edited by
SANDRO PARRINELLO
FRANCESCA PICCHIO

Historical architecture and settlements along Kama river in the Perm region

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THE DIGITAL DOCUMENTATION OF THE CITY HISTORICAL CENTER OF SOLIKAMSK

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Changes and transformations of built shapes in the historical center

Side Page Fig. 01
Solikamsk's bird view
Aerial view of the historic core of the center of Solikamsk (2019)

The historical transformations that affected the Upper Kama area have brought characters of social and productive change, with inevitable reflections on the identity image of the urban landscape and cities. The industrial adaptation and the infrastructure of the territory, to optimise resources and exchange flows, have profoundly influenced the arrangement of settlements along the route, as well as the formal reference systems of monuments at different scales: architectural, urban and landscape.

The historic center of Solikamsk bears witness to a complex building history, developed in each architecture within singular events of transformation. The ensemble consists of two cathedrals, a bell tower, two churches, and one chapel: they present different states of preservation, between abandonment and musealisation, which can be related to the historical documentation on the functional uses, landscape conformations, and formal characterizations undergone by the building apparatuses of each site.

The Cathedral of the Exaltation of the Holy Cross was built between 1698-1709 on the embankment of the Usolka River, but in 1741 a fire event caused its partial reconstruction[1].

Industrial uses during the Soviet period - since 1929 it was also a brewery - caused invasive and destructive interventions in the building's interiors. The masonry structures were demolished, changing the planning and symbolic design of the building to accommodate industrial machinery structures. As a result, the distributional arrangement and the spatial perception of the religious environments were compromised.

By contrast, the outer wall envelope and its decorative brickwork apparatus remained almost intact, preserving the main volumes and the rich design of the facade decorations[2]. Even though the abandoned building is repeatedly affected by Usolka overflows and flooding, as well as a cyclical painting of the exterior, it preserves a monumental historical image in the urban landscape.

[1] During the city fires of 1741 and 1743 the cathedral was severely damaged and rebuilt at the expense of the Solikamsk merchant Surovtsev, with a profound variation of the original architectural and stylistic features. Cfr. E. N. Gontsov (eds.) (2011) Historical and architectural heritage of the Perm region: catalog-reference. Perm: Reykjavik Design Bureau, p. 210.

[2] The outer shell of the Cathedral features a rich decorative apparatus in the Russian Baroque style, with a composition of cornices, coupled columns and corbels with *sekirovidnymi* motifs that frame the fronts of the main block above. The platbands of the windows of the temple part are similar to the windows of the refectory. The upper part is framed to the full height with an arcature-columnar belt resting on bundles of hanging three-quarter columns. In the center of the southern and northern façades, there are large icon cases framed by columns with a *kokoshnik* decoration.

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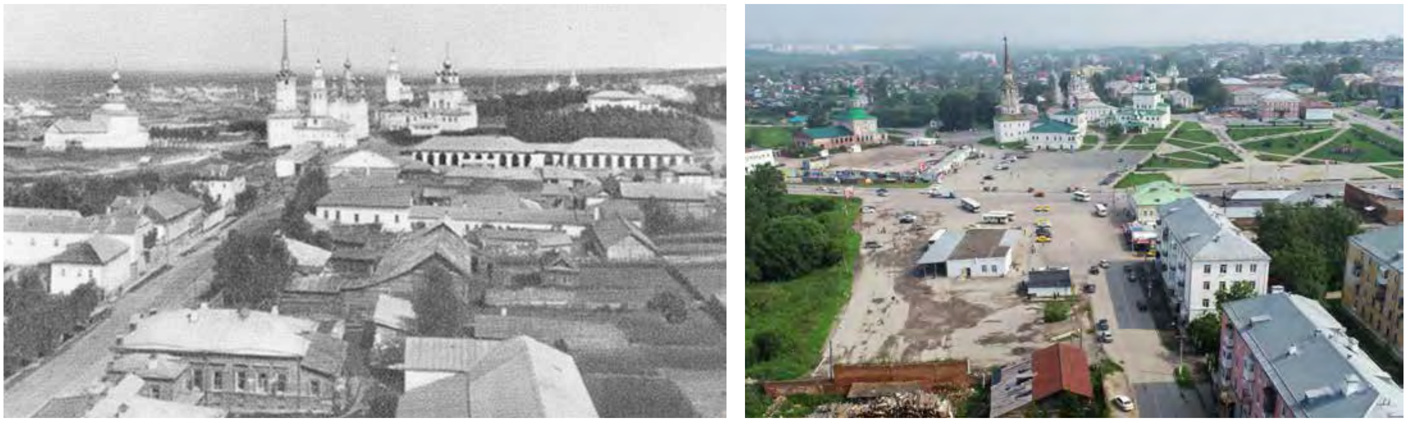


