A Geospatial and Time-based Reconstruction of the Venetian Lagoon in a 3D Web Semantic Infrastructure*

Ludovica Galeazzo[1], Remo Grillo[2] and Gianmarco Spinaci[2]

[1] Università degli Studi di Padova, Piazza Capitaniato 7, Padua, 35139, Italy
[2] I Tatti – The Harvard University Center for Italian Renaissance Studies, Via di Vincigliata 26, Florence, 50014, Italy

* Sections 1 to 3 are by Ludovica Galeazzo, section 4 is by Remo Grillo, and section 5 is by Gianmarco Spinaci. All authors contributed to the conclusions.

Abstract

Throughout the early modern period, the over sixty islands shaping the Venetian lagoon constituted an integral component of Venice's urban framework. The ERC Starting Grant project *Venice's Nissology* (VeNiss) reconstructs this dilapidated cultural heritage site by examining the urban, architectural, and social patterns connecting the capital with its aquascape through a web-based research infrastructure accessible to the broad public. With the idea of understanding and visually narrating the many transformations of Venice's lagoon settlements over time, this research employs a cutting-edge methodological approach to effectively capture both the physical and functional changes that have occurred to these built works throughout the centuries. Leveraging on the most advanced digital tools (i.e., digital photogrammetric and laser scanner surveys, HGIS mapping, HBIM modelling, and semantic technologies), researchers and the general public alike can explore the material alterations of the islands' spaces while interactively discovering their historical, socio-economic and cultural changes. This paper proposes an innovative operational methodology that, through a semantic data model and knowledge graph, develops a 3D geospatial and time-based semantic infrastructure. This platform acts as a comprehensive repository that integrates and renders navigable historical data, research findings and 2D and 3D interoperable models, which allows for a nuanced representation of the articulated and long-term relationships that once bonded the cluster of islands with the historical city centre and states across the Italian Peninsula and the Mediterranean.

Keywords

Digital urban history, HGIS and HBIM modelling, Knowledge graph

1. Reconstructing digitally a tangible and intangible space

The ERC project *Venice's Nissology. Reframing the Lagoon City as an Archipelago* (VeNiss) bears on the critical question of how scholars can holistically investigate and digitally represent through time and space historic settlements and architectures that no longer exist, blending their geomorphological transformations with the nexus of socio-functional mutations that have determined their material organisation. Looking at urban sites and their change over time requires understanding their physical change as much as embracing the more complex topic of reconstructing the polysemic nature of built places. This compels us to consider also the far-reaching urban structure of a settlement – from productive activities to economic practices, from demographic to census data, from social movements to cross-cultural artistic exchanges. Although being a physical settlement, a city is, in fact, the space of incessant social and cultural processes, the material point of encounter of political actions, economic practices, and jurisdictional functions. Studying its phenomenology thus means to overcome its purely morphological reading in order to investigate the interweaving relationships between its landscape, buildings, and actors – private or institutional – in the light of various heteronomous factors [1].

The specific focus of VeNiss' inquiry is the hitherto neglected cluster of over sixty islands of varying sizes that, scattered across the Venetian lagoon, shapes the archipelago of Venice, the crucial

Proceedings Acronym: Proceedings Name, Month XX–XX, YYYY, City, Country
ludovica.galeazzo@unipd.it (L. Galeazzo); rgrillo@itatti.harvard.edu (R. Grillo); gspinaci@itatti.harvard.edu (G. Spinaci)
0000-0002-2932-7280 (L. Galeazzo); 0000-0003-3585-0198 (R. Grillo); 0000-0002-3504-3241 (G. Spinaci)

water territory of the city. This peculiar environment is today in a state of severe disrepair since most of the islands have been razed to the ground and lie abandoned and detached – physically and conceptually – from the city centre [2]. The demolition of entire urban complexes, monasteries and convents, as well as architectural monuments, offers a compelling gauge for experimenting with new techniques of digital visualisation applied to urban history research. The first objective of the project is therefore the reconstruction of the ancient urban and architectural configuration of Venice's archipelago throughout time in order to determine the nature and extent of its transformation, enabling the exploration of an almost completely lost cultural heritage. In addition, VeNiss aims at digging into the social, political-economic, and cultural dynamics that determined the historical organisation of the lagoon archipelago over the centuries. In contrast to today, from the middle ages and throughout the early modern period, the belt of islands surrounding Venice functioned as capillary structures for the interests of the city, addressing the different needs of the city's urban framework. In place of this "archipelagic thinking," today the lagoon no longer appears or operates as an interdependent chain of islands as the geo-political changes that occurred in the last two centuries irrevocably interrupted the centuries-old bond that connected the water settlements with each other, with the city, and realities outside the lagoon's contours.

With a view of filling this knowledge lacuna, the project VeNiss proposes an online 3D geospatial and time-based semantic infrastructure that allows users to digitally navigate the historic lagoon while discovering its ancient appearance and socio-urban configuration. Leveraging on the capabilities of digital surveys, HGIS mapping, HBIM modelling, and semantic technologies, the infrastructure enables the intersection of historical data with 2D and 3D reconstructions to visualise the far-reaching historical patterns of the archipelago by addressing all the tangible and intangible elements that composed its space and societal structures within a long-term perspective and in relation to its protean urban fabric [3].

Few other studies have correlated urban and architectural transformations with socio-political, economic, and cultural factors or described these interwoven dynamics visually within a single and interactive framework. If projects like *Visualizing Venice/Visualizing Cities* have mainly focused on visual aspects and the digital reconstruction of historical buildings [4], other research studies such as *DECIMA* or *Venice Time Machine* have sought to represent the history of urban landscapes at scale, but they allow users to explore solely a specific societal component of the cities considered. Whether *DECIMA* investigates the socio-economy of Renaissance Florence by mapping sixteenth-century census data on a historical bird's-eye view, thus excluding any comparison with the present city [5], *Venice Time Machine* seeks to build a multidimensional model of Venice and its evolution over a thousand years through a massive dataset of primary and secondary organised in a semantic graph, but it lacks a real connection with the urban and architectural fabric of the city [6].

