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Open-oriented algorithmic approach for BIM modelling of complex historic water infrastructure

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Abstract

The management of water resources has underpinned the history of settlement systems for centuries. The introduction of railways often led to neglect the previously fundamental hydraulic infrastructures that characterised the landscape. The "Naviglio" of the city of Pavia (Italy), an artificial water channel built to allow uphill navigation from Pavia to Milan, is the perfect example of a relevant historic infrastructure worth of management and refurbishment interventions. To this end, monitoring strategies and a digital ecosystem to implement them are required. Namely, the proposed methodological workflow integrates semi-automated modelling procedures for the fast development of a LOD 200 GeoBIM model of the "Naviglio" starting just from 2D cartographic data and literature information. The objective is indeed to set up a digital ecosystem, taking advantage of the strength of the BIM methodologies, optimised for implementing monitoring strategies both at architectural and urban scales. Furthermore, the approach seeks to employ open tools when possible, relying on a transferable parametrisation algorithm so as not to constrain further researchers to a specific BIM authoring tool.

1. Introduction

The management of water resources has underpinned the history of settlement systems ever since the earliest times and, on a more general level, has conditioned the development of different civilisations. Many territories, then, are entirely conditioned by water management systems, whose infrastructures have changed their appearance by assigning significance to space (Vallerani & Visentin, 2019). Representing such complexity implies referring to a multidimensional framework where the drawer, the scholar, has to deal with multiple extents (Purini, 1996), e.g., the physical and the temporal extents – also connected to a more specific physical dimension tied to the dynamism of the moving element, i.e., the water – or to a metaphysical dimension, addressing the past and ascribable to memory.

The task of representation is to hypothesise a critical synthesis, to define lemmas and symbols that can convert a complexity of infinite relations into an ordered and tidy network of signs and symbols, i.e., a language (Parrinello, 2013). In digital representation, this network of relationships is structured in models that collect and support data of different nature, information systems (Picchio, 2016). The interest towards the use of the element of water in place transformation processes can be justified firstly in the challenge offered by the complexity of detecting and graphically rendering what lies submerged, in representing a landscape that is in part not only difficult to reach or measure, but that only partially shows up and reveals itself. Secondarily, in the fact that such a landscape expression provides the pretext for a transversal reading of the territory, highlighting an aspect that is particularly relevant today for ecological and environmental sustainability issues (United Nations, 2023).

This very broad subject has been oriented and narrowed in relation to an international and topical debate that addresses the themes of the recovery of the memory of places, the narration of cultural and identity heritage and the facilitation and conscious management of water in urban and agricultural realities (La Placa, 2021). Drawing and digital representations are the fil rouge tying cultural heritage's tangible and intangible values as expressions of historic insight and reflection on what surrounds us (Parrinello & Dell'Amico, 2019).

1.1 From HBIM to InfraBIM

Today, several research studies have provided answers to the main incompatibilities between BIM and GIS systems (Ma & Ren, 2017; Saygi et al., 2013). The two systems work with data characterised by different levels of detail and, in order to succeed in managing these, it is necessary to unite them in a single platform toward the definition of fully functional GeoBIM models (Bruno et al., 2020). Additionally, interoperability problems are still open regarding incorporating HBIM (Historic Building Information System) models related to historical or cultural heritage in a GIS environment (Colucci et al., 2020; Palomar et al., 2020; Vacca et al., 2018). The setting up of architectural detailed models for tangible heritage artefacts poses challenges related to their distinctive geometric and formal complexity (Gonizzi Barsanti & Rossi, 2021). The challenge lies in reproducing, through the standardised modular forms offered by BIM, the individual articulated construction elements that make up, for instance, masonry structures, and floor slabs (Gonizzi Barsanti & Rossi, 2021). Furthermore, when working on an existing building, the location of the building has to be considered. When referring to the HBIM/HGIS combination, it is therefore also necessary to assess the accuracy of the georeferencing of the asset under investigation (Matrone et al., 2019). This latter challenge can be addressed through the specific plugins (e.g., FME – Feature Manipulation Engine – Exporter for Revit), although recent GIS software developments have introduced in-built tools for the direct implementation of BIM products (e.g., ESRI ArcGIS Pro). However, an effective system of dialogue and integration between spatial and architectural data, each characterised by the most appropriate level of detail, remains to be developed (Deng et al., 2016).

