when Mount Vesuvius erupted in 79 Common Era (CE). This eruption provides a *terminus ante quem* for all Pompeian artefacts recovered by archaeological excavations. Imagine archaeologists could determine that the style of the Roman wall painting with the sitting bird only started to appear in 41 CE; this would date the wall painting between 41 CE and 79 CE. 41 CE would also be a *terminus post quem* for the inscription on the wall painting, as this scratching could only occur after the wall was painted. Between the wall painting's production and the digital photograph, 1963 years ± 19 years have passed. On a side note: most Roman archaeologists would only call the inscription a graffito, not the wall painting itself. However, what are the significant differences between the Roman wall painting and the contemporary KUPER graffito besides age and dominant colours? Similar and other considerations on using the term graffiti are covered by Schlegel et al. (2023).

Even though the date and time of the two photos—one depicting the Roman painting and the other the contemporary spraying of a bird—are identical, they are unrelated to the production of the graffito they represent, or the temporal fuzziness/uncertainty of dating that production event. Often, the older a recovered artefact is, the more extended the temporal uncertainty of its production. The same holds for the two graffiti illustrated in Figure 1. However, the production event is only one of many properties that can be temporally quantified. What about visibility?

Since its inception, the KUPER graffito had been entirely visible until at least the photo was acquired on the 16th of June 2023. In contrast, the Roman bird painting remained visible until volcanic ashes buried it in 79 CE, and a second visibility phase started when it was excavated. The temporal uncertainty characterising that second visibility phase is much narrower, as the exact excavation date is likely known. However, what about ancient graffiti inscribed on the walls of the Colosseum in Rome, Italy? Since its initial construction ended in 80 CE (Hopkins & Beard, 2011), this impressive amphitheatre has remained a visible, prominent symbol of the imperial Roman empire. Despite this extended visibility, the building has undergone many repurposing phases during its almost two millennia-long visibility. Can we treat its visibility and the visibility of graffiti on its walls as one long, extended phase with a relatively narrow temporal uncertainty? Or should we subdivide the entire Colosseum in chunks—some of which got destroyed when the amphitheatre functioned as a quarry, while others were covered with shops and houses—and track the visibility of the entire building and its graffiti in segments?

Examples like this illustrate three essential aspects concerning the temporality of archaeological objects and phenomena in general, and graffiti-scapes in particular:

1. <u>Temporal idiosyncrasy</u>: Temporality quickly becomes complex and messy. Different properties of the same object—like production and visibility—might come with unique temporalities, each of which can have a specific fuzziness (a topic Section 3 will tackle).
2. <u>Temporal specificity</u>: None of these properties and their temporality are related to a graffito's documentation via (digital) photography, even though the next section will explain how increasing the frequency of photo tours can reduce specific temporal uncertainties in a contemporary graffiti-scape. This temporal separation was already noticed in 1985 by Snodgrass and Ahn, when they distinguished between so-called "valid time" (when the event took place in the real world) and "transaction time" (when that event got stored in a database) (Snodgrass & Ahn, 1985). In other words, a physical graffito's metadata must always be clearly distinguished from the metadata of its analogue or digital approximations. Not only do a digital photo's temporal metadata differ from those of a real-world graffito, but standard metadata like copyright holder, creator, and location also differ for both resources. This divergence can vary enormously depending on the

graffito, even if the approximations are the same type, such as a digital photo. This dichotomy explains why project INDIGO developed metadata schemas for the real graffito on the one hand (i.e., a physical resource) and all its digital approximations on the other (i.e., digital resources), even though several well-known metadata schemas do not—or only partly—make this distinction explicit. However, having dissimilar metadata elements for physical and digital resources is essential to track their different aspects of temporality, amongst many other resource-specific metadata (see also the editorial introduction, Schlegel et al. or Trognitz et al. in this volume).

3. Temporal freeze: When looking at graffiti photos, it might be easy to forget that each photo compresses the entire history of that graffito up to the acquisition of that photo. While a digital photo always represents 'a moment' in the lifespan of the gafffito, that arbitrary moment becomes the graffito's 'definitive moment' as it will define all analytical and virtual viewing events. The former can be problematic as digital approximations decay differently than their physical counterparts (Burns, 2014). Physical resources like graffiti can suffer various slow or instant modifications: overpainting, paint flaking or the destruction of the carrier medium. The decay of digital approximations comes in accidental data overwriting, bit rot or technological obsolescence. Although a digital photo thus virtually arrests a graffito's colours (and maybe surface) in time, that photo stops serving as a surrogate for these real-world characteristics directly after its acquisition because of the different ways and rates of both deterioration processes. As soon as the photo camera's shutter button is pressed, the resulting digital approximation and physical graffito increasingly become more disparate. Project INDIGO tried to partly tackle this issue by tracking each graffito's various temporalities (like all its modification stages). Without these efforts, the graffito's unique lifetime is solidified in—and simplified to—one photograph; such an approach discards all unique chronological changes in a graffito's visibility and wear, thus making them meaningless.

3. Graffiti Observations

Several graffiti aficionados have been interested in the temporal aspects of graffiti and tried to document—either by inventorying existing photos or actively photographing—the dynamic, palimpsested nature of graffiti-scapes (Curtis & Rodenbeck, 2004; Hale, 2018; Hansen & Flynn, 2015; Levin, 2019). Project INDIGO monitored the graffiti-scape along the Viennese *Donaukanal* (Eng. Danube Canal) via follow-up photography tours. At least once per week, new graffiti that had appeared since the previous follow-up tour got photographed (see Verhoeven et al. (2023) for all details on this procedure). Figure 2 depicts how these observations allowed building a corpus of visibilityspans for each graffito.

Consider a scenario involving a graffito, denoted graffito 1. Upon being observed and photographed for the first time (Figure 2-A1), the visibility of graffito 1 stands at a 100 % certainty. That graffito is still there during the subsequent follow-up tour, so this second observation extends the temporal visibility of graffito 1 (Figure 2-A2). This pattern continues in two successive follow-up tours (Figure 2-A3), until there is a first observation of graffito 2 at the location where graffito 1 appeared before (Figure 2-B1). Although one cannot determine when graffito 2 was produced exactly, this first observation of graffito 2 implies that graffito 1 is now totally covered. In other words, graffito 1's invisibility is 100 % certain, indicated by the downward-sloping orange line reaching the "invisible" state at the moment of graffito 2's first observation (Figure 2-B2). Figure 2-C shows how the same reasoning can be applied to the start of graffito 2. Graffito 2 was invisible at the last observation of graffito 1. When the switch from visible to invisible happened for graffito 1 cannot be determined; the crossing orange and blue lines in Figure 2-C represent this uncertainty. Inset C also depicts a single observation for a third graffito. This observation also equals graffito 3's last observation, which could happen if the graffiti monitoring project stopped. Although the visibility start and end of, respectively, graffito 1 and graffito 3 are un-determinable, Figure 2-C represents them with a semi-transparent orange and pink line for completeness.

