PROJECT INDIGO – DOCUMENT, DISSEMINATE & ANALYSE A GRAFFITI-SCAPE

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ABSTRACT:

Graffiti is a short-lived form of heritage balancing between tangible and intangible, offensive and pleasant. Graffiti makes people laugh, wonder, angry, think. These conflicting traits are all present along Vienna's *Donaukanal* (Eng. Danube Canal), a recreational hotspot – located in the city's heart – famous for its endless display of graffiti. The graffiti-focused heritage science project INDIGO aims to build the basis to systematically document, monitor, and analyse circa 13 km of Donaukanal graffiti in the next decade. The first part of this paper details INDIGO's goals and overarching methodological framework, simultaneously placing it into the broader landscape of graffiti research. The second part of the text concentrates on INDIGO's graffiti documentation activities. Given the project's aim to create a spatially, spectrally, and temporally accurate record of all possible mark-makings attached in (il)legal ways to the public urban surfaces of the Donaukanal, it seems appropriate to provide insights on the photographic plus image-based modelling activities that form the foundation of INDIGO's graffiti recording strategy. The text ends with some envisioned strategies to streamline image acquisition and process the anticipated hundreds of thousands of images.

1. INTRODUCTION

Graffiti and street art are multifaceted, 'self-authorised' (Blanché, 2015) forms of personal expression that exploit the public space using a visual intervention. Graffiti and street art have found their detractors and admirers, their collectors and destroyers, and even their superstar artists. In the past three decades, there has been a considerable expansion of the techniques in which those 'graffitists' express themselves in the public sphere: from graffiti writing to murals, cut-outs, stencils and stickers (Monschein-Oberreither, 2019).

This ever-evolving nature and constant need to reinvent itself are characteristic of graffiti and street art (Lewisohn, 2009; Kimvall, 2014), but they also explain the lack of scholarly agreement on the scope of these terms. This paper considers 'graffiti' to be the umbrella term for all mark-making practices, including engravings, paintings, sprayings, stickers, and other personal expressions attached to public (urban) surfaces in legal or illegal ways. This definition allows us to state that graffiti have been created for millennia (Lovata and Olton, 2015).

Despite its long history, the phenomenon remains fascinating and debateable because it continually fluctuates between tangible and intangible heritage, between vandalism and art, between graphical and textual, between legal and illegal, between subversive and humorous, between pleasingly acceptable and socio-political criticism. These contradicting features are also present along the *Donaukanal* (Eng. Danube Canal) in the city centre of Vienna (Austria). The public surfaces surrounding this central waterway have constituted a graffiti hotspot since the early 1980s (Ringhofer and Wogrin, 2018), with works ranging from colourful murals, anarchistic symbols on bridge pillars to bike stand writings (Figure 1).

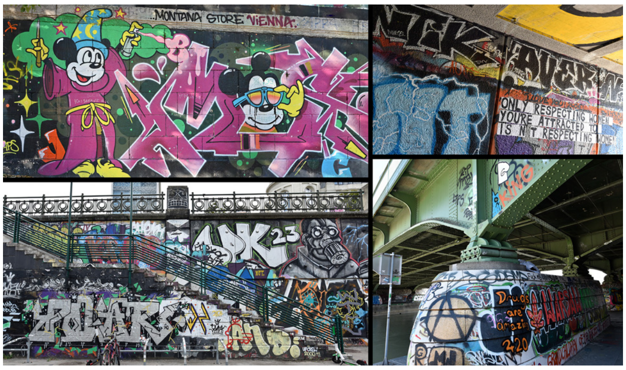

Figure 1. The large variation in graffiti at the Donaukanal.

Every day, new graffiti appear along the Donaukanal. However, a graffito's mere creation automatically implies the (complete or partial) destruction of one or more existing graffiti beneath. Although graffiti are subject to similar post-depositional processes found on archaeological sites and in landscape formation, one does usually not 'excavate' a graffiti-scape. Pre-existing graffiti simply become a lost and forgotten part of the Anthropocene's global stratification (Edgeworth et al., 2014).

That is why in the summer of 2020, the idea arose to monitor, digitally safeguard, and analyse a large part of this unique, complex, ever-changing, and socially fascinating cultural heritage that flanks Vienna's central waterway. More than a year

This contribution has been peer-reviewed.
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later, this concept culminated in the international and interdisciplinary academic project INDIGO: IN-ventory and DI-sseminate G-raffiti along the d-O-naukanal.

This paper first presents INDIGO's research questions and objectives, simultaneously discussing how they fit within the broader framework of graffiti and archaeological research. Afterwards, the five primary research pillars of INDIGO are summarised. In doing so, the text also outlines the challenges plus expected results that characterise them. Thereafter, the paper focuses more on the documentation part of the project by detailing some of the photographic and image-based modelling research that takes place in pillars one and two. More specifically, the first steps towards generating a base 3D model of the whole research zone are covered, along with some strategies that the INDIGO team currently explores to acquire and process the anticipated hundreds of thousands of graffiti photographs.