Although BIM was born for construction, in recent years researchers are also focusing also on infrastructural scales (Abbondati et al., 2020), especially in the field of transport, public service, environmental, and energy infrastructures (Badach et al., 2022; Collao et al., 2021). In these cases, the scientific literature refers to BIM as I-BIM or InfraBIM (Infrastructures Building Information Modelling) (Dell'Acqua,

2018; Osello, 2019). Infrastructural design (understood as construction process but also as planning of intervention activities) implies, differently from what happens for buildings, dealing with considerable extensions and with consequent multiple and diversified interferences with surrounding elements and spaces (Leone et al., 2017), making the aspect of georeferencing and GeoBIM particularly relevant (Barazzetti & Banfi, 2017). In detail, I-BIM comprises different applications. Among the main ones are the one related to Structural Health Monitoring (SHM) and the one aimed at Modelling the "new", as opposed to the "existing", with different degrees of automation (Osello, 2019). In turn, SHM can take different forms, depending on the structures under investigation, among these, a well-known example is that of applications for bridges, BMS – Bridge Management Systems (Dang & Shim, 2020; Hajdin & Samec, 2022). Despite the aforementioned developments and growing application areas, the use of I-BIM still poses significant challenges from a technical point of view (Biancardo et al., 2020). These are especially due to the difficulty of parameterisation of infrastructure geometries and as a consequence of the still small number of specific libraries for such components (Pasetto et al., 2020).
In the organisation and use of the mass of data and information useful for the most suitable digital management of infrastructures, computerised systems are generally used to support critical decision-making strategies (Saback de Freitas Bello et al., 2022).

2. Materials and Methods

Regarding the highly historicised and fast ageing Italian infrastructure heritage, looking for efficient solutions to define reliable monitoring strategies then becomes crucial; its comprehensive survey and digitisation show many issues, specifically related to the uneven and significant dimensions and the amount of information to handle at once. Indeed – especially in light of the introduction of “informative digital management by means of specific electronic methods and tools” envisaged by the Italian regulation as mandatory for public works costing more than 1 million euros, as already mentioned in the legislative decree 50/2016, the “Code for Public Tenders” (D.lgs. 50/2016), and further recalled by its updated version the recent legislative decree 36/2023 (D.lgs. 36/2023) – it is necessary to implement digital repositories, in the form of informative three-dimensional systems, suitable for storing monitoring data and supporting scheduled maintenance (Morandotti et al., 2019). Thus, an informative model derived from GIS data that can be fully developed in a few hours once the manual input data has been retrieved becomes an essential support tool to serve as a reference for future survey and inspection campaigns. The innovative solution relies mostly on free and easily acquirable data to develop a BIM model suitable for storing further acquired information and can be updated, enhanced, and detailed according to time and necessity. Namely, the open-access-shared (thoroughly described and made available to download via the Zenodo Research Repository) custom scripts developed via Dynamo for Autodesk Revit are based on that method implemented by the leading modelling pieces of software for generating models of ex-novo assets and characterised by a high level of standardisation. The proposed VPL scripts and the Autodesk Revit environment in which they are implemented allow the kind of flexibility that BIM-oriented software for infrastructure does not guarantee due to rigid packages of cross-sections that are difficult to modify both in terms of structural layering of constituent materials and longitudinal adaptation to the peculiarities of the surrounding orography, where also a VPL-based algorithmic approach (AIM) is more limited and often cause malfunctions due to the constraints imposed by the very software programmes. Finally, very few other pieces of software offer the possibility to manage and add custom parameters easily; on the other hand, it is also customary to rely on BIM software designed for higher detailed elevation structures.
Therefore, the hereby presented methodological approach proposes an algorithmic approach for modelling historical linear infrastructures, starting from georeferenced cartographic and literature data aimed at developing a detailed, albeit still generic, system, object, or assembly with approximate quantities, size, shape, location, and orientation and the possibility also to add non-graphic information, corresponding to a LOD 200 according to the American Institute of Architects (AIA) definitions (BIM Forum, 2019) or a LOD B in the Italian regulation (UNI 11337-4:2017).
Although the geometric modelling process always requires working within a BIM authoring environment, the VPL algorithm and the custom node made available in open-access allow for full replicability of the process within any environment linked to a programming tool.

