Linked Data in Architecture and Construction Week

Terrestrial Laser Scanning for Surveying and 3D Modelling of Underground Built Heritage: A Case Study of Hypogea in the Sassi of Matera

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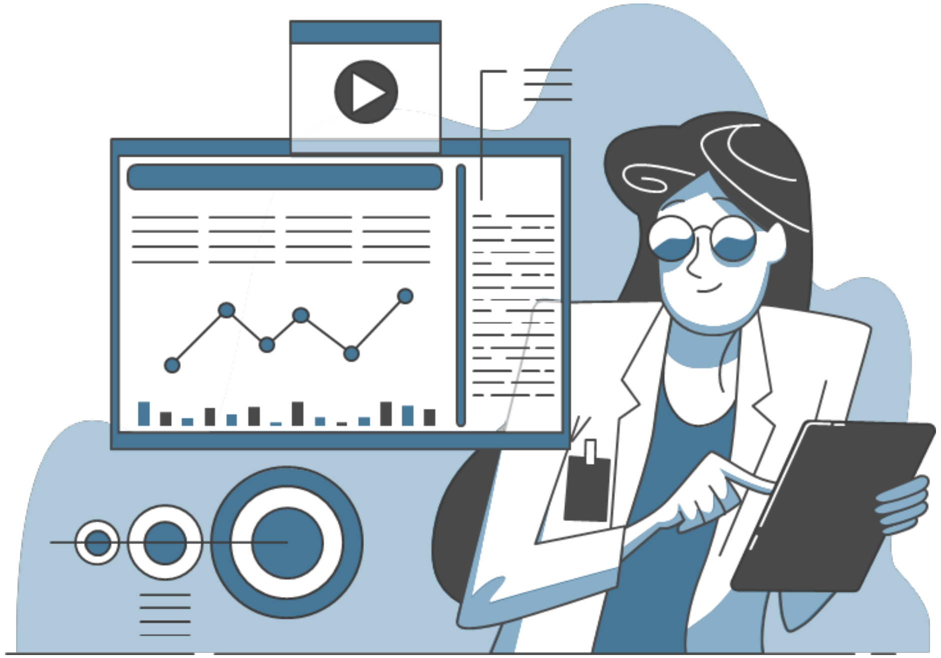


Underground Built Heritage

Underground Built Heritage (UBH) includes valuable historical artifacts embedded within the local cultural heritage, possessing both material and immaterial significance

Challenges:

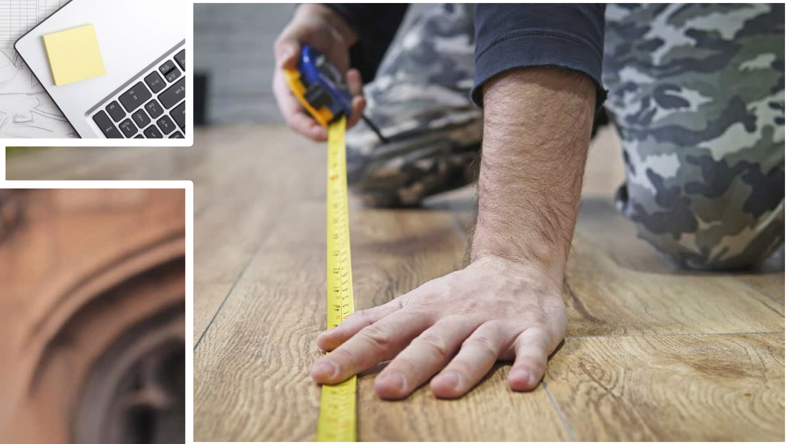
- Limited knowledge
- Limited documentation
- Little valorization and exploitation

To have a comprehensive and reliable representation of UBH architectural spaces and geometry is crucial for documentation purposes.

