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Master thesis

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2023

TECHNISCHE UNIVERSITÄT WIEN
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Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

"The Nuances of Mapping Street Art – Developing a Web Map for Interactive Graffiti Exploration"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Dresden, 7 September 2023 Oskar Baumann

Abstract

Graffiti and street art are dynamic urban art forms characterized by their ephemeral nature and dependence on the urban environment for context. This research delves into the spatial dimensions of graffiti and street art, with a particular focus on cartographic perspectives and considerations.

The research unfolds in three key phases: a comprehensive literature review, the development of a web map prototype, and an empirical user study. The literature review identifies the challenges of mapping graffiti and street art, explores existing web map approaches, and investigates symbolization techniques suitable for representing these diverse art forms across various scales. Drawing from this knowledge, a web map prototype is developed using MapLibre GL JS, integrating multiple graffiti representations and interactive features, including a 3D map mode. The final phase of the research entails an evaluation of the prototype, including its graphical user interface and interactive functionalities, through a qualitative user study.

The findings reveal that users predominantly favor a 3D map environment when exploring graffiti along Vienna's Danube Canal. While the prototype's interactive features enable users to address complex spatial, temporal, and semantic queries regarding graffiti, usability issues, particularly graffiti visibility, are identified. Ultimately, this research contributes to a deeper understanding of how cartography can effectively capture and preserve the spatial nuances of graffiti and street art in an evolving urban landscape.

Keywords: *web mapping, graffiti, street art, interactivity, feature generalization, 3D maps*

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List of Abbreviations

CSS	Cascading Style Sheets
DEM	Digital Elevation Model
GL	Graphics Library
GUI	Graphical User Interface
HTML	HyperText Markup Language
JS	JavaScript
LOD	Level of Detail
OSM	Open Street Map
OSS	Open-Source Software
PNG	Portable Network Graphics
UI	User Interface
WGS	World Geodetic System

1 Introduction

1.1 Motivation and Innovation Aimed at

The public perception of graffiti, particularly with the emergence of street art, is undergoing a notable transformation, moving away from being primarily viewed as an annoyance and gaining greater acceptance, particularly among scholars. Yet, graffiti remains an underexplored and undervalued research topic.

Graffiti and street art are inherently ephemeral art forms, relying on various media for preservation and dissemination. While graffiti artists continue to create their works in the physical world, digital representations of these artworks are increasingly shared online. The digital realm is becoming more widely adopted and utilized by practitioners of graffiti and street art. The social media platform Instagram stands at the forefront of efforts to garner more attention for these intricate artworks (Honig and MacDowall, 2017). Without such platforms, these creations would remain visible only to fortunate passersby, who may inadvertently overlook them, as they are often destined to be concealed by subsequent layers of graffiti paint.

Among the many digital ways to share and disseminate these artworks is the map medium. While there has been a fair bit of research and attention on spatial analysis of graffiti (Tokuda *et al.*, 2021; Bartzokas-Tsiompras and Konstantinidou, 2023), exploring the intersection between the domains of street art and cartography is still a relatively unexplored area. This research seeks to delve into the connection between cartography and graffiti, both in theoretical and practical terms, in an effort to initiate the exploration of this intriguing crossroads between domains.

The cartographic medium provides a clear and visual representation of how graffiti and their surrounding environment relate to each other, particularly in a spatial context, thereby effectively preserving this connection. This approach prevents the loss of contextual information that is essential for gaining a more comprehensive understanding of graffiti and their cultural and social messages.

Numerous projects currently exist that gather (geo-)data for individual graffiti artworks (Masilamani, 2008; de la Iglesia, 2015; Hansen and Flynn, 2015; G. Verhoeven *et al.*, 2022), and there are several web-based maps dedicated to graffiti with the goal of engaging audiences in interactive exploration. Nevertheless, the majority of these maps do not fully exhaust the technological capabilities offered by modern web mapping technologies, nor do they prioritize cartographic practices like feature-targeted generalization for optimal graffiti representations.

Spatial data related to graffiti exists, but in most cases, maps have not kept pace. Progress in this field is a significant gain. By identifying applicable cartographic design principles and harnessing modern web mapping techniques, including 3D mapping technologies and adaptive symbologies with varying levels of detail achieved through targeted simplification of features, it becomes possible to craft more visually captivating and informative map-based representations of graffiti data. This, in turn, is expected to enhance the effective dissemination and understanding of the phenomenon that is graffiti and street art.

1.2 Research Objectives and Questions

The research objectives are as follows:

RO1: To perform a literature review examining the spatial aspects of graffiti and street art, particularly as they pertain to cartographic perspectives and considerations. This review aims to collect relevant works, including (web) maps focused on these urban artforms.

RO2: To implement the insights gained from literature and related (web) maps in the development of a web map prototype. The primary purpose of this prototype is to demonstrate a compelling interactive map-based exploration of graffiti along Vienna's Danube Canal (Donaukanal). To accomplish this objective, multiple interactive functionalities will be integrated into the map, including an optional 3D map mode. The prototype will also employ simplified geometric representations of graffiti to adapt to varying scales or zoom levels. These varied map feature representations will be generated from polygon geometries using feature-specific map generalization techniques.

RO3: To evaluate the finalized web map prototype by conducting a user study, involving participants who will be observed during their interaction with the prototype. and provide feedback to questions in an interview setting. The primary objective of this evaluation is to gauge the prototype's usability.

These research objectives are designed to provide answers to the following research questions:

Literature-based research questions:

- **RQ1:** What are the (unique) challenges of mapping graffiti and street art?
- **RQ2:** What approaches exist for presenting graffiti (and graffiti-like structures) in web maps?
- **RQ3:** What symbolization types can be used to represent graffiti across varying scales or zoom-levels?

Implementation-based research questions:

- **RQ4:** How can these symbolization types be derived from polygon geometry data?
- **RQ5:** How can the insights gained from previous research questions (RQ1-3) be applied in the development of a web map prototype for exploring graffiti?

Evaluation-based research questions:

- **RQ6:** How useful is the web map prototype - its design and interactive features - for exploring graffiti in a spatial context?
- **RQ7:** How does the user-experience differ when exploring graffiti in the prototype's 2D or 3D map mode?
- **RQ8:** How could the web map prototype be improved in terms of usability?

2 Graffiti: Definitions and Spatial Perspectives

2.1 Defining Graffiti and Street Art

There exist many contesting definitions for graffiti. A substantial portion of these definitions characterize graffiti based on their unauthorized and illegal nature, as exemplified in Ross's (2016) definition in the 'Routledge Handbook of Graffiti and Street Art': "graffiti typically refers to words, fig-

ures, and images that have been drawn, marked, scratched, etched, sprayed, painted, and/or written on surfaces where the owner of the property (whether public or private) has NOT given permission to the perpetrator" (Ross, 2016, p. 1). With the exception of the emphasis on the illegality of graffiti, this definition already serves as a solid foundation for this research. Further elaboration on its nuances will be offered shortly.

It is preferable to avoid defining graffiti solely on the basis of its legal status, since the words, figures, or images that fall under graffiti can be both legal and illegal. Otherwise, such a narrow definition would exclude graffiti on personal property, on explicitly endorsed public surfaces or commissions.

As the definition given earlier suggests, in this research, something that can be considered graffiti is not limited by the type of visual content, nor is there a single technique that is valid for its creation on a surface. At this point, however, it is worth noting the typical style of modern graffiti. as evident in the Oxford English Dictionary definition of graffiti, which highlights a particular technique when defining graffiti as "words or images marked (illegally) in a public place, especially using aerosol paint" ('Oxford Dictionary of English (2nd edition, revised)', 2006). Aerosol spray dispensers were an iconic part of and the most used technique in the emergence of modern graffiti in the USA beginning in the 1960s as part of hip-hop culture (Masilamani, 2008). The spray cans with their spray nozzles (or caps) were and continue to be a frequently depicted motif in image (or character) based graffiti (Schmieding, 2011).

However, the majority of graffiti content of that era was letter-based (Waclawek, 2008). As a consequence, graffitists, active participants in graffiti creation, are commonly known as 'writers' (Lachmann, 1988). Within the graffiti subculture, 'graffiti writing' primarily entails the creation of bold, vibrant renditions of 'tags' and 'crews'. A 'tag' signifies an individual's self-fashioned graffiti identity, while a 'crew' represents the collective identity of a group of writers collaborating together (Iveson *et al.*, 2014). Typically, these 'tags' are concise, often consisting of around four to five letters.

The term 'graffiti' dates back to the writings of the Italian Renaissance painter Giorgio Vasari who used the word 'sgraffito' in 1550 to refer to a technique of scratched patterns on the facades of houses related to fresco (Vasari, 1550). Around 1850 the meaning of the term 'graffiti' shifted from its technical meaning towards its use by researchers of ancient history (Blanché, 2015) to describe words or inscriptions discovered on ancient remains, such as those unearthed in the ruins of Pompeii (Stahl, 1990). Indeed, the term may refer to both ancient as well as contemporary graffiti.

While in everyday conversation, 'graffiti' has become both singular and plural, in this research, as in many scholarly works, we will maintain a clear distinction. The term 'graffito' will be employed for the singular form, and 'graffiti' will be reserved for the plural form, in line with its initial usage by Vasari (Schlegel *et al.*, 2022).

This research considers graffiti, even hastily marked signature-like tags, as a personal human expression and, therefore as art. Consequently, a 'graffito' is also referred to as an 'artwork' and its creator can be identified as a 'graffiti artist', a 'street artist', or simply an 'artist'.

Here, it is fit to acknowledge and mention 'street art' as a relative of 'graffiti' and an art genre and movement itself (Blanché, 2015). What is now widely referred to as 'street art' made its breakthrough as an established term in the media in 2005, as explained by Reineke (2007). It is worth noting that in terms of nomenclature, things could have taken a different turn, as terms such as

"post-graffiti" or "urban art" were all competing for relevancy at that time. John Fekner, who is considered a street art pioneer, offers a notably simple yet broad definition of street art as "all art on the street that's not graffiti" (Lewisohn, 2008, p. 23). This definition seemingly distinguishes street art from conventional, text-centered aerosol spray paint-based graffiti, thereby allowing for a broader spectrum of artistic expressions. By the same token, this is what makes defining street art even more difficult which Bengtsen (2014, p. 11) echoes that the "term street art cannot be defined conclusively since what it encompasses is constantly being negotiated". In any case, the label street art has gained more public acceptance than that of graffiti, which is often associated with pure vandalism. Another clear difference between the two, as Kramer (2019) points out, is the differing social backgrounds of graffiti and street art practitioners.

Street art is not the same thing as graffiti. Yet the borders between the two art forms are somewhat fluent (Blanché, 2015). For instance, there are graffiti that showcase artistic, out-of-the-box thinking, pushing the boundaries of conventional graffiti, just as there is street art that heavily emphasizes text and writing.

For the purposes of this research, it is suitable to use the terms graffiti and street art interchangeably, acknowledging the blurry boundaries and shared elements between these two art forms. However, street art is generally more flexible in its artistic manifestations with sculptures, statues and installations aligning more fittingly with the street art category specifically.

According to Parker and Khanyile (2022), there is significant merit in refraining from making a rigid distinction between graffiti and street art. They support this sentiment by referencing Avramidis and Tsilimpounidi (2017, p. 11), who argue that this more inclusive approach enables the establishment of "theoretical, methodological, and empirical connections". Additionally, they cite Ferrell (2016, p. 27), who describes graffiti and street art as evolving through "a series of dialectical tensions".

2.2 Graffiti and Related Terminology

As with any other subject or subculture, it can be astonishing for an outsider to discover the richness of the vocabulary used by its members. This terminology is indispensable for people immersed in the culture, as it allows them to have precise and meaningful discussions about different aspects of the graffiti sphere.

There is no general set of graffiti-related words and definitions that has been agreed on. There is a wide, flexible albeit unofficial terminology developed and passed on by insiders of the graffiti culture. The broader public and the media employ a more limited vocabulary to describe graffiti-related phenomena, often unaware of the distinctive terminology used by graffiti practitioners.

Scholars entering this subject from various disciplines have also developed their own intricate terminologies, which partly adopt and partly distance themselves from terms used by graffiti artists. This divergence may stem from an attempt to convey a sense of professionalism, as some of the terms used within the graffiti community may have been perceived as too simplistic, vague, confusing, or unsophisticated by researchers.

As the academic graffiti community continues to mature, there have been recent efforts to refine scholarly terminology (Schlegel *et al.*, 2022). These efforts go beyond mere lists of terms found on websites catering to specific subsets of the community or cumbersome glossaries that are used

only within a single scientific article. More recently, efforts have also been made to address the linguistic fuzziness and take on the challenge of creating a graffiti thesaurus, "[b]eing a finite set of terms (i.e. a controlled vocabulary) with hierarchical relations" (Schlegel *et al.*, 2022, p. 203).

Now, to briefly summarize the graffiti-related terminology and synonyms used in the context of this research:

- The terms 'graffiti' and 'street art' are largely interchangeable. Graffiti may also be referred to as '(street) artworks', 'markings', or '(master-)pieces'.
- An individual creating graffiti is denoted as a 'graffitist', an 'artist' or a 'creator' (of graffiti). When emphasizing the production of textual graffiti, they may be referred to as a 'writer'.
- The act of producing graffiti is also described as 'mark-making' or 'art-making'.
- When it is spoken of 'walls' in connection to graffiti, it generally serves as a concept that can be applied to any surface capable of bearing graffiti.

2.3 Temporal Context of Graffiti

Graffiti stands out as one of the most transient forms of human expression, marked by its ephemeral nature. This distinctive trait of graffiti is generally expected by artists, who often create with the understanding that their works are destined to be fleeting and temporary (Curtis, 2005).

Most graffiti walls undergo frequent repainting, a result of the dynamic interplay between various writers who compete and collaborate on the shared public canvas. In most cases, such as in very active graffiti areas, the use of the term 'lifespan' may be somewhat misleading when referring to the initial duration of a piece's visibility, since numerous creations lie concealed beneath layers of fresher paint, potentially gaining new life when resurfacing under certain conditions (MacDowall, 2016). Conversely, on more secluded or less accessible surfaces, the same graffiti may never be covered and endure until it is eventually removed by natural forces. Thus, a particular work can last for years, weeks, or mere hours.

The average time it takes for graffiti to get covered by new graffiti varies greatly from wall to wall and depends on numerous factors including weather conditions. A compelling case study to consider is MacDowell's (2016) investigation into graffiti's temporalities. Based on near-daily visits, he tracked six walls at a single fenced suburban site in Melbourne, Australia, for over 600 days starting in mid-2014. His data shows a total of 186 pieces that were painted by 73 artists resulting in a weather-adjusted average time of visibility for each graffito lasting 20 days before being repainted. These results are interesting and help to demonstrate the short-lived nature of graffiti. However, to use the words of the study's author, "due to the many complex factors through which graffiti is produced, the results can't be extrapolated to other sites nor can a causal link be demonstrated" (MacDowall, 2016, p. 57).

As with any art form, graffiti is undergoing a continuous evolution on a broader scale, having undergone significant shifts since its earliest manifestations among ancient civilizations (Benefiel and Sypniewski, 2018; Helms, 2021). Turning points in its ongoing journey include the emergence of modern graffiti during the 1960s as part of the rise of New York City's hip-hop culture (Masilamani, 2008). Other significant milestones include the diversification and subsequent rise of the street art

genre, which is still gaining increasing public acceptance, and graffiti's integration into the age of globalization and digitization (Waclawek, 2008). The moment of a graffito's creation is telling as it positions it time-wise within a broader macroscopic frame.

Graffiti is notably shaped by preceding works, whether in proximity, partially covering, or completely concealed beneath the same surface. In the latter case, the newly created works can be interpreted as successors to the ones they obscure. Graffiti writers perceive this creative process as an ongoing dialogue. The way this interaction unfolds through the medium of aerosol spray paint on a wall is what led Hansen and Flynn to describe it as "a form of asynchronous, yet sequential, communication" (Hansen and Flynn, 2015, p. 30). At times, the dialogue can escalate into a graffiti battle, a scenario where rival artists or crews engage in a competition for surface space, consistently obscuring each other's creations in an attempt to maintain control of the territory (Merrill, 2015).

The discourse on the walls takes on an additional layer of temporal complexity by the nature of more elaborate graffiti pieces, which can take several days to complete. This requires the artists to revisit the site in subsequent days to continue their work. Consequently, in the meantime, the graffito may already be covered by other artists while it was in its unfinished stage of creation.

The persistence of new graffiti occurring over existing is indeed noteworthy. Nevertheless, most urban residents tend to perceive this ongoing transformation only at a subconscious level (Curtis, 2005). The intricate additions and explosive reinventions of these surfaces often go unnoticed during sporadic visits. Retrospectively, they can only be understood through continuous (photo)documentation (Wild *et al.*, 2023). Without such documentation, graffiti remain temporary, accessible only to fortunate eyewitnesses, potentially introducing bias into research (G. J. Verhoeven *et al.*, 2022).

Photo records of graffiti become more insightful as they capture the gradual changes in a site's appearance over time. A chronological record of substantial changes occurring at a site can reveal the markings' relationship to their context, far surpassing the insights of a single static image (Chmielewska, 2009).

An understanding of the temporal context of graffiti is part of the basis for any form of legitimate social content-based interpretation and analysis. For it is crucial to not only place them correctly in their time setting but to comprehend the sequence and chain of causality in which subsequent graffiti are placed to influence, reference, interact with and reframe each other's messages.

2.4 Spatial Dynamics of Graffiti

Graffiti or street art can be regarded as one of the most spatial forms of artistic expression, by virtue of its underlying proposition: the entire urban landscape as an intricate, boundless canvas open to creative visual art-making. Thereby, graffiti art transcends the spatial confinements and restraints of conventional art galleries, as Austin (2010, p. 33) puts it, "[it is] no longer paintings on canvas that mimic the image-strewn city walls, but the city walls themselves as the canvas for new image-making". In other words, the city walls themselves are the medium for image creation. This introduces a new dimension as graffiti artists not only have to think about where to place their markings in relation to each other on the canvas itself but also take into account their placement within the broader physical environment.

First, let's consider the practical implications of the spatial flexibility of the artists or creators of graffiti where to place their pieces. The global phenomenon of graffiti is not restricted by geographical or cultural boundaries. It emerges on public civilized infrastructures, often captivating the attention of unsuspecting passersby who were not actively seeking it.

Individuals traversing urban spaces can encounter graffiti artworks in a multitude of locations and across various surfaces of the public square. While most of these viewers do not intentionally seek out these artworks, on the side of the graffiti creators, however, there sometimes lies a distinct thought process guiding the creation of the artwork. Within this process, the choice of location for a graffiti piece holds particular significance.

Among the critical considerations is the choice of location for a graffiti piece. Above all, graffiti writers aspire for recognition, a pursuit that necessitates the exposure of their work to a wider audience. Consequently, every instance of graffiti creation involves a purposeful evaluation of factors like visibility, location, and associated risks (Ferrell and Weide, 2010). As a result, graffiti often emerges in an array of settings, ranging from accessible spots to seemingly unreachable locations like highway overpasses or elevated rooftops, extending to mobile surfaces like train carriages.

This diverse spatial distribution of graffiti's occurrence underscores its potential as a feature for cartographic representation, presenting the opportunity to unveil diverse patterns within urban landscapes.