2.1 The proposed methodology implemented via a procedural algorithmic approach

Information systems may change significantly depending on the type of infrastructure. Anyhow, from the perspective of an automated system, if input/output data judgement and responsibilities are not tightly controlled, the risk of error propagation increases; moreover, it is also necessary to consider the degradation of system performance when including different parameters and geometric constraints (Rapetti, 2019). On the other hand, the inspection workflow must also be improved (Dang & Shim, 2020).
Therefore, we propose here a methodology developed according to a Top-Down approach that follows five steps (Fig. 1) to set up a digital ecosystem (Parrinello et al., 2023) for the posterior implementation of monitoring and maintenance procedures. (1) Starting from the acquisition of literature (1.1) and georeferenced GIS data (1.2) concerning the infrastructure under investigation, (2) discretisation of the relevant elements comprising the artwork is carried out in a CAD environment in order to identify the type of smart objects to be developed and define the most suitable modelling procedure according to their nature; indeed, 3D model can be designed and placed on the basis of different initial variables, i.e., punctual coordinates, lineal references or projected installation area. Namely, the CAD vectorial drawing is organised into layers, each serving as a reference for the subsequent importing procedure to the BIM authoring tool. (3) Once imported into the BIM environment, the vector geometry is filtered by means of the specific layer properties and vertically displaced to reconstruct the three-dimensional geometry and altitude of the infrastructure components. The shape of the linear elements is first broken down into significant cross-sections and subsequently modelled as a solid interpolating said cross-sections and generated as BIM instances, also with assigned names, materials and categories. (4) Conversely, the complementary components can be placed employing either “system” or “loadable families” according to the imported reference lines and areas. In detail, the semi-automatic modelling procedure consists of various VPL scripts (Sanseverino & La Placa, 2024a, 2024b, 2024c, 2024d, 2024e, 2024f, 2024g), making it possible to check and manually fix possible inaccuracies both in-between and after their execution; furthermore, detailed elements can be implemented at any time, thus increasing the Level of Geometric Detail (LOG). (5) Once the base BIM model has been realised and the sub-parts adequately assigned to the relative categories, it is easy to implement additional descriptors – in the form of “shared parameters” – to enhance the Level of Information (LOI) and meet the possible legislative or project requirements. The LOI – originally seen as part of the equation that, together with the Level of Geometric Detail (LOG), defined the general

concept of Level of Development (LOD) – is currently moving toward the concept of Level of Information Need (LOIN), where the specific information that "needs" to be connected to the geometric 3D model is defined by the contractor. The LOIN, as introduced by the ISO 19650–1 & 2:2018 and the EN 17412–1:2020, is indeed meant as a framework to define the extent and granularity of "information", i.e., reinterpretable representation of data in a formalised manner suitable for communication, interpretation, or processing (Pavan, 2019). Additionally, due to the BIM software working with cartesian coordinates and Visual Programming tools employing a user-defined scale that affects the maximum and minimum precision of the represented geometry, it is advisable to run the first stages of the semi-automatised modelling procedure within a local reference system and proceed to georeference the project by the end of the procedure, just acquiring the corrected reference system from the linked CAD cartography. The information populating the monitoring parameters eventually implemented can also connect the smart objects to detailed tables and schedules via unique identifiers (ID) in BIM and within other information system environments, such as 3D GIS.

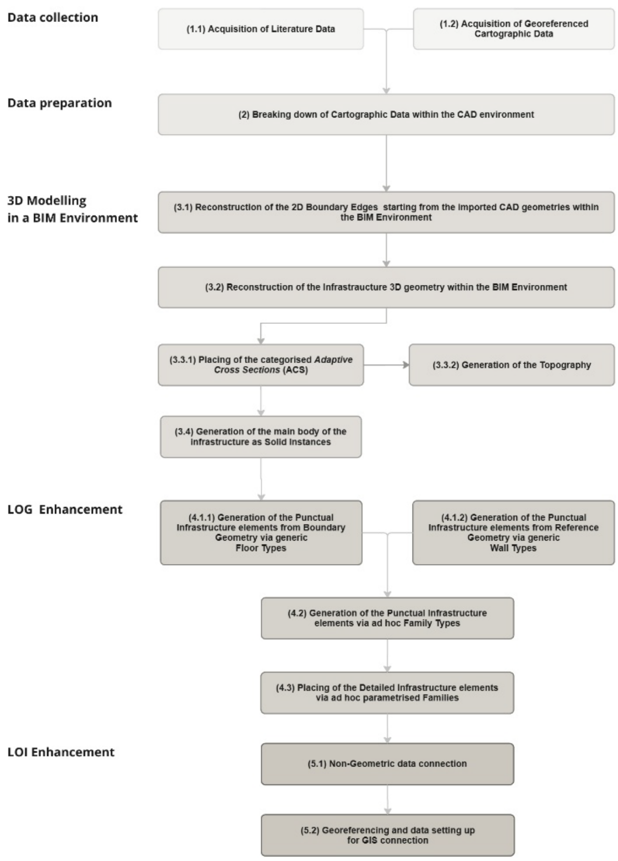

Figure 1. Flowchart of the proposed algorithmic methodology.

