# Underground canal 3d survey and mapping

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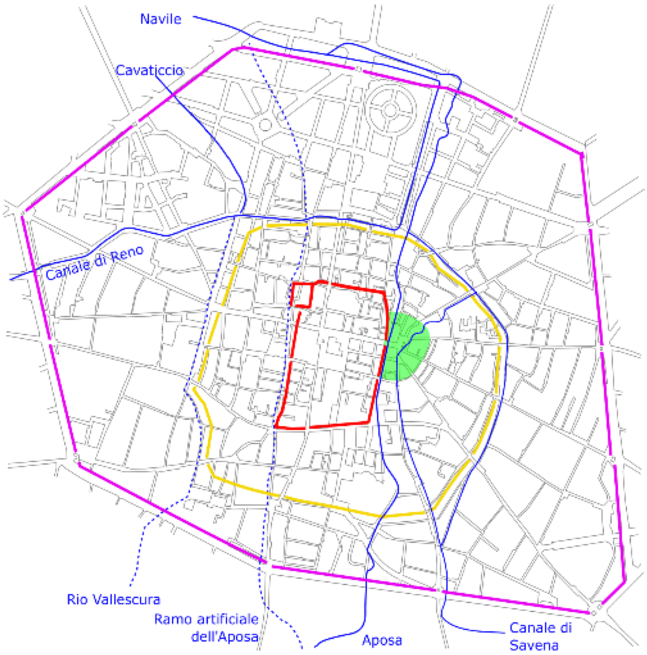
## SUMMARY

Bologna is an ancient city located halfway between Venice and Florence. The city is crossed by several watercourses with most parts of their path running underground. In the middle-ages, Bologna became very important for its handcraft sector especially in the production and commerce of silk, and because of its ancient University built in 1088.

During those years, canals run opencast and bring water to the city's silk mills. The lack of free lots within the city's fortifications caused the covering of them in the last centuries.

One of these canals named Aposa, is the only natural waterway that passes through and underneath Bologna's historic city center. Originally running as an opencast in its entire 7.5 km length, as said before, since the middle-ages, some citizen obtained the possibility of closing some of its parts with masonry vaults to be able to build dwellings above them, In the following centuries, the whole canal was completely covered and built on.




In the past years, after serving as a communal sewer, the municipality did various maintenance works and after the creation of a new closed-system sewer in the early 90s, it finally became accessible.

Actual maintenance conditions however, does not allow it to be a real tourist attraction, and Bologna's Municipality has a limited information about the original canal pathways, its private sewer insertions, the current conservation state of vaults and arches etc.

The aim of this project, undertaken by the Collegio Geometri di Bologna, is to create a 3D model analyzing different approaches and technologies, trying to find the best solution to achieve the goal.

The model will have to respond to different purposes and after completion will be given to Bologna Municipality.

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### 1. GENERAL AND SPECIFIC PROBLEMS FACED

The project will involve, in the future, all the underground path of Aposa, but the first section we decided to undertake is the centremost section of the entire canal, which is about 550mt in length. We choose this section because of its accessibility, its state of maintenance, and its touristic aspect as well. This section in fact, was already suitable for tourist visits in the past, because there are several existing heritage spots and it contains varying characteristics due to its different building periods.

At the ends of this section are two big manholes with staircases leading to underground. Going down we find the ancient canal bed that has been replaced with a new thick layer of concrete with a smaller lateral engraved path. In normal conditions, water fills only this small section of the whole canal bed. As the canal was covered in small pieces since 12th century 'til the late 19th century, there are different type of structures and materials even though the very large part of vaults were built in masonry. Depending on the surroundings, we can find many arches very close each other or long sections with no arches at all.

*Figura 1 - Internal sight of the canal Aposa*

We needed a quick yet precise survey technique, technology and/or instruments as we can't spend too much time underground because of the risk of water level growing rapidly. We also need a whole 3D info that are accurate enough to fit to our use. Furthermore, we need to have a somehow accurate georeferenced survey that would tackle the lack of information about the real underground path of canal. Also, we need a good photographic documentation to use as touristic and as maintenance support.

The techniques/technologies/instruments we evaluated that may suit the this present case study were Close Range Photogrammetry, Terrestrial Laser Scanner-TLS, and Mobile Laser Scanner (Mobile Mapping).

All of them have some advantages and some disadvantages.