2.5 Graffiti and their Environment

Graffiti and street art are highly contextual art forms that are deeply intertwined with their location and time of creation in more than one way. The role of the spatial context of graffiti goes deeper than pragmatic considerations on the part of their creators regarding location, visibility and lighting.

Indeed, location assumes a crucial role from the outset, beginning with preparation, planning, artistic inspiration, and the conceptual vision behind the artwork. However, this significance extends further into the act of creating a graffito, its visual content, its intended audience, its underlying meaning, the interpretation thereof and the conveyed message to the audience.

Each phase surrounding graffiti is distinctly characterized by spatial considerations. According to Pugh (2015, pp. 421–422) : "graffiti should be understood as a composite practice, consisting of an image as well as an act and a specific space. The action that creates a graffito is as important as its visual component, and its spatial context is also crucial to its analysis". Once a location has been chosen for a graffiti piece, and the creative process has given rise to the artwork, the chosen spot itself becomes an intrinsic component of the artwork's identity (Ferrell and Weide, 2010).

How is a graffito's visual content related to its location and spatial conditions? The content and theme of graffiti often draw inspiration from their immediate environment including infrastructure, nature or other graffiti (Wild *et al.*, 2023). Pieces can reference their surroundings and engage in a creative dialogue with them (see Figure 1). All of them are scaled according to their spatial limitations and the space available in a wall section. Some are tailored in a way so the usually two-dimensional surfaces they cover seem to cleverly interact with or incorporate their three-dimensional surroundings. This dialogue between neighboring graffiti and their environment partly leads some to view graffiti walls as 'narrative space' (Sennett, 1990; Carver, 2018).

Figure 1. Contextual graffiti. Left: Nature themed at a grassy area in Gdańsk, Poland (2019). Right: Pirate treasure map themed near a harbor in Szczecin, Poland (2019). Photos by Nathan Winder.

In a similar fashion, graffiti content may allude to and address local political, ideological, and cultural issues (see Figure 2). Given the traditionally textual character of graffiti, they can function as both a form of public visual communication as well as direct public speech. Coupled with the fact that they are bound to and occupy space, it becomes evident that graffiti are inherently political (Carver, 2018). In every instance, an artist's creation mirrors the distinct political and cultural dynamics of the time and location in which they are crafted to at least some degree.

A graffito's politically charged content can vary in meaning according to its spatial context. For instance, consider a graffiti tag that reads, "Transparency Demanded Here". The interpretation of this message can range from directedness to ambiguity, and its interpretation is greatly influenced by its spatial proximity to entities such as banks or government offices. Likewise, the location of the graffito assumes a pivotal role in terms of potential impact. This distinction becomes evident when comparing, for instance, political murals in public versus private spaces. Notably, graffiti upon significant objects wields a comparable influence to the inherent power of the object itself (Ermolaeva, 2014).

Graffiti offers insights into cultural dynamics, territories, and can amplify marginalized voices while sparking political discourse (Lorah, Shirey and Lawrence, 2023). The Urban Art Mapping research project (https://www.urbanartmapping.org/, accessed on 7 September 203) for example, has compiled a database of more than 3,000 geographically tagged graffiti associated with widespread protests against racism and police brutality sparked by the death of George Floyd in 2020 (see 3.7.1). Examining the city of Minneapolis, USA, the project found geographical clustering aligned with the pathways traversed during the protest marches. High concentrations were prominently positioned around intersections, public transit hubs, and commercial properties. There was a discernible spatial pattern wherein graffiti content near areas of conflict between protesters and law enforcement showed an increased sense of confrontation and emotional intensity (Bishara, 2021).

Figure 2. Political graffiti: Left: “EULEX” and “Made in Serbia” in Pristina, Kosovo (2009). Right: Dove in bullet-proof vest by Banksy outside the Palestine Heritage Centre near Jerusalem (2017). Photos by Nathan Winder.

In fact, a dual and reciprocal relationship exists between graffiti and their urban environment. Once created, graffiti become a part of the environment, influencing and reshaping it in return. Ferrell and Weide (2010, p. 50) call it a “dialectic relationship” in which the world of graffiti and the city develop through their symbiotic social process. Chmielewska (2007, p. 147) further describes this process by stating that graffiti “interact with their urban contexts in ways that are shaped by their linguistic, iconic, and territorial significations and, in turn, inflect their specific context with different meanings”.

Ermolaeva (2014) offers an illustrative example of how graffiti can exert control and influence how individuals perceive and behave in public spaces. She lists areas under bridges, near subways and trains, and abandoned buildings as overlooked and underused parts of the city that graffiti transforms into vibrant social centers, turning these spaces into semi-official canvases for artistic expression and platforms for marginalized groups to participate in political discourse. In her words: "In this sense, spaces that previously held no significant role in the social agenda are integrated into everyday life" (Ermolaeva, 2014, p. 24).

That applies, for example, to Vienna's Danube Canal (see 4.2), which was transformed from a relatively unremarkable and mundane part of the city into an iconic and vibrant destination. This transformation was primarily achieved by establishing it as a hub for graffiti and street art, making it an attractive place for people to visit and socialize (Ringhofer and Wogrin, 2018).

Alternatively, a controversial perspective on this matter is the ‘broken windows theory’ put forth by social scientists Kelling and Wilson (1982). The theory explores how various indicators, including graffiti, can signify to people that law and order are not upheld in a specific location, potentially encouraging criminal behavior in individuals.

2.6 Degrees of Site-Specificity

The level of evident connection between a graffito's visual content or text and its environment can vary significantly. While some pieces are more clearly and outright contextualized as previously discussed, others appear disconnected, for instance, those resembling posters.

Not all street art adheres to the same level of site-specificity. While some works are intricately tailored to their locations, others could potentially fit into various settings. The degree of site-specificity in street art varies, and the quality of this specificity can evolve over the lifespan of a piece due to the ephemeral nature of street art. A street art piece might reference a particular wall, a specific area, a street, a city, a country, or even encompass all of these simultaneously (Blanché, 2015).

Contrary to that, the philosopher Nicholas Riggle (2010, p. 246) highlights a meaningful connection of street art to its environment as a requirement to be considered as such in the definition he gives: “An artwork is street art if, and only if, its material use of the street is internal to its meaning.” This prompts the question of whether poster-like street art pieces lacking apparent site-specificity should be categorized as street art. Bengtsen (2014) critiques this defining criterion as being too vague, remarking that it is unclear who is to judge if the use of the surroundings is indeed essential for an artwork.

In the case of poster-like graffiti their use of the street may seem more arbitrary. That is not sufficient proof, however, that the site has no bearing on it. Site specificity is not dependent on conscious deliberations. According to Bengtsen (2013), any artwork can be construed as site-specific (in one or more senses) regardless of the artist's intentions. He goes on to suggest that it is better to speak of site-oriented works when they are intentionally designed to interact with the environment in which they are placed in order to generate meaning.

2.7 Decontextualization of Graffiti

As outlined, all forms of street art hold implicit, or in some cases, intentional site-specific meaning to varying degrees. The central question relates to the extent that meaning is lost when artworks are displayed outside their original spatial context, for example, when they are physically removed by being cut out of a wall.

When graffiti is dislocated from its original environment, it is referred to as ‘decontextualization’. This concept is of high significance, especially when it comes to graffiti documentation, including archives, collections, databases and (web-)platforms, the latter of which most applies to this research.

To commence, let's address the issue of physical removal. For many graffiti artists, the act of physically detaching and subsequently relocating their works from their native environment is considered far more objectionable than their mere chemical removal as it contradicts their fundamental principles. Therefore, in the case of most artists, any form of alteration may cause them to disassociate themselves from their work. Street artists generally refuse to vouch for the authenticity of dislocated street artworks (Bengtsen, 2019).

With respect to graffiti that has been physically detached, often for the purpose of for-profit sale, there is consensus among scholars about the detrimental effects on graffiti's authenticity. The core meaning of a street artwork is shaped by its fixed, ephemeral, and noncommercial context on the

street. When it is transplanted to a gallery or warehouse and labeled with a price tag, the inherent street context dissipates. This is particularly evident in the artworks that are applied directly to solid surfaces with spray paint, making them difficult to physically separate. Even if it is technically possible to remove such artworks from their original location without materially damaging them the authenticity of the work is damaged, leading to its conceptual and financial devaluation as it is separated from its ideological environment. Thus, there is certainly a basis for the assertion that a work of art is fundamentally altered and thus destroyed and or rendered inauthentic once it is removed from its original site (Bengtsen, 2013).

This viewpoint is echoed by Ferrell and Weide (2010, p. 50), who were both active graffiti writers for a combined time of 25 years. Their perspective on the matter is very absolute: “it remains the case that each instance of graffiti takes on meaning only as it is literally and precisely situated in the urban environment”. This contrasts with advertisement posters or billboards for instance (Riggle, 2010). The meaning of an advertisement remains unchanged when removed from the streets. Its core message of urging viewers to purchase a product or observe an event remains consistent regardless of its placement. The impact of an advertisement can diminish when it is removed from its public setting, potentially rendering it ineffective as commercial art. Yet its fundamental meaning persists. On the other hand, if graffiti is taken away from its original wall and relocated to a warehouse or gallery, the integrity of the artwork's meaning is substantially compromised, if not entirely lost.

Still, there is a basis for adopting a more nuanced perspective concerning the displacement of graffiti. This view acknowledges that specific facets of meaning may remain, while others may emerge or undergo alteration. When graffiti transitions to a gallery setting, its meaning may be transformed through the new interpretive lens that the audience brings to it. For the graffiti writers and the broader graffiti scene, the particular (territorial) meaning of a graffiti piece is forfeited when it is dislocated from its spot. To them, a moved graffito is no longer the same graffito, even if the lettering styles remain identical and the symbols of identity and crew affiliation persist (Ferrell and Weide, 2010).

However, new meanings may emerge for certain viewers. The negative qualities associated with graffiti are gone and graffiti takes on an entirely new meaning as an actual piece of art – a commodity (Cresswell, 1992). Thereby the art world has, as Hagopian (1987, p. 107) puts it, “domesticated a formerly feral animal”. Through the transformative effect of displacement, for some, graffiti may be changed from a wild, criminal, unintentional, and underappreciated creation of a vandal to a creative, inspired, and aesthetically pleasing product by the artist. It can be appreciated from an entirely fresh perspective, one that focuses more on the artwork's aesthetic qualities. Through the process of relocating from the street to say a gallery the meaning of graffiti and its moral assessment are changed dramatically. In addition, it is plausible that some meaning survives the threshold of its new context, perhaps through additional background information conveyed via an accompanying text.

2.8 Digital Context Expansion

Now, let’s examine the digital circulation of photos of graffiti pieces as it pertains more directly to this research. In the classical sense, a “graffiti painting is enclosed within a proper space and time and delimited for consumption as a singular artifact" (Stewart, 1988, p. 173). However, the present

norm involves encountering graffiti through digital photographs, a departure from the conventional 'painting' on surfaces. Images of graffiti, whether shared in print magazines or posted on platforms like Instagram, effectively extract it from its intended spatial and temporal confines.

Consequently, the model of site-specificity, as delineated by Kwon, becomes fractured as graffiti artworks cease to be "singularly and multiply experienced in the here and now through the bodily presence of each viewing subject, in a sensory immediacy of spatial extension and temporal duration" (Kwon, 2002, p. 11). While the instantaneous dissemination of images through the internet, with its infinite replicability per client, appears to diminish the significance of physical space (Carver, 2018), in parallel, it amplifies an artwork's reach and visibility, in a sense broadening its spatial context. Moreover, the digital share-button, bypassing the need for labor-intensive printing and publishing processes, allows a digital copy of a graffito to be viewed online while the physical artwork itself is still visible out there, freshly painted upon a tangible wall. The apparent 'context collapse' (Carver, 2018) due to digital propagation might, in fact, signify a 'context expansion'.

There exists a "[l]ong-standing love affair between photographers and graffiti" (Chmielewska, 2009, p. 1). Brassaï, a pioneer in graffiti photography who first documented the art form in Paris in the 1930s (Scott, 2007), noted that "[m]ore than any other form of artistic endeavor, graffiti are dependent on photography" (Brassaï, 2002, p. 8). Photography is what allows the survival of the ephemeral artworks beyond their removal, decay or covering. It fosters discussions, appreciation, exchanges, artist interactions, and serves as documentation for future historical analyses. Photography offers the most effective way to preserve and archive short-lived graffiti as cultural heritage. When employed for documentation or authentic dissemination, photos should remain neutral and unbiased, revealing the artist's creation while minimizing the photographer's personal interpretation. Early guidelines for documenting graffiti emerged during the infancy of the internet. One of the earliest websites on graffiti, Art Crimes (graffiti.org), offered advice on photographing graffiti: "First of all, you are documenting an art form, and not creating art on your own - don't be creative with your shot" (Webb, 1996). Another factor in photographically documenting graffiti that has seen some research attention is color fidelity. Bold and vibrant colors are a widely recognized feature of graffiti. Colors should be reproduced as accurately as possible, which represents quite a challenge as "[t]he science of color (called colorimetry) is non-trivial" (Molada-Teba and Verhoeven, 2023, p. 86).

Graffiti and street art are increasingly viewed through screens, albeit with varying levels of abstraction from their spatial and social context (MacDowall, 2016). Spatial context may often take the form of geo-tagged locations – an accurately set pin on an integrated map frame. Social context may come in the form of an artist's about-page, the Instagram caption text attached to the graffiti picture posted and the ongoing time-stamped discourse in the comment section.

However, not all digital manifestations of a given graffito are created equal. A single graffito photograph by itself rarely conveys its full message as intended by the graffitist. MacDowall (2008) sees the interactions between graffiti and forms of media primarily leading to graffiti's reproduction beyond its initial spatial context. He cites Brassaï as an example who supplemented his recorded graffiti data with contextual information about its spatial surroundings. Recognizing the limitations of his initial documentary approach, Brassaï began to include small sketches and diagrams with his photographs, describing the locations of the works so that he could photograph them again in various stages of decay.

A digital photograph of a graffito, accompanied by metadata detailing its creation time and geographic coordinates, is thus digitally "enclosed within a proper space and time" (Stewart, 1988). Furthermore, besides simply promoting the art form, photos shared digitally can motivate viewers to venture out and experience the original work in person. A map might guide them in their search, preserving the spatial context of the graffiti long after its physical form has decayed.

Contemporary graffiti artists are increasingly embracing the digital realm, integrating it into their creative process and considering its implications as they create their street artworks. Hale and Anderson (2019) touch on this trend when showcasing notable graffiti works they have documented. One such piece depicts a profile portrait of a man with an open mouth, from which a speech bubble emerges containing two lines of numbers: '55.870056 -5.306956', representing the latitude and longitude coordinates of its location in Pollphail, Scotland (see Figure 3). When these coordinates are input into online mapping tools, they direct the viewer to the central recreation block of the village. Through digital media, the work quite literally puts Pollphail on the map, allowing remote viewers to discover its location while viewing a photograph of the piece. In doing so, the artist initiated the documentation process by geo-referencing the work for future archival purposes, prompting contemplation about the role of the digital archive in the artistic lifecycle. As the village has since been demolished (Galloway, 2022), any traces of the artwork or clues for placing the photograph would have vanished in the absence of this specific documentation approach.

Figure 3. A photograph of a graffiti piece in Pollphail, Scotland, incorporating geographical coordinates of its location into the artwork itself. Photo by Alexgchale. Link to the license (accessed on 7 September 2023).

3 Graffiti as a Primary (Web) Map Feature

The following sections delve into the intricacies of mapping graffiti, encompassing reflections on the visualization of both individual and collective graffiti map features. These discussions explore the implications and considerations associated with maps in which graffiti or street art takes center stage as the primary feature, with a particular emphasis on presenting geospatial graffiti data through web maps.

The sections follow a logical flow, transitioning from theoretical considerations to more practical mapping concerns. To conclude the exploration, related works in the form of interactive graffiti maps currently available on the internet are cataloged and examined.

3.1 The Map Medium in Uncovering Spatial Relationships of Graffiti

As delineated in chapter 2, graffiti are deeply connected to the environment they are placed in. As a highly contextual art form, the loss of connection to its spatio-temporal context is detrimental to graffiti's meaningfulness. When preserving and presenting graffiti data, associated spatial information is of great importance and should not be neglected as "each instance of graffiti writing comes to life at a particular location - and within a network of locations that, taken as a whole, chart contours of status and meaning within the world of urban graffiti" (Ferrell and Weide, 2010, p. 50).

To visualize graffiti in their spatial context, revealing such literal contours of status and meaning within a city, one may use the established medium of a map. A map allows for a clear and intuitive way to present spatial realities and their relationships, making them arguably the most suited solution for conveying graffiti data precisely as situated in its surrounding spatial context. By utilizing maps as a medium for presenting graffiti data inherently counters the risk of spatial decontextualization, thus preserving the crucial locational information of graffiti.

Furthermore, the map is an appropriate medium as according to a definition by the International Cartographic Association, "[it] is designed for use when spatial relationships are of primary relevance" (ICA, 2003) which they are, in the case of graffiti. Especially due to their contextual nature, graffiti make for appropriate main mapping features. They deserve to be selected as a main mapping feature and thereby be highlighted in prime visual hierarchy on maps dedicated solely to giving insights into this phenomenon. They may be represented by map symbols conveying their shape in different levels of abstraction.

Concerning graffiti-dedicated maps, all other map features, be they streets, buildings, parks, or rivers play a larger role than just providing relative spatial orientation for the graffiti features. As they represent the actual spatial context of graffiti, they give hints to better understanding of their meaning. To grasp their nuanced relationship with each other, relevant parts of the urban landscape must be present on the map in the first place. The proximity of these parts to graffiti becomes increasingly significant, as they exert more profound influences on one another - a principle encapsulated in the first law of geography, according to Waldo Tobler, that states: "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970).

Thus, among the urban landscape, the most crucial parts are those directly covered by graffiti. Logically, a graffito never exists in isolation within space; it necessitates a backdrop, a canvas, so to speak. A Graffito always exists in conjunction with other objects whose surface's it wholly or partially covers. A map can answer the simple question of what object a given graffito covers. When the scale of the map is sufficiently close, the information about what a graffito covers becomes easily readable on the map as a map faithfully reflects the real spatial relationship between a graffito and its covered object. However, it is crucial not only to incorporate these secondary features into the map but also to maintain a sufficient level of spatial accuracy and alignment. This is necessary to accurately depict their topological spatial relationships (Egenhofer and Franzosa, 1991).

As graffiti can cover nearly all objects of the urban landscape. Therefore, a map must be sufficiently detailed to shed light onto the spatial nature of the graffiti-surface-interaction. For instance, graffiti are commonly found on small or minor walls, dumpsters, trash bins, utility boxes manhole covers, or other elements of the infrastructure which many maps omit. To ensure comprehensive coverage of all surfaces boasting graffiti, an aerial imagery map appears to be the most suitable choice. However, it is worth noting that such a map has its separate drawbacks compared to a more abstract representation, such as a topographic map. For instance, an aerial imagery map may not capture underground spaces and areas of the city concealed by overhangs, roofs, bridges, all of which can potentially feature extensive graffiti.

In general, conventional top-down view maps have inherent limitations when it comes to representing the vertical dimension of our environment. While this perspective is useful for revealing spatial relationships between objects or entities horizontally, such as their relative positions in front of, between, behind, to the left, or to the right of one another (Bertin and Berg, 2011, p. 286), it falls short in providing vital information on what lies above or below a specific graffiti artwork.