VeNiss aims to overcome these critical issues by developing an analytical and operative methodology to study, interconnect, and communicate the layered histories of Venice's archipelago, blending its physical and functional dimensions together to enable a more comprehensive knowledge of the city. In doing so, the project intends to offer users the possibility of visualising its ancient physical conformation but, above all, of knowing its social, economic, cultural and artistic functions by experiencing the relationships between the centre and the "liquid suburbs" of Venice.

This research – developed at the Department of Cultural Heritage of the Università degli Studi di Padova (DBC) in partnership with I Tatti (Harvard University) and the Department of Architecture of the Università degli Studi di Firenze (DIDA) – was granted an ERC Starting Grant by the European Research Council for five years (2023-2027). In re-reading the Venetian archipelago as a large urban fringe of the city, this project aims to re-evaluate, thanks to the help of the most advanced digital tools for urban storytelling, the lagoon sites as crucial connective tissues of the city as well as rediscovering their role as fundamental players in the geographical, socio-political and administrative governance of the Republic.

2. Interrupted landscapes: The fragmentation of Venice's archipelago

Strips of land that today are mostly abandoned or awaiting imminent reconversion, the islands of the Venetian archipelago contain a centuries-old history that inextricably links the lagoon environment with the historic city centre. This event had profound consequences not only for the islands' geography but also for the perception of the articulated network of relationships that sustained the archipelago's life. Two centuries of depredation and abandonment have irreversibly altered their aspect, often leaving nothing more than a handful of land infested by vegetation at the mercy of capricious waters. Above all, however, the nineteenth- and twentieth-century interventions have erased the memory of these fundamental pawns on the "chessboard" that was so masterfully orchestrated by the Republic. For centuries, the Serenissima had programmatically included the lagoon and its islands within all its governmental activities, transforming them into crucial sites for the city's food supply, defence, healthcare, and civic rituals.

Figure 1: The islands of Madonna del Monte, S. Giorgio in Alga, S. Secondo, and S. Angelo della Polvere

Over time the lagoon opened its doors to almost all the main Christian religious orders to compose that kaleidoscope of monastic and conventual communities which represents one of the many singularities of the Venetian society. Benedictine, Augustinian, Dominican, Carthusian and Camaldolese institutes, just to name a few, colonised this crown of islands, giving rise to cultural and humanistic centres of great social value, which entertained continuous exchanges not only with the city but also with other realities in the Italian Peninsula and beyond the Alps. While being forerunners in early landfilling operations, these congregations also played major roles as active patrons of pioneering works of art and architecture which, through their agency, travelled far outside the lagoon's contours. Free from the stricter constraints of the city centre, the water settlements turned out to be fertile ground for experimenting with new designs.

Islets were also key sites in a capillary network called upon to sustain the socio-economic life of the territory, in particular the city's food supply. For centuries they were the only supply centres of a capital that, although celebrated by travellers as the "most abundant city," was almost totally devoid of agricultural spaces and arable land. In addition, they functioned as sites for housing infrastructures that served the daily needs of the larger Venetian community, such as public boathouses, customs houses, and gunpowder magazines. They hosted a series of military structures – forts, garrisons, and watchtowers – that helped preserve the State's invulnerability. Likewise, lagoon settlements proved to be crucial for the public health facilities of the city. Two islands – the Lazzaretto Vecchio and Nuovo – were permanently used as lazarettos to quarantine people and goods, while a number of other sites operated as supplementary shelters in times of crisis. The aqueous environment was finally the stage set on which the Republic promoted the glory and power of the State through ostentatious ceremonies and events contested on water and offered bespoke state lodging services to visiting foreign dignitaries [7].

The organisation of the diverse islands into a single archipelago was the result of a lengthy and complex socio-political but also conceptual construction process developed by the Republic, encapsulating the city's rising consciousness of its geographically and functionally granular identity. Only a philological reconstruction of the lagoon islands, as it regards both their appearance and protean functional activities, can lead to a radical revision of the role of these aquatic fringes in Venice's framework in a long-term perspective. To these extents, VeNiss is currently developing an interactive 3D infrastructure that combines digital reconstructions of physical spaces over time with their pertinent historical data. This platform is meant to help users grasp not only the lagoon's ancient morphology over the past five hundred years but also how this operated and conceived itself as an integrated network. By mapping, quantifying, and visualising the functional use of space, the regulation of lagoon state infrastructure as well as the city's principal socio-economic, political, and artistic events through the lens of the archipelago as a whole and in a long-term perspective, the project seeks to yield crucial insights into the ways the islands supported the governance of the capital comprising their role of mediators in major Venetian and European events and of places for innovative forms of art and architecture.

3. The analytical and operational methodology

The methodological approach adopted in this project includes a quite dynamic and articulated workflow that reflects the variegated composition of its inquiries and requires the integration of different methodologies and digital techniques, not necessarily developed as a diachronic model. The project combines historical and digital methods by intersecting historical data from different disciplines and integrating them into spatial and time georeferenced 2D and 3D reconstructions. Archival sources, digital media, and historical entities are displayed in a web-based research infrastructure that allows their interlinking, visualisation, and interrogation [8].