2. INDIGO VS EXISTING GRAFFITI RESEARCH

Project INDIGO was launched in September 2021. Funded by the Heritage Science Austria programme of the Austrian Academy of Sciences (ÖAW), this two-year project aims to build the basis to systematically document, monitor, disseminate, and analyse a large part of the graffiti-scape along Vienna's Donaukanal in the next decade. INDIGO focuses on nearly 13 km of continuous graffiti-covered urban surfaces between the Friedensbrücke and Verbindungsbahnbrücke (Figure 2): 5.3 km on the left and 7.6 km on the right bank. Circa 2/3 of these surfaces are formed by walls, staircases, bridge pillars and ramps surrounding the Donaukanal. However, 4.4 km of this graffiti-scape are found just above the water level on the concrete embankments that contain much of the channel. Strikingly, graffiti are only legal over a combined stretch of less than 300 m (see Figure 2). In this diverse research zone, INDIGO operates with three central aims:

1) **Documenting** the geometrical (i.e. shape and dimensions), spectral (i.e. colour), geographical (i.e. location), temporal (i.e. time of creation and lifespan) and contentual (i.e. subject matter and meaning) aspects of this graffiti-scape along Vienna's Donaukanal to digitally preserve and monitor this volatile and peculiar cultural heritage.
2) **Disseminating** this distinctive graffiti-scape through the creation of a spatial database and open access online platform that facilitates interactive, multi-temporal querying and visualisation of all graffiti records.
3) **Analysing** the (meta)data stored in the spatial database to disclose new socio-political-cultural research questions and graffiti-specific insights.

Usually, anthropologists, sociologists, and art historians cover graffiti research. Since these fields place the creator above their work (Blanché, 2015), proper documentation and monitoring of ever-changing graffiti never got the attention some scholars demanded (Masilamani, 2008). Although online archives like Global Street Art (http://globalstreetart.com), Urban Layers (https://www.urbanlayers.city), Graffiti Archaeology (http://grafarc.org) and Art Crimes (https://www.graffiti.org) exist, they feature partial and biased graffiti records with incomplete, unstandardised metadata (de la Iglesia, 2015). On the other hand, more comprehensive archives such as INGRID (https://www.uni-paderborn.de/forschungsprojekte/ingrid) and SprayCity (https://spraycity.at) lack photographic colour accuracy, extensive metadata querying, 3D visualisation and – in the case of INGRID – free access. In other words: INDIGO will create the first long-term, accurate, exhaustive, open access and interactive archive of graffiti in a vast stretch of urban space.

INDIGO thus aims to mirror the real public urban space in the virtual public space of the internet to digitally preserve and investigate an urban graffiti-scape in time and space. Since this exploration leverages numerous graffiti recordings that digitally encode the stratified graffiti-scape, INDIGO can be considered an unconventional archaeological or heritage science project dealing with the contemporary past, much like the 20-year old 'Graffiti Archaeology' project (Curtis and Rodenbeck, 2004).

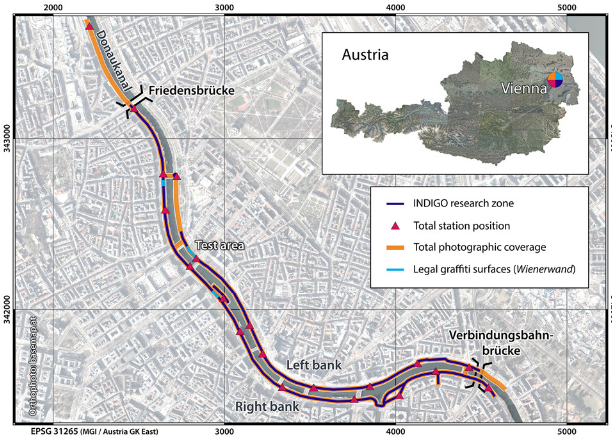

Figure 2. The INDIGO research zone in the centre of Vienna.

However, using the words '(contemporary) graffiti' and 'archaeology' in one sentence is not something that goes undebated. Already two decades ago, the 'Graffiti Archaeology' project (http://grafarc.org) raised many questions regarding the definition of archaeology and the discipline's exact subject matter (Patel, 2007). INDIGO takes the stance that archaeology is an academic discipline trying to understand (our complex relationships with) the material remains of the stratified past, whether that past was centuries (i.e. the remote or ancient past) or days (i.e. the contemporary or recent past) ago. And graffiti research aptly illustrates that view because there is a considerable overlap between the research aims and methods for prehistoric rock art, Roman artefact inscriptions, medieval church carvings and present-day mark-making activities like spraying or pasting stickers (as discussed by Frederick and Clarke (2014)). This notion should also transpire in the next section, which describes INDIGO's approaches to contemporary graffiti as social practice and cultural artefacts.

3. ENVISIONED METHODOLOGY

INDIGO wants to ensure the digital survival of a large part of Vienna's graffiti-scape and disclose new socio-political-cultural insights. To accomplish those aims, INDIGO is structured around five research pillars: 1) acquisition, 2) processing, 3) management, 4) dissemination and 5) analysis. All of them are explained below. The remainder of the paper will then focus on aspects contained within research pillars 1 and 2.

1) **Acquisition**: To provide clean and relevant data for the spatial database and online platform, i) three-dimensional (3D) surface geometry of the Donaukanal, ii) photographs of the graffiti, and iii) auxiliary data must be acquired. The 3D surface is vital to remove the geometrical image deformations; it is also the backbone onto which the graffiti images will be mapped for display in the online platform. A challenge lies in the acquisition of accurate and complete 3D geometry of the canal's banks. Although INDIGO can use laser scans collected in a mobile mapping campaign part of Vienna's *Wien gibt Raum* initiative (Eysn, 2020), extra

image-based modelling might be needed to avoid potential data gaps that are common in mobile mapping data due to object occlusions. However, the real challenges relate to INDIGO's photo acquisition. Colour-accurate photographs should be obtained shortly after the finalisation of each graffito. INDIGO solves this last issue via engagement with graffitists and photo tours on an approximate three-day basis. A bi-annual photography campaign of the entire research zone will allow change detection algorithms to pick up graffiti that went unnoticed. However, reliable change detection, smooth transitions between overlapping images, and graffiti pigment identification all need colour-accurate photographs. Even if hard to achieve outdoors (Verhoeven, 2016), INDIGO expects to do better than anyone has accomplished so far. Since colour is a function of incoming radiation, the latter is measured for every photographed graffito with a spectrometer. Finally, relevant auxiliary data must be collected: graffito metadata (like creation date or date of first observation, creator, graffiti type) or the videos and pictures that graffitists record during spraying. The challenge here lies in collecting all the necessary metadata for every graffito. Many creators prefer anonymity, so the online platform should feature anonymous login for metadata entry.