Fig. 02
A transforming landscape
Comparison between the photographic survey of the historic center of Solikamsk between the 20th century and 2019. The change in the surrounding urban asset is clearly visible.

Next page Fig. 04
Cathedral of the Exaltation of the Holy Cross and Church of the Epiphany
General view of the architectural complexes and detail of the constructive and decorative apparatus of the windows. In the second one, the crack due to the structural assessment of the church is clearly visible.

Fig. 03
Historical photogallery
Gallery of historical pictures between the 19th and 20th century documenting the architectural development of the historic center of Solikamsk and the urban and social context of its monuments.

The Church of the Resurrection of Christ, or Voskresenskaya Church, was built between 1714-1752 as a five-domed temple with a central bell tower, for winter religious services. Due to later interventions, the domes were demolished, and the central body lowered, losing the stylistic features associated with the church type and its perception in the urban skyline. The site has undergone an altered cultural role within the Solikamsk ensemble, and today serves as an exhibition hall and local history museum.

The Bell tower of the Trinity Cathedral represents the most noticeable and symbolic monument of the Solikamsk ensemble. Built in 1713 starting from the basement block of the mercantile rooms, the bell tower features an octagonal plan body developed on three orders with kokoshnik exterior decorations. The formal structure has remained untouched during the cyclical transformations of the Old Town. Still, the monument is frequently affected by repainting according to different colour palettes, which characterise an incongruent perception in its chromatic relationship with the surrounding monuments and the landscape.

The Trinity Cathedral was built between 1684-1697 in the Moscow Baroque style[3], envisaging from the original design a five-domed double-height body. The theme of the "gallery" distinguishes the stylistic design of the monument, repeating itself both three-dimensionally in the external porch of access and in the flat decoration developed on the facades of the main body, made with modules and profiles obtained through shaped bricks.

[3] The main church of Solikamsk was built on the model of the Kazan Church in the royal estate Kolomenskoye, near Moscow. The tsars John and Peter Alekseevich partially funded the construction of the cathedral and, in honour of this, the imperial crown was laid out on the cathedral.