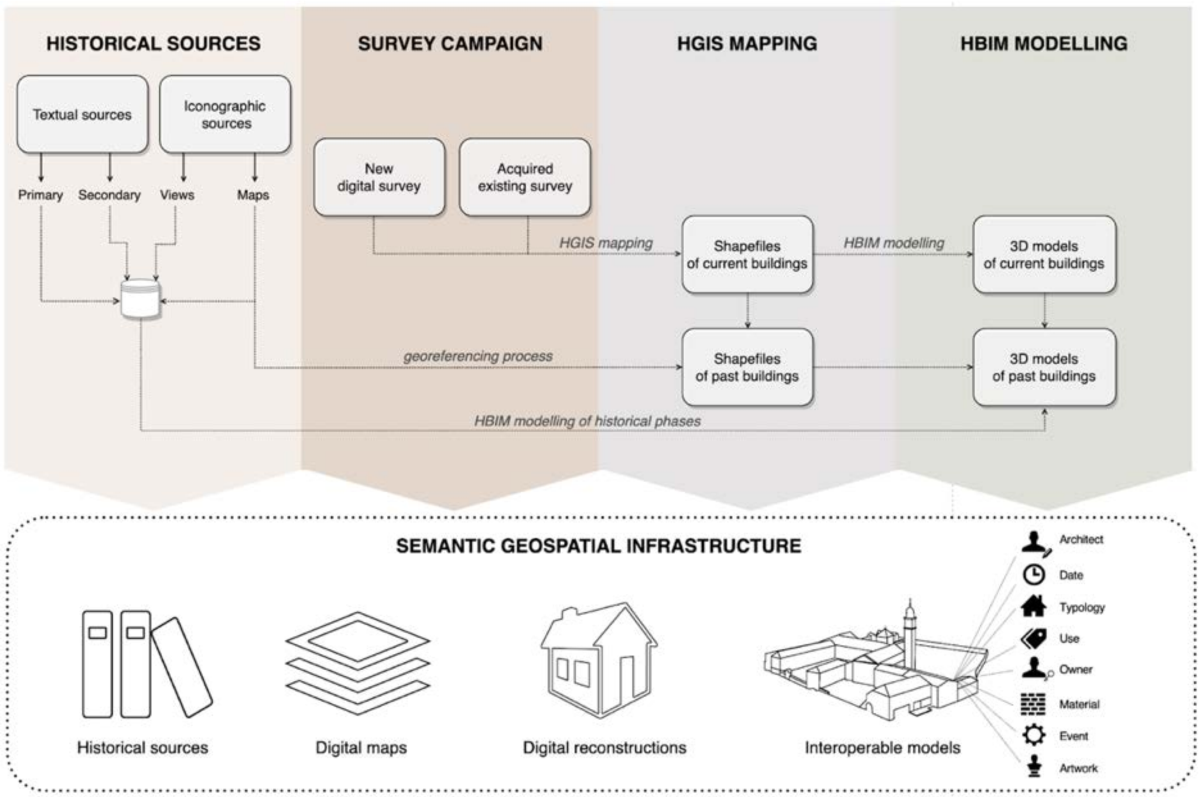

Figure 2: Diagram of combined historical- and interpretation-based reconstruction workflow

The very first step of the workflow involves collecting all historical sources pertaining to the layered histories of the islands and their built works. These are disseminated across a profuse number of textual and iconographic documents, ranging from descriptions, rental contracts, and notarial deeds to maps and drawings, paintings and, for more recent times, accurate surveys, aerial photographs, and orthophotos. This extensive documentation, in myriad formats, is compiled on the platform through online forms and classified into four main categories or "entities": the *sources* (primary and secondary), the *events* recalled in the historical documentation, the *actors* involved in these sequences of actions, and the *built works* themselves marked as buildings, islands, open spaces, and waterways. In the following sections, we will be presenting a more accurate example about the built works' form.

Likewise, the project requires the acquisition of morphometric information related to the existing space and architecture. Despite demolitions and abandonment, islands still preserve some traces of their centuries-old stories: buildings, substructures and foundations of ancient constructions, or just scattered architectural fragments, in some cases barely emerging at low tide or entirely submerged. Therefore, the research group from the Università degli Studi di Firenze is currently developing a series of topographic and laser scanner survey campaigns (with mobile and TLS laser scanners but also flying and submarine drones) to measure the still-extant architectural structures. These results constitute the indispensable basis for acquiring the ground control points necessary to support the digital two- and three-dimensional reconstruction processes.

In order to visualise the physical transformations of each lagoon settlement, the entire survey documentation – both newly acquired or already existing – is then transferred into a historical geographical information system (HGIS) as this tool is capable of integrating and displaying spatial information derived from cartography as well as combining it with quantitative and qualitative data. Exploiting the georeferencing, mapping, and spatial analysis techniques, this system enables the digital reconstruction of the islands' former configuration comprising all their transformations over the past five centuries. Among the many iconographical sources amassed, only maps and cartographic drawings are selected, re-ordered chronologically, georeferenced, and vectorised working backwards in time – from present-day cartography to sixteenth-century documents – with the aims of tracing each building's change.

Building on the geospatial features (spatial descriptions of built structures) and the extensive historical documentation, the project also produces the elevations of selected islands over time. For the digital reconstruction operations, the Building Information Modelling technique for historical representation (HBIM) is deployed because this system allows the construction of interoperable and semantically enriched 3D models. These outcomes not only visualise the built works' geometry in three dimensions, but they also embed time-based data about each building's temporal parameters (date of construction and demolition), functions, uses, typologies, materials, architects, owners or spatial relationships over the centuries as well as the constellation of actors, events, ideas, and practices related to a given context.

Historical sources, research findings, digital surveys, georeferenced maps, and 2D or 3D models are finally integrated and rendered navigable as open datasets in the geospatial semantic infrastructure, which allows for their seamless interconnection while preserving their contextual meaning in time and space. These are displayed as either textual metadata or on a time-based map interface in the form of Linked Open Data (LOD), thus enabling their free access and linking to external vocabularies.

The user interface has been designed following the common layout of web mapping services. The platform is centred around a single map with which the user can interact to visualise the whole lagoon or discover specific islands that have undergone multiple transformations over time. The page displays a current base map with overlaid historical GIS features (polygons describing buildings, islands, open spaces or waterways) that represent the ancient landscapes (see Figure 3). These digital reconstructions are superimposed on the base map and shown according to the selected year on the timeline, located at the bottom of the page. The time slider enables users to choose a specific point in time, allowing the map to display coeval features, which have a timespan that traverses that year.

In addition, all entities directly related to the features are displayed on a sidebar – called the *navigator*. In doing so, the platform collects the various sources that served as the foundation of the research in a single cross-referenced environment. These entities may include archival materials, bibliographic items, iconographic sources but also actors, events, and places that can be filtered at any time by type. Information can be retrieved by hovering over a specific object and displaying entry-level information or by accessing directly the original sources and their associated metadata.