2.2 Semi-automated parametric approach for elevation reconstruction

The third step of the testing procedure consists of three scripts – developed via the open tool Dynamo 2.12 for Autodesk Revit – that vary little from one another due to the necessity of generating three types of instances with relevant differences in their cross-sections and the inconsistent slopes for some sections of the infrastructure. Generally speaking, they can be broken down into five substeps graphically identified as coloured groups (Fig. 2) as opposed to the input data group identified in grey blocks. (3.1) The first step concerns reading the imported CAD geometries and reconstructing the continuous "Curves" representing the boundary edges of the infrastructure as "Polycurves". Concurrently, the "Polycurves" are divided into homogeneous sections according to the infrastructure changing in the type of substructure in order for these groups to be reordered according to a selected criterion – in this case, with ascending the "Y" coordinate. (3.2) The ordered sections are then translated altimetrically according to their function – e.g., delimiting the left or right upper or lower bank or the deck – using an average height difference for the homologous cross-section parts of the infrastructure. To obtain spatial coordinates as reference points, the reconstructed boundaries are then intersected with planes placed along the chosen infrastructure alignment, perpendicular to it, at a fixed distance, i.e., 20 m for the areas allowing for a higher degree of approximation due to the simpler structure and 1m for those peculiar components needing more detailed geometric modelling. (3.3.1) For the proper generation of the cross-sections as BIM instances that could be manually edited between the execution of the third and the fourth phases of the proposed methodology, if necessary, an ad hoc "Adaptive Components" categorised as a structural element was designed (Fig. 3). The planar component envisages eight "Adaptive placement points" to be input following the predetermined placing order and connected by lines forming a closed loop. Therefore, the "intersection points" groups obtained in the previous step are ordered accordingly and then subdivided again into homogeneous sections of the infrastructure, presenting a constant elevation from zero and an eventual constant slope. The uniform infrastructure sections are then additionally translated in batches to be eventually placed at the input elevation derived from the literature review. Lastly, the adaptive components differentiated into types for each homogeneous section are generated as BIM instances with an associated structural category to ease any required filtering procedure. (3.3.2) Additionally, the reference points used for the "Adaptive Cross-Sections – ACS" can be employed to generate an initial editable topography of the infrastructure surroundings.

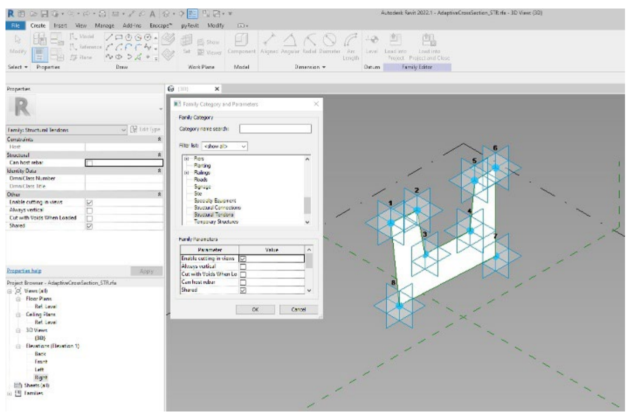

Figure 2. "Adaptive Cross-Section" (ACS) ad hoc designed family (RFA) with indication of its ordered control points.

2.3 The "Naviglio" water infrastructure of the city of Pavia

The Lombardy flatlands, although distant from the ports of the Mediterranean and the Adriatic, had been connected to it through skilful management of water resources, connecting the great rivers of the landscape, the Po, the Ticino and the Adda.

The first major change to the territory for this purpose was due to the construction of the "Naviglio Grande" which, by diverting part of the waters of the Ticino, allowed the city of Milan to be supplied with water. Since the construction of the "Naviglio Grande", more than seven hundred years of projects, excavations and current diversions have transformed the flatland area between the Ticino and Adda rivers, reshaping it via a complex and extensive navigation network, known today as the "Navigli Milanesi" system (Boatti & Prusicki, 2018). The system's multi-functionality, emblematic of its ingeniousness, its far-sightedness in embracing an overall regional vision, and the efforts made, defines the groundwork for the development and economic growth of the plain (Cattaneo, 2020).

The role of the "Navigli" in the constitution of the Lombardy landscape is significant not only from a strictly environmental point of view, but also from an economic and social one, on which it has considerable repercussions. The entire system underlies the interconnection processes between different urban and rural realities, supporting the definition of a polycentric settlement network in the territory (Boatti & Prusicki, 2018), which in turn permanently marks the landscape.

During the various foreign dominions that followed from the mid-16th century onwards, the interest of empires and kingdoms was mainly oriented towards the possibility of connecting Milan to the sea, which is why most of the investments were directed towards the design and the construction of the "Naviglio" of the Pavia city, representing the waterway that would most directly enable the connection. However, the main challenge for the construction of the navigable canal was to overcome, with adequate technical and engineering knowledge, the height difference of approximately 56 metres between the two cities (Bobbi, 2019).

During Napoleon's French government, which intended to markedly improve connections with the Italian provinces, an official decree was issued on 20 June 1805 to complete the construction of the Naviglio canal, which was then completed under the Lombardo-Veneto kingdom in 1819. The Naviglio not only boosted trade, but ensured that agriculture and Lombardy's first industries flourished, which used the waterway to irrigate the land and obtain motive power for manufacturing (Brichetti, 2017). From the Milan dockyard, the channel bypasses the city and its suburbs to flow throughout the flat countryside to Pavia and then to the Ticino River. The clear-cut height differences created along its course to allow upstream navigation prompted the construction of numerous businesses and workshops along the banks of the water channel. The arrival of the railway in 1862 slowed down the traffic on the "Naviglio", which soon, in the late 1830s, lost its function as a transport route and was progressively abandoned, along with the structures and the facilities depending on it.