2) **Processing**: the 3D surface geometry of the Donaukanal, the graffiti photographs and the auxiliary data must go through one or more processing steps before being inventoried in the spatial database. As a start, all datasets receive the necessary metadata (e.g. IPTC tags for the imagery). The photographs will go through a strict routine to create 16-bit colour-accurate TIFFs (Molada-Tebar et al., 2018). The challenge here is to create a robust and repeatable workflow that maximises throughput. Afterwards, an orthorectification process removes the geometric distortion of the images. To that end, the 3D point cloud is meshed into a continuous surface. Here, the tricky task awaits of keeping the 3D model up to date; some parts of the Donaukanal have a rather dynamic character with temporary structures that come and go. INDIGO needs a bespoke tool that can load just the necessary mesh segments to create orthophotographs and mesh textures. The bespoke software solution should also support the change detection operation required by the bi-annual photographic campaign described in pillar 1, making its development challenging. Finally, finding and documenting new graffiti is useless if the resulting data are not searchable. Therefore, INDIGO expects this tool (or set of tools) to support image segmentation and annotation (e.g. new graffiti, old graffiti, no graffiti zones) and the attribution of metadata through a spatial database link.

3) **Management**: Collecting and processing data without a solid data management system is irresponsible. This pillar aims to create a spatial database to manage and query all (meta)data. Besides a robust integration with the online platform (see pillar 4), this database should support spatio-temporal queries and adhere to the CIDOC Conceptual Reference Model (https://www.cidoc-crm.org). At the same time, data entry should be customisable and painless. Due to the existing Vienna-based OpenAtlas software (https://openatlas.eu) and targeted programming, INDIGO expects its database and underlying data model to be exemplary for the Digital Humanities at large. Other aspects of this pillar concern managing and hosting the graffiti thesaurus (see pillar 5). To tackle the long-term preservation challenges of the project's digital data, INDIGO has partnered with the CoreTrustSeal-certified ARCHE repository (Trognitz and Ďurčo, 2018).

4) **Dissemination**: INDIGO envisions an open-access online platform that offers interactive visualisation and exploration of the data. Textured 3D views should enable visitors to look at present-day graffiti in their geographically-correct urban setting or scroll through time and visually experience the works' timespan. A section to browse through detailed graffiti orthophotographs plus functions to download and extensively query (meta)data must also be present.
Creating such a platform with a slick user experience is a challenge (e.g. a pleasing layout, smooth data streaming, robust database integration), but could lead to an augmented reality app in a post-project future. Although articles and conference talks accomplish international outreach, they do not instigate the graffitists' essential engagement. The latter is currently conceived via graffiti workshops by SprayCity and regular Instagram posts – Instagram being a vital communication channel for graffitists (MacDowall, 2019).
In the near future, QR codes tagged along the Donaukanal could further improve graffiti reporting and increase awareness, both necessary to extend the foundations laid by INDIGO into the next decade (e.g. via citizen science). Finally, INDIGO plans two international symposia: one covering the technical aspects of recording, storing, and disseminating graffiti, while a second symposium focuses on graffiti's socio-political and cultural impact. Via these symposia, specialists in art history, philosophy, cultural studies, law, urbanism, psychology, and communication will see the potential of this massive open-access archive, thereby ensuring INDIGO's transdisciplinary sustainability. Both symposia proceedings might also become foundational publications on graffiti research.

5) **Analysis**: Most of the scholarly literature on graffiti is exclusively descriptive, often devoid of essential metadata (e.g. Wacławek, 2011; Reinecke, 2012). This led some scholars to blame graffiti research for its overall lack of academic rigour (de la Iglesia, 2015). Given the exhaustive and spatially + temporally + spectrally impartial inventory of graffiti data and metadata, INDIGO's open access archive will open new analytical pathways for graffiti research that support novel socio-political-cultural research questions. For instance, Vienna counts several legal spraying surfaces, jointly labelled *Wienerwand* (http://www.wienerwand.at). Along the Donaukanal, there are approximately 300 m of Wienerwand. One may wonder if those who spray in legal graffiti zones have the same profile as those who do not. These walls could also offer insight into 'crossing', a phenomenon where a major graffito gets scrawled over, usually by 'tags'.
Analyses like these also directly tie into existing graffiti definitions and classifications. Some scholars and graffiti creators voice that legally permitted graffiti do not deserve the label 'graffiti'. Even though such terminological distinctions do not guide INDIGO's recording, the project must strive for terminological clarity to populate the database with unambiguous metadata. Creating a graffiti and street art thesaurus in the first project months will accomplish this. Being a finite set of terms (i.e. a controlled vocabulary) with hierarchical relations (Pomerantz, 2015), this thesaurus will make INDIGO's graffiti classification explicit and serve as a reference for the broader academic graffiti community.

The remaining part of the paper will first focus on the creation of the 3D geometric backbone, after which it explores different strategies to acquire and process new graffiti records.

4. 3D GEOMETRIC BACKBONE

INDIGO needs a complete and gap-free 3D surface mesh (triangle or quad-based) of the Donaukanal onto which all graffiti photographs can be mapped. Even though this digital surface might mainly be generated from the mobile laser scanning data provided by the city of Vienna in 2022, a total photographic coverage would 1) provide the necessary image data to fill potential gaps in the laser-scanned 3D point cloud, and simultaneously 2) constitute a complete record of the graffiti-scape at a particular moment in time. Since this record would effectively establish a starting point for tracking change in the graffiti-scape, all sprayed surfaces (indicated in indigo in Figure 2) were photographed in October 2021 (see Table 1).