When dealing with graffiti, which are typically applied to predominantly vertical surfaces with multiple artworks potentially stacked above and below each other, this fixed 2D map view obscures crucial details. Furthermore, the bird's-eye view perspective, described by philosopher Thomas Nagel as "the view from nowhere" (Nagel, 1989), does not align with our natural perception of the world.

Tilting the map view angle introduces improvements into understanding the spatial situation of graffiti along the vertical dimension. While an oblique map view, or one nearly perpendicular to a given surface, akin to the approach of Kolecka (2011) to map and visualize steep (close to vertical) rock walls, allows deeper insight into individual sections like singular walls, its applicability on a broader scale remains inadequate due to the intricate nature of graffiti. Graffiti frequently spans multiple directions across surfaces, presenting challenges for comprehensive cartographic visualization.

An effective solution emerges with the use of digital 3D maps, offering full control for interactive camera rotation of 360°. This reveals to map-users what's both directly above and below any given graffiti features, thereby enabling a comprehensive representation of complete graffiti-covered walls. When integrated with 3D terrain data and other abstracted 3D map layers such as buildings, it yields an enriched understanding of the environment while still consistently serving its fundamental purpose as a map medium. This forms the concept behind the web map prototype (see 5.1).

Ultimately, it is vital to acknowledge that the attempt to uncover the influences between graffiti and their spatial environment solely through the medium of a map is somewhat limited. While it can provide insights to some extent, it's important to recognize that a map, by its very nature, is an abstracted model of spatial realities. Consequently, it can only illustrate fractions of the multifaceted relationship between graffiti and the environment.

For instance, a map can help indicate spatial trends, for instance where certain locations have a higher concentration of graffiti with fish- or water-related themes by showing the presence of bodies of water nearby. Similarly, it can highlight the proximity of nature-themed graffiti to parks and green areas. However, to fully capture all the aspects of the intricate interactions, relying solely on

a map may prove inadequate. Maps on their own, whether 2D or 3D, cannot offer an exact impression of what it's like to stand and observe graffiti from a grounded perspective. They can only provide hints of how graffiti authentically interacts, merges with, and is influenced by its surface material and immediate spatial surroundings.

3.2 Multimedia Graffiti Maps

A pure map itself as an inherently abstracted and generalized representation of spatial information (Lapaine *et al.*, 2021). While being a visual medium, it is limited and cannot display the exact visual content of graffiti as a photo can. A map on its own can show the positioning and spatial dimensions of graffiti within the given locality, but not how the graffiti looks to the human eye. For illustration, a thematic map representing graffiti map features with various color-categorized symbols may indicate the attributes of a graffito. It can thus provide information about a graffito' visual gestalt and attributes such as colors, information content, etc., but will never and is not intended to directly display the appearance of graffiti.

A photo can capture a scene the way our eyes perceive it – how the light falls and is reflected by objects including those covered by graffiti. Comparatively, a map by itself is abstract and not as realistic. Therefore, a graffiti map relies on supplementary visual information like photos or sketches beside the standard textual attachments such as a title and legend.

A map is easily merged and enriched by other media. With the steady emergence of increasingly user-friendly and more functional multimedia (web-)mapping technologies, the notion of abstraction being the ultimate goal in cartography seems outdated (Peterson, 2007). Instead, "[m]ultimedia Cartography is based on the compelling notion that combining maps with other media (text, pictures, video, etc.) will lead to more realistic representations of the world" (Peterson, 2007, p. 64). Web maps are capable of grounding graffiti data spatially while complimenting it with information in various media formats. This makes multimedia graffiti web maps ideal to avoid (spatial) decontextualization by letting users interact and gain a varied nuanced understanding.

Interactive media being so commonplace, users are accustomed to interactive multimedia web maps and benefit from increased knowledge formation through hands-on explorative learning (Cartwright and Peterson, 2007). As remarked by Cartwright and Peterson (2007, p. 2): "People want to 'go into' the map, both spatially and conceptually. They want to explore at a deeper level". This aspiration has transitioned from a mere desire to an actual reality. A web map as a base can facilitate user engagement with graffiti through immersive new media experiences.

A compelling illustration of this concept is evident in the 'street artifacts' project's web map (https://streetartifacts.xyz/, accessed on 7 September 2023, see 3.7.1). They provide a web map that serves as an intermediary interface between users and textured 3D models with Augmented Reality viewing capabilities (see Figure 4). This example represents an approach to map-based graffiti exploration, offering users an immersive, multimedia experience.

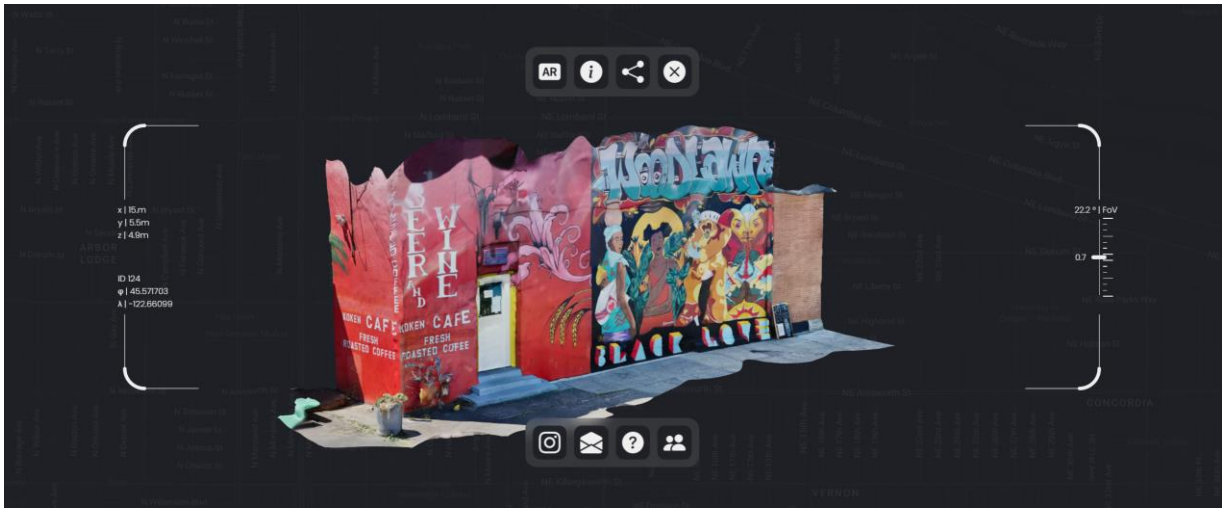

Figure 4. Screenshot of a textured 3D scan by the street artifacts project located in Portland, USA. Note the darkened but still visible corresponding web map in the background. This 3D model can be accessed at: https://streetartifacts.xyz/?id=124 (accessed on 7 September 2023).

A broader example of this immersive trend can be seen in the case of Google Maps (https://www.google.com/maps, accessed on 7 September 2023), which has been providing users with navigable ground-level perspectives of streets since the launch of Google Street View in 2007 (Rundle *et al.*, 2011). This feature allows users to immerse themselves in a virtual exploration of physical spaces. The Arte per strada Torino project (https://www.arteperstradatorino.it/index_EN.html, accessed on 7 September 2023), for example, integrates this service into their street art web map (see 3.7.1), allowing users to jump straight from selected symbolized artwork representations on a 2D web map into the more natural 3D view that points directly to the indicated artwork (see Figure 5).

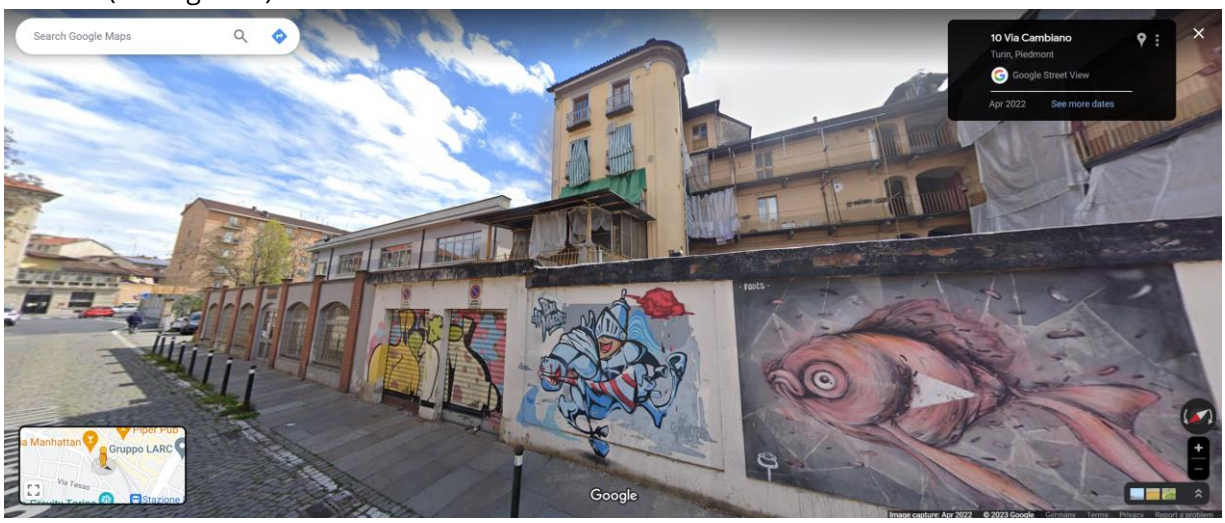

Figure 5. Screenshot of graffiti in Turin, Italy, as viewed in Google Street View. This view can be accesses at: https://www.google.it/maps/@45.0922461,7.6755557,3a,90y,124h,99t/data=!3m6!1e1!3m4!1sEza-EzIHL7sO29XKSr51fEw!2e0!7i16384!8i8192?hl=en&entry=ttu (accessed on 7 September 2023). This view is linked to by the Arte per strada Torino project through the corresponding artwork page that

can be accessed at: https://www.arteperstradatorino.it/schede/scheda_109.html (accessed on 7 September 2023)

3.3 Variability in Graffiti Size, Shape, and Orientation

Graffiti is a highly diverse and variable art form, which presents unique challenges when it comes to cartographic representation. Finding a simple yet effective visual representation that accurately conveys the diverse phenomenon of graffiti and street art can be a challenging task.

One of the primary attributes to consider, the size of graffiti artworks, can vary drastically. The size spectrum is wide of what is considered graffiti and street art. It is influenced by several factors, including the artist's intention, available space, and the level of risk associated with the act (Ferrell and Weide, 2010). Consequently, the diverse range of sizes in individual graffiti artworks presents a challenge when producing dedicated graffiti maps, particularly in establishing consistent symbology to effectively represent key characteristics of graffiti.

Over time, graffiti culture has given rise to numerous types or categories of graffiti. These types are in part distinguished based on their style, intricacy, location, and size (Tokuda *et al.*, 2021). These categories exhibit general patterns, with certain types of graffiti typically adhering to specific scales. However, these patterns are not rigid rules, as graffiti frequently deviate from the conventional size norms associated with their type.

Among the common types of graffiti (see Figure 6), ranging from the smallest to the largest, ‘tags’ are usually seen as the smallest ones (Parker and Khanyile, 2022). They resemble personal signatures, often created swiftly with a single-color marker. Moving up in size, we encounter 'throw-ups,' which typically consist of bubble-style letters rapidly applied to surfaces using aerosol spray cans, often featuring only a few colors, typically a base color and an outline (Penfold, 2017). 'Wildstyles,' although in a similar size range, are more intricate, incorporating elements like arrows and decorations and demand greater skill and time (Whitehead, 2004). Finally, at the larger end of the size spectrum, we find 'blockbusters,' which can extend to the dimensions of entire building facades and are frequently commissioned as large-scale mural projects (Poon, 2023).

Figure 6. Different types of graffiti illustrating the variable size. Top left: A tag. Photo by Author. Top right: A throw-up. Photo by Nathan Winder. Bottom left: A wildstyle. Photo by Joost Derks. Bottom right: A street art mural covering an entire building facade. Photo by Nathan Winder.

Evidently, graffiti exhibit a considerable range in terms of size differences from one piece to another. While there are established conventions associated with various graffiti types, adherence to these norms is not always strict. Many artists are pushing the boundaries, evolving their styles, and deviating from traditional frameworks. Consequently, not all graffiti pieces neatly fit within defined typologies, highlighting the limitations of categorization. Again, it is noteworthy that specific characteristics attributed to graffiti types, such as height or length, do not consistently determine the actual type of graffiti. The diversity of graffiti defies simplistic categorization based solely on physical dimensions.

As an exceptional case illustrating the variability in graffiti scale even within a single type of graffiti, consider MOMO's famous Manhattan tag (Riggle, 2010). In 2006, street artist MOMO embarked on an ambitious artistic venture that left an enduring mark, arguably the largest tag ever created, on New York City's urban canvas. The artist tagged the imprint of his name "MOMO" across the width of New York City with a thin orange line of paint measuring almost 13 km in length from the far reaches of West Village to East River Park. This extraordinary creation defies conventional artistic dimensions, challenging one's capacity for visual comprehension. Interestingly, the best suited medium for grasping the artwork in its entirety is on a map represented by polyline geometry (see

Figure 7). MOMO's creation operates on both minuscule and monumental scales, leading some to regard it as a form of cartographic self-expression (Schacter, 2013).

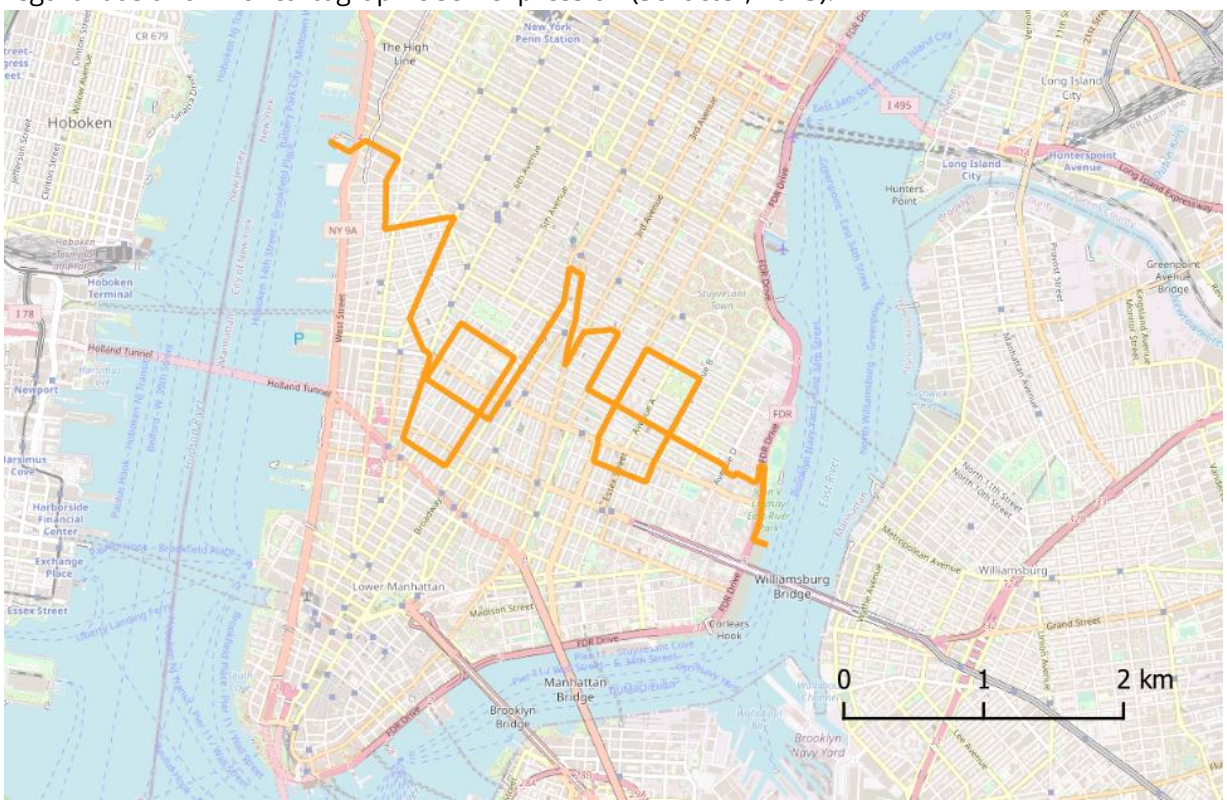

Figure 7. Possibly the longest single graffiti piece: MOMO's Manhattan tag visualized on a map. Map by author based on the map found in The World Atlas of Street Art and Graffiti (Schacter, 2013). Basemap by OpenStreetMap.

Another aspect of variation with graffiti that has implications for mapping is their shape. As an art form unrestrained by the dimensions of regular canvases, graffiti exhibits irregular shapes, devoid of fixed aspect ratios.

The variability is further heightened by their orientation in space. As previously discussed in 3.1, graffiti predominantly extend along vertical surfaces, giving them a slim appearance when viewed from above. However, in other instances, graffiti conform to a more horizontal plane when covering nearly level surfaces. Examples include graffiti applied directly onto roads or sidewalks, flat roofs, basketball courts, skateparks, or the upper sides of electrical boxes (see Figure 8). This diversity in shape and orientation can complicate the process of mapping graffiti effectively.

In contrast to classical graffiti, some street art comes in the form of constructs exhibiting a three-dimensional structure and depth, such as sculptures, statues, or installations. This further underscores the need for thoughtful considerations when designing comprehensive cartographic representations for all forms of street art encountered within specific areas.

Figure 8. Examples of graffiti on near-horizontal surfaces. Left: A marker tag on the top surface of an electrical box. Right: Artwork on an outdoor basketball court.

3.4 Visual Representations of Graffiti in Mapping

Given the inherent variability of graffiti and street art in terms of their size, shape, and orientation, cartographers face the challenge of effectively abstracting and displaying them on maps. There are different design approaches when visually representing or symbolizing the diverse phenomenon of graffiti. There is no universally correct approach; instead, the choice depends on factors such as the available data, the scale, and the conditions specific to the area of interest being mapped. Ultimately, the map's purpose dictates its format (interactive or static) and dimensionality (2D/3D).

Drawing from the theoretical foundations as explained earlier and the insights gained from practical experience in visualizing graffiti through map media, the subsequent table suggests different types of 2D map symbols to represent discrete graffiti artworks:

Map Symbol Type	Data Required	Optimal Map Scale	Graffiti & Area Conditions	Level of Detail Needed
Point features (dots, markers, icons)	1 Coordinate pair or street address	Global to continental scale (world maps, entire countries or regions displaying multiple cities)	Graffiti are rather small	Only approximate locations of graffiti, not their detailed area or length
Line features (polylines)	At least 2 coordinate pairs	Medium to close scale (single city or a neighborhood)	Graffiti are on vertical surfaces & there are continues walls	The extend of surfaces covered by graffiti & the length of individual graffiti, not their area
Polygon features	At least 3 coordinate pairs	Close scale (neighbourhoods or districts)	Horizontally oriented graffiti & sculptural street art	Accurate shape of graffiti (length and area)

Table 1. Overview of the visual representations for graffiti as a primary map feature in 2D maps with additional information to guide their purposeful selection.