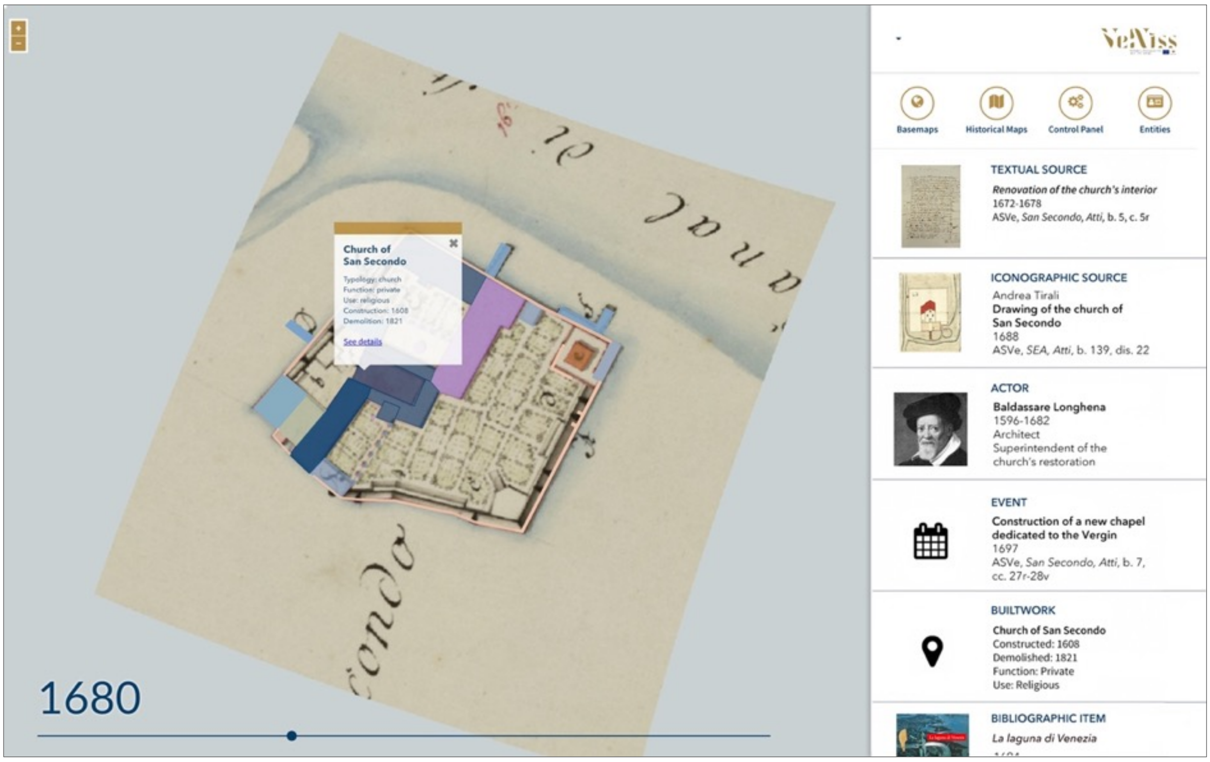

Figure 3: Layout of the 3D geospatial semantic infrastructure

The infrastructure also enables the overlay of georeferenced images on the base map, which served as the basis for drawing the geospatial features in the HGIS system. In addition, it allows users to interact with the map by fine-tuning visualisations themselves to create personalised views. By applying a series of queries and manipulating features' colours and labels, scholars can effectively visualise links and relationships between places, events, and actors. Finally, the infrastructure gives the possibility to navigate through the 3D virtual models imported from the HBIM environment and to move across time. These integrated models provide a crucial tool to structure complex-level spatial and interpretative analyses for mapping and visualising the archipelago's change over time in terms of urban space, social activities, private/state jurisdictions, and interaction between different actors broadly involved in the place-making process. Exploiting the capabilities of computational analyses, these data-embedded 3D models also enable comparisons of architectural solutions, spatial typologies, materials, and building techniques.

By giving the possibility to visualise and interrogate historical information and archival data directly on the pertinent digital reconstructions, the infrastructure not only helps rediscover a cultural heritage that has almost completely disappeared but it also re-evaluates the city's borderlines as sites of incessant synergistic cultural, social, and economic dynamics, thus helping to move the discourse away from the typical schema of "centre-to-periphery."

4. The development of a Data Model

For the aim to represent, store, and disseminate this intricate and nuanced historical data, a knowledge graph database has been adopted as the ideal choice. The VeNiss platform is therefore developed on ResearchSpace, an open-source infrastructure designed to work with knowledge graphs and knowledge patterns in full, providing semantic components, interfaces tailored for scholarly collaboration, and SPARQL endpoints that make gathered data naturally woven to the LOD ecosystem [10]. A peculiar aspect of ResearchSpace is its direct integration with the triplestore – Blazegraph as default, as in our case – and ontologies that can be visualised and managed in a dashboard. There is an inherent challenge in developing a formal data model to represent knowledge about objects that may change dramatically over time [11]: ontologies are usually rigid formal systems intrinsically demanding consistency, while the knowledge regarding deep transformations can challenge basic logical assumptions like identity over time, existence, form, substance, etc. This is particularly true in the case of buildings that, throughout their existence, undergo several transformations to adapt to new functions and uses. Built works constitute an important focus of interest in the research of VeNiss, and their heterogeneous and protean aspects must be expressed fully. In this context, Cidoc-CRM represents an ontology with remarkable expressiveness, capable of allowing us to distinguish between physical objects themselves and their representations (both two- and three-dimensional), between physical and functional changes, between representations visualised in the primary sources and the digital reconstructions, between partial modifications and integral transformations [12].

4.1. Physical forms

The material history of a built work forms a space volume that is projected in time at the historian's discretion by construction and destruction events (the temporal extremes of a built work's existence) and in space by the physical shapes it assumes, which in turn it finds representation in the illustrations and descriptions of primary sources, as well as in 2D (HGIS) and 3D (HBIM) drawings (see Section 5).

Cidoc-CRM (version 7.1.1) can express this concept through the E92 Spacetime Volume class, which corresponds to the spatial and temporal extension of the built work, namely its physical history. The "slices" of this space-time volume (which represent the individual "physical phases" of the object) coincide with instances of the E93 Presence class, which will have specific time spans, obviously contained in the time span that defines the entire "Spacetime Volume". For each new physical shape of a built work, the existence of a "modification event" that determined it is logically implied: we can talk about additions (a part is added to the object), subtractions (a part of the built work is demolished), substitutions (reducible to "simultaneous" removals and additions).