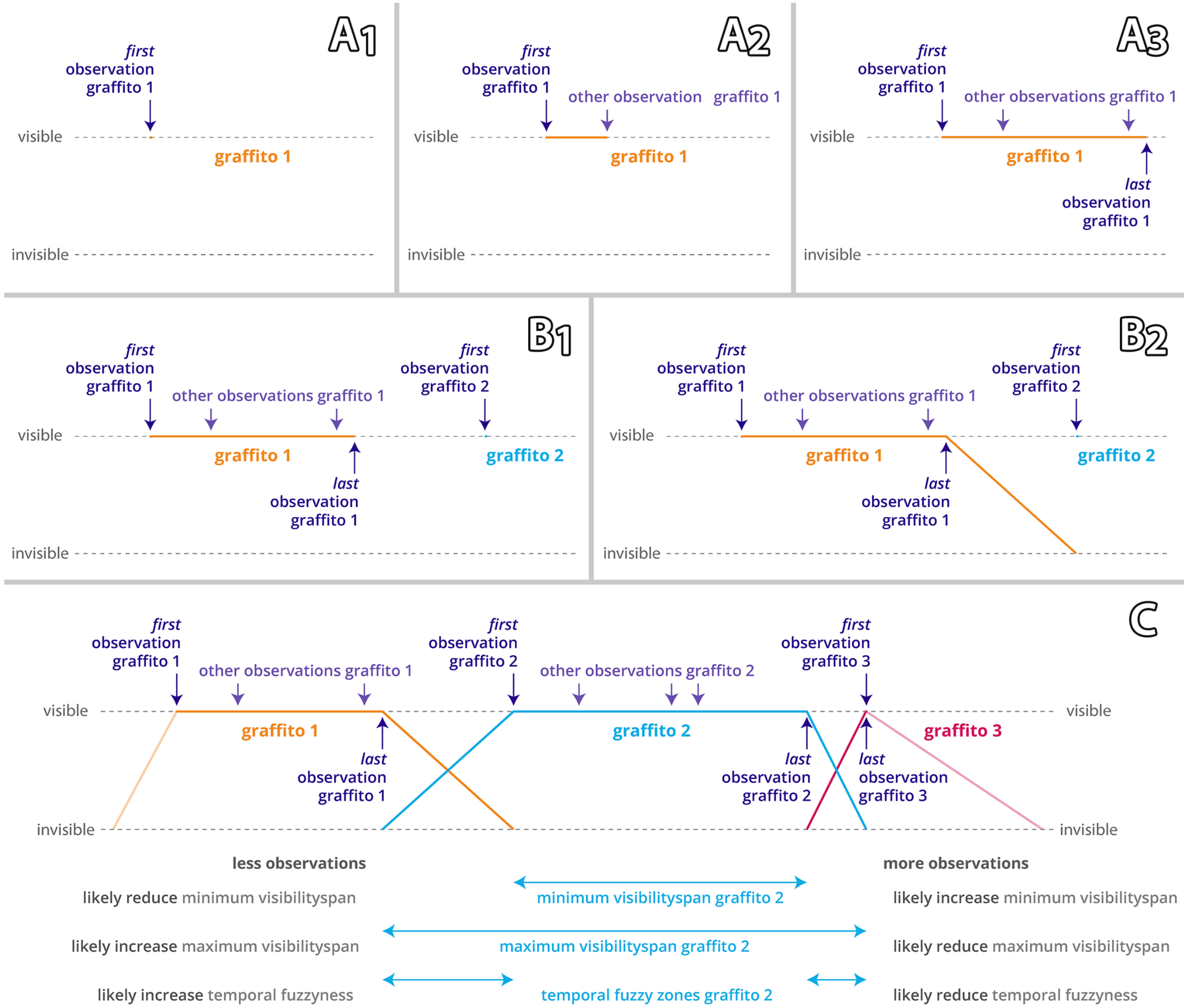

Figure 2. Extracting graffiti visibilityspans from observations.

The horizontal arrows at the bottom of Figure 2-C illustrate that the visibilityspan of each graffito has a minimum and a maximum. The difference between those two spans provides the temporal fuzzy zones, whereby fuzzy still relates to the visibility of that graffito. Reducing this temporal fuzziness can be achieved with more observations; a higher frequency of follow-up photo tours likely reduces the maximum visibilityspan and simultaneously increases the minimum visibilityspan. Even though increased observations do not guarantee the reduction of the temporal fuzzy zones—for example, when extra photo tours occur between the first and last observation of graffito 2—more observations will increase the likelihood of reducing them.

Simplifying and cleaning the graph in Figure 2C yields Figure 3. This multi-coloured line is a simple yet effective way to represent the visibility status of subsequent graffiti at a given location. Figure 3 shows that one can also infer a graffito's visibility status and corresponding certainty levels. For example, at time *t*, graffito 1 is visible with 100 % certainty, while the other two graffiti are invisible. Two days later (i.e., *t* + 2 days), graffito 3 is still invisible, but the exact visibility status of graffito 1 and 2 is unclear. However, given the observations, there is a 30 % chance for graffito 1 and a 70 % chance for graffito 2 to be visible. Another six days later (i.e., *t* + 8 days), graffito 1 is certainly invisible, while graffiti 2 and 3 are equally likely to be visible.

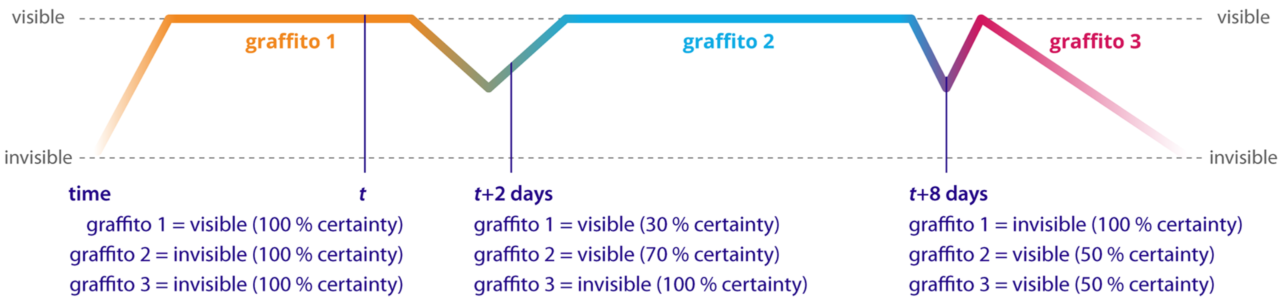

Figure 3. The visibility status of subsequent graffiti at one location, assuming that each new graffito entirely covers the previous one. The (in)visibility certainty of the three graffiti is derived at three moments.

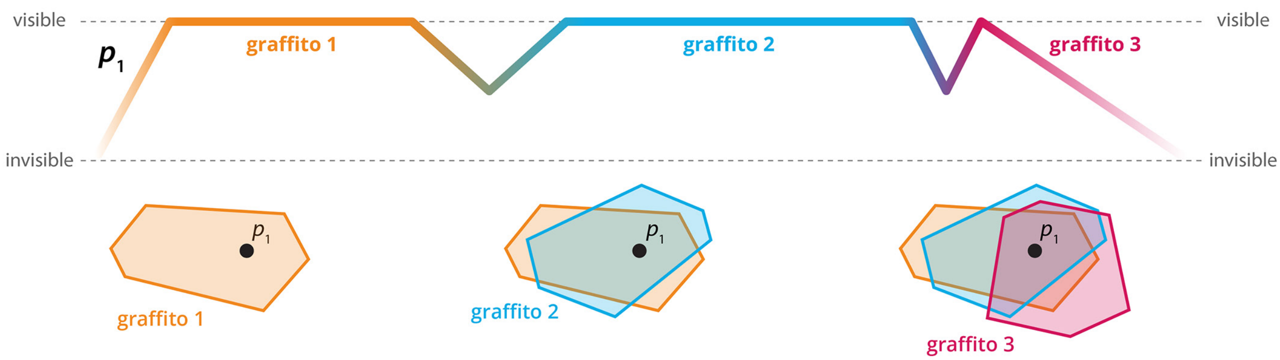

Figure 4. When polygons represent graffiti, it becomes clear that the time-dependent visibility line only applies to a few points of the initial graffito.