The idea was to utilise only one camera model in the project. Even though the INDIGO cameras did not arrive at the end of September 2021, the water level in the Donaukanal was low, which presented a unique opportunity to photograph all graffiti just above (and in some places below) the usual water level. That is why this 'total coverage' image acquisition campaign took place at the beginning and end of October 2021 using different camera setups (see Table 1). Both campaigns only contained consecutive days to minimise potential graffiti-scape changes while acquiring photos (although change was inevitable between both campaigns – see the photographs in Figures 3 and 4). The following subsection describes this image acquisition in detail.

4.1 Image acquisition

The first image acquisition mainly targeted the 4.4 km of reinforced concrete embankment (see Figure 3) that channels a large portion of the Donaukanal in the INDIGO research zone (the channel's bed is only hardened with boulders in the other parts; see Figure 4 on the left). Photographing these concrete walls took place from the opposite bank using an 85 mm lens on a Nikon D750 24-megapixel full-frame reflex camera. With an average distance of 51 m between the embankment walls and the D750's detector pitch p of circa 6.0 µm, the mean Ground Sampling Distance or GSD on these concrete surfaces is 3.6 mm (with all GSD values in the [2.9, 4.8] mm interval, corresponding to a minimum and maximum embankment separation of 42 m and 68 m, respectively). This is four times larger than the average GSD obtained when photographing the embankment's surrounding urban surfaces (all possible walls, staircases, bridge pillars, and ramps) with the 20 mm lens on the 45-megapixel full-frame mirrorless Nikon Z7 II (see Table 1).

Date	Camera	Lens	Mean GSD	Acquisition time	Image count
30/09/2021	Nikon D750 (24.2 MP p = 5.95 µm)	Nikon AF-S NIKKOR 85mm 1:1.8 G @ *f*/5.6	3.6 mm	3 h 45 min	2065
01/10/2021				3 h 20 min	2544
26/10/2021	Nikon Z 7II (45.4 MP p = 4.33 µm)	Nikon NIKKOR Z 20mm f/1.8 S @ *f*/5.6	0.9 mm	7 h	6042
27/10/2021				7 h 45 min	6591
28/10/2021				3 h 40 min	2856
29/10/2021				7 h	6608
			Total	32 h 30 min	26706

Table 1. Total photographic coverage acquisition parameters.

Although INDIGO aims for a GSD of roughly 1 mm in all graffiti photos, this larger GSD on the embankments is not considered problematic because most of their graffiti are quite weathered (see the Nikon D750 image in Figure 3). In addition, one would need to fit the Nikon D750 with a lens of minimally 300 mm (or 220 mm for the Nikon Z7 II), but acquiring images along many kilometers with such long-focus lenses is not straightforward.

Figure 3. The location of all photographs acquired around the *Marienbrücke* (Marien Bridge) is indicated in semi-transparent blue. The location of the depicted Nikon Z7 II and Nikon D750 photographs is shown via a red rectangle. The scene's structure is represented by a cleaned cloud of 3D tie points.

In total, 26.7k photographs were acquired during both photography campaigns, covering 14 km of graffiti, graffiti-less and unstudied surfaces (Table 2). For instance: graffiti surfaces around the U6 station Spittelau were photographed but the INDIGO team decided later to remove them from the research zone as they are separated from the central zone by 300 m of graffiti-less surfaces. Since it was planned to orient all photos with a Structure from Motion (SfM) approach, the image acquisition had to be executed according to specific rules. SfM pipelines with camera self-calibration are prone to drift in the estimated exterior camera orientations or might yield inaccurate interior orientations, certainly when the photographs do not feature a large enough image overlap, or the image collection lacks variation in camera roll angle and fails to include inter- plus intra image scale changes.

From a practical point of view, this means one should acquire photographs with a camera-lens combination that features a fixed focal length and principal distance (i.e. not zooming and not refocusing). Moreover, the image set must include portrait and landscape images (rotated both clock- and anti-clockwise) collected with the optical axis perpendicular as well as inclined to the scene; ideally, the latter is three-dimensional and covers the whole image sensor (Luhmann et al., 2016). Finally, any lens or in-camera vibration reduction should be disabled. More photos are always beneficial because high observational redundancy averages better the interior orientation instability effects that can characterise off-the-shelf imaging systems (Fraser, 2013).

INDIGO's total coverage survey applied all recommendations mentioned above. Every day, the focusing ring was immobilised with cellophane tape at a focus distance of circa 4 m (for the Z7 II) and 50 m (for the D750). The cameras captured 14-bit lossless compressed RAW photos next to in-camera generated JPEGs, with *f*/5.6 dialled in for all exposures. This aperture provided sufficient depth of field: [23 m, ∞) for the D750 and [1.5 m, ∞) for the Z7 II given a 30 µm circle of confusion threshold; *f*/5.6 also effectuated a very high and uniform lens resolving power. However, even adherence to this image acquisition protocol does not prevent drift in camera poses (and the resulting network deformations) when imaging long, elongated scenes (Barazzetti, 2017). The nature and the length of the urban surfaces under study make it hard to avoid a particularly drift-prone image sequence when photographing the banks of the Donaukanal. Although scholars proposed extended structural image features to reduce this endemic SfM issue with long-spanning artificial structures (Holynski et al., 2020), INDIGO relies on a loop-closed multi-camera network and a dense network of control data (see 4.2) to achieve accurate exterior camera orientations.