However, speaking of "presence" may seem counterintuitive in this context, as it would make one think of relating a moving entity in time and space, which may or may not be "present" in a specific place at a specific moment: to these extents, we can talk about the presence of Antonello da Messina in Venice in the years 1474-75. This assertion would in fact be correct, but is it appropriate to talk about "presence" in the case of a built work we want to grasp its many shapes? Upon closer inspection, even the discrete physical forms of a built work over time embody a particular case of "presence" as:

- Built works in a few cases can literally be moved;
- More likely the structure of a built work can be modified, and this implies that its physical phase (its presence) is defined as nothing else than the portion of space occupied by the entity at a certain time.

In fact, as we read from Cidoc-CRM documentation 7.1.1, relating to the E93 Presence class means that:

> "This class comprises instances of E92 Spacetime Volume, whose temporal extent has been chosen in order to determine the spatial extent of a phenomenon over the chosen time-span. Respective phenomena may, for instance, be historical events or periods, but can also be the diachronic extent and existence of physical things [...] to reconstruct the total passage of a phenomenon's spacetime volume through an examination of discrete presences" [13].

4.2. Functional phases

The functional history of a built work, on the other hand, outlines all those attributes not strictly related to the material aspect. Names, uses, typologies, functions, possessions: all these characteristics are defined by people's decisions, cultural conventions, material practices, etc. These components are intimately linked to built works and, therefore, they tend to change over time and, most of the time, they can be independent from other architectural changes.

4.3. Identity

As mentioned, a built work can survive while changing some of its physical components or functional aspects (or both), but there may also be cases in which it becomes another built work for which scholars wish to keep track of its history. Here are some possible cases:

- A built work that has undergone many radical physical and functional changes can be considered a new one;
- Two or more distinct built works are merged into a single built work;
- A built work is divided into two or more separate structures.

In all these examples, there is no longer an identity relationship between the two or more built works involved in the transformation process (they are not the same object anymore). This means that, as separate entities, they hold concrete implications in the knowledge graph, as the assertions are predicated on separately materialised nodes with different identities (and distinct corresponding interfaces). The only existing relationship between the original built works and the resulting ones is that of a "transformation event" (E81 Transformation). It is no coincidence that in Cidoc-CRM the E81 class is a subclass of both the "E63 Beginning of Existence" and "E64 End of Existence" classes since it represents a passage that links the end of existence of a built work to the beginning of the existence of another.

4.4. Existence and uncertainty

The existence or non-existence of a built work at a given year is usually testified by historical sources, but sometimes it can be logically deduced indirectly: let's suppose that a built work is represented in two historical maps, dated 1500 and 1600 respectively. We can infer that the built work existed in the year 1550, although no direct evidence has been found for that specific time period (Fig. 4). This deduction has an inherently uncertain epistemological status and must be represented as such in the interface.

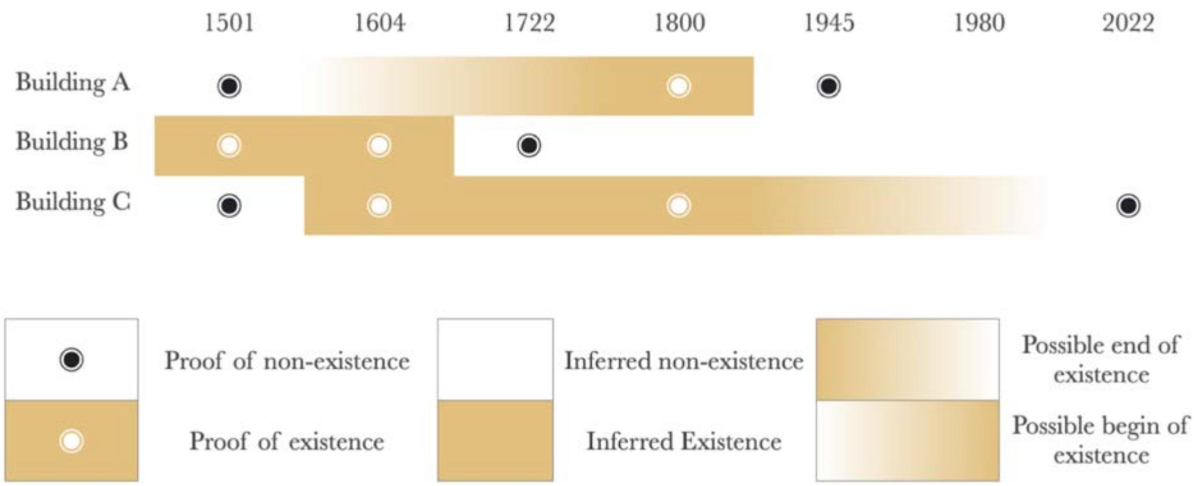

Figure 4: Three examples of timelines that document the existence of a building based on its representation within the historical sources

5. Integrating built works' digital representations into the platform

As we embarked on our project, we observed the continuously growing thread of Spatial Humanities [13,14,15,16] in which numerous projects have been developed to represent geospatial data in a digital environment. A shared common point is the importance of modelling data and databases (SQL, NoSQL, Graph databases) for annotation and organisation of sources [17,18]. Database modelling is, in fact, often pursued to facilitate internal research and external reuse [19] of data (LOD). While all these projects produce artefacts representing data in physical spaces, their inputs and techniques are more complex and unique. For instance, other projects deal with historical maps from assurance bodies and, leveraging Artificial Intelligence components, they detect buildings' information and automatically create their 3D representations [20]. Others may start from historical documentation to generate intangible data, such as migrations of people groups [21], and plot their movement in time on a map. The technologies to display their output are diverse, varying based on the projects' different objectives and scopes [22,23], and many choose to incorporate pre-built 3D viewers directly on their websites. While we recognise the value of such visualisations in creating digital objects that represent new elements on a map, our primary focus is to develop a seamless integration between 2D and 3D components within our platform. To achieve this result, we have designed a custom implementation of interactive visualisation components: the map, a timeline, and the *navigator*. The map addresses VeNiss' spatial requirements, performing both the input and output tasks, searching and showing built works in space. The timeline is another crucial component of the infrastructure as it allows users to navigate seamlessly through the rich history of the lagoon in the temporal dimension. The *navigator* is an output component showing all the entities, such as sources, people, and events related to the built works retrieved with temporal and spatial research.

Besides visualisations, VeNiss considers the crucial task of authoring data where, similarly to the other projects, custom forms handle the process of inputting data into the platform. In this article, we specifically address the functionalities of the built work form, which allows scholars to report buildings' various changes throughout their existence and link them to their 2D and 3D representations with visual and textual sources stored in the infrastructure.