As evident from the information in Table 1, the utilization of point-features offers a practical means to streamline data collection efforts, reducing both time and complexity. This approach expands the range of valuable data sources, including Volunteered Geographic Information (VGI), which may take the form of geo-tagged images or even a single recorded street address. In many instances, the provision of a basic coordinate pair, translated into a simple icon representing individual graffiti, promises to be both adequate and versatile, effectively fulfilling diverse mapping needs.

(Poly)Lines offer an effective and straightforward representation method that closely approximates the shape of most graffiti. The advantage of being able to visualize the actual length of individual graffiti is notable, especially when considering the relatively minimal added effort required for data collection. Gathering this data involves the simple acquisition of one additional coordinate pair. The person collecting the data only needs to position themselves at the two approximate ends of the graffiti and record these positions using a GNSS receiver. Therefore, this approach appears to strike a favorable compromise between the level of detail achieved on the map and the effort expended in data collection.

Using polygon-features to represent graffiti necessitates high-detail data acquisition methods, such as photogrammetry. However, there are limited evident use cases for developing maps that aim to prioritize the more precise delineation of the area covered by graffiti.

The general challenge in selecting graffiti symbols lies in the diverse and often intricate spatial characteristics of graffiti, making it difficult to capture their shapes adequately with a single type of visual representation. The effectiveness of maps with a singular type of graffiti symbolization depends on the unique characteristics of the displayed area and the specific type of graffiti present.

Interactive web maps, which allow users to adjust zoom levels dynamically, hold the potential to provide multiple visual representations that automatically adapt as users zoom in or out. This adaptability may involve transitioning between point, line, and polygon symbology, leveraging the respective advantages of each type of map symbol as it relates to graffiti's variability. This technique is demonstrated in the developed web map prototype (see 4.4).

3.5 Graffiti Boundaries and Visual Clutter

The concept of boundaries in graffiti refers to the demarcation between individual graffiti, often found in close proximity to one another. The borders between individual graffiti artworks can be unclear, presenting a challenge for documentary and cartographic endeavors alike to determine exactly where one work ends and another begins. Practically, it is difficult what part of an intricately painted wall to attribute to which artist. In fact, there often is an ambiguity in where to draw the boundaries of graffiti.

While some graffiti artists purposefully leave spaces between their pieces, others may intentionally overlap or blend their work with existing graffiti, creating collaborative artworks that can merge, interact, and intertwine. Frequently, subsequent unsolicited additions to or alterations of graffiti pieces occur through other graffitists. This renders the categorization and delineation of a single graffiti artwork's boundaries ambiguous and, at times, nearly impossible. This necessitates a case-by-case assessment, often placing the responsibility of interpretation on map authors and data providers rather than the artists themselves.

Furthermore, during the documentation process, it may not always be clear whether a graffiti artwork is finished or still a work in progress, leaving room for ambiguity. On top of that, certain more intricate graffiti compositions may incorporate other types of graffiti such as tags or consist of multiple different components, whether textual or image-based. Consequently, it can be less intuitive to discern what is intended to belong together to form a single, cohesive artwork.

The inhomogeneous distribution of graffiti, marked by areas of intense spatial density within urban environments poses further challenges. For instance, a single wall may be densely covered with hundreds of tags (see Figure 9), creating a concentrated graffiti hotspot. Conversely, other areas of a city might display sporadic occurrences of larger murals or isolated tags. When attempting to delineate each individual graffiti instance as a distinct map feature, these highly concentrated graffiti hotspots become even more prominent, further complicating the task of mapping graffiti, due to limited space on a map. This complex approach to mapping graffiti often leads to visual clutter as graffiti features, representing actual graffiti stacked above or below each other on a wall, are inevitably overlapping each other. This effect stems from the inherent limitations of projecting three-dimensional data onto a two-dimensional map.

Figure 9. A photograph of a graffiti-covered wall showcasing the abundance of overlapping graffiti, highlighting the overwhelming challenge of deciphering each graffito's individual boundaries and spatial extent.

The decision to consider each individual mark, graffito, or complete wall a single feature on a map can significantly impact the level of detail and accuracy in graffiti mapping. Thus, defining the extent of an individual graffiti becomes a crucial task in accurately representing the distribution of graffiti on maps. Capturing every individual graffiti feature on a map can lead to information overload, visually cluttered maps, and reduced readability. On the other hand, ignoring the variability of graffiti can lead to oversimplification and loss of valuable information about street art culture in a given area.

To address the challenge of spatial variability, cartographers can adopt different mapping approaches. The approach to symbolize each individual graffiti by its own discrete mapping feature, provides for a comprehensive and detailed representation of graffiti distribution. This level of granularity allows for a more nuanced understanding of street art hotspots, artist styles, and evolving trends.

However, mapping every individual graffiti feature may not always be feasible or practical, especially in densely graffitied areas. In such cases, a second approach may involve treating an entire area, graffiti-covered wall, building, or a large graffiti composition as a collective feature. To achieve this, the cartographic generalization operator referred to as ‘merge’, ‘dissolve’ or ‘amalgamating’ may be used, that was first delineated by Imhof (1936). This approach simplifies the map by representing graffiti as concentrated clusters or continuous stretches, reducing visual clutter while still acknowledging their presence.

The approach of amalgamating all graffiti within a specific area, such as a public transportation station, into a singular collective map feature is frequently employed in graffiti web maps (see 3.7.2). Similarly, the technique may be adopted when the available data is of low spatial accuracy, as seen, for instance, where multiple artworks on a single building are associated with that same street address, resulting in a convergence to a single spatial location.

Dynamic or adaptive clustering represents a commonly used variation of collective map features in web mapping to address visual clutter, often described as simply “too many markers” (Fürhoff, 2019). In this method, the number of individual features clustered together is contingent on the map's current zoom-level and the distance between these features. Cluster symbols usually show the numerical count of individual features they represent, often additionally indicating the number through use of visual variables (Bertin and Berg, 2011). As the user zooms in to decrease the map scale, a growing number of clusters break down into sub-clusters, eventually revealing the individual features once the map is zoomed in sufficiently.

Ultimately, striking the right balance between providing intricate details of individual graffiti features and utilizing generalization techniques is crucial in creating effective and informative cartographic products. Cartographers must be mindful of the map's intended purpose, the target audience, and the specific objectives of the cartographic representation.

For example, when designing a map for graffiti artists and enthusiasts, a more detailed and individualized representation of graffiti may be preferable. Such an approach offers insights into the unique artistic expressions and the specific spatial context of each graffiti feature. Conversely, maps intended for different audiences might prioritize a more generalized representation to emphasize distribution patterns in various neighborhoods.

3.6 Temporal Considerations in Graffiti Mapping

Expanding the observation time period of visible graffiti on a map, in other words, creating a temporal window rather than the traditional single snapshot depiction, can further increase the concentration of graffiti within hotspots. This increase results from the ephemeral nature of graffiti and the continual creation of new artworks atop existing ones. Naturally, as the temporal scope of documented graffiti at a specific location broadens, so does the potential for an increased number of map features overlapping each other and competing for limited map space grow with it.

These overlapping features caused by a longer time period could be dealt with by representing the temporal dimension along an additional measurable axis, such as the z-axis, in this case, to represent time differences rather than height differences.

Displaying graffiti from different time periods on the same map, especially when the depicted graffiti were never contemporaneous, presents an intriguing concept but also introduces more challenges. When the basemap stays constant, only representing a specific moment in time, it becomes misaligned with some of its time-varying graffiti map features. While this misalignment might be negligible over a short time span, in certain cases, the urban environment can undergo dramatic changes, resulting in incorrect spatial and temporal contexts. A potential solution for interactive maps is to have various adjustable basemaps, possibly capable of changing automatically to align with graffito features as selected by the user. To note, in some cases, obtaining access to multiple basemaps from different dates to adequately span the time frame of graffiti features to be mapped may not be possible or feasible.

Animated maps provide a solution to the challenges posed by varying time frames in mapping graffiti. Animations can enable both the background map and the foreground graffiti features to change dynamically, aligning with real-time periods through shorter yet proportionate time intervals.

3.7 Related Works – Graffiti Web Map Examples

The related works listed below are limited to interactive web maps dedicated to the display of graffiti as they have more relevance on this research work. The web maps show where artworks are located within different urban areas and facilitate the exploration of their attributes through additional (integrated) multimedia content and descriptions.

At present, numerous web maps are available online, with graffiti as the primary map feature. Given the ongoing advancements in internet technologies and software development libraries for web mapping, coupled with the increasing public interest in graffiti, especially street art, it is foreseeable that the number of graffiti dedicated web maps published online will continue to grow.

For a selection of examples of static graffiti maps as part of academic research, see the following works: Dovey, Wollan and Woodcock (2012), Krauthausen et al. (2019), Novack et al. (2020), Bloch (2021), Simmons et al. (2021), Parker and Khanyile (2022) and Wild et al. (2022).

3.7.1 Overview of Graffiti Web Maps

The following overview of graffiti web maps is presented in no particular order. It was compiled based on viewing on a desktop device and not on mobile.

Turin map by Arte per strada Torino (https://www.arteperstradatorino.it/mappa_EN.html#12/45.0696/7.6732, accessed on 7 September 2023, see Figure 10)

- Area covered: the city of Turin, Italy, and its surrounding towns.
- Total number of graffiti map features: around 400.
- Graffiti map symbol: point-features (triangles).
- Symbol classes: differentiated by color, based on artwork type.
- Default basemap design: muted colors, mainly grey tones.
- Web mapping library: Leaflet (via QGIS plugin: qgis2web).

The web map presents five different categories of graffiti features (multiple paintings, single painting, installation, mosaic, panel, sculpture). One of these classes (multiple paintings) represents a collective feature which reduces the total number of symbols on the map and their overlap. Each

map feature links to a corresponding graffiti artworks identification page listing metadata and another link to the artwork as seen from the passersby perspective via Google Street View.

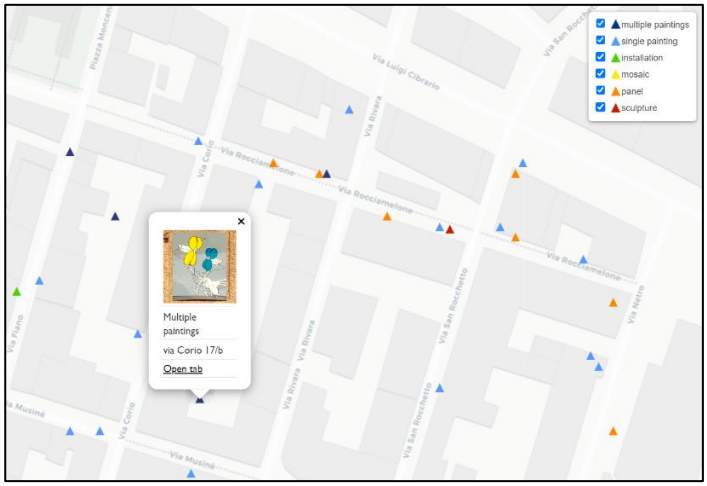

Figure 10. A partial screenshot of the map view of Arte per strada Torino's at large scale.

Atlanta Street Art Map by streetartmap.org (https://streetartmap.org/atlanta-street-art-maps/all-neighborhoods-street-art-mural-map/, accessed on 7 September 2023, see Figure 11)

- Area covered: the City of Atlanta, USA.
- Total number of graffiti map features: 1274.
- Graffiti map symbol: point-features (markers).
- Symbol classes: differentiated by color, based on geographical neighbourhood.
- Default basemap design: Google Maps standard.
- Web mapping library: Google Maps JavaScript API.

While the web map incorporates collective features, it tends to appear rather cluttered when viewed at smaller scales. Moreover, it distinctly supports users to travel and visit the artworks in person by suggesting multiple street art tour routes shown as red polylines with recommended directions of travel indicated by the placement of start-symbols. Leveraging the underlying Google Maps infrastructure, it can easily be used to navigate from one artwork to the next without the use of additional applications.

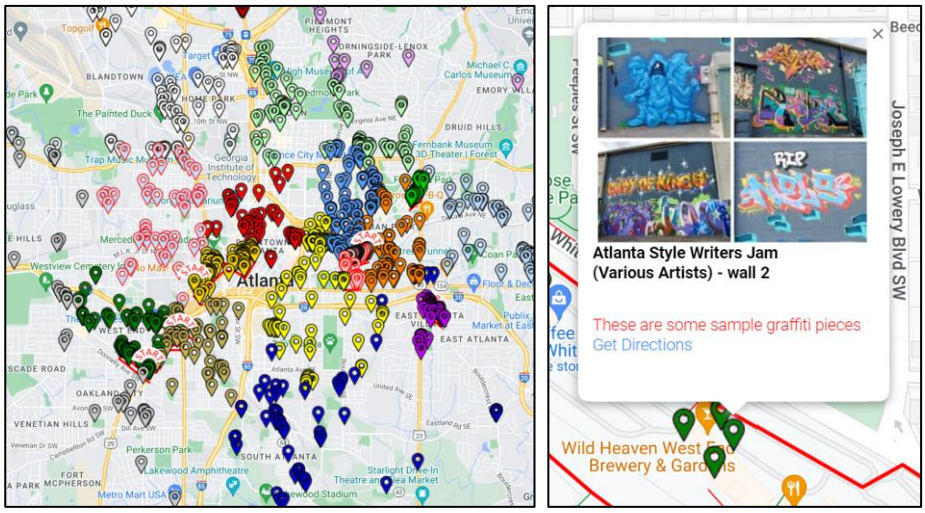

Figure 11. Two partial screenshots of the Atlanta Street Art Map. Left: An impression of the map at city scale. Right: A popup box illustrating the common occurrence of a single map feature representing multiple graffiti.

George Floyd & Anti-Racist Street Art Map by Urban Art Mapping (https://georgefloydstreetart.omeka.net/geolocation/map/browse, accessed on 7 September 2023, see Figure 12)

- Area covered: Worldwide (mostly USA).
- Total number of graffiti map features: 2942.
- Graffiti map symbol: point-features (blue markers).
- Symbol classes: none.
- Default basemap design: muted colors, mainly grey tones.
- Web mapping library: Leaflet.

The map is rather basic, including its symbology, which might not be very inviting for interaction. However, it effectively highlights clear spatial patterns, indicating the paths of protest marches. In terms of performance, there is a slight lag spike whenever the zoom-level is adjusted. Noteworthy are the textual descriptions of each artwork's visual content included in each feature's popup box, potentially improving the experience for visually impaired users.

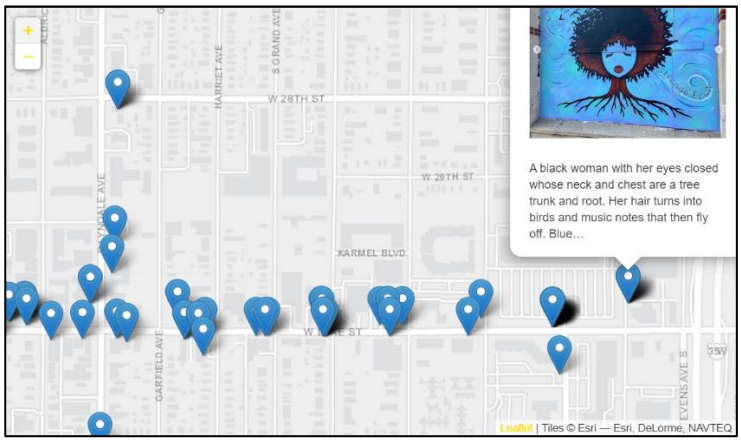

Figure 12. A full screenshot of the George Floyd & Anti-Racist Street Art Map at large scale.

Mural Map - Open Urban Art Museum Mannheim by Stadt.Wand.Kunst (https://www.stadt-wand-kunst.de/mural-map/, accessed on 7 September 2023, see Figure 13)

- Area covered: The city of Mannheim, Germany.
- Total number of graffiti map features: 38.
- Graffiti map symbol: point-features (black markers with labelling).
- Symbol classes: none.
- Default basemap design: urban environment in grey tones and sand-colors, building shapes are subtle, low contrasts, streets and buildings are not labelled.
- Web mapping library: Google My Maps.

This web map contains a relatively small number of artworks, which removes the need for clustering and similar techniques. When web map features are clicked, a sidebar displays multimedia information, including videos. This digital map is supplemented by a well-designed printed static map with several circular zoomed-in insets.

Figure 13. A partial screenshot of the Mural Map - Open Urban Art Museum Mannheim at large scale.

Map by street artifacts project (https://streetartifacts.xyz/, accessed on 7 September 2023, see Figure 14)

- Area covered: cities Portland and New York City, USA; and Karachi, Pakistan.
- Total number of graffiti map features: 213.
- Graffiti map symbol: point-features (semi-transparent yellow circles).
- Symbol classes: none.
- Default basemap design: dark theme - roads in blue, urban environment in grey with buildings in black.
- Web mapping library: Leaflet.

A distinctive and, presumably, aesthetic feature of the map is the presence of crosshairs that move with the mouse cursor, dynamically updating geographical longitude and latitude values. The unconventional color scheme further enhances its visual impact and conveys the technological sophistication of the project.

Upon close examination of the map at a high zoom level, it becomes evident that there is limited detail concerning the precise locations of the scanned graffiti artwork scenes represented by the rather large circular symbols. This uncertainty can likely be attributed to variations in scan sizes, which are not accurately reflected by the map symbols.

Figure 14. A partial screenshot of the street artifacts map at large scale.

Graffiti Map Vienna by SPRAYCITY (https://spraycity.at/map/, accessed on 7 September 2023, see Figure 15)

- Area covered: the city of Vienna, Austria.
- Total number of graffiti map features: 2786.
- Graffiti map symbol: point-features (markers), line-features, and polygon-features.
- Symbol classes: differentiated by color, shape, and feature type; based on artwork type, geographical area, and subway line.
- Default basemap design: muted colors, mainly grey tones (“OSM Positron”).
- Web mapping library: uMap (Leaflet & Django).

This map is particularly noteworthy in the context of this research because it covers the same area of Vienna as the web map prototype developed as part of this study (see 4.2). As a major graffiti hotspot, the Danube Canal (Donaukanal) area is divided into several polygon features representing numerous artworks.

The use of collective features along with dynamic clustering helps mitigate visual clutter and enhances readability to some extent. However, given the total number of map elements, which include points, lines, and polygons, and the fact that some of these are part of separate dynamic clusters, the map still appears somewhat overloaded when viewed at smaller scales.

The map, which includes the layout of the Viennese subway system as part of its interactive web elements, offers insights into the iconic connection between graffiti and public transportation.