Distance type (applicable to the INDIGO project)	Length (km)
Stretch of Donaukanal researched (measured in the centre of the waterway)	3.3
Buildings-staircases-ramps-bridges with graffiti [left bank]	3.2
Buildings-staircases-ramps-bridges with graffiti [right bank]	5.3
Buildings-staircases-ramps-bridges with graffiti [total]	8.5
Concrete channel embankment [left bank]	2.1
Concrete channel embankment [right bank]	2.3
Concrete channel embankment [total]	4.4
All studied surfaces with graffiti [left bank]	5.3
All studied surfaces with graffiti [right bank]	7.6
All studied surfaces with graffiti [total]	12.9
Legal graffiti surfaces (Wienerwand) [left bank]	0.2
Legal graffiti surfaces (Wienerwand) [right bank]	0.1
Legal graffiti surfaces (Wienerwand) [total]	0.3
Graffiti-less surfaces photographed [left bank]	0.4
Graffiti-less & unstudied surfaces photographed [right bank]	0.5
Graffiti-less surfaces photographed [across banks]	0.2
Graffiti-less & unstudied surfaces photographed [total]	1.1
All graffiti, graffiti-less & unstudied surfaces photographed	14.0

Table 2. Some INDIGO-relevant distances.

Loop-closure in the camera network was something specifically sought after. At three locations, the channel was bridged with photographs: twice with the 85 mm and once with the 20 mm configuration. The latter was only possible after photographing about 400 m of graffiti-less surfaces: trees, benches, and grass patches (Table 2). However, obtaining loop closure in the 20 mm image set outweighed the awkwardness of photographing people relaxing on benches and staring into the camera. Although INDIGO masks all people appearing on images, everybody was asked to cover their face or look away if they felt uncomfortable.

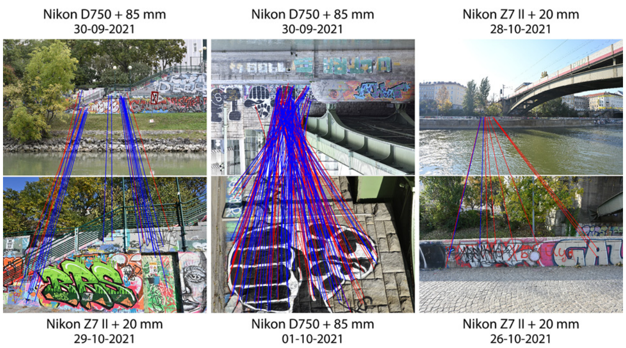

Figure 4. Metashape established valid image matches (blue lines) between photographs acquired from opposite sides of the Donaukanal. Red lines represent rejected tie points.

Because the GSD of the 85 mm images is about four to six times bigger than the GSD of the 20 mm images for the same graffiti, tie points were anticipated between both image sets despite possible changes in the graffiti-scape (the left part of Figure 4 confirms this). In addition, many images were acquired in a panorama-like fashion just before and after the bridges to establish tie points among the 20 mm photos (as well as the 85 mm ones) acquired on the opposite sides of the Donaukanal. Usually, the GSD difference between these photos is slightly higher (a factor five to ten difference for the 85 mm images and an eight- to fifteen-fold GSD increase for the 20 mm images since they are more distant to the opposite bank than the 85 mm images). Although fewer tie points were found within the set of identical focal length images, the central and right examples of Figure 4 indicate that some ties could still be established.

4.2 External photo control acquisition

The image network must be constrained with external photo control data to further reduce accumulated drift effects in the estimated camera orientations and express the SfM result in a real-world coordinate reference system. The main idea was to collect the 3D coordinates of numerous Graffiti-scape Points (GPs): object/scene points that are well-identifiable in many photos (even when potentially sprayed over) and whose long-term positional stability can be assumed (see Figure 5). These GPs are collected in 21 clusters: L1 to L9 for the left bank and R1 to R12 for the right bank of the Donaukanal. L0 denotes the GPs cluster at a dedicated test area (i.e. where INDIGO methods are tested; see Figure 2); L5 remained unused as it covered an area that the team decided later to exclude from the research zone.

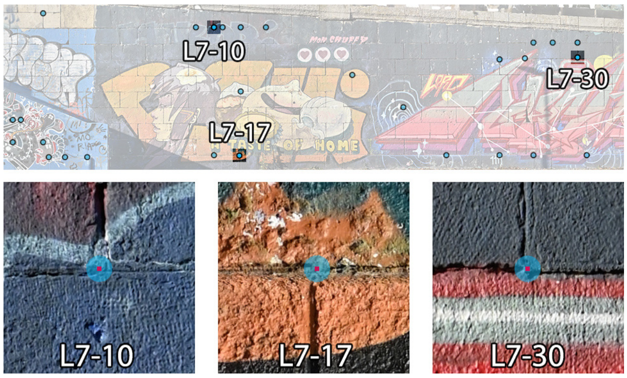

Figure 5. Three typical GPs out of the thirty that constitute cluster L7 on the left Donaukanal bank.

During a terrestrial surveying campaign lasting several days, the 3D coordinates of many image-identifiable GPs were acquired using free stationing with a Leica Viva TS16 total station and a Leica GPR121 circular prism. The TS16 was freely positioned on twenty locations within the INDIGO research zone (Figure 2). Distances and bearings were measured to at least four and on average to twelve visible Control Network Points (CNPs) from each TS16 location. These points are part of an extensive network of control points established by the City of Vienna during a city-wide terrestrial surveying campaign. They are mainly associated with artificial objects and structures such as drainage covers, edges of walls, or bridge pillars; the coordinates of these CNPs are expressed in the MGI/Austria GK East coordinate reference system (EPSG 31256) and freely available (CC BY 4.0 license) at https://www.wien.gv.at/ma41datenviewer/public/start.aspx.