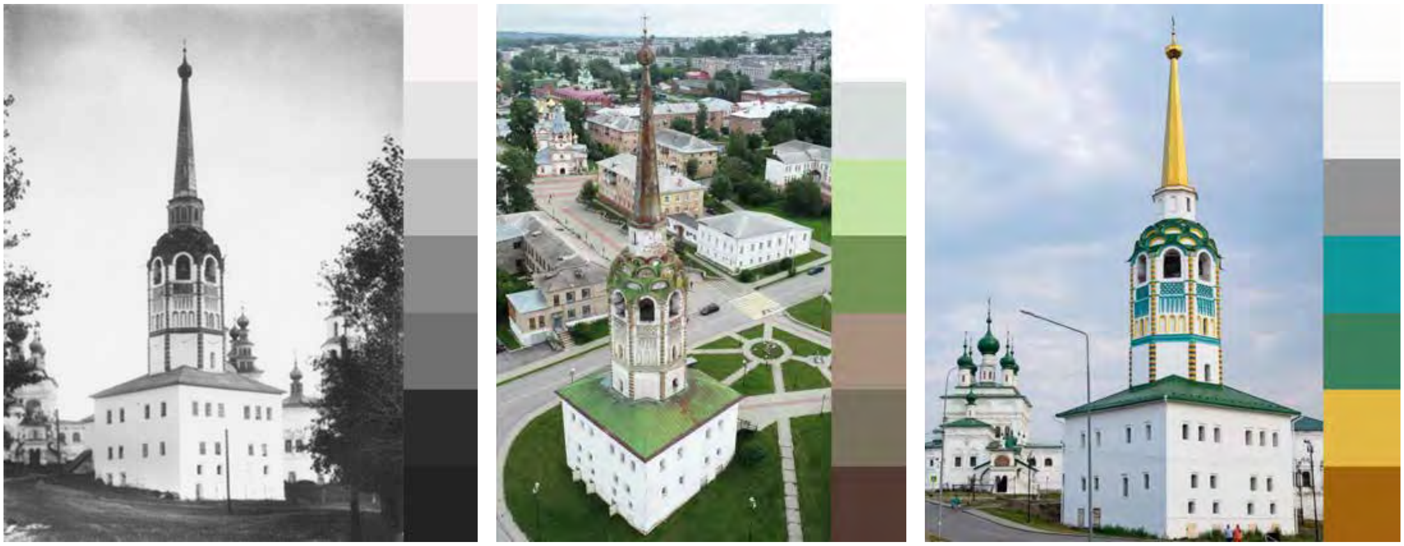


Fig. 05
Color palette analysis
This study has been applied on the photographic documentation available on the Bell Tower from the 20th century, 2019 and 2020. It is clear the effect of restoration activities on the architectural and landscape perception of the urban context around the main building.

The Church of the Epiphany, built between 1687-1695, was planned with a five-domed double-nave body. The bell tower was added to the main front of the complex in the 18th century, with later intervention in the original design. The building addition caused a subsidence of the foundation structures, and during the Soviet period part of the new structure was removed, lowering the body of the bell tower to its present configuration. The rich exterior decoration consists of corbels, cornices, gables and platues of elementary geometric modules and kokoshnik, composed in multiple and unique solutions that frame the openings and fronts. Stylistically adherent to the main church, the Chapel of St. Peter and Paul is located on the perimeter of the site area. Today the church hosts the Museum of Old Russian Art.

Solikamks: objectives and targets for an urban representation

The process of analysis for the study of Solikamsk's urban context, treated as a unified documentation program on its monuments, started by identifying the main characters of urban image influence and variation, and the visual perception of architecture in the contemporary landscape.

Formal building geometries, shaping of urban space, and variation in their chromatic features emerged as the main aspects for evaluating the effectiveness of conservation and restoration strategies. The preservation of the cultural relationship between the history of the historic center and its management in the administration of the area is directly reflected in the perspectives of the attraction and enjoyment of visitor flows in Upper Kama.

In this sense, the “instant capture” of the image of urban landscape becomes central to the incessant dynamics of city transformation, and it values the integration of multi-source data to produce a reliable and comprehensive database as a basis for knowledge, analysis, and communication of diffuse heritage in the Cultural Heritage Route dimension.

The information contained in the historic center, which image turns out to be the result of multiple events over the years, constitutes a heterogeneous and complex data set of geometric and colourimetric nature, including compositional modules of the landscape.

The visual transformations of the urban system testify to the impacts of a social and economic nature as well as purely stylistic and formal changes. At the same time, these changes have obvious repercussions in the spatial conformation of sites, concerning urban infrastructure, road routes and the preservation of basins directly connected to waterways of the Kama network. Therefore, the visual documentation itself returns a complex landscape, reflecting a specific cultural identity defined through history and spread today within the contemporary pattern of expansion.

Documenting the formal qualities and relationship characters between monuments and urban compartments recalls the adoption of digital entities and virtual environments extended to both architectural and landscape dimensions to produce a catalogue of forms and patterns that condense the cultural and social narrative dimensions of place.

The goal for the digitization of the historic centre of Solikamsk is to compare forms and models to establish a network of information that qualifies the complex space, envisioning in the descriptive values aspects useful for the preservation, management, control and even development of the city in respect of its cultural heritage.

The database aims to define an associative structure between the image of urban form and the organisation of data in the digital database. It does not only reproduce the morphology of the context, by following the different instrumental applications, but intends to thematise the analysis of urban configuration as a projection of the image of the historic city into the future.