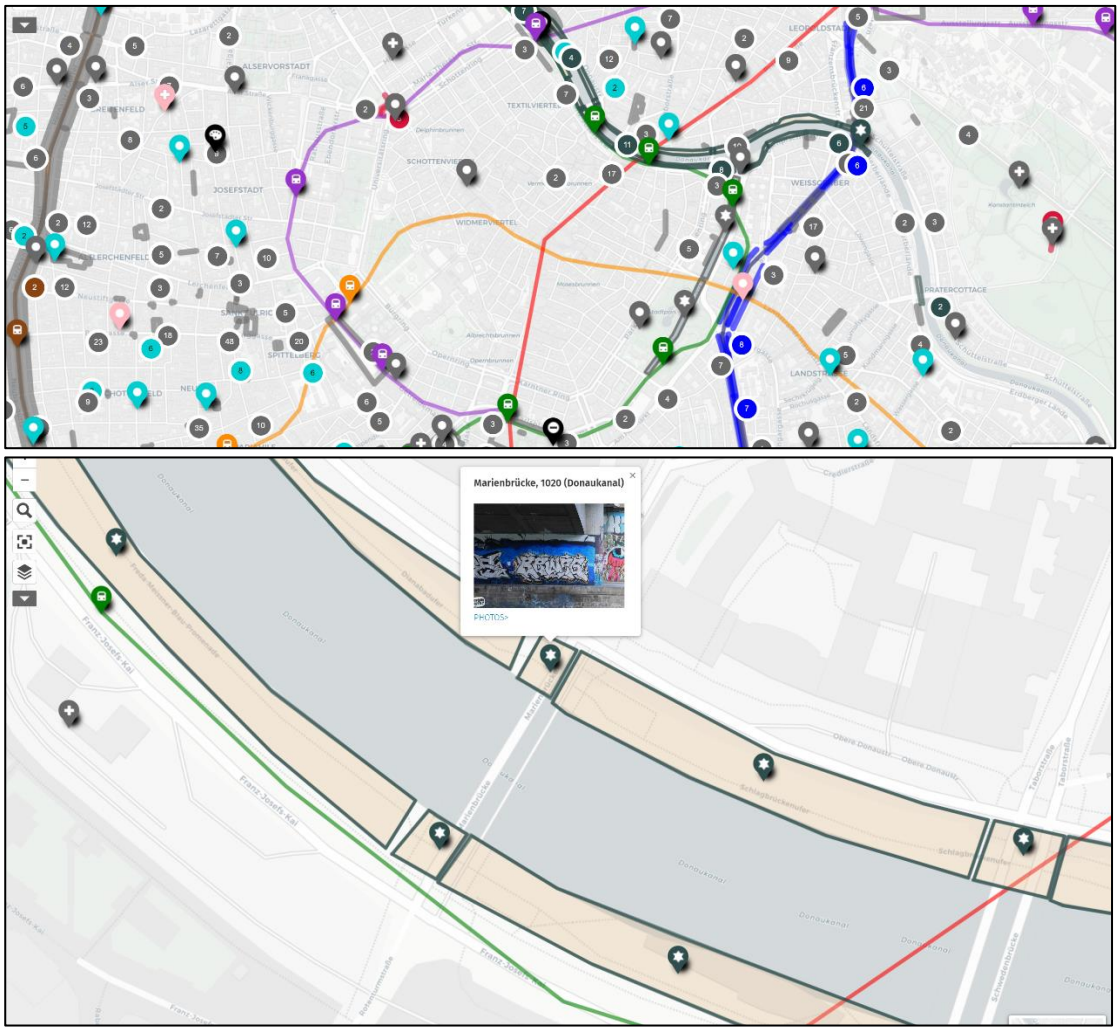

Figure 15. Two partial screenshots of the Graffiti Map Vienna. Top: Showing the city center with subway lines. Bottom: A more zoomed-in look on part of the Donaukanal area.

World Map by Bombing Science (https://www.bombingscience.com/graffiti-map/, accessed on 7 September 2023, see Figure 16)

- Area covered: worldwide.
- Total number of graffiti map features: 1331.
- Graffiti map symbol: point-features (yellow camera icons).
- Symbol classes: none.
- Default basemap design: highly generalized two-color map (bodies of water in blue, land in black), not designed for large scales (does not show streets or buildings).
- Web mapping library: Google Maps JavaScript API.

Dynamic clustering is prominently featured on this map, utilizing three distinct colors to differentiate between levels of clusters based on the number of individual features they represent. However, the accuracy of graffiti map features is limited to a city-level, making the map effective only at small scales.

Figure 16. A full screenshot of the World Map by Bombing Science at small scale.

Worldwide Street Art, Graffiti & Urbex Map by urbanpresents (https://www.urban-presents.net/en/map/, accessed on 7 September 2023, see Figure 17)

- Area covered: worldwide (mostly Germany and Belgium).
- Total number of graffiti map features: 227.
- Graffiti map symbol: point-features (markers).
- Symbol classes: differentiated by color, based on category.
- Default basemap design: Google Maps standard.
- Web mapping library: Google My Maps.

The map includes several collective features, possibly due to a lack of spatial accuracy of the graffiti data. It employs seven color-coded classes: gallery/exibition, graffiti hall of fame, streetart/graffiti, urban exploration (graffiti), trainspotting, festivals, and stores. It's worth noting that the 'stores' class represents actual stores potentially affiliated with the map author, suggesting that part of the map's purpose may be related to selling graffiti-related items.

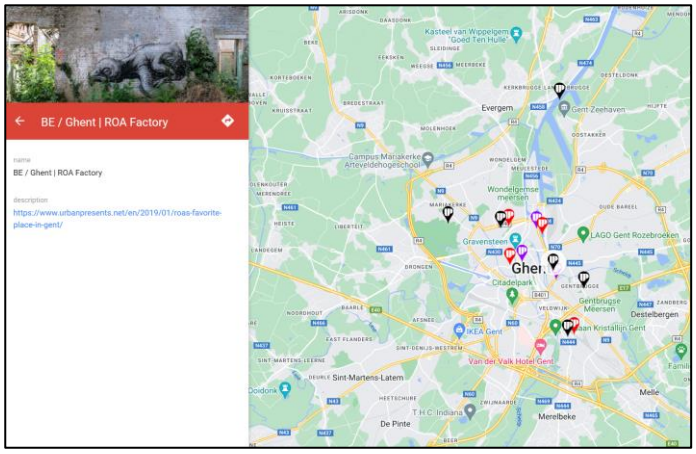

Figure 17. A partial screenshot of the Worldwide Street Art, Graffiti & Urbex Map by urbanpresents at relatively large scale

Los Angeles Map by Street Art Cities (https://streetartcities.com/cities/losangeles, accessed on 7 September 2023, see Figure 18)

- Area covered: the city of Los Angeles (USA) and optionally worldwide.
- Total number of graffiti map features: 2246 (4505 worldwide).
- Graffiti map symbol: point-features (circular thumbnail photos of individual artworks).
- Symbol classes: each artwork is represented by its photo.
- Default basemap design: bright colors, urban environment in light grey tones, parks in green, bodies of water in dark grey, residential buildings are not shown.
- Web mapping library: MapLibre.

This map stands out in several notable ways among the related works. Firstly, it distinguishes itself through the sheer volume of graffiti features it displays. While it initially focuses on Los Angeles, users can pan the map to explore other cities, resulting in a total of 4505 individually placed graffiti symbols. The map employs dynamic clustering to maintain clarity, although this may make it somewhat challenging to discern specific spatial patterns.

Secondly, what sets this map apart is its use of unique symbols, with each one tailored to represent the individual artwork it signifies. Basically, when zoomed in far enough to reveal the individual symbols, they themselves are circular photo images of the artworks. This approach greatly enhances the browsing experience for users looking for visually appealing artworks on the map.

Lastly, the map offers a useful filtering functionality, allowing users to search for specific terms of interest within the graffiti dataset.

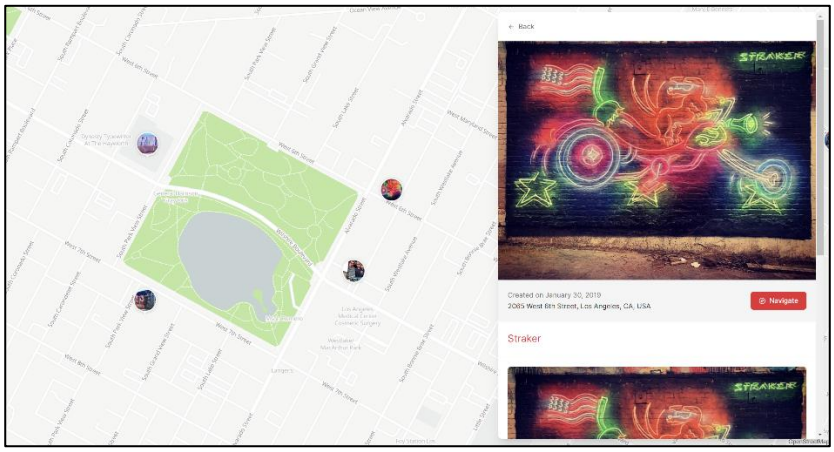

Figure 18. A partial screenshot of the Los Angeles Map by Street Art Cities at large scale.

World Collection Map by Google Art Project: Street Art (https://streetart.withgoogle.com/en-gb/world-collection, accessed on 7 September 2023, see Figure 19)

- Area covered: worldwide.
- Total number of graffiti map features: hundreds.
- Graffiti map symbol: point-features (red circles).
- Symbol classes: none.
- Default basemap design: Google Maps (less detailed).
- Web mapping library: Google Maps JavaScript API.

This web map distinguishes itself through its sophisticated design and smooth functionality, resulting in an outstanding user experience. Clicking on a map feature triggers a responsive sidebar that can be adjusted in size. This dynamic sidebar unveils a slideshow of photographs related to the selected feature. The map includes a selection symbol on the map itself, pinpointing the location of the chosen feature. Hovering over features reveals photos, enriching the user's interaction.

Other highlights in functionality, include a 'Surprise me!' button, which leads users to a randomly selected street artwork, and a way to filter artworks by artist name, with artists listed alphabetically for ease of use. Unfortunately, the level of detail of graffiti features is somewhat limited. In certain instances, it provides only city-level accuracy, and frequently, the features represent spatially scattered collections of artworks.

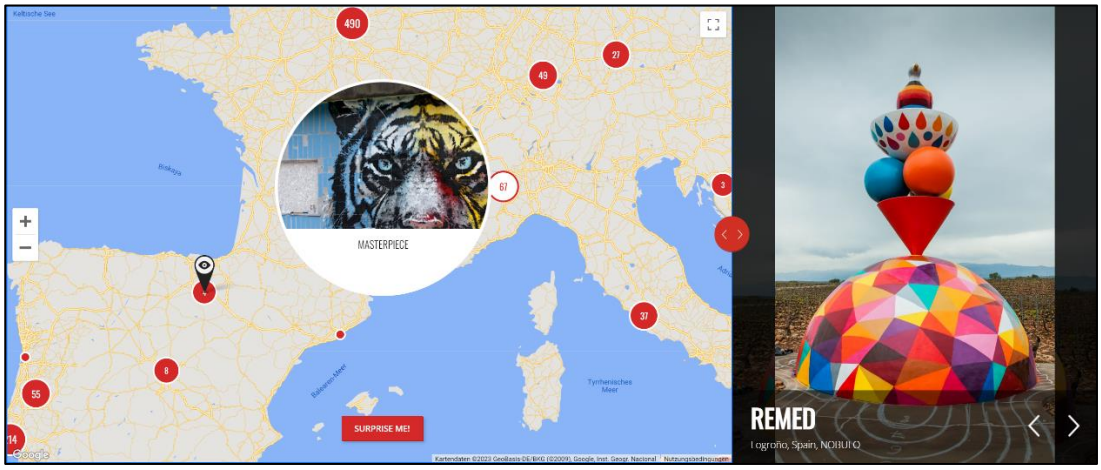

Figure 19. A full screenshot of the World Collection Map by Google Art Project: Street Art.

Street Art Map Berlin by Vagabundler (https://vagabundler.com/germany/streetart-map-berlin/, accessed on 7 September 2023, see Figure 20)

- Area covered: the city of Berlin, Germany.
- Total number of graffiti map features: 1911.
- Graffiti map symbol: point-features (icons).
- Symbol classes: differentiated by color and icon; based on artwork type and object covered.
- Default basemap design: urban environment in beige and sand-color, streets in white, bodies of water in blue, parks are not shown.
- Web mapping library: Google My Maps.

In addition to the Berlin map, the Vagabundler project currently provides 47 city maps that showcase graffiti from various locations worldwide. Each of these city maps may have differently classified graffiti features, reflecting localised graffiti trends. At the same time, local data contributors focus on different types of artworks, leading to these variations in the classes presented. Berlin offers ten classes, which appears to be the maximum limit supported by the web mapping tool used (Google My Maps). These classes include Halls of Fame, Mighty Murals, Golden Nuggets, Electricity Boxes, Exhibitions & Urban Art, Complex Craft, Streetart & Graffiti, Bridges & Highways, Trainstations & Tracks, and Urbex & Lost Places.

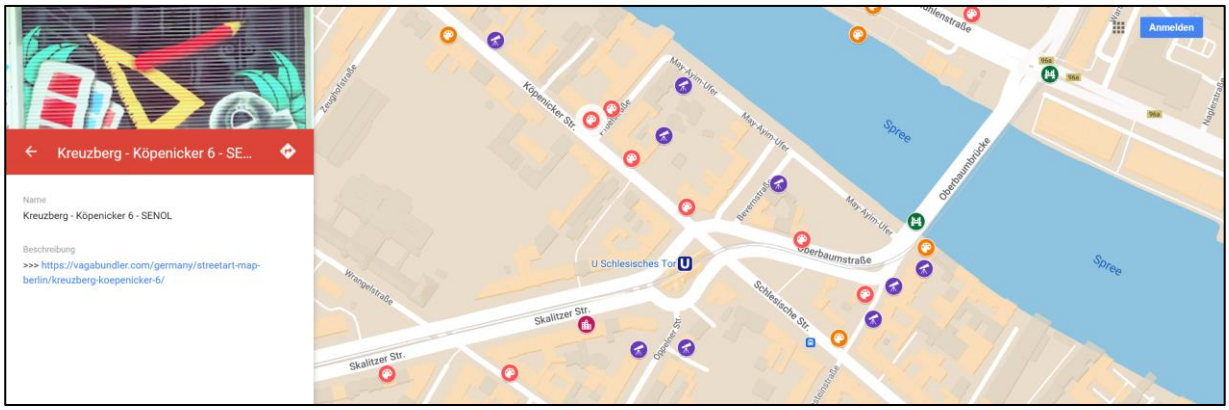

Figure 20. A partial screenshot of the Street Art Map Berlin by Vagabundler at large scale.

3.7.2 Evaluation of Graffiti Web Maps

The compiled web maps dedicated to graffiti and street art show remarkable similarities, with some of them sharing common software technologies and libraries, resulting in almost identical user experiences.

Across the board, these web maps provide users with a consistent set of basic interactive functionalities to interact with the map and its graffiti features. These include zooming, panning, and retrieving of more information aligning with certain work operator primitives identified by Roth (2013). When users interact with features on these maps, such as clicking or hovering over them, individual popup boxes or sidebars appear, providing details on specific graffiti such as photo images, textual descriptions, artists, street addresses, and more. Most of the web maps also offer links that allow users to retrieve additional information and media related to the specific graffiti. Beyond these shared basic functionalities, some web maps allow users to search for a particular location or map feature of interest or to filter the map content. However, beyond these functions, the range of interactive options remains relatively limited.

Concerning basemaps, all employ responsive web tiles ensure seamless user experiences and adjust the basemap's level of detail based on the current zoom level.

Dynamic clustering is a widely utilized technique among these web maps, mainly due to the volume of data represented by map features. Most maps include collective features, which, in certain cases, may not be due to the presence of actual, near impossible to map, graffiti hotspots but rather attributed to limitations in the spatial accuracy of the underlying data.

Regarding the level of detail, presumably for the same reason, none of these web maps prioritize intricate graffiti feature representations when zoomed in, such as line and polygon features. They typically provide information at the level of a single coordinate pair, omitting any finer-grained spatial details indicating the actual shape and extent of individual graffiti.

In terms of innovation, only a few web maps deviate from the standard purpose of documenting and preserving street artworks while presenting them via the map medium for spatial reference. None of the maps introduce 3D capabilities or allow users to reproject the map in other ways. Most of the web maps simply serve as platforms for users to explore and engage with street art on their

own terms. Goals across these web maps appear to be preservation, entertainment and fostering an appreciation for street art found in urban environments.

4 Data and Methods

4.1 Data Sources

For the creation of the web map prototype, multiple freely accessible data sources converge to ideally harmonize and produce an effective and informative visual composition.

Project INDIGO currently provides a sample graffiti dataset in the form of 97 orthorectified image files in the PNG format and 97 corresponding individual geo-referenced high-detail 3D polygons in ESRI shapefile format (MultiPolygonZ). These polygons accurately delineate the spatial dimensions of each graffiti border. A detailed explanation of the methodology used for deriving the polygons and the orthorectified graffiti images can be found in Wild et al. (2022).

Basemaps (raster tiles) for integration into the web prototype are requested from the following hosts using their service-URLs:

1. Basemap.at (https://basemap.at/en/, accessed on 7 September 2023)
    - Grau (grey)
    - HighDPI
    - Orthofoto (orthophoto)
2. OpenStreetMap (https://www.openstreetmap.org/, accessed on 7 September 2023)
    - Standard Tile Layer

Notably, the map tiles from basemap.at exhibit the best alignment with the graffiti data, placing them on walls in a manner that appears highly plausible and accurate where observable.

The data related to buildings comes from two sources. One is again OpenStreetMap (OSM) in the form of their (at the time) latest buildings layer in the ESRI shapefile format covering all of Austria. This source primarily contributes semantic information stored as attributes. The other is Open Government Data (OGD) by Vienna city office department 41 (Magistratsabteilung 41 – Stadtvermessung), specifically, the buildings floor plans dataset in the shapefile format with a specified level of detail (LOD) of 0.4, made up of 500 times 500 meter blocks (available at https://www.wien.gv.at/ma41datenviewer/public/start.aspx, accessed on 7 September 2023). Several blocks were aggregated to cover the area of the Danube Canal. This dataset primarily serves a visual purpose, due to its comparably high level of detail and the inclusion of attributes, such as absolute elevation and base markings.

4.2 Area of the Danube Canal (Donaukanal)

The Donaukanal is a water channel that runs along the edge of Vienna's city center. The canal, along with the pedestrian pathways beside it, is situated at a lower elevation compared to the surrounding urban infrastructure. This configuration results in high-reaching walls or surfaces that enclose the area, effectively separating it from the rest of the city.

Throughout the last two decades, the Donaukanal has achieved iconic status as a lively urban leisure and party area within the city that attracts tourists and residents alike (Ringhofer and Wogrin, 2018). Much of its appeal can be attributed to the presence of graffiti artworks that adorn many of the area's surfaces and are, to some extent, tolerated by the city. These artistic expressions decorate the canal, effectively turning it into a collaborative open-air gallery.

The graffiti data used for this research, provided by the INDIGO project, is located along both sides of the Donaukanal. The dataset specifically encompasses graffiti found between the bridges Donaukanal and Friedensbrücke (or technically Verbindungsbahnbrücke).

Project INDIGO estimates the Donaukanal between these two bridges to contain 13km of continuous graffiti-covered urban surfaces such as wall, staircases, bridge pillars and. This means a lot of room and varied surfaces for graffitists to express themselves on by spraying or otherwise creating large or small-scale graffiti.

The INDIGO project estimates that the Donaukanal between these two bridges encompasses nearly 13 kilometers of uninterrupted urban surfaces covered with graffiti, including walls, staircases, bridge pillars, and ramps (G. Verhoeven *et al.*, 2022). This extensive space offers a diverse range of surfaces for graffitists to express themselves through both large and small-scale artworks, whether through spraying or other creative methods.

Some of the walls along the Donaukanal are designated as legal graffiti walls officially endorsed by the city, while graffiti artworks are de facto tolerated on most other surfaces. As a result, graffiti artists are active even during daylight hours. This constant activity means that artworks in this area often have a very brief period of visibility, before being covered up by newer works, exemplifying the ephemeral nature commonly associated with graffiti.