Even though the availability and visibility of surrounding CNPs largely determined the location of the 21 GP clusters, it was the intention to have approximately equal intervals between them. At spots with more massive structures (usually bridges), a GP cluster was established on both sides of the Donaukanal. In between those pairs of clusters, additional clusters alternate between the left and the right bank (see Figure 2). An orthophoto or textured 3D model was generated from each location to select and indicate the GPs before surveying them (Figure 5). Each cluster counts between 17 and 37 GPs for a total of 593 GPs (see Table 3).

4.3 Data processing

As stated above, the total station was freely positioned at each cluster to control the visibility of CNPs and GPs. The EPSG 31256 *x* and *y* coordinates of the TS16's centre were calculated using a 2D Helmert transformation followed by a trigonometric determination of height to determine the *z*-coordinate. The parameters of the Helmert transformation were calculated from the CNP coordinates, which are known in both the target and the source system (a local coordinate system with the total station's centre as origin). Because more than two CNPs were available for each cluster, the transformation parameters were determined by minimising the sum of the squares of the residuals. Residuals over 4 cm were considered outliers, and these CNPs were removed. Table 3 indicates that the average standard deviation of the residuals at all clusters equals 8 mm in planimetry and 12 mm for the *z*-coordinates. Based on the total station's known position and the reflectorless measured distances and bearings to the GPs, their 3D coordinates were determined in EPSG 31256. All above-mentioned geodetic calculations were conducted in IDC EDV's Geosi Verm v. 21 (https://idc-edv.at/geosi/geosi-verm).

Cluster	σ_{xy} [mm]	σ_z [mm]	Number of CNPs used	Measured GPs	GPs used as GCPs
L0	9	5	9	37	28
L1	8	11	10	17	17
L2	13	8	7	30	27
L3	12	25	5	22	20
L4	8	12	8	30	21
L5	N/A	N/A	N/A	N/A	N/A
L6	10	15	5	23	23
L7	8	14	7	30	30
L8	7	10	8	27	26
L9*	3	7	10	23	21
R1	8	8	4	36	30
R2	10	13	6	26	23
R3	5	15	7	37	29
R4	7	24	5	30	30
R5	12	7	4	26	26
R6	8	6	7	26	26
R7	4	9	8	32	32
R8	9	14	5	27	27
R9	6	22	6	29	29
R10	5	14	7	27	27
R11	12	6	4	31	30
R12*	3	7	10	27	23
Minimum	3	5	4	17	17
Maximum	13	25	10	37	32
Mean	8	12	7	28	26
Total	N/A	N/A	N/A	593	545

Table 3. Cluster-specific metrics: the first two columns provide precision metrics for the derived TS16 centres, computed using the number of CNPs in column three. The last two columns give the number of measured GPs and used GCPs (Graffiti-scape Control Points are GPs that constrain the bundle adjustment). *Observed from the same total station position.

All photographs were oriented in Agisoft Metashape Professional 1.7.5 using a maximum of 25k interest points and 3k tie points per image. Since most SfM-based image-based modelling packages establish camera calibration groups solely based on the lens' focal length and not its focusing distance, manual intervention was needed to establish two camera groups for the 85 mm photographs and three groups of 20 mm images. For each group, Metashape computes a set of interior orientation values. The 20 mm images were not divided into four groups (i.e. one for every day) because the focusing ring was kept immobile with cellophane tape for the first two days (keeping the principal distance invariant). At the end of day two, the tape was removed to avoid glue residue on the lens. The same protocol was intended for days three and four, but the outer part of the lens got slightly covered by graffiti paint spray on day three and needed to be cleaned. Five different interior orientations were thus computed with similar recovered principal distances for each lens: 85.155 mm and 85.184 mm | 20.412 mm, 20.410 mm, and 20.402 mm.

Metashape failed to estimate camera poses for only four photos, which is a success given the spectral and spatial invariance of the entire scene. The graffiti-scape clearly changed during the four weeks between the photo campaigns (e.g. Figure 3 and the left side of Figure 4). The image set is also characterised by significant illumination changes (sun-lit vs shadowed areas, and shifting shadows due to moving foliage) and alterations in scene geometry. Besides the people that are unavoidably photographed (occasionally even graffitists at work), new but often temporary constructions frequently appear along the channel; ships are also passing by, in turn moving the docked vessels. Finally, dust bins, bikes, e-scooters, and fishermen come and go. This spatial variability and a minimum of masking notwithstanding, Metashape dealt very well with these unstable tie points.

After visually examining the cloud of 14.5 M 3D tie points for possible artefacts and ensuring that every camera was approximately in its correct position, the GPs were indicated. This occurred on a cluster-by-cluster basis to identify potential problematic GPs. For every cluster, the respective GPs were indicated in as many D750 and Z7 II photographs as possible. Only a minority of GPs had to be omitted because they could not be accurately indicated in the photos. A few GPs also featured larger than average residuals (≥3 cm in object space). As these GPs either represented edges or were located at the border of a cluster (creating a narrow angle between the laser beam and the surface), their higher residuals are likely due to less accurate GP coordinates resulting from the reflectorless measurements.

545 from the 593 GPs were kept (Table 3) after examining each cluster. Combining the precision numbers of Table 3 with an assumed additional uncertainty of ±5 mm to indicate the GPs in the images yields a total precision of about 1.5 cm. This number was used in Metashape to weigh these 545 external observations, so they could function as GCPs (Graffiti-scape Control Points) and constrain a final self-calibrating bundle adjustment. This operation mitigated any drift in the recovered camera locations, and georeferenced the network of 26.7k photographs. Table 4 presents some accuracy metrics computed from the SfM output.

Georeferencing accuracy metric	Value
$RMSE_x$	1.1 cm
$RMSE_y$	1.1 cm
$RMSE_{xy}$ (total planimetric accuracy)	1.6 cm
$RMSE_z$	0.8 cm
$RMSE_{xyz}$ (total 3D positional accuracy)	1.8 cm

Table 4. Accuracy metrics for the oriented image network.