4. Towards Polygons

Figure 4 shows a critical limitation in the preceding analysis: the erroneous assumption that every new graffito entirely covers the previous one. Although that can be the case, it is not a given. Figure 4 represents the area covered by every graffito with a polygon. When all polygons are overlaid, it is clear that the multi-coloured and time-dependent line only represents the graffiti visibility at locations where all three polygons overlap, such as at position p_1. For most other points of graffito 1, 2 and 3, other temporally-dependent visibility lines must be constructed. For example, the upper left part of graffito 1 stays visible the entire time. Since it is impractical to divide a graffito into thousands or millions of points, each with its temporal history, we propose representing graffiti by polygons onto which temporal information gets attached as metadata.

Upon its first observation, an entire graffito is represented by a polygon (or a multi-polygon if the graffito consists of separate parts). If a second graffito partially covers the first one, the latter gets split into minimally two polygons, each with a different visibilityspan. Figure 5 clarifies this idea. On top, one finds the visibility lines presented before for location p_1. Every first and last observation of a graffito at p_1 is temporally stamped from t_1 to t_5.

In the grid that follows, there are three main sections. The first section contains one row with polygons, each representing the area covered by graffito 1, 2, and 3. The polygons also divide the table into columns. These resemble the three stages in the graffiti-scape, each corresponding to the observation of a newly produced graffito. The remaining

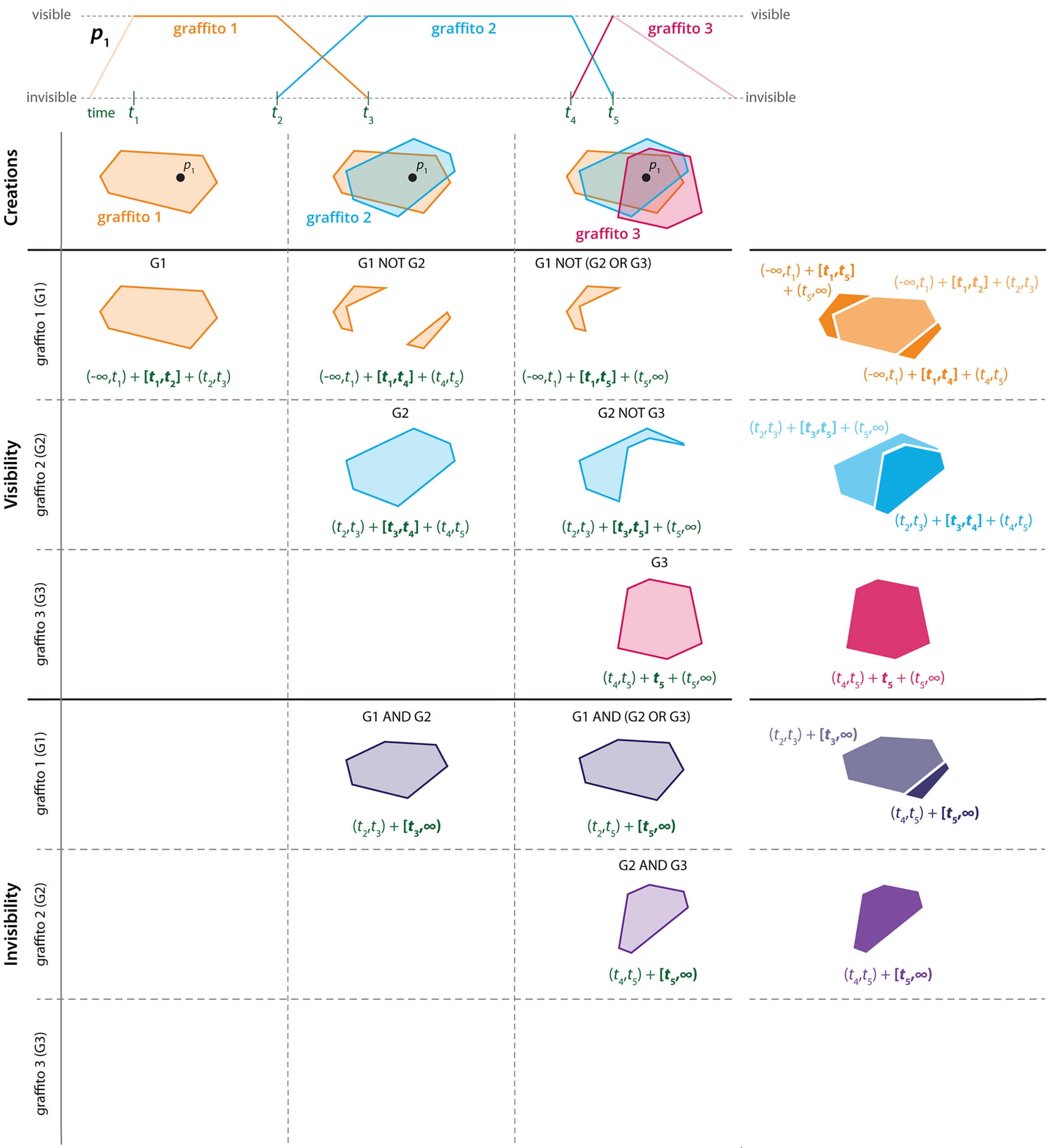

Figure 5. When polygons represent graffiti, tracking which part(s) of each graffito become(s) invisible over time becomes possible. Every derived polygon comes with two pieces of information. Above each polygon, one finds the boolean algebra used in its computation. The mathematical formulation below each polygon represents the certain and fuzzy portions of its visibilityspan.

second and third sections each consist of three rows. The second section indicates the initial polygons (or parts of them) that are visible at any of the three stages; the third and last section contains the (parts of the) initial polygons that are invisible at any of the three stages.

Let us focus on the row labelled "graffito 1 (G1)" of the table's Visibility section. When graffito 1 is observed for the first time, the entire polygon is undoubtedly visible from moment t_1 until, and including, moment t_2. Mathematically, this is written as $[t_1, t_2]$. Since there is no observation to infer the approximate production of this graffito, one can say that there is a fuzzy visibility zone ranging from minus infinity until, and excluding, t_1. Mathematically, this is written as $(-\infty, t_1)$. The uncertain visibilityspan ends with (but excludes) moment t_3, so the second fuzzy temporal zone equals (t_2, t_3). Upon combining these three pieces, the visibility of polygon G1 can be expressed mathematically as:

$$\text{G1} = (-\infty, t_1) + [t_1, t_2] + (t_2, t_3).$$

When graffito 2 (G2) gets observed, the central portion of polygon G1 is definitely invisible, leaving only its two outer portions visible. Column 2 depicts the two polygons that represent these visible parts. With boolean algebra, both polygons would result from an operation G1 NOT G2. Temporally, the visibility of both polygons builds upon the visibility of the entire G1 polygon. The certain or minimum visibilityspan extends from t_1 until, and including, t_4. Its leading temporal fuzzy zone remains identical, but the trailing temporal fuzzy zone changes to (t_4, t_5). After the production and observation of graffito 3, only one part of the initial G1 polygon remains. G1 NOT (G2 OR G3) is the Boolean operator formulation that yields this polygon. The entire maximum visibilityspan of this polygon can be written as:

$$\text{G1 NOT (G2 OR G3)} = (-\infty, t_1) + [t_1, t_5] + (t_5, \infty).$$

As long as no new graffito gets recorded at this spot, the paint does not entirely weather or the wall is not destroyed, this small portion of graffito 1 will remain visible. Until then, the entire temporality of graffito 1's visibility can be represented by three polygons with their specific temporal metadata. Figure 5 depicts this in the last column of the table.

The same reasoning applies to the visibility of graffito 2 and 3. Figure 5 also displays these results, along with the polygons and mathematical specifications of the graffiti's invisibility. Here, it is essential to note that an invisibilityspan can be interrupted. For instance, a sprayed tag covered by a sticker becomes invisible; however, removing the sticker restores that tag's visibility.