4.3 Purpose and Target Audience of Web Map Prototype

The web map prototype's development direction is inspired by project INDIGO's initial plans concerning dissemination. As stated on the official website, it includes the creation of a

> "freely accessible online platform that enables scholars, graffitists, and non-specialists alike to visualize, explore, and query graffiti inside the INDIGO database. This web-based interface allows [...] the display of graffiti through time, while simultaneously supporting spatio-temporal-semantic questions like 'where were all political messages from 2021 located' or 'which graffiti was visible for more than three months and featured animals' " (Project INDIGO, 2023).

This outline has been the guiding principle behind the design of the web map prototype, emphasizing its purpose as a map-based platform for interactive exploration of its graffiti map features. This approach stands in contrast to other potential approaches, such as a storytelling-centered web map or one primarily for documentation alone.

The primary objective of the web map prototype is to provide users with the means to explore the main area of focus, the Donaukanal, through the lens of its graffiti map features. Users may apply filters to these features to effectively seek answers to their questions. Moreover, the prototype

serves as an illustration of how a map-based platform aimed at addressing these inquiries can initiate the inclusion of more sophisticated cartographic principles and more innovative functionalities by leveraging the immersive capabilities of the web map medium. This includes, for instance, functionalities such as a 3D map mode and camera animations.

Given the growing popularity of graffiti and street art (de la Iglesia, 2015; DeTurk, 2015), the target audience for this project is broad. It extends beyond the graffiti community and includes individuals of virtually all ages with at least some interest in street art. This audience primarily comprises people from or familiar with the city of Vienna, whether they have lived, studied, visited, or plan to visit the city. This also encompasses tourists interested in street art, as they can use the prototype to gain insights into the Donaukanal area as a de facto outdoor street art gallery before or during their visit.

However, it's worth noting that the finalized prototype, which has been developed with desktop controls and screen sizes in mind, may not be appealing to certain audiences, particularly those who prefer viewing web content on their smartphones.

4.4 Data Preparation and Processing

The separate graffiti shapefiles by project INDIGO, originally in the coordinate reference system MGI / Austria GK East were transformed into WGS 84 commonly used for web mapping via QGIS. They were also combined and converted into a single GeoJSON file of type ‘FeatureCollection’ made up of features of type ‘MultiPolygon’. Additional attributes were added manually to each multipolygon feature, including its ID (graffito #), start and end date of visibility (synthetic dates, not real ones), and other attributes for filtering purposes.

The generated GeoJSON’s graffiti geometry data structure was accessed to generate feature-specific map generalizations through geometric simplification. Different simplification methods were used, partly using QGIS tools and partly through short programming scripts (JS), to create geometries of different complexities (see Figure 21). Starting from the most complex to the simplest, the process unfolded as follows: The original data, consisting of complex polygons with approximately 10 to 30 vertices, served as the foundation. From these complex polygons, simpler polygons were derived, namely oriented minimum bounding boxes (OMBBs), each comprising four vertices. Also, from the original polygons, simple line geometries were created by retaining and connecting a pair of the two furthest vertices from the original polygons. Finally, simple points were generated by identifying the centroids of the original polygons, or more precisely, their convex hulls, as constrained by the QGIS tool function used.

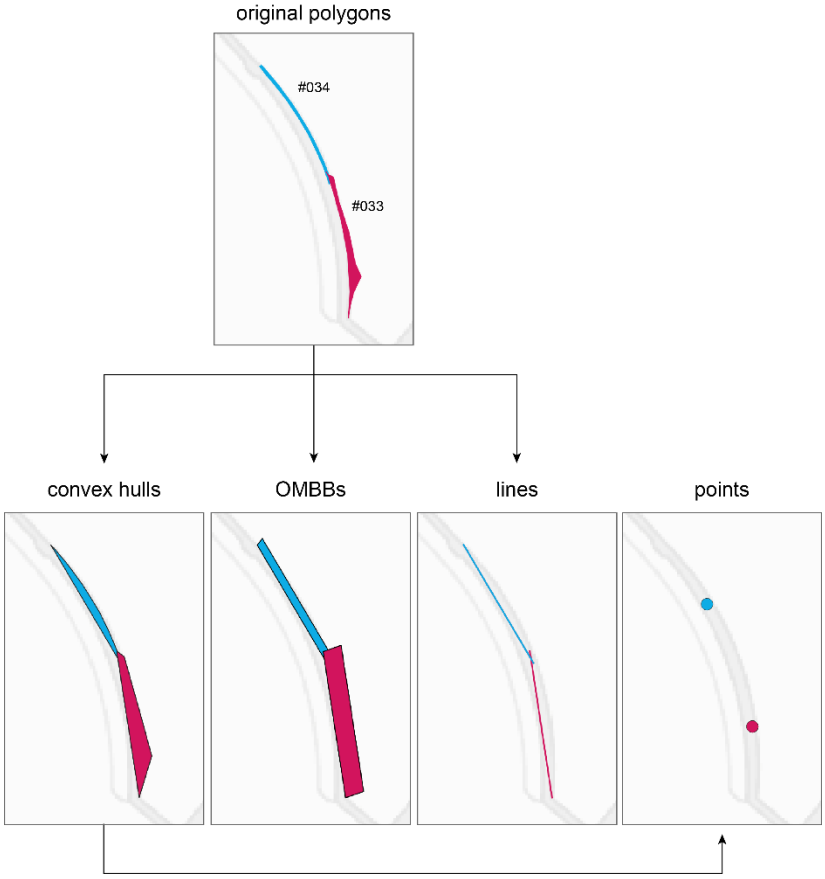

Figure 21. A schematic showing the derivation of simpler representation geometries of the graffiti polygons and their visualization illustrated by two example features.

Moving on, the building data was prepared in QGIS by manually certain eliminating buildings from the geometrically more detailed dataset by the city of Vienna, keeping only those in close proximity to the Donaukanal. This was done to eventually be able to highlight only the area near the Donaukanal.

Following an alignment of the two building datasets to the same coordinate reference system (WGS84), a spatial one-to-one join was performed to add additional attributes to the more geometrically more detailed dataset. This join was based on their intersecting geometries, which is why they first needed to be in the same coordinate reference system. This operation allows the semantic attributes from the more semantically rich OSM dataset to be appended onto the other dataset. Subsequently, the geometrically detailed dataset, now enriched with OSM attributes, was divided into three separate GeoJSON files. This division was carried out to achieve easier import into the web map prototype and the ability to assign them distinct visualization styles.

4.5 Web Mapping JavaScript Libraries and Development

Similar to the larger domain of web development, the field of web mapping is subject to rapid and continual change (Dorman, 2020). The web-based interactive map prototype is developed using established technologies, mainly HTML, CSS, and JavaScript.

In the process of selecting the most suitable web mapping library for the prototype, the guiding resource was Table 2, which provides a comparison of several web mapping libraries:

Feature	MapLibre GL	Leaflet	Openlayers	Harp.GL	Tangram GL	CesiumJS
License	BSD 3	MIT	BSD 2	Apache 2	MIT	Apache 2
Commercial	no	no	no	yes	no	yes
Contributors last month	3	2	10	2	1	5
Stars	971	30,000+	7,800+	803	1,800+	6,600+
Raster maps	yes	yes	yes	yes	yes	yes
Vector maps	yes	plugin	yes	yes	yes	yes
MVT Vector Tiles	yes	plugin	plugin	no	no	no
MVT Vector Styles	yes	plugin	plugin	no	no	no
3D maps	yes	no	plugin	yes	yes	yes
GPU accelerated	yes	no	yes	yes	yes	yes
WebGL	yes	no	yes	yes	yes	yes

Table 2. Comparison of modern web mapping libraries (as of February 2021), specifically alternatives to Mapbox GL JS. Table taken from Geoapify (2021).

After a period of initial familiarization with different popular web mapping libraries and their capabilities, such as Leaflet and CesiumJS, MapLibre GL JS was identified as the most suited for ongoing development. The choice fell on this library as it is open-source, relatively easy to delve into, has many code-examples listed on the official website (https://maplibre.org/maplibre-gl-js/docs/examples/, accessed on 7 September 2023) and offers a lightweight 3D map option. On its background, according to the GitHub repository of MapLibre GL JS (https://github.com/maplibre/maplibre-gl-js, accessed on 7 September 2023), it began as an open source fork of Mapbox GL JS in response to Mapbox switching to a non-OSS license in December 2022.

A notable difference in the web map development between Mapbox GL JS and, for instance, Cesium JS is the perceived complexity in incorporating actual 3D models, which, in personal experience, tends to be more challenging and less intuitive in Mapbox GL JS, especially when lacking prior 3D rendering knowledge. Conversely, MapLibre GL JS offers a notably straightforward approach to creating 2.5D maps or 3D objects by extrusion along the height or z-axis. This extrusion method can be employed to present graffiti web map features in 3D by extruding the initially flat 2D polygons.

From a technical standpoint, this is accomplished by iteratively processing each vertex of the original 3D polygon and determining both the overall maximum and minimum height values. These values are subsequently used to establish the elevation above ground for the entire, horizontally oriented, polygon forming a solid 3D feature. While this solution may not reflect perfect accuracy, it offers a more simplified approach in comparison to Cesium (see Figure 22). It contributes to create a web map that delivers a fast and reliable performance, making it a more light-weight and practical choice, especially when dealing with a relatively small geographic area compared to the extensive global model that Cesium is designed for.

In a similar manner, the 3D building features were implemented and visualized using the values found in the data attribute “O_KOTE” and “U_KOTE” for each element’s elevation above ground and object height, giving them a simplified yet recognizable look.

The building data is meant to be mainly viewed three-dimensionally as the basemaps already contain two-dimensional building outlines. The 3D buildings, as map features, serve a multifaceted role: initially, they offer orientation; following that, they complement the graffiti, providing context to potentially unveil their interactions with one another; then, they guide the user's focus toward the Danube Canal, where graffiti are located; finally, they provide the area with a hinted-at three-dimensional character by depicting the rising heights around the canal, preventing the graffiti from appearing isolated in space.

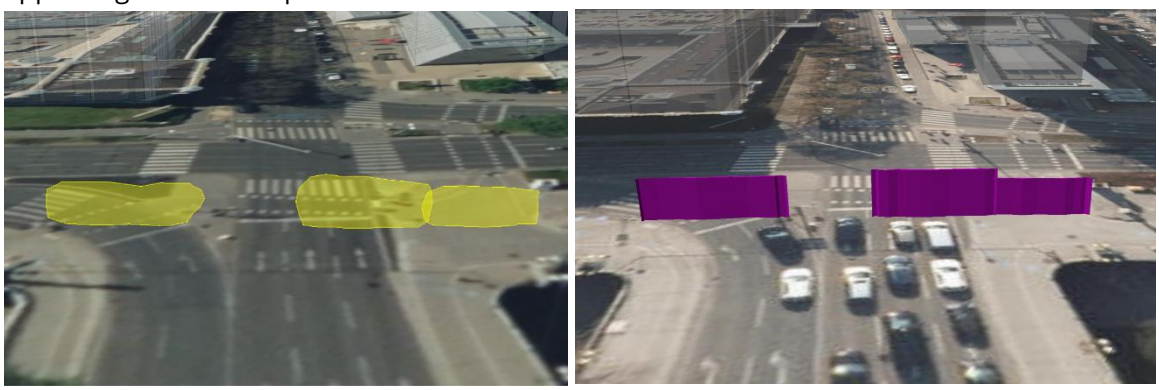

Figure 22. Side-by-side comparison of the 3D visualizations of graffiti features (#048, #049, #050) using CesiumJS (left) and MapLibre GL JS (right). Basemap sources: Bing Maps (left) and basemap.at (right).

Additional secondary libraries that are imported and aid in the development of the web map prototype include Turf.js (https://turfjs.org/, accessed on 7 September 2023) allowing advanced geospatial analysis in a JS environment and noUiSlider (https://refreshless.com/nouislider/, accessed on 7 September 2023), simplifying the creation of range sliders.

4.6 Development Challenges

Challenges and limitations pertaining to the development of the web map via MapLibre GL JS include the aforementioned inability to load actual 3D models to represent graffiti and buildings. Then there was the inability to have an outline around the graffiti features in 3D. The outline also did not look good in 2D mode for the line and polygon representations. Also, due to the visualization method used, the solid colored, otherwise texture-less 3D graffiti features make it impossible for users to tell which side the graffiti are facing, due to not having a backdrop for every graffiti feature in the form of for example high-resolution DSM.

Furthermore, for users to better understand the urban environment of graffiti along the Donaukanal, it would be nice to present the area enriched with more details on the basis of the terrain. It is possible to freely request low-resolution global terrain data from certain hosts. But that is of not much use, as high-resolution terrain data is needed to give a real idea of the terrain of the small area (see Figure 23).

Integrating custom 3D terrain data into a web map built with MapLibre turned out to be a challenge. MapLibre only supports Mapbox terrain RGB and Mapzen Terrarium tiles.

Therefore, many elaborate processing steps were needed. First, a freely accessible high-resolution DEM file of Austria was downloaded and subsequently processed and tailored to align with the Donaukanal area. Following these preparations, a Mapbox terrain RGB file in the MBTiles format was generated, which stores all map tiles within a single file. This was done following a tutorial by Thomas Halwax (https://github.com/syncpoint/terrain-rgb, accessed on 7 September 2023). The file was then uploaded onto a map tile hosting service. However, when integrated into the web map prototype, the results showed drastic distortions and errors of unknown sources (see Figure 23).

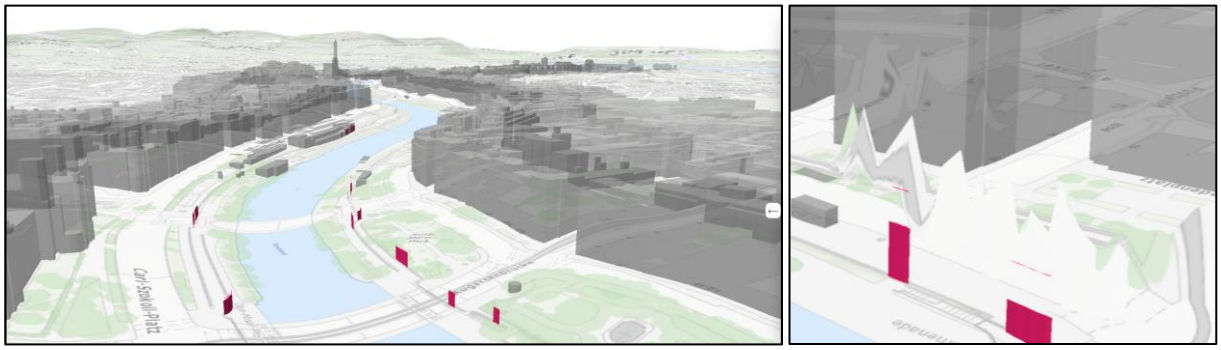

Figure 23. Partial screenshots of integrated terrain elevation data into the web map prototype. Left: Low-resolution data showing very roughly interpolated elevation details of the Donaukanal area. Right: Attempts to generate high-resolution terrain data resulting in noticeable distortions and inaccuracies.

4.7 User Study

Once the web map prototype reaches its final stage, a user study will be carried out. This study aims to effectively evaluate the prototype's graphical user interface (GUI) for usability. It serves as the initial external evaluation step within the iterative user-centered design cycle (Abras, Maloney-Krichmar and Preece, 2004; Roth, Ross and MacEachren, 2015), potentially guiding future enhancement and development efforts. Simultaneously, it is designed to yield some insights into how individuals engage with maps dedicated to graffiti. Lastly, the study aims to ascertain whether users prefer to interact with graffiti as map features within a 2D or 3D map environment.

4.7.1 User Study Methods and General Design

The user study combines three usability testing methods applicable to maps such as observation of interaction including performance measurements (Edsall, 2003), thinking aloud (Roth and Harrower, 2008), and (semi-structured) interviews (Slocum *et al.*, 2004).

Observation studies “involve the systematic recording of observable phenomena or behavior in a natural setting” (Gorman *et al.*, 2005, p. 40). In this context, what’s observed is the way participants interact with the web map through its GUI.

Thinking aloud refers to participants being asked to verbalize any thoughts or impressions they have while using a system and performing actions like using interaction functionality tools in a web map (Lea and MacLeod, 2019). This method holds great potential in revealing usability matters causing Nielsen to say of it that it “may be the single most valuable usability engineering method” (Nielsen, 1993, p. 195).

Semi-structured interviews, while preparing and asking predetermined questions, allow for a certain flexibility to take additional detours of discussion, so to speak, to go into unforeseeable territory by asking additional questions and follow-up questions (Gill *et al.*, 2008).

Generally, a combination of several methods is expected to provide the best results, as it contributes a certain responsiveness to emerging insights as a question can be approached from different ways (DiCicco-Bloom and Crabtree, 2006; van Elzakker, Delikostidis and Oosterom, 2008).

The user study is leaning towards bringing more qualitative results. However, some numerical data will be gained. The study is designed to be done in a one-on-one setting with the participant representing a potential user of the web map prototype, who is given full attention. It is designed to work remotely using videoconferencing technology. Participants therefore view the prototype via their own personal devices, including their preferred input device. Besides the convenience of no travel time and the comfort of the home, this approach allows the built-in benefit of recording audio as well as the screen of participants as they are using the prototype, to gain insight into the way they are interacting with the GUI. This includes which map mode (2D or 3D) participants select.

4.7.2 Procedure of User Study Sessions

Each user study session comprises three main parts. Initially, a brief explanation is provided to the study participants to ensure their comprehension. It is emphasized that they will be using a web map prototype featuring graffiti along the Donaukanal to gather insights for its enhancement, specifically focusing on its GUI. However, no details regarding the user interface's components, functionalities, or controls are disclosed during this explanation. Subsequently, the procedure is briefly outlined, including the participants' expected roles and activities throughout these three main parts.

First part – free exploration

In the first part, participants are to use the web map freely, without any task, assignment, or input from my side. However, they are instructed to try to test out all functionalities of the web map in whatever order or way they like. I only interrupt when absolutely necessary for instance if the user is totally stuck. In this step, screen recording is already active, and the participants already verbalize their thoughts and impressions. They start off by following a link to an initial neutrally designed and purely for the purpose of the user study provided screen-covering menu page that lets them choose in what map mode (2D or 3D) to initially launch the web map prototype in (see Figure 24). This part ends when the user has had the chance to test all functionalities or states that they have done so. This part is expected to last between 10 and 15 minutes.

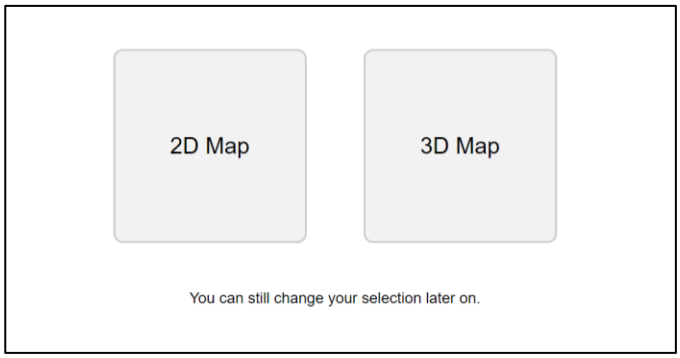

Figure 24. The initial map mode menu selection screen that participants encounter before launching the web map prototype.