4.4 Future challenges

The entire total coverage survey fulfils two aims: 1) it documents the status quo to establish a starting point from which new graffiti get recorded, and 2) allows to extract 3D surface geometry that can complement the mobile mapping data of the Donaukanal from the City of Vienna. It is still unclear how the integration of both data sources will occur. The mobile laser scanning data might be filtered and fused with a dense point cloud extracted from (some of) the photographs; this 3D point cloud can then be meshed. Or, the base 3D mesh is extracted from the photos and enhanced with the mobile mapping data. In any case, the generation of one or more clean, error- and gap-free 3D surface meshes of the entire research zone will be a time-intensive operation, not only due to the extent of the research zone, but also due to its geometrical and spectral invariance.

As mentioned in section 4.3, new constructions are often built along the Donaukanal. These surfaces get usually marked with graffiti within a few days after completion, which raises the question of whether (and when) INDIGO should make a new 3D base model. This is relevant since graffiti on these new urban surfaces can otherwise not be adequately mapped. However, every of these new 3D base models takes time to generate. Finally, these 3D meshes should enable (ortho)rectification and smooth online streaming as textured surfaces. INDIGO explores ways to decimate and retopologise huge meshes to that end.

5. RECORDING AND PROCESSING NEW GRAFFITI

One of INDIGO's biggest challenges is turning the expected 100,000s of graffiti photos into absolutely georeferenced, colour-accurate, (ortho)rectified photographs and seamless textures for the Donaukanal's 3D model(s), all segmented per graffito and accompanied with the correct metadata. Each step comes with technical and logistical challenges, and the last part of this paper will shed some light on the three main (ortho)rectification and georeferencing strategies INDIGO is exploring.

5.1 Manual (planar) rectification

A photograph of a planar object is a projective transformation. This photo is perspective distortionless if photographed with a perfect central projection system (i.e. the pinhole model) whose optical axis is perpendicular to the object. Tilting the optical axis in any direction induces perspective distortions and a variable image scale. (Planar) rectification projectively transforms this tilted photo to a plane to remove the scale differences.

To determine the eight parameters that characterise the projective transformation, one indicates a minimum of four points in the photograph and object space. However, the assumptions made for rectified images do not entirely hold for photographs acquired along the Donaukanal. First, lens distortions are always present. Although they can be modelled to undistort the photo before rectification (Figure 6), this requires extra effort. Second, some Donaukanal surfaces might visually appear flat. Still, they are slightly curved or feature other deviations from planarity, causing displacements and scale variations in a rectified image. Even though spline algorithms or piecewise affine warpings could substitute the projective transformation when surface undulations are moderate, they cannot eliminate all image displacements.

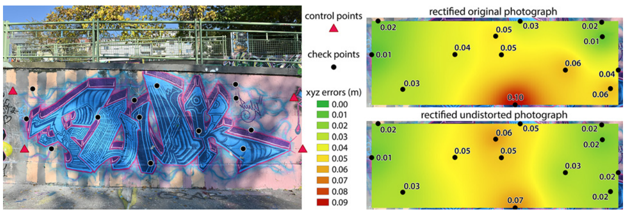

Figure 6. A graffito photo (left) and the error distribution of its planarly rectified variants with and without lens distortion (right).

Although all these methods have the advantage of working with a single photograph and being straightforward to implement in Python or MATLAB, they also share the disadvantage of being time intensive. Typically, one manually identifies corresponding points in the image and on the object. A planar rectification of one INDIGO photo took, on average, 15 minutes. Given the large number of new graffiti that weekly appear along the Donaukanal and the non-planarity of most surfaces, INDIGO needs a more automated solution that ideally generates true orthophotos.

Orthorectification can overcome the issue of surface undulation. This process leverages an object's 3D surface geometry to correct for relief displacement besides displacements caused by camera tilt, thus creating planimetrically correct true orthophotographs. In addition, orthorectification applies to any urban surface as long as its 3D geometry is sufficiently known. Then again, creating orthophotos requires knowledge of the camera's in- and exterior orientation parameters, either obtained by extra hardware or via a separate processing step. The text discusses both options next.

5.2 Orthorectification with direct georeferencing

Approximating the interior and exterior orientations becomes possible by equipping the camera with a Real-Time Kinematic GNSS receiver paired with an IMU (Inertial Measurement Unit). As in the previous solution, one image per graffito could suffice if the interior camera orientation was predetermined. More photos would only be required to ensure a 1 mm GSD for a sizeable graffito (because the GSD might become too large when encompassing the whole graffito by the camera's field of view).

Compared to planar rectification, this workflow offers a high degree of automation while software requirements can be kept low. However, the dependency on the measurement accuracy of the GNSS/IMU sensors and their cost are a substantial drawback. INDIGO has tested high-end hardware such as RedCatch's 3D ImageVector (https://www.redcatch.at/3dimagevector). Still, the photo georeferencing accuracy obtainable with such solutions will often be lower than from a planar rectification. Furthermore, direct georeferencing likely fails at scenes where no exterior orientation parameters can be derived due to obstruction of the GNSS signals (e.g. beneath bridges). Finally, suppose a 3D surface model has only been determined once. In that case, it most likely does not incorporate the latest geometric arrangements of the graffiti surfaces (e.g. newly built staircases).