The proposal to use polygons for managing spatio-temporal data is not new, of course. Polygons are fundamental geographical primitives, so they have been used to represent spatial extents for as long as vector-based Geographic(al) Information Systems (GIS) have been around. However, this does not make polygons the default optimal solution for managing temporal data. Space-time data come in so many variants that the field of Geographic(al) Information Science (GIScience) has put much research into representing and questioning the variety of spatio-temporal dynamics in a space-time GIS (Peuquet, 2002). Among all these techniques, temporal sequences of polygons—each with time-specific attributes—are considered one of the seven primary ways to deal with spatio-temporality (Goodchild, 2013). However, this does not imply there is a fixed recipe for polygon creation and reasoning. That is why project INDIGO had to develop bespoke software and workflows, some of which the next section details.

5. Polygon Tools

Project INDIGO relied on different software tools to create and store a graffito's temporal and spatial data. Section 5.2 first describes how a graffito's two- and three-dimensional locational data were created via GRAPHIS and AUTOGRAF, two software packages programmed within INDIGO. Afterwards, Section 5.3 explains why and how GeoJSON became the format of choice to save all these spatial data, and why the same format also stores the temporal data (Section 5.4). Since the process to automatically infer temporal data was only prototyped (as of September 2023), this paper can only provide an example in which the temporal GeoJSON data are derived manually (Section 5.5). However, before delving into polygon creation, Section 5.1 introduces some necessary terminology.

5.1. Some Terminology

A polygon can represent any bordered planar surface. But what are polygons? Polygons are geometrical shapes bounded by a curve, but not just any curve. The curve must consist of connected line segments—called a polyline, polygonal chain, or polygonal curve—and be closed. Although these line segments or edges may intersect, the term 'polygon' often means 'simple polygon', simple being a qualifier denoting non-intersecting line segments (Preparata & Shamos, 1985; Schneider & Eberly, 2003). These line segments meet at corners or vertices (singular: vertex), whose spatial position is described by two coordinates: *x* and *y*. Polygons are thus always spatially two-dimensional or 2D (Berger, 2010). As a 2D object, 'polygon' refers to the polyline perimeter and the region it bounds (Gomes et al., 2012; Preparata & Shamos, 1985; Schneider & Eberly, 2003). Because all vertices of the polyline lie in a plane, a polygon's boundary is known as a plane curve. However, polygons are bounded by a particular kind of plane curve, as plane curves can also be open or feature curved and intersecting segments.

Some types of polygons are well known, like triangles (shapes formed by three line segments and three vertices) and rectangles, but polygons can have arbitrarily many edges *n*. These *n*-edged polygons are called *n*-gons (Preparata & Shamos, 1985). Since the number of edges and vertices are identical for polygons, the 13-gon polygon in Figure 6 features thirteen vertices and thirteen edges. Even though a disk is formed by a closed and non-intersecting plane curve (called the circle), this curve does not feature line segments, which disqualifies a disk from being a polygon.

5.2. Creating Location

5.2.1. In Two Spatial Dimensions: GRAPHIS

The spatial extent of each graffito is initially defined in GRAPHIS, an open-source and freely available Python-based software to create, annotate, visualise and store image regions. Users can load one or more photographs into GRAPHIS and draw disks or polygons—either a rectangle or any arbitrary *n*-gon—on them. Specific attribute data (like the creator of the region, the transcript of a text-based graffito or the unique identifier of that graffito) can be linked to each of such regions. Storage of the image region coordinates and related attribute data adheres to the Photo Metadata Standard (IPTC Photo Metadata Working Group, 2023) defined by the International Press Telecommunications Council (IPTC; https://iptc.org).

The backbones of GRAPHIS are two free and open-source software technologies: SQLite (https://sqlite.org/index.html) and ExifTool (https://exiftool.org). SQLite provides a self-contained, small and fast relational database engine. GRAPHIS' SQLite database stores links to the photos of interest and tracks every image region operation. This principle enables users to start/exit the software at will without the risk of losing work. It also enables collaboration on various photo collections, as each can have its own database. At any moment, the user can write the image regions back into the photo's metadata segment, an operation for which GRAPHIS utilises ExifTool, the Swiss army knife of file metadata manipulations. For more details on GRAPHIS, please consult the paper by Verhoeven, Wieser, & Carloni in this volume.

Delineating the entire region occupied by a graffito usually relies on arbitrary *n*-gons with more than four edges. The polygon's boundary (i.e., the closed polyline) equals the border of the graffito. The polygonal region (i.e., the area enclosed by the closed polyline) corresponds to all image pixels that digitally depict that graffito. If a graffito consists of multiple parts (such as separated letters in verbal graffiti), a grouping of polygons or a so-called multi-polygon is needed to indicate all image regions that graffito occupies.

Indicating the polygon(s) is based on the overview photos INDIGO acquired during its follow-up photo tours. As detailed in Verhoeven (2023), follow-up photo tours took place at least weekly to document new graffiti. Every graffito was documented via a collection of overlapping photographs, a photograph of a colour reference target (to achieve colour consistency) and an overview photo that captured the entire graffito. After finishing a follow-up photo tour and downloading the images, a MATLAB (https://nl.mathworks.com/products/matlab.html) script automatically finds all overview photos and copies them