5.1. The process of creating representations

In section 3, we have briefly described the pipeline adopted to transform the historical documentation (textual and iconographic) about the islands into digital 2D and 3D representations that will be subsequently implemented into the semantic infrastructure. The very first step of this methodology is to georeference the historical cartography to determine, on a bi-dimensional level, all major changes that occurred in the lagoon settlements over time. We resolved to use QGIS, an open-source HGIS software, as it allows us not only to collect and query geographic data easily but also to store drawn features in a PostgreSQL database running the PostGIS module.

Within the HGIS environment, information is stored according to a systematic operational methodology that allows us to address some articulated temporal aspects: for each island, we produce four different QGIS layers (buildings, islands, open spaces, and waterways) with the idea to map and represent all the different physical components of the lagoon space over time. Each layer contains all current and historical representations of a given built work (namely its shape today and the shapes it had in the past), thus allowing scholars to visualise the many changes that occurred throughout the centuries on the very same layer.

This process of creating new features starts with a close examination of historical maps. These documents represent the physical appearance of an island and its pertaining structures at a given time and constitute the reference point for drawing their temporal phases (see Fig. 5). After being georeferenced on a current base map or digital survey, historical maps and drawings are vectorised in QGIS, working backwards in time and creating the four layers previously mentioned. For each feature (namely a single built work), we adopted an identifier (ID) that is composed of the acronym of the island, the acronym of the layer and a number (i.e., *LZV_BLDG_1* for a building located on the island of the Lazzaretto Vecchio). In the case of a building that has changed its morphology during its lifespan, we need to create two or multiple features (according to the number of transformations) and assign them a different identifier that, however, needs to immediately remind scholars of the original feature and maintain a record of the relationship between the different objects. In this way, scholars can easily recognise when two features correspond to two different built works and when, on the contrary, they are the results of architectural modifications (additions, alterations, or partial demolitions). Because of the backward drawing process, the feature with the shortest ID is the most recent one, while the precedent feature has the same ID plus a scalar number (i.e., *LZV_BLDG_1.1*, *LZV_BLDG_1.2*, and so on).

Given this nomenclature, all cartographic maps can be georeferenced and digitised to create new vector features for each current and past built work, as shown in Figure 5.

Figure 5: QGIS interface with vectorised features (in red) on top of a 1813 historical map of the Lazzaretto Vecchio (Venice, State Archives, *Magistrato alla sanità marittima*, b. 60, dis. 1)

Besides the vector features, the resulting output is a GIS attribute table in which each row corresponds to a specific feature. At the same time, each column indicates the date of a historical map used for the georeferencing process. Within this table, dates are stored using Boolean data type, where "TRUE" and "FALSE" values indicate the existence or non-existence of a given feature at a given year. In other words, a "TRUE" value specifies that a built work exists on the historical map, while a "FALSE" value marks that it does not. As shown in Figure 6, this approach allows us to map all the physical changes of a specific built work over time chronologically. In the following case, the building named LZV_BLDG_1 took its current configuration from 1839, while in 1818, it appeared with a different shape (LZV_BLDG_1.1).

	identifier [PK] character varying	today boolean	1984: orthophoto boolean	1982: orthophoto boolean	1839: austrian cadaster_revision boolean	1818: ufficio provinciale pubbliche costruzioni boolean
1	LZV_BLDG_1	true	true	true	true	false
2	LZV_BLDG_1.1	false	false	false	false	true

Figure 6: PostgreSQL table showing two features (rows) and their existence on historical maps (columns)

At this stage of the process, within the GIS environment, we are only vectorising the historical maps, thus creating a series of digital versions of them. By doing so, scholars are responsible for exclusively filling in the features' attribute table according to the existence of a built work on the many historical maps. To these extents, this process does not imply any interpretation of built works' specific temporal parameters (dates of construction and demolition), which are actually deferred to a second step within the infrastructure, thus ensuring that data remains accurate and reliable.

The following step involves the actual linking between historical metadata and the actual GIS features. To accomplish this task, we have integrated the previously described form into our platform, serving as an environment where scholars can integrate information about the various aspects of a built work.

5.2. Visualising digital representations

The platform displays images through a map using the 2D representations connected to each built work by scholars during the first step of the process. The system is designed to answer two primary use cases pertaining to visualisation. The first is related to data authoring within the forms. It enables the view of a single island's features within a fixed bounding box but it does not consent to move the map as this is integrated only into the built work form. The second use case involves the general map, which allows users to navigate through the lagoon settlements and their representations moving the map. This interaction is performed within the bounding box, which is a moveable area defined by two pairs of longitudes and latitude coordinates corresponding to the real estate of the map.

From a technical point of view, our system stores data in a Blazegraph database in which built works' metadata are collected using semantic web technologies. We encountered an important challenge in integrating built works' vectors into the platform: our graph database (Blazegraph), in fact, only supports GeoSparql queries performed over Point, while in this project we ended up using MultiPolygons. For this reason, in performing geospatial queries, those run against the PostgreSQL database containing the drawn features. To make it compatible with VeNiss, we developed a module (the code now resides in the ResearchSpace Github repository) that encapsulates an SQL query within a SPARQL query, taking advantage of the Service construct. By doing so, we can treat bounding box coordinates as variables and pass them to the SPARQL query, thus allowing the system to return the complete set of features' identifiers within the bounding box from the PostGIS internal module. Starting from geographical areas selected within the map, together with the year selected with the timeline component, scholars can further filter through those representations, and consequently, the system displays built works in a specific time and space. Moreover, the platform enables users to explore the vast array of entities, primary and secondary sources, people, and events stored in the infrastructure that are intricately connected to the built works through the *navigator*.