Figure 3. From top to bottom and from left to right present-day images of the "Biconca Botanica", the "Biconca Garibaldi", the "Conca del Cassinino" and the "Conca di Moirago". (Retrieved May 16, 2023, from https://navigliréloading.eu/navigli-lombardi/il-naviglio-pavese/le-conche-del-naviglio-pavese/).

However, the legitimisation of the infrastructure's value dates back only to the end of the 20th century, as part of an overall rediscovery of Lombardy's heritage of industrial archaeology, in which the "Naviglio" was recognised as having unique characteristics within Lombardy's "Navigli" system. Its slow and tortuous construction had in fact allowed the engineers to include, already at the design stage, the improvements that had proved necessary for the other "Navigli", as well as take advantage of the greater hydraulic expertise acquired by the time of its construction. The "Naviglio" of the city of Pavia is over 33 km long and has an average width of 12 m from bank to bank. It is the only one in the Lombard system to have not one but two towpaths running parallel to it, built to facilitate the passage of animals pulling boats on their way up to Milan. Numerous bridges varying in their design, including a floating bridge in the Badile area and an octagonal one for the passage of the waters of the Martignana canal, allowed the "Naviglio" to be crossed at the time of its construction. The 56-metre difference in height between the two towns is overcome with 12 navigation basins, in the following defined "Conche", two of which are coupled, the so-called "Biconche".

3. Results

3.1 Discretisation of the cartographic reference data

Following the import of cartographic data into the CAD environment, a propaedeutic action for the implementation of the proposed workflow envisages the breaking down of the “Naviglio” boundary lines assigning them to different layers according to their function. The layers nomenclature, identified with an alphanumeric codification reflecting the graphic function, is reported in Table 1. Indeed, the CAD layer naming becomes a type property of the “lines” once imported to the Autodesk Revit environment, providing an intuitive filtering rule. Namely, the boundaries of the 3D cross-sections reconstructed and reordered during the third stage of the proposed methodology are derived from the georeferenced 2D cartography elements identified as both upper and lower banks and docks of the “Naviglio” and the “Conche” structures. While the upper and lower banks of the “Naviglio” do not always overlap, requiring a separated discretisation and configuring a variable cross-section from the rectangular to a trapezoidal shape, the docks boundary lines were considered as upper and lower external references. Furthermore, each category’s left and right sides were also separated into different layers.

3.2 VPL scripts developed for altimetric reconstruction based on literature information

In order to properly set up the BIM modelling environment, different levels corresponding to the identified height differences were automatically generated via the first VPL script run by manually inputting via a “Code block” the “Conche” names and their varying levels’ altitude displacements and appropriately combining them. This information was clustered in two main input groups identified in grey and used as source data for the execution of all the VPL scripts. Table 2 presents the identified levels and the corresponding relative elevation retrieved from the literature (Biscardini & Bricchetti, 2020). As previously mentioned, the first part of the scripts developed for stage three of the implemented workflow concerned the reconstruction of an average three-dimensional geometry of the “Naviglio”; for this purpose, a few assumptions had to be undertaken, as listed as follows. An average depth of the main course of the “Naviglio” was set equal to 2.3 m; therefore, the lower bank lines were assigned a translation of -2.3 m. An average bottom thickness of the main structures was considered equal to one, thus, the dock lines were copied and assigned a translation equal to -3.3 m.