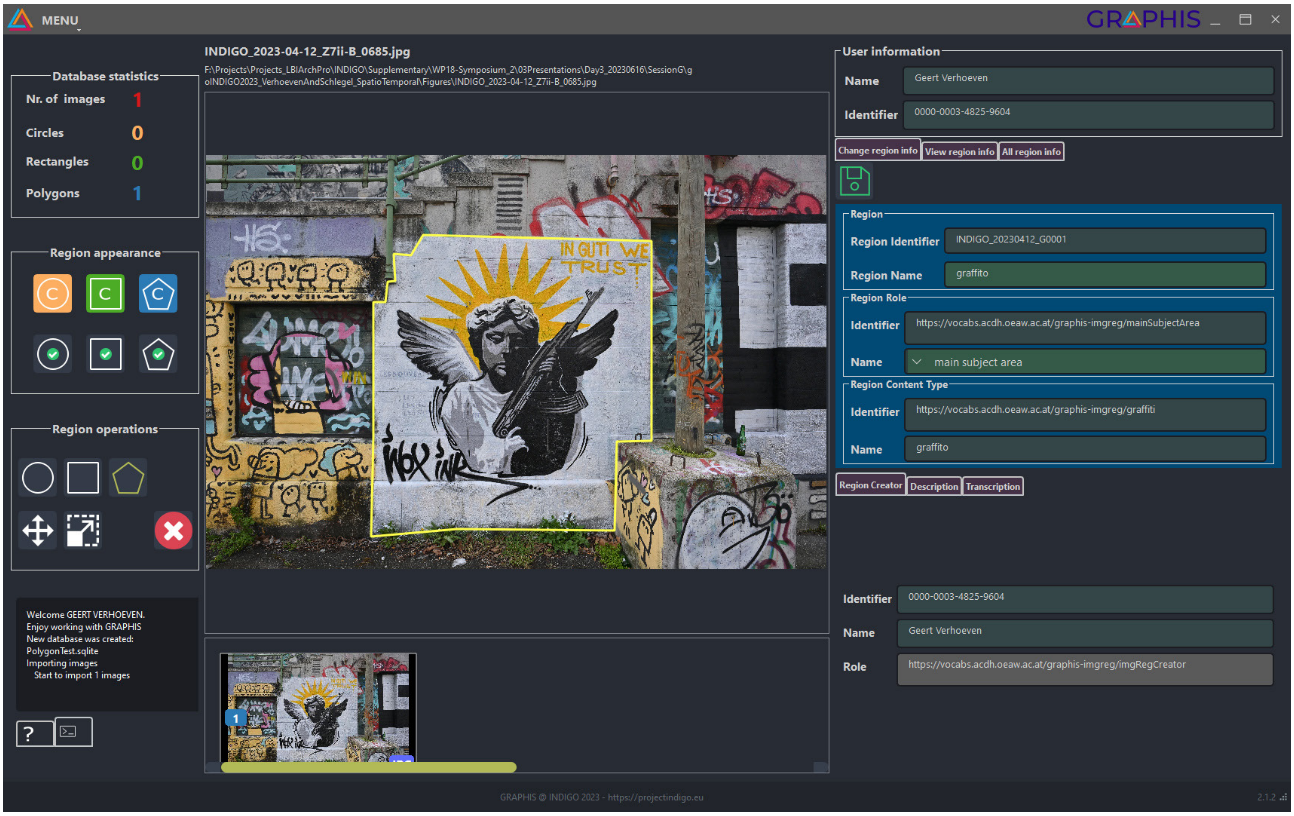

Figure 6. A database with one overview photo is opened in GRAPHIS' graphical user interface. A 13-gon indicates the graffito of interest. On the right, specific IPTC image region metadata get attached to this polygon: region identifier, region role, region content type and region creator.

into a specific subfolder. Afterwards, somebody from the INDIGO team creates an SQLite database in GRAPHIS for this subfolder and imports all overview photographs into this new database. As soon as the border of a graffito is indicated on an overview photograph (Figure 6), the coordinates of its vertices get stored in the GRAPHIS database. At the end of a GRAPHIS session, all newly indicated image regions and related metadata, like the region's creator and identifier, are saved according to the IPTC Photo Metadata Standard within the image file.

5.2.2. In Three Spatial Dimensions: AUTOGRAF

The GRAPHIS image region is a polygon with 2D pixel coordinates. For example, if the upper right vertex of the polygon in Figure 6 has coordinates (x, y) = (4080, 350), this corner is located 4080 pixels from the left side of the image and 350 pixels from its top. Since these coordinates are defined relative to the image, one cannot use them to compute the surface area of the physical graffito. That is why AUTOGRAF—INDIGO's bespoke software for orthorectifying graffiti photographs (Wild et al., 2022; Wild, Verhoeven, Wogrin, et al., 2023)—enters the workflow. AUTOGRAF reads the polygon vertex coordinates saved by GRAPHIS in the photo and projects those vertices onto a georeferenced triangle-based mesh that digitally represents the graffito surface in 3D (Figure 7-C). Using photogrammetric and computer vision principles, AUTOGRAF can extract this digital 3D surface mesh (see Figure 7-A) for every graffito from the series of overlapping photographs acquired during the follow-up photo tour. Since every point on this

Figure 7. AUTOGRAF can compute a 3D surface mesh (A) with texture (B) from the series of overlapping photos acquired per graffito. On this textured mesh, the image polygon can be projected (C) to yield a 3D closed polyline of which the vertices have real-world 3D coordinates.

meshed, digital 3D surface features accurate 3D coordinates expressed in a standard coordinate reference system for East Austria (MGI/Austria GK East, EPSG:31256; https://epsg.io/31256), it is possible to end up with exact real-world 3D coordinates (*x*, *y*, and *z*) for each projected polygon vertex.

AUTOGRAF thus turns the 2D image polygon into a new 3D shape bounded by a polyline with real-world 3D coordinates for every vertex. Although some GIS software calls this geometric entity a 3D polygon, the resulting shape or surface is no longer a polygon because the vertices of the bounding curve have *x*, *y*, and *z* coordinates. This curve is no longer a plane curve but a space curve (Agoston, 2005; Coolidge, 1959). However, not just any space curve; a closed one consisting of non-intersecting line segments. We shall refer to this curve as a 3D closed polyline.

5.2.3. Towards Surface Area and Overlap

The resulting area bounded by this closed 3D polyline could generically be called a 3D surface. The area of this 3D surface should approach the real-world area occupied by the graffito. However, two remarks must be made here. First, the resulting area will only closely approximate the real-world area if the entire polyline—not just its vertices—is projected onto the mesh. Second, computing the area at this stage is still impossible because the Euclidean geometry that allows for this needs planar shapes. Thus, one must break up this non-planar 3D surface into a collection of polygons glued along their edges. Known as tessellation, polygonisation or meshing (but see further for some comments), this breaking-up operation yields a polyhedral surface or polymesh (Kettner, 1998; Preparata & Shamos, 1985). The individual polygons—which can be of any sort—are known as the faces or facets of the polyhedral surface.

Often, the surface faces are triangles. Triangles are simple, easy-to-define polygons that are efficient for many calculation types. Because they are arguably the most helpful type of polygon, triangles are typically the elementary building blocks for complex 3D geometric structures (Botsch et al., 2010). A polyhedral surface consisting exclusively of triangular polygons results from a specific tesselation process known as triangulation (Gomes et al., 2012). Accordingly, the 3D polyhedral surface is then known as a triangulated surface or triangle/triangular/triangle-based mesh/polymesh, precisely like the triangle-based 3D surface mesh extracted from the overlapping graffito photographs.

How the area bounded by this closed 3D polyline gets triangulated is not established yet. One possible option

Figure 8. Creating and storing a graffito's location via GRAPHIS, AUTOGRAF and a hitherto undefined software package.

could be to use the existing triangle-based 3D mesh and cut out all facets encompassed by the 3D polyline. Although the graffito's surface area would be obtainable via the cumulative surface area of all extracted mesh facets, this operation would not allow computation of the graffito's potential spatial overlap with another graffito. To that end, the 3D facets must be flattened or 'unwrapped' to create a 2D surface and 2D polygon again, but now with 2D pseudo real-world coordinates. Any graffiti overlap in real-world space could be inferred from two such polygons, yielding a handful of new polygons that indicate the covered and still visible areas of the oldest graffito. However, all processing steps that trail the polygon's projection in AUTOGRAF are still in development (and indicated by "?" in Figure 8).

5.2.4. A Last Terminological Technicality

One extra technical subtlety can be mentioned before finalising this section. Please note that one can skip these two paragraphs without hampering the understanding of the remaining text. This information is provided here because it is typically hard to find. As the text above seems to imply, a polyhedral surface can be considered a 3D mesh. However, a 3D mesh might refer to a surface or a volumetric mesh. Depending on the industry, the term 'mesh' will almost exclusively mean one of the two. For instance, 'mesh' in the image-based modelling and cultural heritage fields—and in project INDIGO—typically implies surface mesh. Nevertheless, not every surface mesh is a polyhedral surface. Although both are not limited to triangles but can have any *n*-gon as their components, surface meshes can also consist of non-planar facets (i.e., not polygons). For instance, the computer graphics industry often deals with quadrilateral meshes whose four-edged facets are not necessarily flat. In other words, every polyhedral surface is a surface mesh, not vice versa; surface meshes can be polyhedral meshes (also known as polygonal meshes or polymeshes) as well as non-polyhedral meshes (Poranne et al., 2013).

Virtually every surface mesh created by image-based 3D modelling software is triangle-based. Because triangles are planar by definition, it is safe to remove the prefix "poly" when discussing triangle-based surface meshes. Furthermore, these meshes can only represent surfaces since triangles lack volume. What gets then reported in the image-based modelling literature is a 'mesh' generated by a 'meshing algorithm', even though both can technically refer to non-polyhedral or volumetric domains.