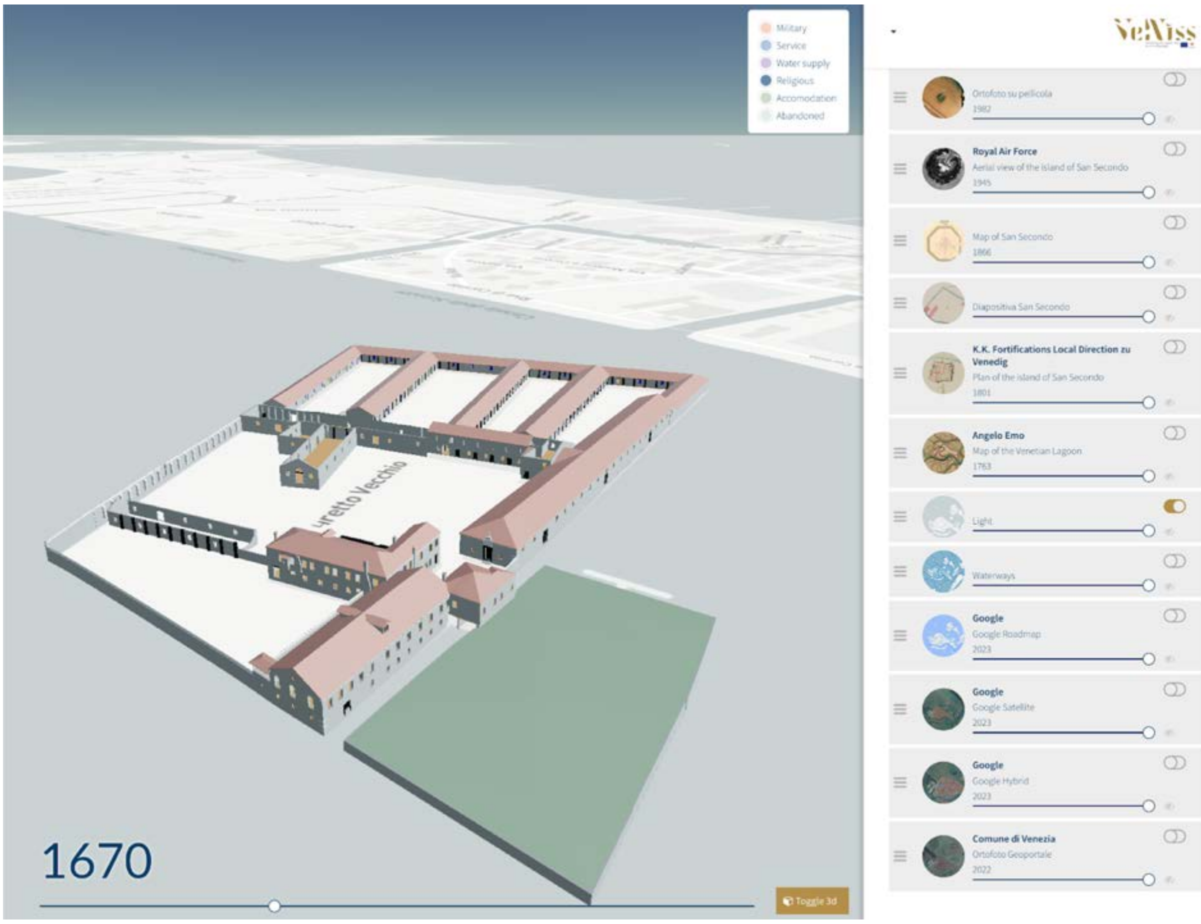

Figure 7: The VeNiss platform displaying the 3D model of the entire island of the Lazzaretto Vecchio

As a next step, our team is currently enhancing the integration of 3D representations created in an HBIM environment within the infrastructure. Scholars with architectural backgrounds create 3D models of islands using the software Revit. These models are then exported in the data model IFC (Industry Foundation Classes), an open format commonly used to grant collaboration among projects based on the BIM methodology. Other than its openness, an IFC file provides a huge amount of technical metadata such as geolocation information, building materials, shapes, etc. Since the VeNiss platform is not able to visualise native IFC files, we resolved to convert IFC files into 3D Tiles, a standard format released by the Open Geospatial Consortium. 3D Tiles are specifically designed for streaming and rendering huge 3D geospatial contents and, to this extent, they are deeply suitable for our case. Given buildings are created in Revit keeping their geographical locations, the exported 3D Tiles are automatically georeferenced on the map. In order to address the conversion from IFC to 3D Tiles, we exploited the generator py3dtilers developed by the VCityTeam GitHub organisation. 3D Tiles are then imported into the Cesium ion platform and consequently linked to the map in VeNiss, as shown in Figure 7. Although this approach results in loss of information about specific metadata generated in the HBIM environment, we are currently working to extract and integrate those into the platform using ifcOpenShell, a toolkit that, among other possibilities, allows us to parse and extract information from an IFC file. Our goal is to advance the representation of 3D elements and tackle the challenges associated with data transformation and information retention.

Conclusions

The VeNiss project aims to represent a significant contribution to urban historical research by proposing an integrated and computational methodology that helps modify our ability to represent the long-lasting dynamics of urban landscapes. It interweaves layers of digital media in an innovative way in order to create a depth of information that is impossible with conventional tools. By employing and interrelating the most advanced digital tools – such as HGIS mapping, HBIM modelling, and semantic technologies – this project provides a more inclusive interpretation of the lagoon system in order to demonstrate its indispensable role in the Venice-making process. This approach overcomes traditional research methods by combining physical and urban analysis in a single web-based application, thus enabling users to explore the long-term and global history of Venice's archipelago in relationship with the protean mutations of its space, architecture, and social processes over space and time.

Coupling historical and digital methods poses some challenges, especially as it regards the balancing between a philological and accurate process of historical reconstruction and the need for a coherent and interactive platform for visualisation. While digitally navigating the historic lagoon requires a user-friendly yet comprehensive 3D geospatial and time-based semantic infrastructure, visualising historical patterns demands a seamless intersection of historical data with 2D and 3D reconstructions, at the same time ensuring accuracy and coherence.

One of VeNiss' ambitions is to offer the broad public a reassessment of Venice as a whole archipelago, while providing a powerful prototype for other urban studies to reset the hierarchical centre-periphery viewpoint traditionally applied to the city and its fringes. This methodology aims at not only preserving the city's heritage and developing fresh perspectives on its history, but also it sets a precedent for future urban history studies. This aspect ideally transcends the historical interest beyond Venice, influencing similar research in other historic cities globally, thus contributing significantly to the broader field of urban historical studies.