Second part – four tasks

The second part consists of four tasks given consecutively, which the participant should complete as quickly and efficiently as possible. It is important to note that before receiving each task description, they have to go back to the initial menu (see Figure 24) to be allowed to make a new thought-through selection of map mode according to their preference and their estimation of how it would support them for the specific task at hand. Note that there is an exception that if a participant has been using the same map mode for all tasks, they are asked to pick the other one for the final task to offer insight into the difference of map mode. The recording of the participant's screen keeps going as well as their uninterrupted verbalization of thoughts continues in this part. The tasks are sent textually one after the other after completion and read:

1. Describe where graffiti with political content was located in the year 2021!
2. Find the (spatially, not temporally) longest animal-related graffiti to be seen on June 15th, 2020! Note: If a certain graffiti is covered up by a building, simply reload the building layer.
3. Search for the section of the Danube Canal between the Salztorbrücke (Salztor Bridge) and the Marienbrücke (Marien Bridge)! On which shore side of that section can you find more graffiti if you consider the entire time period? Tip: It might be useful to change the base map to find the location.
4. Directly on the corner where the Vienna River (Wienfluss) flows into the Danube Canal is a building called the Urania. Which graffito of the visual-centric type, viewed over the entire time period, is located closest to Urania?

Third part – interview questions

The third and last part is a brief interview to get potentially valuable insights and reflections from participants post-using the web map prototype. Possibly deeper thoughts that were not able to be expressed while actively using the web map. The recording of the participant's screen is stopped for this part, however, they may still access the website to refer to if something in the interview comes up. The intent behind it being semi-structured is to put the participant more at ease and allow them to express honest thoughts without pressure. The questions are very open, simple almost a bit on the nose. They are along the following lines as slight deviations of wording are possible.

1. What did you like about the web map?

2. What did you not like about the web map?
3. How could the web map be improved?
4. What were the differences for you between the web map in 2D and 3D?
5. In which situations would you prefer 2D or 3D?

4.7.3 Participants

There are only six participants in the user study (see Table 3), however that is okay as research indicates that as few as 5 participants, it is possible to uncover the majority of usability issues and gather valuable insights. Specifically, Nielsen concludes based on two studies using the thinking aloud method for user interface testing that as few as five test subjects are able to cover and identify 77-85% of the usability problems. He therefore recommends mainly to plan a total of 4 ±1 participants for a study based on this method which is given in this research (Nielsen, 1994). However, including more participants can help validate and strengthen findings, especially if the target audience as given in this case is diverse or if it is to expect a wide range of user behaviors or when the experimenter is somewhat inexperienced.

Half of the participants are familiar with the Donaukanal area, the other half not, making for an additional layer of potential insight gained but also adds another variable to assess.

ID	Age	Familiar with Donaukanal area?	Interest in graffiti	Frequency of web maps used	Occupation	Pointing device used
TP1	50	Yes	High	Daily	High school teacher	Mouse
TP2	30	Yes	High	1-2 times per week	Student	Touchscreen
TP3	26	Yes	Semi	Daily	Law Clerk	Mouse
TP4	41	No	Semi	Daily	English Trainer	Mouse
TP5	28	No	Low	1-2 times per week	Software Developer	Mouse
TP6	23	No	Low	Daily	Student	Mousepad

Table 3. Demographics of the user study participants.

5 Results

5.1 Finalized Web Map Prototype

The finalized web map prototype (see Figure 25) developed as part of this research work, as it was presented to the user study participants, is accessible via GitHub at: https://oacbaumann.github.io/graffiti_map_UserStudy/. GitHub's language analysis for the repository indicates that it comprises 82.3% JavaScript, 9% HTML, and 8.7% CSS.

The prototype offers users an interactive platform for exploring a total of 97 graffiti artworks along the Donaukanal in Vienna. Upon loading the website, all graffiti features are initially on display accompanied by a brief 'map camera' animation that zooms in on the Donaukanal. Users are enabled

to customize their exploration experience by applying spatial, temporal, and semantic filters to the graffiti map features.

The research and its implementation have led to the refinement of the web map prototype through the integration of two components that, while not entirely novel in the broader field of web mapping, represent significant innovations within specifically graffiti-focused web maps. Based on internet research and identification of related works, these distinctive features distinguish it from existing solutions, providing enriched capabilities for users to reproject the map and to resymbolize its content:

Firstly, the web map prototype introduces a 3D mode that facilitates a more immersive exploration of multi-dimensional graffiti representations, providing users with the ability to observe the graffiti's heights and their elevation above ground within a geospatial context. This capability is enabled by the MapLibre web mapping library, which supports 3D cartographic rendering and visualization. This library was utilized in another graffiti-focused web map (see 3.7.1), but without leveraging the 3D capabilities.

Secondly, in 2D mode, the prototype introduces adaptive representation styles for graffiti features. This adaptability involves dynamically transitioning between high-detail polygon representations to more simplified polyline and point features (dynamic clusters) based on predefined zoom level ranges (see 5.2).

Both of these functionalities, namely the adaptive representation styles and the 3D map mode, are made feasible due to the high level of detail inherent in the sourced geospatial graffiti data by project INDIGO.

In the following sub-sections, the various components of the graphical user interface (GUI), as shown and annotated, in Figure 25, will be described and referenced by their corresponding letters.

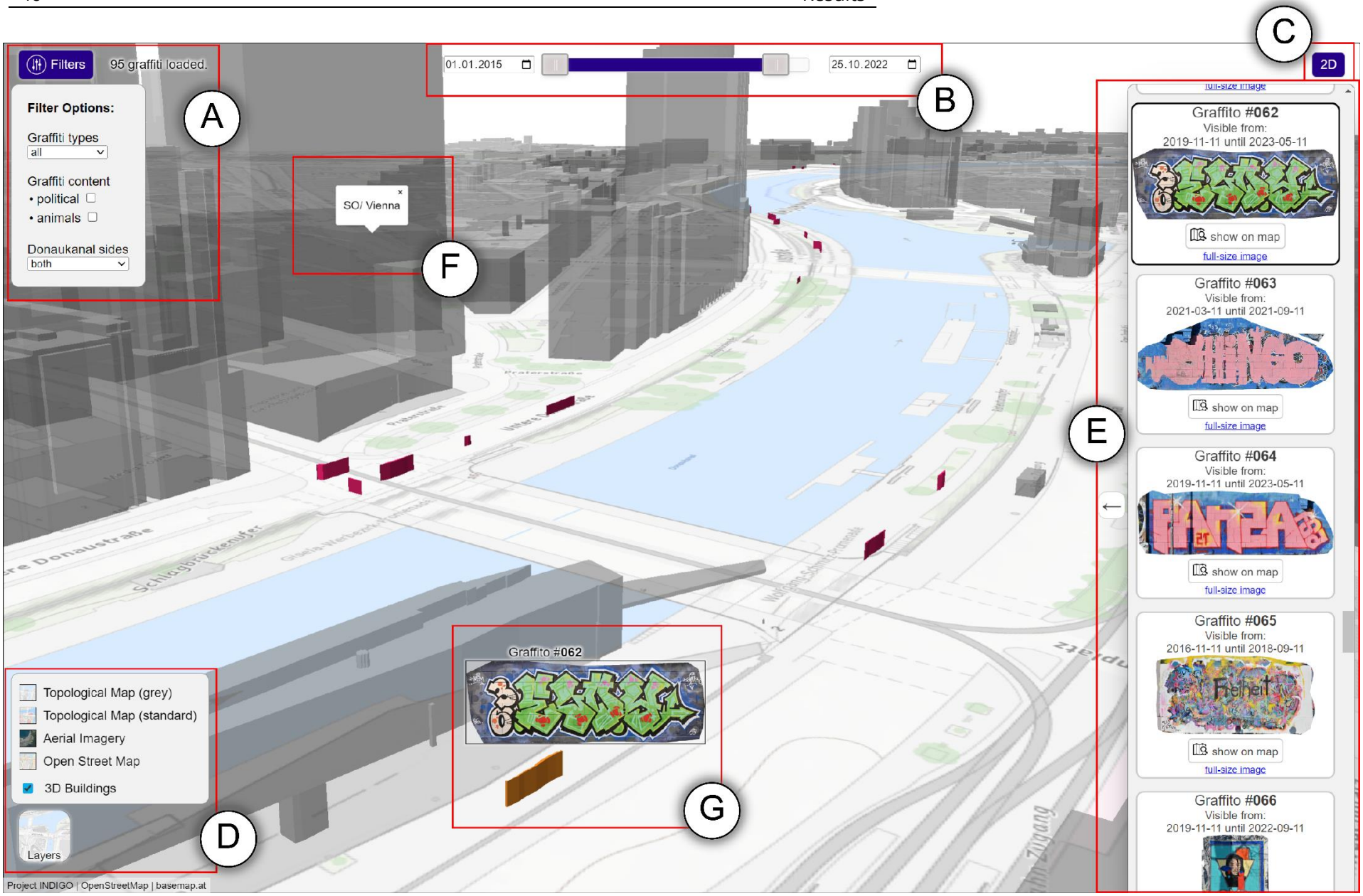

Figure 25. An edited screenshot of the finalized web map prototype with components of the UI highlighted in red. The UI remains the same in 2D and 3D modes.

5.1.1 Design and Functionality of User Interface

A – Main filters
When clicked, the “filters” button, containing a filter symbol, toggles the window underneath containing the filter options. These options consist of two drop-down menus for narrowing graffiti display based on their categorization as either text-centric or visual-centric types and their location on either or both sides of the Danube Canal. Additionally, there are two checkboxes for searching for graffiti with animal-related content or political messages. Another informative element is a text line that informs the user of the current number of graffiti features meeting the applied filters making them visible.

B – Time slider
A range slider allows the user to select time intervals and observe which graffiti artworks remain visible within the maximum visibility timeframe. The shortest selectable time interval is a single day. The slider can be adjusted simply by clicking and dragging its handles or, for more precise adjustments, by clicking the calendar symbols near the start and date displays. A debounce function is implemented to ensure smooth sliding performance.

C - Map mode button
The map mode button reads '2D' when 3D mode is active and '3D' when 2D mode is active. Clicking this button initiates a smooth transition to the opposite map mode without reloading the basemap or resetting the filters. It only involves refreshing the visible graffiti features in the new corresponding symbology. Additionally, the 3D building features are either removed or loaded. The switch between map modes triggers a brief dynamic transition of the map view. It shifts from an overhead perspective (parameters: pitch = 0, bearing = 0) to an oblique view (parameters: pitch = 65, bearing = 20) and vice-versa. In 2D mode, map rotation is disabled, and the pitch remains fixed.

D – Basemap and layers menu
The square button saying ‘Layers’ automatically shows the currently active basemap as a background image. When the button is clicked, it reveals an options box in which four different basemaps can be selected, that are listed as: “Topological Map (grey)” which is the default map, “Topological Map (standard)”, “Aerial Imagery”, and “Open Street Map”. Additionally, users can control the visibility of the 3D buildings layer on the map by checking or unchecking the checkbox.

E – Sidebar
The right sidebar can be expanded or collapsed by left-clicking either on the arrow symbol or on any graffiti feature within the map. It provides a comprehensive list of currently visible graffiti based on the applied filter criteria. The list is scrollable, with each graffiti feature having its dedicated section. These sections are arranged in descending order by their unique identifier (ID). Each graffiti feature section includes the following components: the graffito number, timespan of visibility, a small, rectified photo image, a 'show on map' button and a link to open the image file in full-size in a separate tab. By clicking the 'show on map' buttons within the sidebar, the map smoothly flies to and zooms in on the selected graffiti feature.

F – Building popup box
When an individual building is clicked, a straightforward popup box appears at the cursor's location. It contains the building's name, if available, otherwise it at least indicates the building's type. If there

is no data available for the specific building, it states so. The popup boxes can be closed by clicking the 'x' symbol in their top-right corner or by clicking anywhere else on the basemap.

G – Graffiti popup box

When a graffiti map feature is hovered over with the cursor, a popup box fades in near the cursor. This box displays the number of the graffiti (ID) and a thumbnail. It is worth mentioning that the decision to show these images in their entirety, rather than displaying cropped sections, was highly recommended by graffiti artists who had the opportunity to review a work-in-progress version of the web map prototype during a presentation at the goINDIGO 2023 symposium (Verhoeven *et al.*, 2023).

5.1.2 Color Scheme and Basemap Selection

UI elements and map features

The color scheme of the web map prototype follows the colors of project INDIGO's logo (see Figure 26). Specifically, the time slider (B), filters button (A) and map mode button (C) are in an indigo blue color (#270089) and shift to cyan (#0dace5) when being hovered over. The graffiti map features are in a visually striking pink color (#d2145d) to give them emphasis and to signify the colorfulness of graffiti. While hovered over (G), these features react by transitioning to an orange shade (#f1881f).

Figure 26. Project INDIGO's logo in four vibrant colors, that are also present in various elements of the web map prototype.

The 3D buildings along the Danube Canal on the map are in a light grey color (#808080). Their transparency depends on their distance from the canal. Buildings in close proximity to the canal have a transparency of 60%, while those farther away are rendered with a transparency of 50% and 37.5%. This approach is implemented to achieve a gradual fade-out effect.

Figure 27. A screenshot snippet from the web map prototype showing a view on the 3D building models near the Danube Canal with reduced opacity as their distance from the canal increases.

Moving on to other parts of the user interface, the toggle boxes (A and D), including the building popups (F) and the sections within the sidebar (E), feature a clean design with rounded corners and a light grey (#f2f2f2) to white (#FFFFFF) background color. Their design approach prioritizes simplicity over flashy design choices, allowing the map itself to take center stage.

Default basemap

Taking inspiration from various graffiti web maps, the selected default basemap (see Figure 27) embraces a visually understated aesthetic, predominantly featuring grey tones. Still, it preserves the customary light green hues to represent vegetated areas. Additionally, bodies of water are depicted in light blue which holds particular significance due to the pivotal role of the Danube canal being the core theme of the web map. Additionally, the decision to use this basemap was influenced by its strong spatial alignment with the graffiti geo-data.

The rationale behind favoring this abstracted basemap over alternatives such as the 'aerial imagery map' is that while the latter offers more comprehensive details and a natural representation of urban infrastructure, it can appear cluttered to new users and may not effectively guide their visual focus toward graffiti features, particularly due to issues with contrast and visibility. Nonetheless, users still have the option to switch to the more detailed map for reference, especially when delving deeper into a graffito's immediate environment.

5.1.3 Interaction and Basic Map Controls

The controls for interactively navigating the web map prototype in both 2D and 3D modes remain consistent with the default controls provided by MapLibre, and they conform to established web map conventions.

The interactive prototype allows the use of the following cartographic interaction operations (Roth, 2013): pan, zoom, retrieve, filter, reproject, resymbolize and search.

Panning and zooming functionalities are readily available by default, courtesy of the web mapping library. They can be accessed through standard map controls: left-clicking and dragging on the basemap for panning, and using scroll inputs for zooming.

To retrieve information about the map features, users can hover over graffiti features, revealing individual graffiti popup boxes (G) which also triggers automatic adjustment of the sidebar (E) to display selected graffiti fields containing additional information. For 3D building features, accessing information is achieved by left-clicking the buildings, which opens the building popup boxes (F).

Filtering options are accessible through the main filters (A), encompassing both spatial and semantic filter choices, as well as the time range slider (B) for temporal filtering.

Map reprojection is possible by changing map modes from 2D to 3D or vice-versa (C) and by rotating the 3D map via holding right-click and dragging the cursor.

Graffiti feature resymbolization can be achieved by changing map modes (C) or by adjusting the zoom level in the 2D mode, causing symbolic representations to change.

'Search' in the context of cartographic interaction operators is defined as "interactions that identify a particular location or map feature of interest. [...] *Search* directly enters the map to locate a feature of interest that is already known" (Roth, 2013, p. 2363). This way of interaction is available in the prototype through clicking the 'show on map' buttons within the sidebar (E).

5.2 Graffiti Feature Generalization

In the finalized web map prototype's 2D mode, zoom levels 15 to 19 were defined as breakpoints of the graffiti feature's adaptive symbolization. At an active zoom level value below 15, graffiti features are represented by semi-transparent pink clusters (see Figure 28), and above a zoom value of 19, they are represented by unedited polygon features (see Figure 29). Within the zoom level range of 15 to 19, graffiti are represented by simplified lines. The OMBB (see 4.4) are not used in the finalized prototype.

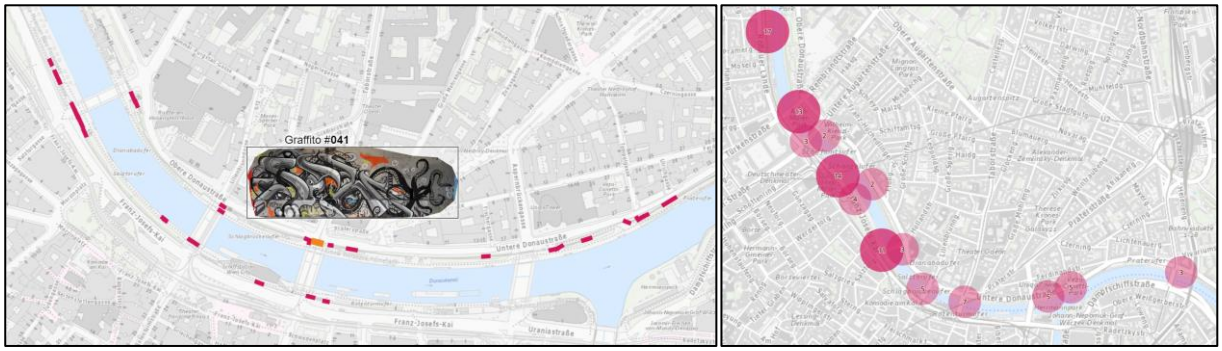

Figure 28. Partial screenshots of the web map prototype in 2D mode showing changing representation style based on active zoom level. Left: Graffiti represented as line features. Right: Dynamic graffiti clusters.

The used simplification method that converts 3D graffiti polygons into 2D line geometries is most effective in eliminating less crucial details for graffiti located on continuous, nearly flat, and nearly vertical surfaces. However, it may not work optimally for graffiti situated on rounded, irregular surfaces or single graffiti artworks that extend around corners.

After conducting a personal visual assessment and comparison, considering the 97 original 2D graffiti polygons and their corresponding simplified line equivalents in a close-scale top-down view of 1:250, the findings indicate that the shape of 87 of the graffiti are accurately conveyed by the line geometry. However, in the case of 10 graffiti features, the representation is less accurate due to the surfaces they adorn not being flat or potential issues with the original data (see Figure 29). This equates to nearly 90% of the graffiti being effectively represented in terms of their approximate shape and length.