5.3. Storing Location

GRAPHIS stores the 2D pixel coordinates of the image polygon as IPTC image region metadata, either inside the image file or an accompanying sidecar file (but see Verhoeven, Wieser, & Carloni in this volume for more details). In contrast, AUTOGRAF stores the real-world 3D coordinates of the graffito outline in the GeoJSON format. JSON (JavaScript Object Notation) is a lightweight, text-based data format (Bray, 2017). Being text-based means that the file's content is easy to read and understand by humans (see Figure 9); at the same time, JSON uses specific syntax rules that make the content machine-readable. In other words, computers can automatically process or parse such data. Because it is a text-only format, code for generating and reading JSON files can be written in any programming language (Bassett, 2015).

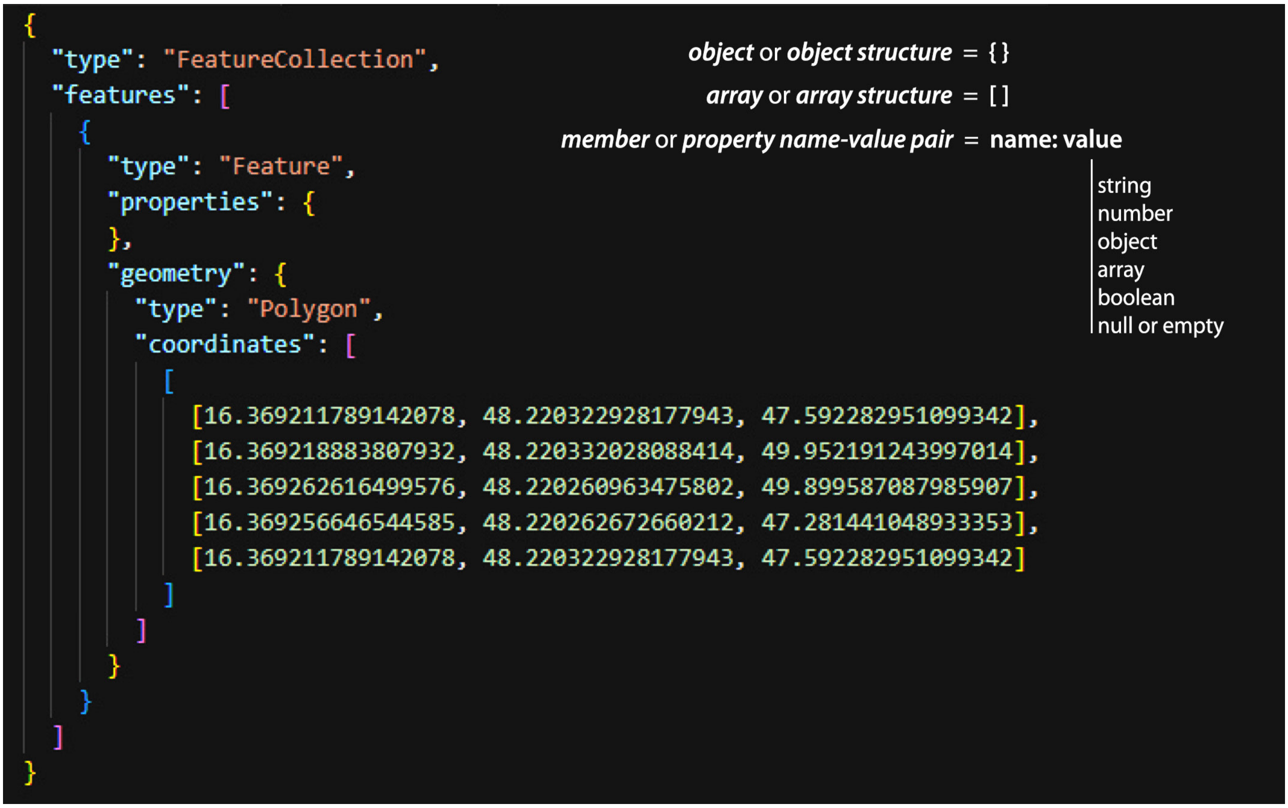

Figure 9. This example shows a GeoJSON file; the white text on the upper right provides some basic info on the GeoJSON syntax. The file describes a GeoJSON object with "type" and "features" as top-level properties. The term 'member' refers to the object property name and its value(s). The first member has "type" as its field name and a string value "FeatureCollection". The "features" member has "features" as the field name and an array as its value. This array has three elements/items, of which "properties" and "geometry" are objects and the field "type" has the string value "Feature". Although the "properties" object is empty in this example, it can store temporal information (see Section 5.4). The "geometry" object has "type" and "coordinates" members. Field "type" has the string value "Polygon", while "coordinates" has an array of linear ring coordinate arrays as its value. The RFC 7946 (Butler et al., 2016) and RFC 8259 (Bray, 2017) standards provide the proper definitions for all these JSON and GeoJSON terms.

GeoJSON extends the JSON format to represent simple geographical features like points, lines, and polygons. The feature's coordinates are expressed in the WGS84 (World Geodetic System 1984) geographical coordinate reference system (EPSG:4979; https://epsg.io/4979) with longitude and latitude in decimal degrees and ellipsoidal height in meters (Butler et al., 2016). Figure 9 displays the contents of a GeoJSON file describing a polygon with five vertices. The polygon is a geometric object that can have additional properties (see the following section). Together, they form a "Feature". Sets of features are contained in a "FeatureCollection". Even though features in a GeoJSON file typically combine geometry and some attribute data, features can also exist without geometry. In that case, the feature's "geometry" member is empty or null (Butler et al., 2016). Finally, note that the geometric feature is called "polygon" instead of "closed polyline" even though every vertex features three coordinate values [longitude (°), latitude (°), and ellipsoidal height (m)]. Such misuse of the term polygon is prevalent in the GIS world.

5.4. Storing Time

Features in a GeoJSON file are typically a combination of geometry and some attribute data or properties. This "properties" object can hold a wide variety of information, so INDIGO used it to store the temporal attributes of a graffito (in contrast to the GeoJSON-T format, which stores temporal attributes in a "when" object; Grossner, 2020). Being a dimension, one could argue that time coordinates could be added to the spatial coordinates. However, the introduction of this paper illustrated that time is typically too complex to fit into one number. How many numbers, then, should one use to store all relevant temporal attributes of a graffito? This problem was given much thought in project INDIGO, resulting in various proposals which all tried to adhere to the following four principles:

- It must be possible to retrieve all temporal properties via *in situ* observation of the real graffito or mathematically derive them using its representative polygon(s). This does not mean that each property will always be filled out for every graffito, but the possibility should exist given enough observations.
- It must be possible to map these properties to the Conceptual Reference Model (CRM) of CIDOC (Bekiari et al., 2022). The CRM is a heritage-specific ontology that forms the semantic basis of INDIGO's graffiti database (see Richards et al. (2023), but also Schlegel et al. and Trognitz et al. in this volume).
- The properties and how they are grouped should make sense on several levels. They should facilitate various forms of temporal reasoning relevant to examining a graffiti-scape and be flexible enough to deal with edge cases.
- The properties are all *in situ* based, meaning they should only relate to the location a graffito was initially meant to be seen. For example, a sticker and stencil graffito need preparation at home, so the production process does not start *in situ*. However, the final graffito is only created at its intended location when that sticker gets pasted on a waste bin, or the stencil graffito is sprayed on a wall. Removing that sticker from the waste bin to paste it on a bridge or cutting out the stencil graffito for display in a museum alters the initial location of the graffito. Since this relocation implies the definition of a new polygon or closed 3D polyline with other spatial coordinates, tracking the temporal properties must also start anew. Conceptually, it means that the relocation event created a new graffito. Assigning a new unique identifier and polygon to this relocated graffito embodies this conceptual change. The metadata of the new graffito will record the unique identifier of the initial graffito it is based on, making it clear that both are related and temporal queries can account for this relationship. INDIGO thus treats graffiti as dynamic objects, but dynamic only because their shape/extent can change through time due to all kinds of modification processes. Following the classification by Goodchild et al. (2007), a graffito is thus an elastic, uniform and stationary geo-object: elastic means that its representing polygon can change in size and shape over time (e.g., when the graffito gets covered), while the graffito's internal structure is invariant (i.e., uniform) and its spatial position unaltered (i.e., stationary). Placing a mural in a museum means that its representing polygon is no longer stationary, hence the need for a new polygon and unique identifier.