Information retrieval methods for architecture

Traditional methods like manual measurement, photography, and 2D sketches often fail to capture the complex spatial relationships, geometries, and details of UBH structures, while being time-consuming, labor-intensive, and error-prone.

2D sketches



Manual measurement

Photography

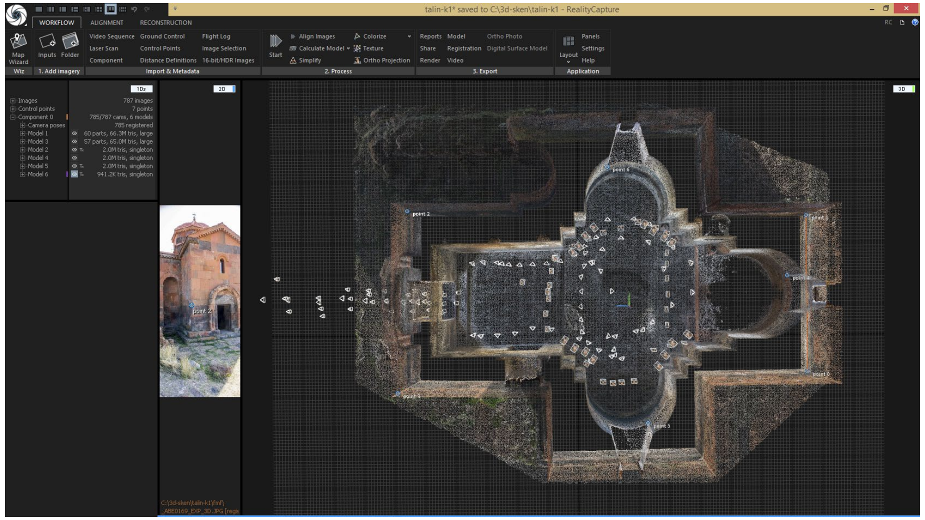
Information retrieval methods for architecture

Terrestrial Laser Scanner (TLS) offers a highly effective technique for documenting complex UBH structures.

TLS enables rapid and accurate capture of high-resolution 3Ddata, including detailed geometry and spatial information of above-ground and underground historical monuments.

Our Approach

We propose a workflow utilizing TLS for surveying UBH and reconstructing realistic and optimized 3D models using Reality Capture (RC).



Case Study: Hypogea in the Sassi of Matera

The case study focuses on the application of TLS and RC technologies in accurately documenting the state of the Hypogea in the Sassi of Matera.

The technologies employed aim to provide a basis for semantic-enriched Building Information Modeling (BIM) for the conservation, restoration, and enhancement of UBH.

Case of Study

- **Matera**, a city in Southern Italy, is a unique example of a city built through excavation, featuring a complex urban system with underground structures.
- The **Sassi of Matera**, a UNESCO World Heritage Site, showcases a well-preserved troglodyte settlement with historical significance dating back to the Palaeolithic era.
- The **hypogea in the Sasso Barisano** neighborhood, owned by the *Fondazione Sassi*, are of particular significance and require precise measurements and advanced modeling techniques.
- Traditional surveying and 3D modeling methods are challenging due to irregular geometries, difficult accessibility, and lack of precise documentation.

Hypogea in the Sasso Barisano

The investigated hypogea are located within the Sasso Barisano neighborhood, between the streets of San Giovanni Vecchio, San Pietro Barisano, and the district of San Biagio.

The hypogea consist of a complex of chambers, passages, and staircases, with intricate details and carvings, covering an area of approximately 410m².

The hypogea served various purposes, including storage, agriculture, and water preservation, with features like a palmento for grape crushing and large cisterns.

To overcome the challenges of data collection, **Terrestrial Laser Scanning (TLS)** was employed as a non-invasive surveying technique, providing precise 3Dmodels of the hypogea.

Terrestrial Laser Scanning System

We used the **TLS Trimble X7:** a high-speed 3D laser scanner with a combined servo-mirror scanning system, integrated imaging, automatic calibration, automatic registration technologies, and self-leveling capabilities for detection.