Close Range Photogrammetry: The 550m path should be divided into more than 150 blocks due to field of view of the camera and the necessary overlap between images to find matching points. For every block we should shoot at least 10 pictures for the needed overlap on the vaults. The lack of artificial illumination in several segments of the path however, should cause some big “gaps” in the entire survey. We’d need to use portable illumination despite having difficulty bringing the batteries and the equipment underground. We gave priority to obtaining homogenous illumination to achieve better results in the search of common points between shots. Moreover, with Close Range Photogrammetry we’d also need a topographic survey to be able to scale point clouds and to reduce drift problems along the path.

Terrestrial Laser Scanner (TLS): with Terrestrial Laser Scanner survey technique, the path could be divided in less than 100 stations accordingly with expected level of detail.

Time to scan from a single station to another could vary approximately from 2 to 9 minutes depending on resolution and photographic quality. Working with reflectance only, could give the best solution for faster survey but might not give the coloured point clouds we look for. Another issue to bear in mind is that on the bottom of canal we would probably find water which may result to problems due to reflection of laser and the consequent lack of information about the ground. Drift could affect the merging of point clouds so the topographic survey is needed as well.

Mobile Laser Scanner: This technique is based on an instrument composed of a LiDAR sensor, an Inertial platform (IMU), and a set of algorithm that resolve in real time or in post processing the information recorded. Instruments could implement reflectance measurement or take pictures while surveying and then “colourize” the point cloud. To become faster, recent algorithms, solve 2D positioning in real time and then calculate 3D information later. As for the first two techniques, drift issue is a problem we have to solve. First of all, doing loops to compensate drift block-by-block and then with a topographic survey. This method would allow a quicker survey but would give less accurate results.

## 2. TASKS UNDERTAKEN AS PREPARATION (PHASE 1)

With all techniques, we focused on the need of a traditional topographic base survey.

First of all, we drove permanent survey markers with washer and survey checkboards underground while only survey markers with washer are drove above ground. The second step was to do two polygonal: one underground and one above, with the two of them starting and ending on permanent survey markers driven before. These points are then georeferenced with Static GNNS measurement on National Reference System of Coordinates (sistema geodetico nazionale ETRF2000 – ETRS89 / UTM Zone 32N).


*Figura 2 - Permanent survey marker with alloy washer*

*Figura 3 - Georeferencing with static GNNS*

*Figura 4 - Underground checkboards*

The GPS instruments used were:

- GNSS Topcon Hiper pro e Hyper + (L1-L2 GPS+GLO) 5 seconds sampling
- Post-processing and compensation with TopconTools e Topcon Pinnacle

*Figura 5 - Survey checkboard*

While the Land Survey instruments utilised were:

- Nikon DTM 520
- Topcon IS 201 2”
- Post-processing and compensation with GeoPro Meridiana

Once the topographic base were completed, it allowed us to georeference every single survey marker and checkboards.

## 3. TLS AND MLS SURVEYS (PHASE 2)

As photogrammetry was the most difficult technique we thought about, we decided to start evaluating the different instruments the market could offer on TLS and MLS. All major manufacturers have different TLS solutions. We asked them if they could join the project to evaluate different solutions. The aim was not to make a comparison on accuracy or other features but we did want to evaluate which instruments would fit better on the purpose. We let them decide how to make it and wait for results. For indoor solutions, the MLS market resulted to be a bit less various and we had only two tests on it.
Survey started on February and ended on March 2017
Bologna’s Collegio Geometri e Geometri Laureati and Amici delle Acque Sotterranee Association have provide logistical, authoritative and security support during all the survey phases.
We asked all the most important market players and we received positive answers from:
TLS solution:

Topcon Positioning Italy S.r.l.
Microgeo S.r.l. (Z+F)
Leica Geosystem S.p.A.

MLS solution:

GexcelS.r.l.
3d Target S.r.l.

All of them autonomously chose an instrument and planned the survey to their preference on which way would be the best to acquire a 3d model of the underground tunnel.
The preliminary results were:

### 3.1 <u>Topcon Positioning Italy S.r.l.</u>

- Instrument: GLS-2000 with integrated camera
- Survey conditions: good (very low water level)
- Survey time: 3 days (8hrs/day)
- Operators: Day 1 -> 2 operators, Day 2 and 3 -> 3 operators
- Field software: none
- Post processing software: Scanmaster + Gexcel Line-Up PRO

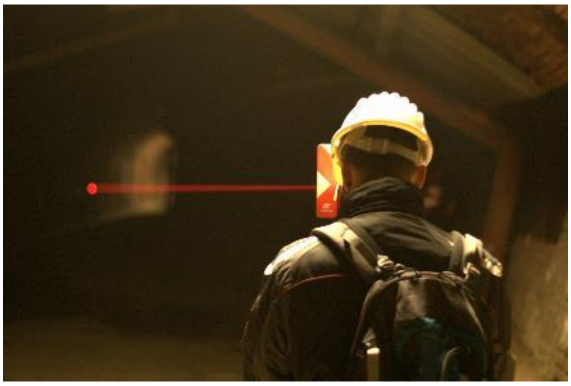

*Figura 6 - Topcon GLS-2000 reading prism underground*

- Acquired data: 35 scan station connected with topographic control points
- Capture resolution: xx mm/10m(unknown)
- Delivered time: 6 week for preview data. Definitive data not delivered.
- Delivered Results:
  - A Fly-through video
  - A little group of five scan with color information processed as data preview as Recap project.