Layer Name	Function in boundary geometry reconstruction
_01_AsseNavigazione	Alignment reference line
_02.1D_Naviglio_Argini_Sup	Upper Right Bank of the "Naviglio"
_02.1S_Naviglio_Argini_Sup	Upper Left Bank of the "Naviglio"
_02.2D_Naviglio_Argini_Inf	Lower Right Bank of the "Naviglio"
_02.2S_Naviglio_Argini_Inf	Lower Left Bank of the "Naviglio"
_02.3D_Naviglio_Banchine	Right Dock of the "Naviglio"
_02.3S_Naviglio_Banchine	Left Dock of the "Naviglio"
_03.1D_Conche_Argini_Sup	Upper Right Bank of the "Conche"
_03.1S_Conche_Argini_Sup	Upper Left Bank of the "Conche"
_03.2D_Conche_Argini_Inf	Lower Right Bank of the "Conche"
_03.2S_Conche_Argini_Inf	Lower Left Bank of the "Conche"
_03.3D_Conche_Banchine	Right Dock of the "Conche"
_03.3S_Conche_Banchine	Left Dock of the "Conche"
_03.4_Conche_Salti_Vert	Height difference walls of the "Conche"
_03.5_Conche_Salti_Orizz	Height difference floors of the "Conche"
_03.6_Conche_Ponti	Bridges as floor over the "Conche"
_03.7.1_Conche_Chiuse_DaVinci	Reference line for "Da Vinci's Closing Mechanism" - Type 1
_03.7.2_Conche_Chiuse_DaVinci	Reference line for "Da Vinci's Closing Mechanism" - Type 2
_04.1D_CanaliScolo_Argini_Sup	Upper Right Bank of the "Conche"
_04.1S_CanaliScolo_Argini_Sup	Upper Left Bank of the "Conche"
_04.2D_CanaliScolo_Argini_Inf	Lower Right Bank of the "Conche"
_04.2S_CanaliScolo_Argini_Inf	Lower Left Bank of the "Conche"
_04.3D_CanaliScolo_Banchine	Right Dock of the "Conche"
_04.3S_CanaliScolo_Banchine	Left Dock of the "Conche"
_04.4_CanaliScolo_Salti_Vert	Height difference walls of the "Canali"
_04.5_CanaliScolo_Salti_Orizz	Height difference floors of the "Canali"
_04.6_Conche_Ponti	Bridges as floor over the "Canali"

Table 1. Table summarising CAD layer nomenclature and BIM function of the imported lines.

Level Name	Elevation
00 - Naviglio Mouth	0.00 m
01 - Conca Confluente	3.30 m
02 - Conca Garibaldi	7.10 m
03 - Biconca Garibaldi	10.90 m
04 - Conca Botanica	14.70 m
05 - Biconca Botanica	18.50 m
06 - Conca Cairoli	23.00 m
07 - Cairoli-Cassinino	23.60 m
08 - Conca Cassinino	27.90 m
09 - Cassinino-Certosa	28.50 m
10 - Conca Certosa	33.10 m
11 - Certosa-Nivolto	33.70 m
12 - Conca Nivolto	37.30 m
13 - Nivolto-Casarile	37.90 m
14 - Conca Casarile	42.40 m
15 - Casarile-Moirago	43.40 m
16 - Conca Moirago	44.80 m
17 - Conca Rozzano	48.40 m
18 - Rozzano-Fallata	49.40 m
19 - Conca Fallata	53.90 m
20 - Conchetta	55.60 m

Table 2. Table summarising the nomenclature assigned to automatically generated elevation levels and their elevation.

Subsequently, for the proper altitude displacement of the cross-sections, each "Naviglio" section was assigned a positive translation equal to the height span covered by the preceding "Conche" structures, each time increased, plus a possible slope according to literature data. Namely, the total height difference covered by the “Conche” is equal to 51.2 m, while the terrain slope along the "Naviglio" course corresponds to 2.4 m (Biscardini & Bricchetti, 2020) for a cumulative amount of 55.6 m.
The detailed operations and scripts employed for the modelling process were made available in open access – via the Zenodo repository – to be downloaded for testing and validation, thus allowing the full replicability of the process. In order to improve the readability and replicability of the proposed algorithmic approach, a summary diagram for each script will is provided, followed by an overview of the actual VPL script within the Dynamo environment. Namely, the "Scripts_01/02/03" concern the spatial reconstruction of the 3D geometry of the "Naviglio" main body, the "Conche", and the "Canali" employing the "ACS" (Sanseverino & La Placa, 2024a, 2024b, 2024c). Then, the "Script_04" allows for the generation of the respective solid geometries (Sanseverino & La Placa, 2024d). Subsequently, the "Scripts_05/06" deal with the modelling of the "height-gap" structural components and the bridges leveraging "System Families", i.e., walls and floors (Sanseverino & La Placa, 2024e, 2024f).

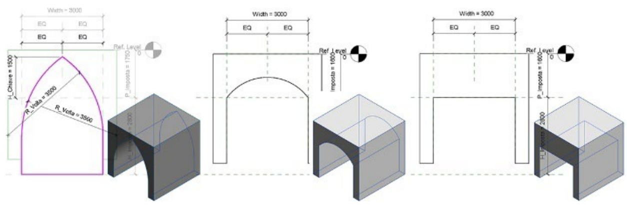

Figure 4. “Parametric Voids” families ad hoc designed to create arched or square openings over the water stream.

Finally, the "Script_07" proposes a tentative workflow for the semiautomatic placement of more detailed "Loadable Families" (Sanseverino & La Placa, 2024g). In detail, two ad hoc designed and parametrised “Door” types of the "Da Vinci’s closing mechanism" – the different ones embedded close to the lower and the higher part of the "Conche" structure – were automatically located on site but the effective placement required a manual checking of the reference line directions to obtain the correct orientation of the family instances (Figs. 5-6) and the script was overly complicated to be able to control the many dimensional parameters.