The scanner is equipped with 3 cameras with $10MP$ (3840×2746 pixels for a picture), providing a spherical photo for each scan.

Spherical photo

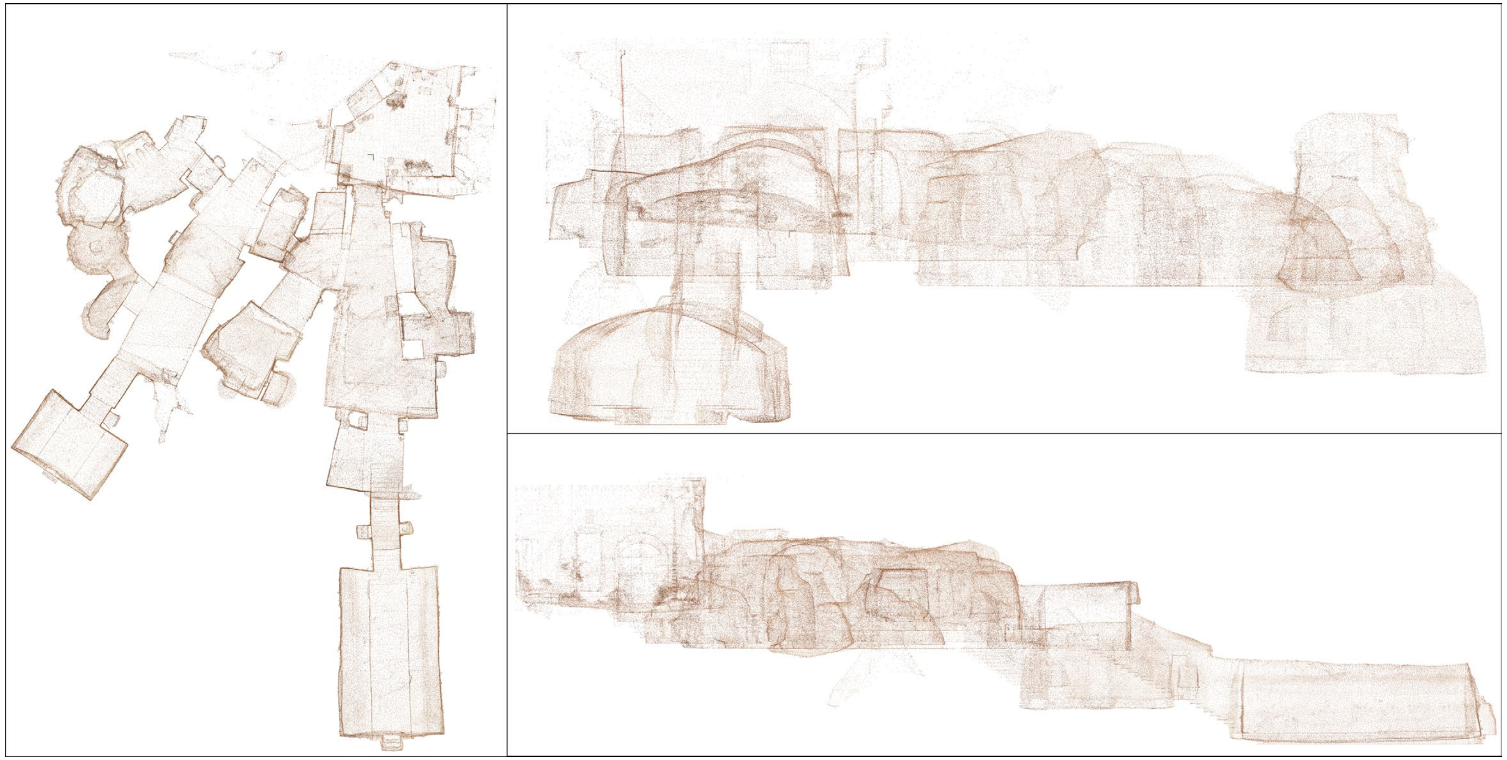
Terrestrial Laser Scanning System

Multiple angles and distances were used to scan the hypogea with a Terrestrial Laser Scanner (TLS), achieving a resolution of 11mln/pt per station.