Using these principles, INDIGO considered the following three graffito events:

- The <u>production</u> of the graffito. As described above, this only relates to the start and end of its *in situ* creation, which can vary between a second (i.e., pasting a sticker) to weeks for a large mural. A police intervention can abruptly end the production event. Depending on the situation, this interruption can mark the end of the production phase, or the production can continue a few hours or days later.
- One or more <u>modifications</u> to the graffito. This can be partial or total coverage by another graffito or a partial graffito removal, such as tearing down a part of a sticker.
- The <u>destruction</u> of the graffito. Destruction happens when the carrier medium of the entire graffito is no longer present at the location of graffito production. A good example is the cutting of a tree bearing an incised graffito, the chemical removal from spray paint on a window, the physical removal of a wall's paint layers or the demolition of a bridge covered with stickers.

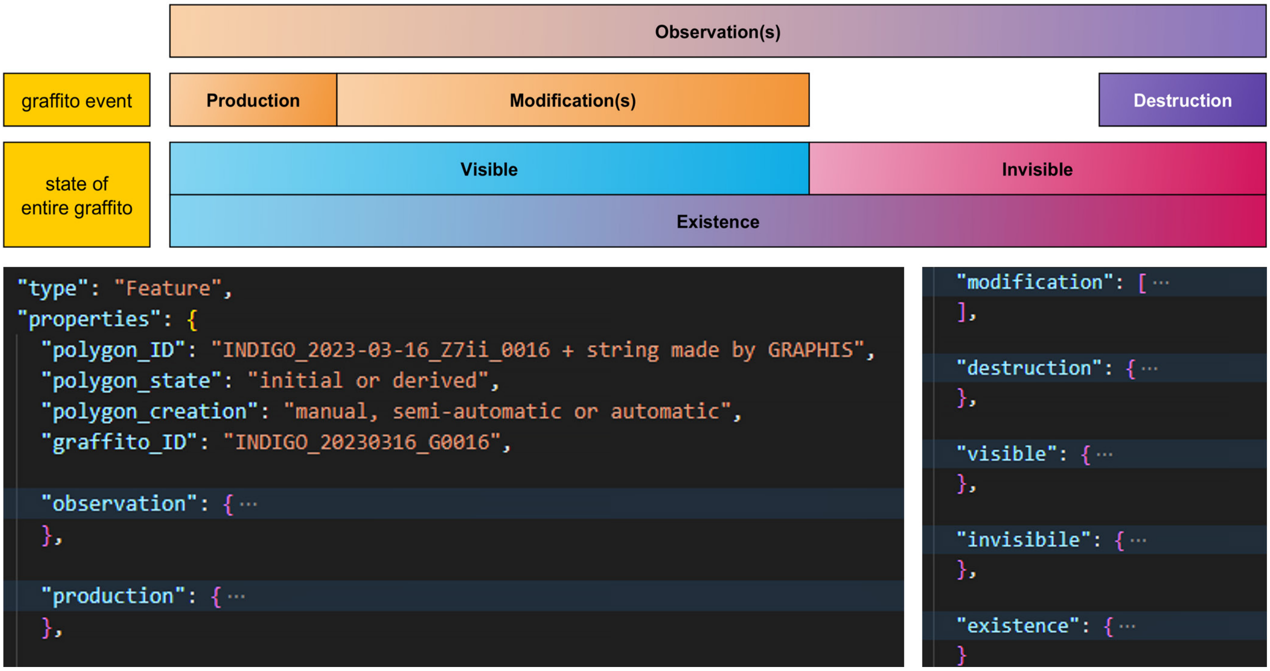

Figure 10. The temporal events and states which project INDIGO records per graffito in a GeoJSON file.

Destroying only a part of the graffito (for example, breaking down the upper part of a wall covered from top to bottom with a mural) is considered a modification event. Relocating a graffito in its entirety is also a destruction event.

Besides those three possible events, INDIGO also defined various states of the entire graffito:

- Visible or invisible: A graffito is considered visible as long as a small part is visible. At that stage, most of a graffito might be indicated by a polygon that carries the invisible attribute, while only a tiny polygon indicates the remaining visible part. Being invisible does not mean that the graffito is destroyed. Often, its last modification event was the creation of a new graffito covering the last remaining visible part. However, if that newly created graffito would be (partly) removed, the underlying graffito becomes visible again. This has happened with many Greek and Roman graffiti; they are characterised by a second visibilityspan from the moment an excavation unearths them.
- Existence: As long as a graffito is not destroyed, it keeps on existing—as already pointed out by MacDowall (2016). Any destruction event ends a graffito's existence.

The GeoJSON defining each graffito-specific polygon contains these six temporal objects (see Figure 10). All temporal objects feature an identical structure. Consider the "visible" member shown in Figure 11 as an example. It is an object with "start", "end", and "span" members. Although all three are objects, only the first two contain the same four field names: "earliest", "earliest_source", "latest", and "leatest_source". Each of those contains a string value, as do the "minimum" and "maximum" fields of the "span" object. Together, they define the different spans identified in Sections 3 and 4.

In addition to these temporal properties, there is also an "observation" object. Observations typically are INDIGO's follow-up photo tours, but could also be Instagram notifications. More observations typically mean less temporal fuzziness. Although Section 3 clarified that, the next section will illustrate this further using a real-world example.

5.5. Computing Time

The authors are currently (i.e., September 2023, one month after project INDIGO officially finished) still programming on POLYGRAF, the software to automate the spatio-temporal reasoning with the graffiti polygons. Similar to how a polygraph records several stress indicators during an interview, POLYGRAF should keep track of all relevant spatio-temporal polygon properties. More specifically, POLYGRAF must 1) check if polygons spatially overlap, 2) subdivide existing polygons into visible and invisible portions, and 3) fill out (or update) the temporal properties of all polygons involved. Figure 11 exemplifies how that might work for one specific polygon. Four photographs acquired during INDIGO's follow-up tours constitute the upper row. Each photograph also features its acquisition data and time (limited to minutes for clarity). The lower part of Figure 11 shows the "visible" element of the GeoJSON file that describes the entire Volodymyr Zelenskyy graffito, indicated with a pink polygon outline in the second photo from the left. Using the acquisition date and times of these four photographs, one can manually complete all temporal values of the indicated polygon (please note again that INDIGO's POLYGRAF should automate the following reasoning based on all graffiti polygons):

- "start" > "latest": The photograph acquired during the photo tour of 2022-09-12 establishes the latest possible start for the Zelenskyy graffito. This graffito could have been created ten minutes before acquiring the photo, but certainly not after that observation. The date and time format used to record this temporal information follows the ISO 8601 standard (International Organization for Standardization, 2019a, 2019b, 2022). The "photoTour" of 2022-09-12 is the source for this information (i.e., "latest_source" in the GeoJSON file).
- "start" > "earliest": Because the photographer did not record the Zelenskyy graffito during the follow-up photo tour of 2022-09-05, this is the earliest possible start because the graffito's production could have started one minute after passing that location.


```
"visible": {
  "start": {
    "earliest": "2022-09-05T10:20",
    "earliest_source": "photoTour",
    "latest": "2022-09-12T12:36",
    "latest_source": "photoTour"
  },
  "end": {
    "earliest": "2022-09-14T09:45",
    "earliest_source": "photoTour",
    "latest": "2022-09-21T17:05",
    "latest_source": "photoTour"
  },
  "span": {
    "minimum": "PT45H9M",
    "maximum": "PT390H45M"
  }
```


Figure 11. Four photographs from the same portion of a legal graffiti wall, acquired by the INDIGO team during follow-up photo tours. With the photos' creation dates and times, one can fill out all temporal visibility attributes of the initial Zelenskyy graffito.