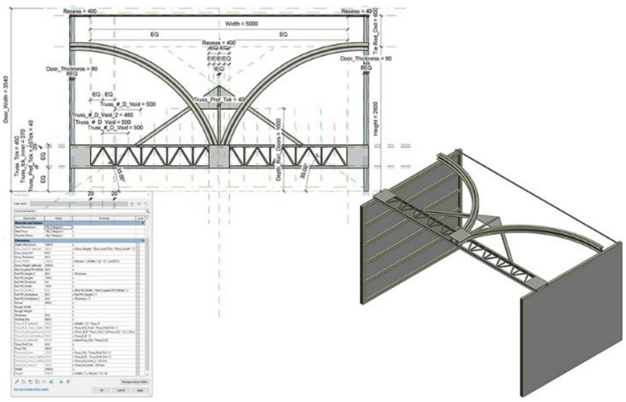

Figure 5. “Da Vinci’s Closing Mechanism” – Loadable Family Type 1 ad hoc modelled and parametrised.

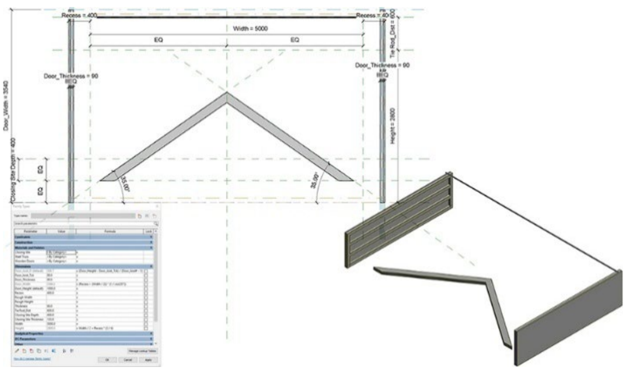

Figure 6. “Da Vinci’s Closing Mechanism” – Loadable Family Type 2 ad hoc modelled and parametrised.

3.3 Generating and populating descriptors concerning monitoring data for the LOI increase

The “Naviglio” complete BIM model was then georeferenced in the EPSG:32632 – WGS 84/UTM zone 32N reference system by acquiring the coordinates from the linked CAD and eventually adding the absolute elevation of its mouth. Having properly set up a georeferenced digital ecosystem, we decided to test the implementation of textual and graphical parameters for the storage of monitoring data, thus optimising it for the posterior management of the modelled asset. Namely, an “Inspection Form ID” and an “Inspection Form Data” shared parameters have been assigned to the modelled elements’ categories.

To follow an open approach then the BIM model was exported to IFC together with the added descriptors by means of properly set schedules. Then we proceeded to import the GeoBIM model back into the QGIS open environment. To do this it is necessary to convert via a free online tool (https://citygeometrix.com/ifc2gis/) the IFC to a GeoJSON format. Unfortunately, this step only preserves the default IFC properties, including the IfcGUID. Using the Ifc unique global identifier as a key was then possible to reconnect the additional attributes – once exported out of the BIM authoring tool as CSV tables – to the corresponding element in QGIS. Namely, the previously filled-out inspection forms concerning the “Cassinino Conca” (Doria et al., 2022) pertaining areas and the modelled “Da Vinci’s closing mechanism” were linked respectively as “AREA_A” and “AREA_A_Elemento_1” (Fig. 7).

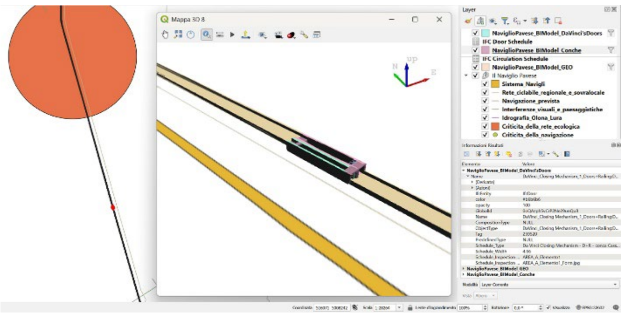

Figure 7. Joining BIM and monitoring data, in the QGIS environment, by means of a common key, i.e., the IfcGUID.

4. Discussion

As mentioned in section 2, the choice of the Dynamo for Autodesk Revit software environment is due to the peculiar elements comprising such historic infrastructure, whose cross-sections are not included within the standardised infrastructural element catalogue and to the possibility of easily implementing further monitoring data using additional parameters. Anyhow, the use of open VPL tools, such as Dynamo for Revit, allow to adapt the scripts to repeat the procedure via different visual programming tools by understanding their logic and reformulating them. For the presented application, we have determined that, upon fitting the algorithmic procedure to the case study and having prepared the source material – which would require a few hours to be replicated on a different case study –, it is possible to run the scripts and obtain the raw model of the entire infrastructure within two-day work, being this the average time required for the modelling of each portion of the "Naviglio" at a low level of detail and further needing – if carrying out manual modelling – additional check-time to assess the faithfulness of the output to the documentation data.