## 3.2 Microgeo S.r.l. (Local dealer of Z+F)

- Instruments: Z+F 5010x with integrated camera and advanced on-field registration software
- Survey conditions: poor (high water level). Some problem to make scanner stable on the ground with intense water flow.
- Survey time: 5 hrs
- Operators: 2 operators
- Field software: Laser control Scout running on rugged tablet
- Post processing software: Laser control for registration and Scantra for compensation phase
- Acquired data: 90 scan station connected with topographic control points (checkboards)
- Capture resolution: xx mm/10m (unknown)
- Delivered time: 1 week for preview data. 4 weeks for definitive data.
- Delivered Results:
  - A Fly-through video of the full path
  - A little group of scan, as data preview
  - The full point-cloud of the underground track connected to the starting/ending plaza without colour information as Recap project.

*Figura 7 - Z+F 5010x scanning underground*

## 3.3 Leica Geosystems S.p.A.

- Instruments: P30 with integrated camera + Ntech iSTAR 360 camera
- Survey conditions: medium (medium water level).
- Survey time: 5 hrs
- Operators: 2 operators
- Field software: none
- Post processing software:
  - Cyclone
  - 3D Reshaper
- Acquired data: 35 scan station connected with topographic control points
- Capture resolution: 3 mm/10m
- Delivered time: same day for preview data. 4 weeks for definitive data.

*Figura 8 - Leica P30 scanning starting zone "Piazza an Martino"*

- Delivered Results:
    - A jet-stream project of the full path for multi-platform browser navigation
    - The full point-cloud of the underground track connected to the starting/ending plaza with colour information on the main sector in pts format.
    - 3D Reshaper  output:
        a. tunnel section every 5 meters
        b. section analysis by comparative analysis between a hypothetical cross-section and actual surveyed section
        c. full path 3d meshed model in cad format
    - Some screen shot of various elaborations

### 3.4 <u>Gexcel S.r.l.</u>

- Instrument: Heron AC-1 with rugged tablet
- Survey conditions: medium (medium water level).
- Survey time: 3 hrs
- Operators: 1 operator
- Field software: unknown
- Post processing software:
    - JRC 3D Reconstructor + Line-Up Pro
- Acquired data: full path connected with topographic control points
- Capture resolution: xxx mm/10m
- Delivered time: 6 week for preview data. Definitive data not delivered.
- Delivered Results:
    - 2 fly-through videos

*Figura 9 - Heron scanning starting zone*

### 3.5 <u>3d Target S.r.l.</u>

- Instruments: Scanfly backpack with rugged tablet
- Survey conditions: medium (medium water level).
- Survey time: 3 hrs
- Operators: 1 operator
- Field software: unknown
- Post processing software: unknown
- Acquired data: full path connected with topographic control points
- Capture resolution: xxx mm/10m
- Delivered time: 2 weeks for preview data.
- Delivered Results:
    - A portion of the job without reflectance/colour information as Recap project

*Figura 10 - 3d Target backpack ready to go*

## 4. FIRST RESULTS

The expected results from all participants were as follows:

- The full coloured point-cloud of the underground track connected to the starting/ending plaza
- Some orthophotos of the historic sector
- A key plan
- Main vertical and horizontal section

Main results obtained were:

### 4.1 Topcon positioning Italy S.r.l.:

Too many missing results. Incomplete data with a very long time on field (3 days). Few scans compromised results giving too many shadow zones in the survey. Chromatic information and overall resolution is too poor to use it as expected.

### 4.2 Microgeo S.r.l.:

With the most scans number, it's the most complete survey. Unfortunately, the time spent in surveying was only 5 hours and the reflectance information only was achieved. No RGB information at all.

### 4.3 Leica Geosystem S.p.A.:

High definition scans but very far from each other. With a low number of scan in this kind of environment, many shadow zones and total lack of information, is normal.