A total of 50 scans were collected, with each scan taking an average of 2.35 minutes to complete.

Artificial spotlights were strategically placed to simulate a diffused light environment, ensuring even and sufficient illumination for effective data capture.

The Trimble X7 hardware-software integration provided precise scans that were registered and aligned in situ, resulting in a high-density Point Cloud (PC) capturing intricate details of the hypogea.



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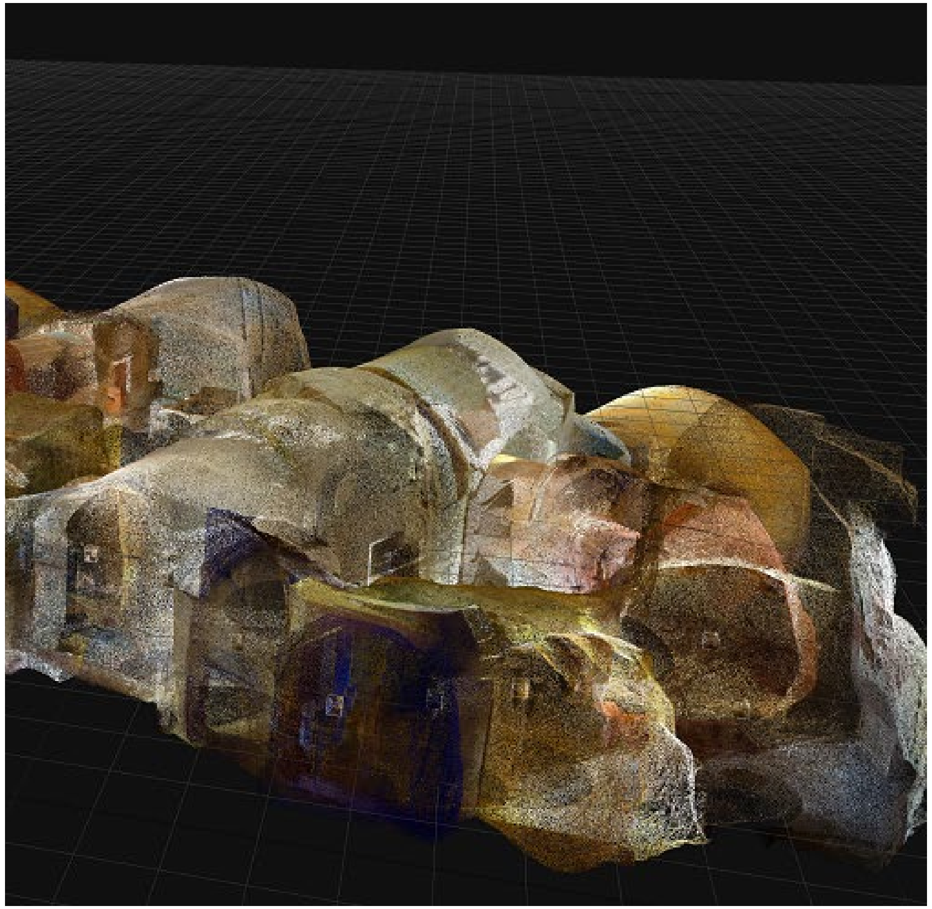
3D Reconstruction and Model Enhancement

Reality Capture (RC) software was utilized for the 3D reconstruction of the hypogea due to its versatility, automation, and high-quality output.