- "end" > "earliest": The earliest ending of the graffito's visibility corresponds to the acquisition moment of the third photograph from the right, which is the last photo on which the graffito is still partially visible. A few moments afterwards, the graffito could have been covered entirely.
- "end" > "latest": This moment corresponds to creating the fourth photograph, as it no longer shows any trace of the Zelenskyy graffito.
- "span" > "minimum": This timespan—expressed in hours and minutes while following the ISO 8601 standard (International Organization for Standardization, 2019a,

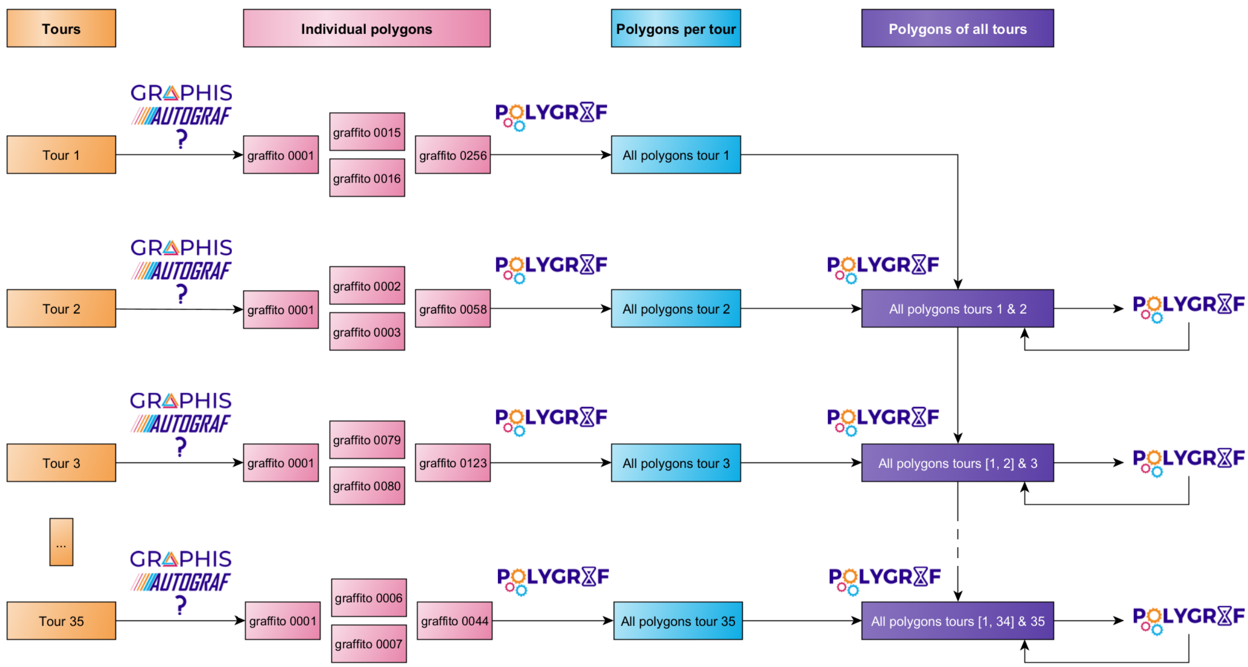

Figure 12. This flowchart presents INDIGO's envisioned pipeline for creating graffiti polygons and attributing them with temporal information.

2019b, 2022)—is computed between the latest start and the earliest end. It is the only visibilityspan one can be sure about and corresponds to the minimum visibilityspan in Figure 2C.

- "span" > "maximum": Computed between the earliest start and latest end, it is a graffito's maximum visibilityspan (see Figure 2C). Only increased observations can reduce the temporal fuzzy zones defined by the "earliest" and "latest" timestamps.

This example disentangles the idea that each graffito has a single, well-defined, continuous visibility. Many of a graffito's temporal properties can only be defined weeks (or even months and years) after that graffito's production, and the only reasonable way to document these temporal aspects of graffiti-scape formation seems to be repetitive photo tours.

The photos from 2022-09-12 and 2022-19-14 in Figure 11 also illustrate the large quantity of new graffiti that might be created over only a few days. Although new graffiti appear daily along Vienna's *Donaukanal*, this exceptional density is due to this wall's legal status; it is part of Vienna's *Wienerwand* (Eng. Viennese wall), a joint label given to the 22 legal graffiti zones in the city (see https://www.wienerwand.at). The photo from 2022-09-14 also shows why it can quickly become time-consuming to indicate every new graffito with a polygon in GRAPHIS: many graffiti can only be adequately defined by complex multi-polygons rather than a single simple polygon like the one used to delineate the Zelenskyy graffito.

Figure 12 shows the workflow that INDIGO envisions as soon as all processing pipeline parts are complete. Ideally, all polygons are created via GRAPHIS, AUTOGRAF and a hitherto undefined software (indicated with "?") directly after the follow-up tour. POLYGRAF fills out the first temporal properties and combines these individual polygons into one large tour-specific GeoJSON file. Afterwards, POLYGRAF appends this file to previous tours' polygons. At that moment, the automated spatial and temporal reasoning can subdivide overlapping polygons and fill out or update temporal properties.

6. Still Puzzling

A graffiti-scape is usually a very dynamic environment with various changes at different locations over time. This paper has covered the approaches—some still in development—that INDIGO used to track and manage a graffiti-scape's spatio-temporality in combination with its frequent photography tours. All pieces of the puzzle were slowly connected. However, some aspects are still puzzling, not in the least because much of this work is trial-and-error based. The GeoJSON data structure that stores the temporal data only came into existence after many iterations, and the INDIGO team still has to map it to the CRM ontology (even though the authors accounted for CRM concepts during the design phase of the temporal structure). The 3D polyline to 2D polygon construction is still in the works, as is the POLYGRAF software to automate polygon splitting and temporal attribute completion. It is unsure if the completion of POLYGRAF will necessitate changes to the current temporal structure. Finally, polygonising each graffito becomes time-consuming for an extended graffiti-scape, so more automated methods—maybe based on the change-detection algorithms INDIGO has developed (Wild, Verhoeven, & Pfeifer, 2023)—would be welcome. Automation would also decrease the subjectiveness in polygon creation. Five people will likely create five slightly different polygons for most graffiti, meaning polygons represent relatively subjective thresholds as long as they result from a manual process.

Despite the need for more understanding, additional developments and never-ending finetuning, the authors believe that the proposed polygon-based approach allows for the sufficient and straightforward management of a graffiti-scape's spatial-temporal aspects. Polygons are digital but nuanced approximations of real-world graffiti, which INDIGO leverages to infer spatial and temporal information about the latter. Once it becomes routine to atomise large quantities of new graffiti into temporally attributed polygons, one can start thinking about ways to visualise and analyse them. In other words, the spatio-temporal reasoning covered in this paper is but one aspect of the entire story, solely needed to create digital entities that can represent graffiti in space and time. A second spatio-temporal engine is needed to visualise and query those entities via INDIGO's online Urban Chameleon platform (see Schlegel et al. in this volume), thereby hopefully revealing various explicit or implicit spatial and temporal relationships among the thousands of documented graffiti. Although it is not unimaginable that some graph-based tools could be of help here, this second can of worms will only be opened upon finishing the entire polygon creation pipeline, likely in a follow-up project to INDIGO.

Conflict of Interest

The authors declare no conflict of interest.

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