5.3 Orthorectification with incremental SfM

A second, potentially more accurate approach to orthorectify photos in a largely automated way involves the application of incremental bundle block adjustments. An incremental SfM approach could utilise the oriented photos of INDIGO's total coverage network to establish the absolute exterior orientation of the newly added images. Their interior orientation is concurrently estimated by the camera self-calibration part of the SfM pipeline. The camera should also be equipped with a moderately accurate GNSS receiver, ideally complemented by an IMU, to make this approach work reliably and efficiently. This exterior orientation data would help constrain the object space when looking for 3D geometry, older photos, or tie point subsets necessary for the orthorectification and texturing phases. However, this strategy requires the photographer to operate in a particular way. Each graffito must be photographed from several sides, including invariant parts of the surrounding urban fabric. In addition, this approach's achievability also depends on how INDIGO manages the temporality of tie points. When a new graffito covers another one, tie points originating from the covered graffito should become invalid. Although this method is still surrounded by many open questions and necessitates more specialised software than the earlier approaches, Figure 7 illustrates its feasibility.

Instead of an incremental SfM, one could imagine a workflow that relies on a local SfM of which the resulting 3D tie points get correctly located and oriented using RTK-GNSS data or via Iterative Closest Point. Like the other methods, also this approach presents shortcomings and technical hurdles. However, the final photo georeferencing process will not only depend on technical feasibility; integrating the colour-correction, photo segmentation, and data management pipelines is equally essential. Finally, the INDIGO team should not lose sight of its aim to create tools and workflows useful for the broader heritage documentation field. Being true to this goal is where the big academic challenge lies.

Figure 7. The upper rendering depicts the exterior orientation of three photo series; the images below present the 3D texture generated from them. Starting from the oriented total coverage photos (in orange), Metashape's incremental SfM managed to orient older September test images (blue) and younger December photos (pink) despite significant changes in the graffiti-scape.

6. CONCLUSIONS

INDIGO wants to ensure the digital survival of a large part of Vienna's graffiti-scape via local community engagement and scientific documentation through time. This paper presented the project's goals and five-pillar methodology, followed by the road towards a complete 3D geometric backbone and some thoughts on georeferencing vast amounts of new graffiti photos.

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REFERENCES

Barazzetti, L., 2017. Network design in close-range photogrammetry with short baseline images. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, 17-23.

Blanché, U., 2015. Street Art and related terms. *Street Art & Urban Creativity Journal* 1 (1), 32-39.

Curtis, C., Rodenbeck, E., 2004. Graffiti archaeology. *Proceedings of SIGGRAPH 2004*. ACM SIGGRAPH, 1.

de la Iglesia, M., 2015. Towards the Scholarly Documentation of Street Art. *Street Art & Urban Creativity Journal* 1, 40-49.

Edgeworth, M., et al. 2014. Archaeology of the Anthropocene. *Journal of Contemporary Archaeology* 1 (1), 73-132.

Eysn, L., 2020. City of Vienna's activity in large scale Mobile Mapping and related image based Artificial Intelligence. In: *Proceedings CHNT 25*. Stadtarchäologie, Vienna.

Fraser, C.S., 2013. Automatic Camera Calibration in Close Range Photogrammetry. *Photogrammetric Engineering & Remote Sensing* 79 (4), 381–388.

Frederick, U., Clarke, A., 2014. Signs of the times: Archaeological approaches to historical and contemporary graffiti. *Australian Archaeology* 78 (1), 54-57.

Holynski, A. et al. 2020. Reducing Drift in Structure From Motion Using Extended Features. *Proc. of the 2020 International Conference on 3D Vision (3DV)*. IEEE, Piscataway, 51-60.

Kimvall, J., 2014. *The G-Word. Virtuosity and Violation, Negotiating and Transforming Graffiti*. Dokument Press, Årsta.

Lewisohn, C., 2009. *Street art. The graffiti revolution*. Tate Publishing, London.

Lovata, T.R., Olton, E. (Eds.), 2015. *Understanding graffiti*. Routledge, Abingdon, New York.

Luhmann, T., Fraser, C.S., Maas, H.-G., 2016. Sensor modelling and camera calibration for close-range photogrammetry. *ISPRS Journal of Photogrammetry and Remote Sensing* 115, 37–46.

MacDowall, L., 2019. *Instafame. Graffiti and street art in the Instagram era*. Intellect, Bristol.

Masilamani, R., 2008. Documenting Illegal Art: Collaborative Software, Online Environments and New York City's 1970s and 1980s Graffiti Art Movement. *Art Documentation: Journal of the Art Libraries Society of North America* 27 (2), 4-14.

Molada-Tebar, A., Lerma, J.L., Marqués-Mateu, Á., 2018. Camera characterization for improving color archaeological documentation. *Color Research & Application* 43, 47-57.

Monschein-Oberreither, K., 2019. *Das politische Graffiti im urbanen Raum. Spurensuche im Geographie- und Wirtschaftskundeunterricht*. Diploma thesis, Vienna.

Patel, S.S., 2007. Writing on the Wall. The Graffiti Archaeology Project challenges the definition of archaeology. *Archaeology* 60.

Pomerantz, J., 2015. *Metadata*. The MIT Press, Cambridge.

Reinecke, J., 2012. *Street-Art. Eine Subkultur zwischen Kunst und Kommerz*, Second edition. Transcript Verlag, Bielefeld.

Ringhofer, A., Wogrin, S., 2018. Die Kunst der Straße – Graffiti in Wien. *Wiener* 428, 46-53.

Trognitz, M., Ďurčo, M., 2018. One Schema to Rule them All. The Inner Workings of the Digital Archive ARCHE. *Mitteilungen der Vereinigung Österreichischer Bibliothekarinnen und Bibliothekare* 71 (1), 217-231.

Verhoeven, G., 2016. Basics of photography for cultural heritage imaging. In: *3D Recording, Documentation and Management of Cultural Heritage*. Whittles Publishing, Caithness, 127-251.

Wacławek, A., 2011. *Graffiti and street art*. Thames & Hudson, London.