RC tools to optimize the 3D model of the ipogea:

- **Simplify Tool:** sets the desired target triangle count, part number, border simplification, and other visualization features.
- **Mesh Cleaning:** removes corrupted triangles and non-manifold edges, checks coloring and texturing
- **Hole Closing:** detects and closes holes

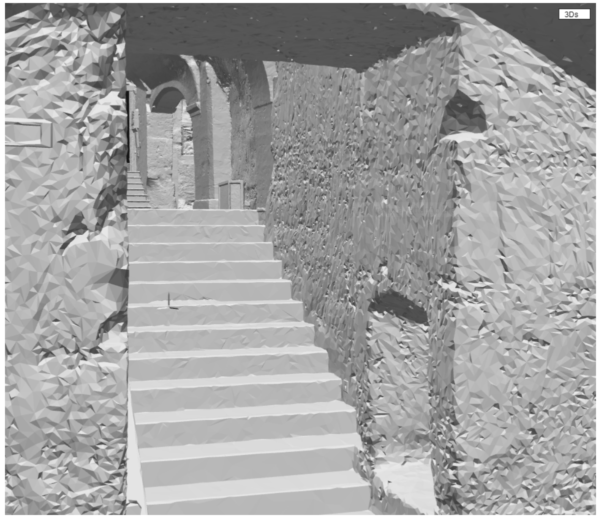
The **textures** were computed using the unscaled images provided from the TLS and unwrapped on the highly detailed 3D model to achieve the highest level of graphical quality.

The obtained model can be exported with several standard formats such as Filmbox FBX, Wavefront OBJ , PLY, Collada DAE, etc.

3D Reconstruction Workflow

- Laser scans were converted to "**LSP**" internal file format, which allowed merging of laser scans and photos.
- A **high-detail 3D model** was reconstructed with 368.4M polygons and 184.6M vertices distributed in 122 parts.
- A **high-resolution texture** was extracted from the highly detailed reconstruction, resulting in a realistic final model.
- **Mesh simplification** reduced polygon count to 3M, vertex count to 1.5M, and created 8 parts for enhanced software compatibility.
- **Unwrapping and reprojecting the high-resolution texture** onto the simplified model maintained realism.

To validate the accuracy of our 3D model, we used a set of **reference points** obtained using the **control points system** of RC.
We placed reference points on the hypogea before scanning and then marked their corresponding points in the 3D model using a control point system. In this way, the 3D model has the same scale size as its scanned environment.



Details of a 3D model fragment of a simplified reconstruction at $3M$.

A reprojected textured 3D model fragment.

The semantic- enriched BIM

The optimized 3Dmodel of the ipogei has been enriched with additional semantic information.
To do so, we used the **AI Classify** function of Reality Capture to segment the 3Dmodel of hypogei.

The AI Classify function detected three different classes of building elements, distinguishing them based on their material and state of conservation.
Then, we manually labeled these three classes as: walls and ceilings, floors and stairs, and non-structural objects.

The resulting segmented 3Dmodel was then imported as a mesh into **BlenderBIMAdd-on** for Blender, where it was further decomposed in the **Industry Foundation Classes**: a standardized format for sharing BIMdata.

Benefits of Our Approach

- Historical buildings and underground built heritage (UBH) present challenges for data collection
- Complex geometries and ornamental features require detailed data acquisition

- Our workflow offer a solution for accurate modeling
- Our approach provides effective surveying and 3Dreconstruction in underground contexts

The obtained models can build essential documentation record needed for different purposes:

- assess the state of fact of the considered built heritage;
- guide the conservation process;
- provide monitoring and managing tools;
- communicate and disseminate cultural values.

Semantically enriched models can be used for digital twins, web publishing, visualization and dissemination purposes.

Future Works

- Future research should further explore the integration of TLS data with other types of data through the use of BIM and semantic web technology.
- Further investigations could be conducted on the combination of TLS and photogrammetry techniques to overcome the limitations of both methods and improve the accuracy and realism of 3D models for underground environments.

Thank you for your attention!