However, the generation of the "solid instances" may be tricky when working with too-distanced cross-sections and/or when significant changes in the shape occur; in such cases, the software may interpolate data incorrectly or not be able to generate the solid at all in that determined portion. The problem is fixable by reducing the spacing among the sections, but this increases computational effort. Additionally, near intersections, it is possible – due to the reduced distance between the cutting planes and their narrower curvature radii – that there is an extra or lesser intersection point for the left or right side of the deck, particularly in the case of the broader upper cross-section, leading to the impossibility of generating a cross-section at all due to missing control points; thus, a manual check is required at this stage. We recognise that the issue of an unequal number of cross-sections may be further improved by developing an additional "custom node"; hence, an ad-hoc CPython3 script was developed and tested to generate the "List.UnevenSublistsTrimmer" node (Sanseverino & La Placa, 2024b, 2024c) which aims to even out unequal lists by cutting the first, the last or both the first and the last items out of a list according to a user-defined choice. However, all other "manual inputs" employed – clustered as grey groups –, while visually occupying a significant part of the graphic script, simply serve to define the specificity of the naming and the peculiar geometry of the case study, such as the height difference that varies for each modelled portion, and therefore cannot be reduced any further.

Finally, although the modelling of the general infrastructure at a low level of detail is sufficiently automated, even given the few issues highlighted, we recognise that, at this stage, the modelling of punctual instances for the improvement of the LOD still requires too much of a manual approach to be fully automatised. Indeed, even though generating new types of floors and walls and placing them to reproduce elements of the bridges and overpasses roughly and to fill the height difference gap works flawlessly using the proposed approach, upon experimenting with more complex and detailed structures, the script required to fit the real geometry cannot be easily standardised; thus the time employed would exceed the time needed for the manual implementation of the same elements, while also relying on in-built features of the BIM authoring tool that may not be reproduced by other pieces of software. Therefore, future applications will address the indicated issues by working on further standardisation of the proposed parametric approach and developing a set of cross-sections that may fit different and possibly more detailed types of infrastructures.

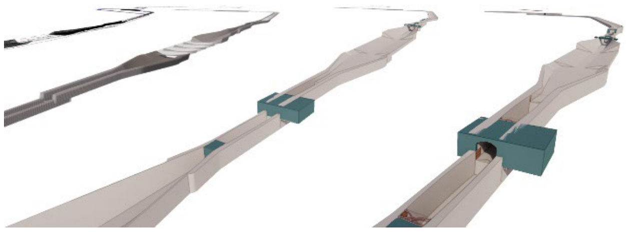

Figure 8. Photobashing of the semi-automated modelling procedure implemented.

5. Conclusion

Obtaining a GeoBIM LOD 200 model, ready to store comprehensive monitoring documentation regarding the state of preservation of such a relevant and sizeable historic infrastructure and optimised to interact with other information systems, i.e., GIS, in a few hours of work – once the semiautomated modelling procedure has been calibrated – and just based on easily collectable data represents the main strength of the proposed methodology. Furthermore, the approach seeks to employ open tools when possible, relying on a transferable parametrisation algorithm so as not to constrain further researchers to a specific BIM authoring tool. Via the method provided, the informatisation aspects could also be fully handled via external text tables linked when necessary to the GeoBIM model within the QGIS environment, just by employing the IfcGUID as a field for further attributes joining.

Automation in modelling extensive historic infrastructure while working in a BIM environment provides the basis for setting up a GeoBIM model to which inspection data can be connected. The information model provides the tool basis for the systematisation of inspection data. Indeed, starting from the georeferenced model, it is possible to break it down into "pieces" as required while also dialoguing with the GIS environment. Using VPL languages will facilitate the reproducibility of the proposed algorithmic approach for AEC professionals working on historical, and therefore non-standardised, artworks by quickly modifying the open-access-provided scripts to fit the geometry. Moreover, working with adaptive components makes it possible to intervene within the process manually and adjust the cross-sections, if necessary, thus allowing for great flexibility of the BIM model in increasing the level of development according to additional data availability and specific requirements. As a matter of fact, even though the final solid geometry is not directly adjustable, it is always possible to manually edit the Adaptive Cross-Section generated as Revit instances by moving the "Control Points" and running the first script of the fourth stage as many times as needed. The LOD 200 model, also, represents a suitable base for placing additional ad-hoc detailed elements, both manually and automatically, and integrating as many required descriptors; thus, enabling complete customisation of the type and quantity of data required to comply with the up-to-date regulations that are moving from the overly constrained LOD framework to the user-defined Level of Information Need (LOIN), which focuses on the granularity of information in relation to clients' demand.

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