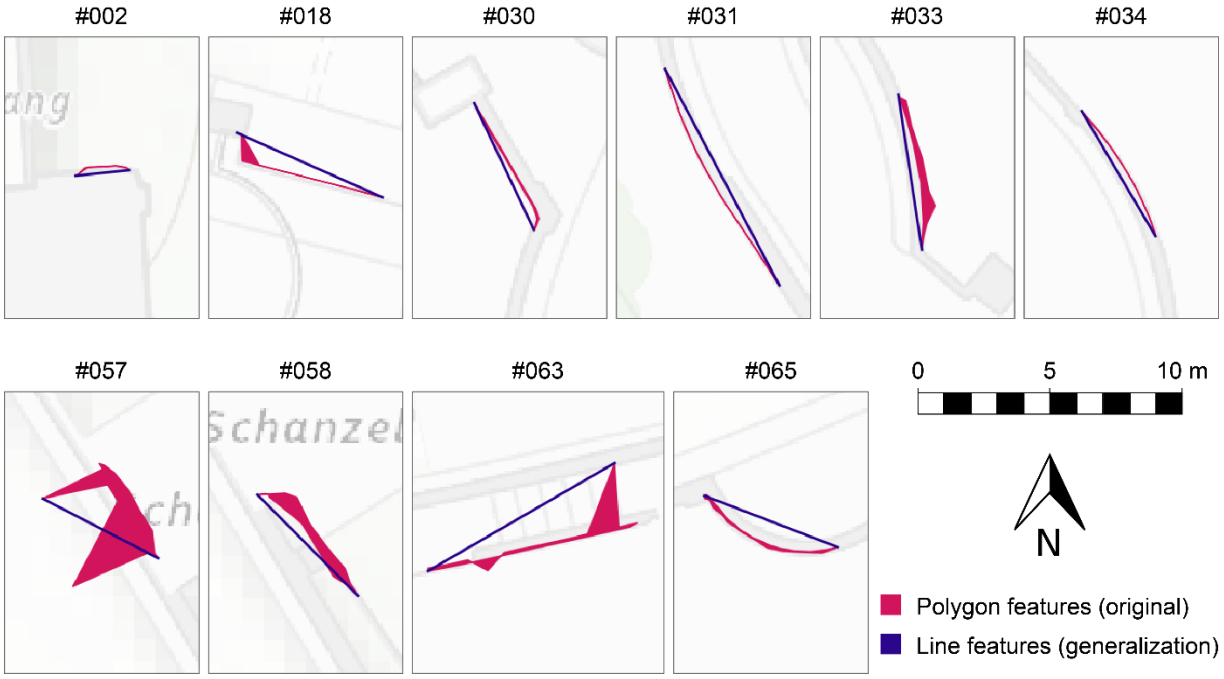

Figure 29. Map sections showing the only ten original graffiti polygons which are not satisfactorily represented by generalized line features. The map sections are in the same scale. Basemap: basemap.at raster (grau).

The process of selecting the original graffiti from the Donaukanal study area by project INDIGO, that yielded the original polygon data, had the background of an experimental setup to test a custom-written software package. For the experiment, "100 graffiti were randomly selected from all graffiti documented between November and December 2021" (Wild *et al.*, 2022, p. 2999). That selection was only biased in the sense that smaller graffiti, such as tags, may have been neglected because they are more easily overlooked when photographically documenting graffiti. However, the exclusion of small tags is not detrimental to the generalization method as they typically do not form lengthy curved shapes.

Thus, based on the resulting 90% fit for this limited dataset, it indicates that the simplification method used to generate the line geometry based on INDIGO's graffiti geo-data offers a highly satisfactory cartographic representation style for the graffiti present throughout the entire Danube Canal area. This approach is particularly well-suited for creating large-scale to city-scale 2D maps, as it effectively preserves the graffiti's approximate shape and enhances the visual clarity of their lengths. This supports the suggestions in Table 1 and signifies that, when focusing on 2D maps, spatial graffiti data collection along the Danube Canal can predominantly rely on recording just two coordinate pairs, one at each end of the graffiti's length.

5.3 User Study Results

In the initial phase of free and relatively unstructured exploration, as observed, nearly all participants began by testing the fundamental map controls like zoom and pan, which is a typical starting point. Another common behavior was users subsequently zooming out to the maximum extent to explore the geographical boundaries of the map. Excluding these prevalent actions, the remaining

interactions constituting the participant's first two interactions and likely their points of attention are shown in the following pie charts (see Figure 30).

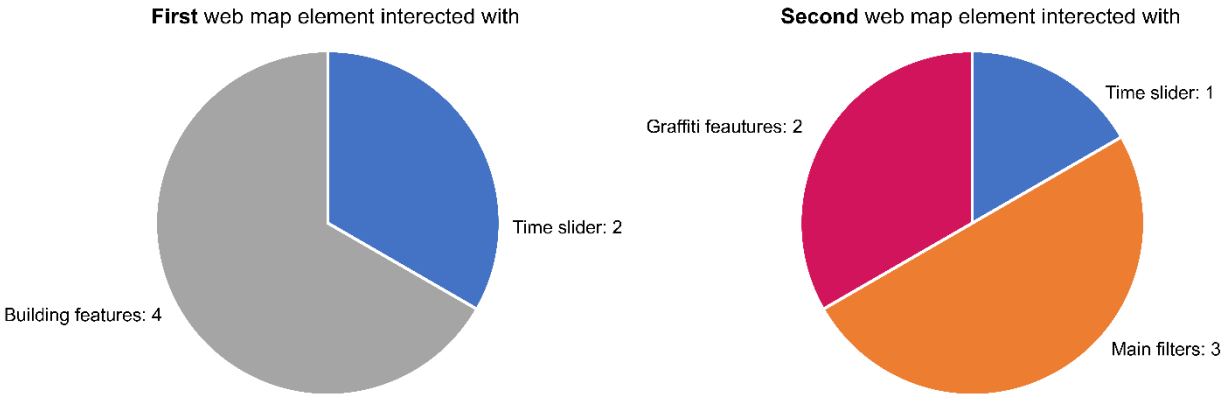

Figure 30. First and second elements participants interacted with when using the web map prototype for the first time.

Prior to becoming familiar with and launching the web map itself, participants were evenly split when it came to their initial selection of the map mode (see Table 4). However, after acquainting themselves with the web map's interface and functionality, when it came time to choose a map mode for the first task, all users except for one consistent 2D mode user opted to begin the task in the 3D mode. Task 1 was intentionally designed to be solvable in either mode, with neither mode expected to provide significant advantages over the other.

As participants progressed to tasks 2 and 3, a trend emerged where more of them opted for the 2D mode to complete these tasks. This shift was influenced by the nature of these tasks, which required solving problems related to distances and horizontal areas; aspects that are often more straightforward to interpret in a 2D map mode. Consequently, the most significant and impartial indicator of user preference remains their choice of map mode in task 1, which happened after first familiarization with the map. This choice predominantly favored the more immersive and perhaps visually engaging 3D map mode.

This sentiment is partially echoed in the interviews with participants after they had the experience of using the web map. Their reasons on favoring the 3D map mode over the 2D mode are (with minor paraphrasing):

- TP1: "It is more real, and I choose it if I want to go on a free journey of discovery"
- TP2: "3D is easier to navigate and provides more flexibility for complex spatial questions."
- TP3: "It gives you a bit more of a feeling for the perspective. For example, as seen from the Urania you can choose the perspective as if you were sitting there on a balcony looking down on graffiti."
- TP4: "3D maps are generally more informative to me and help me orient myself better."
- TP5: "3D feels more modern. I choose it when I want to have fun with the map. It allows me to see the 3D buildings, and there is no disadvantage compared to the 2D mode."
- TP6: "The mode is there just for fun and to see the buildings and their shapes."

On the question of why they would choose the 2D mode over the 3D mode the resounding answers are: it is more familiar, it is faster to find search and find something specific, simpler, sufficient, and efficient to find graffiti.

ID	Selected map mode: exploration	Selected map mode: Task 1	Selected map mode: Task 2	Selected map mode: Task 3
TP1	2D	3D	2D	2D
TP2	2D	3D	2D	2D
TP3	3D	3D	3D	2D
TP4	3D	3D	3D	3D
TP5	3D	3D	3D	3D
TP6	2D	2D	2D	2D

Table 4. Participant's initial selections of map mode (2D or 3D) for the free exploration and the subsequent three tasks.

On average, the completion times for all four tasks do not show significant deviations from each other. The exact times, including the averages, are detailed in Table 5. Additionally, Figure 31 presents a line graph illustrating these completion times, which highlights some outliers, particularly in the last two tasks where participants may have benefited from prior geographical knowledge of the area.

	Task 1	Task 2	Task 3	Task 4
TP1	02:56	04:12	02:13	02:45
TP2	04:23	03:43	05:58	05:54
TP3	01:52	03:06	01:36	00:59
TP4	01:25	02:02	01:23	01:14
TP5	01:07	02:01	02:21	02:09
TP6		01:51	03:18	06:18
Average	02:21	02:49	02:48	03:13

Table 5. The actual time duration it took for each participant to complete the four tasks, including the average.

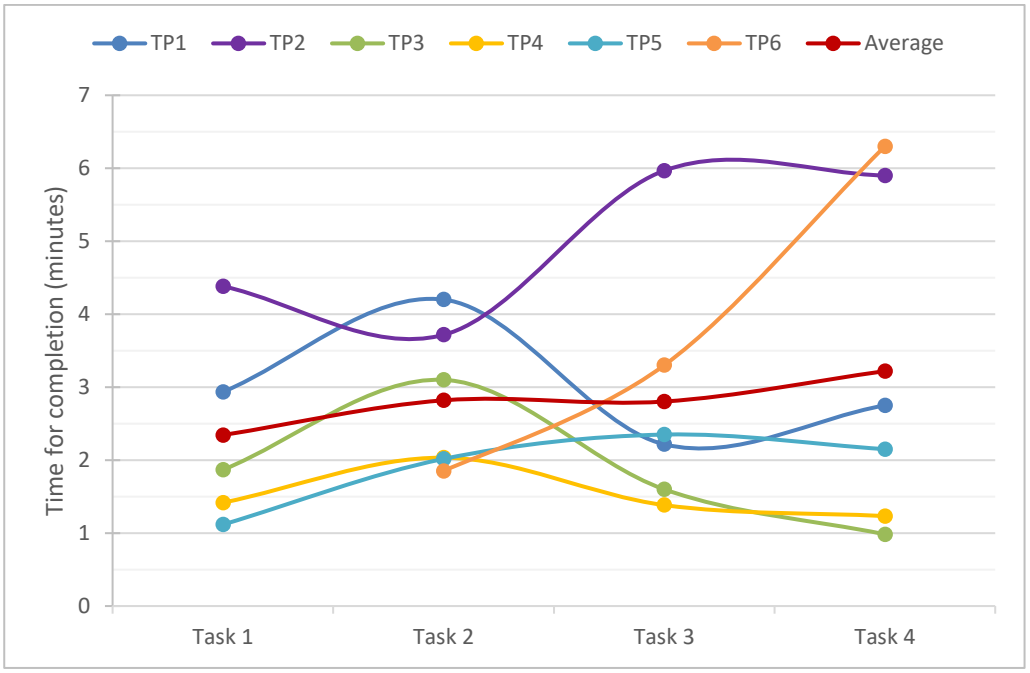

Figure 31. Line chart showing participant's task completion times and the resulting average times of completion.

The observation and thinking aloud methods employed during the first and second part of the user study sessions provided valuable insights into common usability issues experienced by participants, which are expected to be indicative of problems shared by a broader user base. These issues, characterized by recurring patterns observed in at least two participants, are detailed in Figure 32.

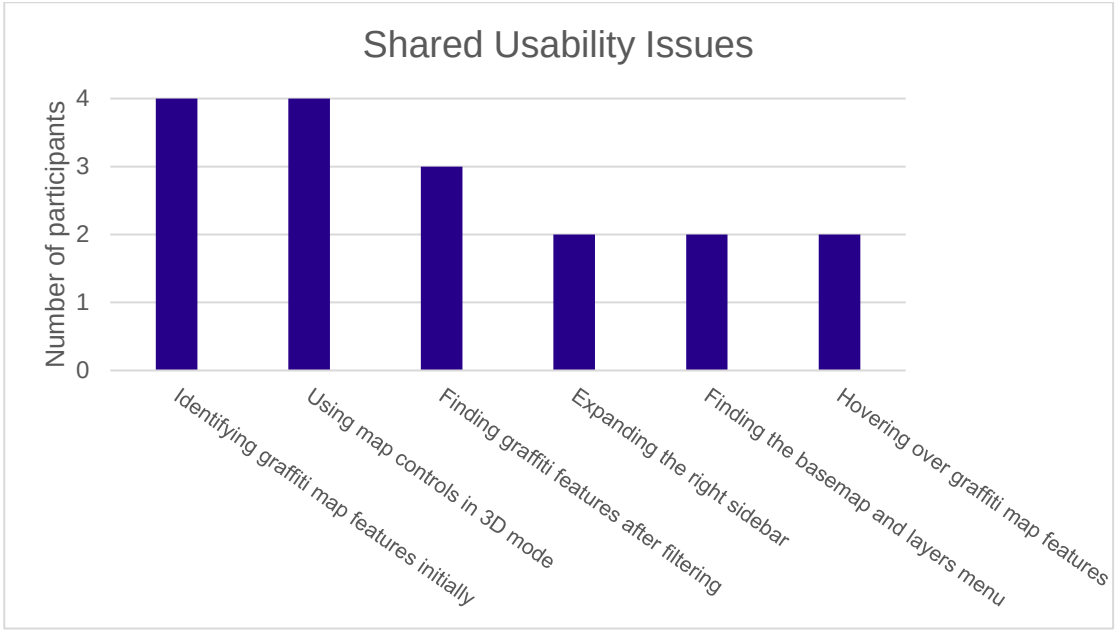

Figure 32. Common usability issues encountered by at least two participants.

During the third part of the user study sessions, when participants were asked about potential improvements for the web map, common themes emerged in their responses. Specifically, several concrete and relatively easily implementable adaptions, each mentioned by two different participants, are as follows:

- Enhancing the visibility of graffiti map features to make them more noticeable.
- Increasing the visual prominence of the sidebar expansion button.
- Adding a filter option to allow users to filter graffiti by artist.
- Enabling the ability to rotate the 2D map around the vertical axis.

Furthermore, three participants each put forth a minor suggestion, proposing to reduce the number of available basemaps. On the other hand, four participants suggested enhancing the user experience by providing additional information. Their suggestions encompassed various unique ideas, such as:

- Additional information regarding the locations of legal graffiti walls.
- Clear delineation of the boundaries of the focus area that can contain graffiti features.
- Details about the specific surfaces covered with individual graffiti.
- Inclusion of more zoomed-out graffiti photos to provide more context.
- Information on public transportation lines and nearby stations.
- Visual highlighting of landmarks like the Stephansdom.
- Additional explanatory information about the filter options.

5.3.1 Discussion and Takeaways

While certain tasks were designed to encourage users to explore how graffiti interacts with the environment, this approach somewhat conflicted with the instruction to complete the tasks promptly. In other words, the pressure of completing the tasks hindered the exploration and connection of graffiti with their surroundings. Instead, tasks primarily served to gauge the speed and effectiveness of the user interface in responding to user queries. Although a study focused on this aspect could be intriguing, it would be challenging to conduct.

The relatively long task completion times, even with prior familiarization with the GUI and its functions, were unexpected and highlight potential areas for usability improvement. One of the primary objectives of the map is to efficiently facilitate nuanced filtering of graffiti features, which is currently not fully achieved.

The use of both thinking aloud and interviews may seem redundant, based on the broad interview questions, as most usability issues are covered during the thinking aloud process. However, it remained partially valuable, as it reduced the risk of overlooking important insights, since users were able to recount their experiences.

The overarching insights derived from all aspects of the user study suggest the following key takeaways in context of the web map prototype:

- Intricate details of graffiti in their current style, especially when zoomed in, are not crucial for individuals even those with a high interest in graffiti.
- Symbolizing graffiti via (poly)line representations proved to be an effective representation style.

- The visualization of graffiti features lacked sufficient visual prominence especially in 3D mode, particularly when compared to building features.
- Providing both 2D and 3D options seems wise, as most users found value in both modes.
- Integrating additional background information about map elements is generally advisable.

Furthermore, a general impression that emerged from observing users with limited interest in graffiti and street art is that the current state of the web map may not provide sufficient entertainment value for individuals without a particular affinity for graffiti. While introducing additional features and use cases, such as using the map for trip planning with public transportation or enabling social interaction through comments, as well as expanding the data and filter criteria for personalized searches, could potentially enhance the map's appeal to these neutral users. However, while accommodating neutral users is considered, they are not the primary target audience.

6 Conclusion

Approaching the subject of graffiti from a spatial perspective has revealed its inherent complexity and intricacy. This complexity becomes particularly pronounced in the context of mapping when considering how graffiti can be effectively represented as dominant map features. The research concludes that maps indeed offer a suitable medium for depicting graffiti as their main feature, especially when integrating more associated media. Graffiti and street art present themselves as distinctive elements within the realm of maps, characterized by their notable variability. This variability encompasses various aspects, including their size, shape, orientation, and the often ambiguous boundaries that define them.

Additionally, graffiti's inseparable connection with their urban environments, upon which they depend for context and understanding, sets them apart as unique map features. This distinguishes them from other phenomena like billboards, which are also colorful, visible to passersby, and typically exhibit a predominantly flat and vertical spatial character.

To address this variability and faithfully represent the unique shapes and spatial characteristics of graffiti within a map context, it is advisable to utilize different symbolization methods based on factors like scale or zoom level. When visualizing graffiti on a 2D (web) map, point features work well for global to continental scale representations, (poly)line features are suitable for medium to close scale visualizations, and polygon features prove effective for close-scale representations. However, feedback from user study sessions suggests a preference for (poly)line features in the medium to close scale range. Users have expressed that they respond positively to this simplified representation, as it maintains a higher level of detail compared to simple point geometries, thus more accurately capturing the shapes of graffiti.

Throughout this research, various representations based on different geometries were generated from complex graffiti polygon structures using feature-specific simplification-based generalization methods. To be more specific, line geometries were produced by connecting the vertex pairs within the polygons that are the most distant from each other. For the original dataset of 97 graffiti, these line representations demonstrated a 90% satisfactory performance in terms of satisfactorily depicting the shape and length, within the focus area, Vienna's Danube Canal (Donaukanal).

A web map prototype was created using the MapLibre GL JS web mapping library. This prototype drew inspiration from existing graffiti web maps, which were identified and evaluated. The prototype integrates diverse graffiti representations, including points, lines, and polygons, adapting them based on the current zoom level. Additionally, the prototype provides a range of interactive functionalities, including a 3D mode, to enhance user interaction and exploration.

The findings from the user study indicated a prevalent preference among participants for experiencing graffiti along the Danube Canal (Donaukanal) within a 3D map environment. In most cases, users chose this mode, with the exception being instances where time constraints necessitated a more conventional 2D approach. The prototype's interactive graphical user interface enabled users to address intricate spatial, temporal, and semantic inquiries related to graffiti. On average, participants required approximately 2 to 3 minutes to navigate and utilize these features effectively to answer complex questions.

Nonetheless, the study identified several usability issues that merit improvement, with the primary concern being the visibility of the graffiti map features themselves. These insights hold significant value and can inform future design improvements as part of an iterative user-centered design cycle.

During the user study, participants did not exhibit a strong inclination to explore nuanced connections between graffiti and elements of the environment, which were presented through a basemap and nearby buildings.

Given that the basemap was not originally tailored for the explicit purpose of highlighting graffiti, exploring the development of basemaps specifically designed to showcase graffiti and provide a detailed spatial context could be a promising avenue for future research. This approach would involve a more integrated fusion of basemaps and graffiti, rather than simply overlaying graffiti map features onto existing maps.

Appendix

The **code of finalized web map prototoype** and the raw **user study interview transcripts** are accessible via a GitHub repository: https://github.com/oacbaumann/graffiti_map_UserStudy.

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