Acknowledgements

The project *Venice's Nissology. Reframing the Lagoon City as an Archipelago. A Model for Spatial and Temporal Urban Analysis (16th-21st centuries)* – VeNiss – has been generously funded with a five-year ERC Starting Grant (2023-2027) by the European Research Council (ERC-2021-StG, GA n. 101040474).

The project, led by Ludovica Galeazzo, is based at the Università degli Studi di Padova, in the Department of Cultural Heritage: Archeology, History of Art, Cinema and Music (DBC) in partnership with I Tatti – The Harvard University Center for Italian Renaissance Studies (coordinator: Lukas Klic) and the Department of Architecture (DIDA) of the Università degli Studi di Firenze (coordinator: Sandro Parrinello).

References

[1] J. Rykwert, La seduzione del luogo. Storia e futuro della città, Einaudi, Torino, 2008.

[2] G. Crovato, M. Crovato, Isole Abbandonate Della Laguna. Com'erano e Come Sono / The Abandoned Islands of the Lagoon. How They Were and How They Are Now, San Marco Press, Teddington, 2008.

[3] L. Galeazzo. "Venice's Nissology. Mapping and Modelling Venice's Aquascape in a Historical Perspective." Storia urbana 173 (2023): 31-45. doi:10.3280/SU2022-173003.

[4] K.L. Huffman, A. Giordano, C. Bruzelius (Eds.), Visualizing Venice: Mapping and Modeling Time and Change in a City, Routledge, London, 2018. doi:10.4324/9781315100685.

[5] N. Terpstra, C. Rose (Eds.), Mapping Space, Sense, and Movement in Florence. Historical GIS and the Early Modern City, Routledge, London-New York, 2016. doi:10.4324/9781315639314.

[6] A. Abbott. "The 'Time Machine' Reconstructing Ancient Venice's Social Networks." Nature News 546.7658 (2017): 341-344. doi:10.1038/546341a.

[7] L. Galeazzo, The Venetian Archipelago: Society, Everyday Life, and Cultural Exchange in the Early Modern Lagoon, in: E. Svalduz (Ed.), Market Spaces, Production Sites, and Sound Landscape of European Cities: From History to Regeneration, Padova University Press, Padova, 2022, pp. 69-78.

[8] L. Galeazzo. "Analysing Urban Dynamics in Historic Settlements Using a Geo-Spatial Infrastructure. The Venice's Nissology project." Journal of Art Historiography 27s (2022): 1-13. doi:10.48352/uobxjah.00004202.

[9] D. Oldman, D. Tanase, Reshaping the Knowledge Graph by Connecting Researchers, Data and Practices in ResearchSpace, in: The Semantic Web -- ISWC 2018, ISWC 2018, Springer International Publishing, Cham, 2018, pp. 325–340. doi:10.1007/978-3-030-00668-6_20.

[10] R. Grillo. "Representing change: User interaction and data modelling of an identity paradox." Journal of Art Historiography 27s (2022).

[11] G. Bruseker, N. Carboni, A. Guillem, Cultural heritage data management: The role of formal ontology and CIDOC CRM, in: M.L. Vincent et al. (Eds.), Heritage and archaeology in the digital age: acquisition, curation, and dissemination of spatial cultural heritage data, Springer International Publishing, Cham, 2017, pp. 93-131.

[12] Documentation for Class: E93 Presence | CIDOC CRM. URL: www.cidoc-crm.org/Entity/e93-presence/version-7.1.1. Accessed 26 Dec. 2023.

[13] I.N. Gregory, A. Geddes, Toward Spatial Humanities: Historical GIS and Spatial History, Indiana University Press, Bloomington, 2014.

[14] R. Horne, R. Mostern, Landscapes in Motion: Cartographies of Connectivity and the Place of Physical Geography in the Environmental and Spatial Humanities, in: C. Travis et al. (Eds.), Routledge Handbook of the Digital Environmental Humanities, Routledge, London, 2022, pp. 470-489.

[15] L. Ameel, The Narrative Turn in Urban Planning: Plotting the Helsinki Waterfront, Routledge, London, 2022. doi:10.4324/9781003094173.

[16] F. Moretti, Atlas of the European novel: 1800-1900, Verso, London, 1999.

[17] S. de Beer. "Mapping Visions of Rome and Digital Roman Heritage Connectivity between Literary and Artistic Heritage in a Digital Age." Umanistica Digitale 2 (2018): 9-31. doi:10.6092/issn.2532-8816/7814.

[18] A. Novak, V. Ostash. "Digitizing Historical Maps and their presentation in Online Map Collections." e-Perimetron 17-1 (2022): 33-44.

[19] Y. Yan, K. Dean, C. Feng, G. Hue, K. Koh, L. Kong, C. Ong, A. Tay, Y. Wang, Y. Xue. "Chinese temple networks in Southeast Asia: a WebGIS digital humanities platform for the collaborative study of the Chinese diaspora in Southeast Asia." Religions 11-7 (2020): 1-23. doi:https://doi.org/10.3390/rel11070334.

[20] Y. Lin, L. Jialin, P. Adam, L. Gerika, X. Ningchuan, J. M. Harvey. "Creating Building-Level, Three-Dimensional Digital Models of Historic Urban Neighborhoods from Sanborn Fire Insurance Maps Using Machine Learning." PLOS ONE 18 (2022): 1-24. doi:10.1371/journal.pone.0286340.

[21] M. Venken, A. Sauer. "Arrival declaration forms. A new gateway for mapping migration to Luxembourg." Frontiers in Human Dynamics 4 (2022): 1-19. doi:10.3389/fhumd.2022.931758.

[22] L. Leve, B. Erickson, Visualizing Himalayan Buddhist Sacred Sites in 3D/VR, in: J. Halgren Kilde (Ed.), The Oxford Handbook of Religious Space, Oxford University Press, Oxford, 2022, pp. 176-192. doi:10.1093/oxfordhb/9780190874988.013.38.
[23] J. Schneider, D. Garatly, M. Srinivasan, S. J. Guy, S. Curtis, S. Cutchin, D. Manocha, M. C. Lin, A. Rockwood, Towards a digital Makkah–using immersive 3D environments to train and prepare pilgrims, in: Proceedings of DMACH conference on digital media and its applications in cultural heritage, CSAAR Press, Amman, 2011, pp. 1-16.