### 4.4 Gexcel S.r.l.:

The videos show a complete underground path acquisition, no information, videos, and screenshots from the outside environment. Gexcel is using data without adequate permission, and it could not deliver anything else but a video.

### 4.5 3D Target S.r.l.:

As per the Company policy, 3d Target was able to give us only a sector of the underground survey. The only data we could see was xyz point-cloud, with missing reflectance and RGB information.

## 5. ANALYSIS OF FIRST RESULTS AND COMPLIANCE WITH EXPECTED ONES

The first consideration we can assume is that, the two issues affected all techniques we thought could answer our needs.

All techniques/instruments showed problems with long and narrow survey conducted in a not various environment like a masonry tunnel. All techniques and instruments suffered evidently of drift. To correct these issues, the classic topographic survey was necessary.
Another problem this kind of activity had was the water level in the canal. Working in an underground waterway means that you have a constant presence of water that you have to deal with. External weather conditions could cause a fast increase on water level bringing in a serious risk for surveyors and their instruments, as well. A high level of water may mean a flow strength strong enough to compromise instruments stability. The higher the water is, the less information you could achieve with all the technologies.

We started this project thinking about the fastest and the best way to obtain a 3D virtual environment of the Aposa canal and to be able to give the Municipality of Bologna a product to solve various tasks.

## 5.1 Project purposes:

### 5.1.1 to achieve a georeferenced 3d model of the underground path of Aposa.

Reached. With TLS scans made by Z+F and Leica we have a complete 3d undergroun model. It has some parts to scan again to increase LoD or acquire RGB information.

### 5.1.2 to give the Municipality of Bologna a 3D environment to verify maintenance conditions to plan tasks to open again this sector for tourism.

Work in progress. When we will complete the underground 3D model with RGB informations, we will prepare a 3D enviroment in which Municipality could verify anything visible like electrical and lighting appliances, sewer junctions and private insertions, plan maintenance works to free the canal bed from gravel, tree branches and other materials that could reduce canal capacity.

### 5.1.3 to complete underground and overground 3d enviroment to perform static and dynamic structural analysis

One of the latest request from Municipality was to pair the underground with the overground to verify every section they need to. They ask for this instrument to acquire information about static and dynamic situation of the underground path to prevent any risk of collapse of vaults. In these days, we are planning for the overgroud survey to complete this task. Simultaneously we are working on 2d sections along the path.

### 5.1.4 to create virtual visit for tourism purposes

one of the main goals was to provide a virtual enviroment to let the canal be virtually visitable while waiting for its re-opening for on-site visits. In the next months, we hope to densify point-cloud and to build the virtual reality tour.

# 6. VIRTUAL REALITY AND AUGMENTED REALITY FOR HERITAGE AND CULTURAL SITES TOURIST DEVELOPMENT AND MAINTENANCE MANAGEMENT

Virtual and augmented reality is the natural evolution of this project. If maintenance workers could virtually visit the canal every time they need, maintenance job could be planned correctly without the need for continuous site inspections, measurements, drafting and taking pictures. The need for a simple software to be used from less skilled operators as well, is very important.

Tourism is an essential sector in Bologna’s economy. As of today, access to Aposa canal for tourist purposes is not allowed mainly for security reasons. Meanwhile, as the Municipality plans to recover the accessibility, a virtual tour of canal could be a valid alternative. The 3D environment should offer augmented reality capabilities to give the tourists a realistic guided visit with glasses and other AR devices.

## BIOGRAPHICAL NOTES

Gualtiero Parmeggiani is the current President of Fondazione Geometri (http://www.fondazionegeometrier.it/) and a board member of Collegio Geometri e Geometri Laureati Provincia di Bologna (https://www.collegiogeometri.bo.it/). He organized with Associazione Amici delle Vie d'Acqua e dei Sotterranei di Bologna, the activities of surveying the canals.
The authors, Dalmasso, Manaloto and Brancato, were part of the pioneer group of young surveyors who were chosen by the Consiglio Nazionale Geometri e Geometri Laureati after a thorough screening regarding every aspects of the Surveying profession in Italy. The group is in close contact with each respective Provincial College bringing in new knowledge and prespective in the profession. The group has been active in various FIG congresses since its conception in 2009 and has been in contact with other young colleagues, surveying professionals and researchers. In 2012, both in the occasion of FIG Working Week in Rome and the National Congress of Italian Surveyors in Rimini, Dal Buono showed to be a reliable addition to the group bringing in other competence and expertise to the group. The group aims to be of aid to the National Council in rejuvenating the ever-evolving profession of Surveying in Italy, demonstrating other capabilities and technical capacities while pushing the boundaries towards the future of their chosen field.

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