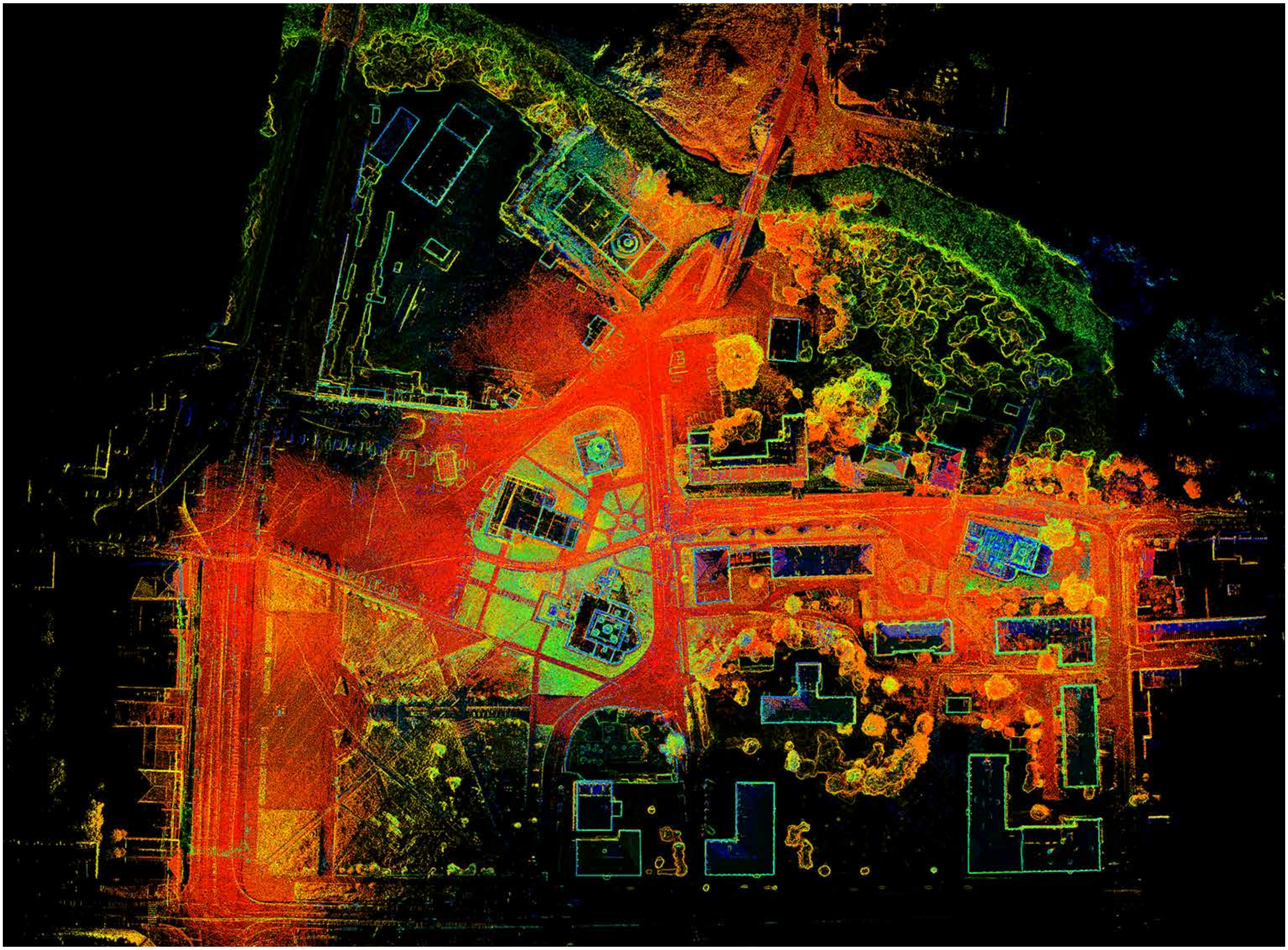
On-site documentation activities: ground scanning and aerial mapping systems

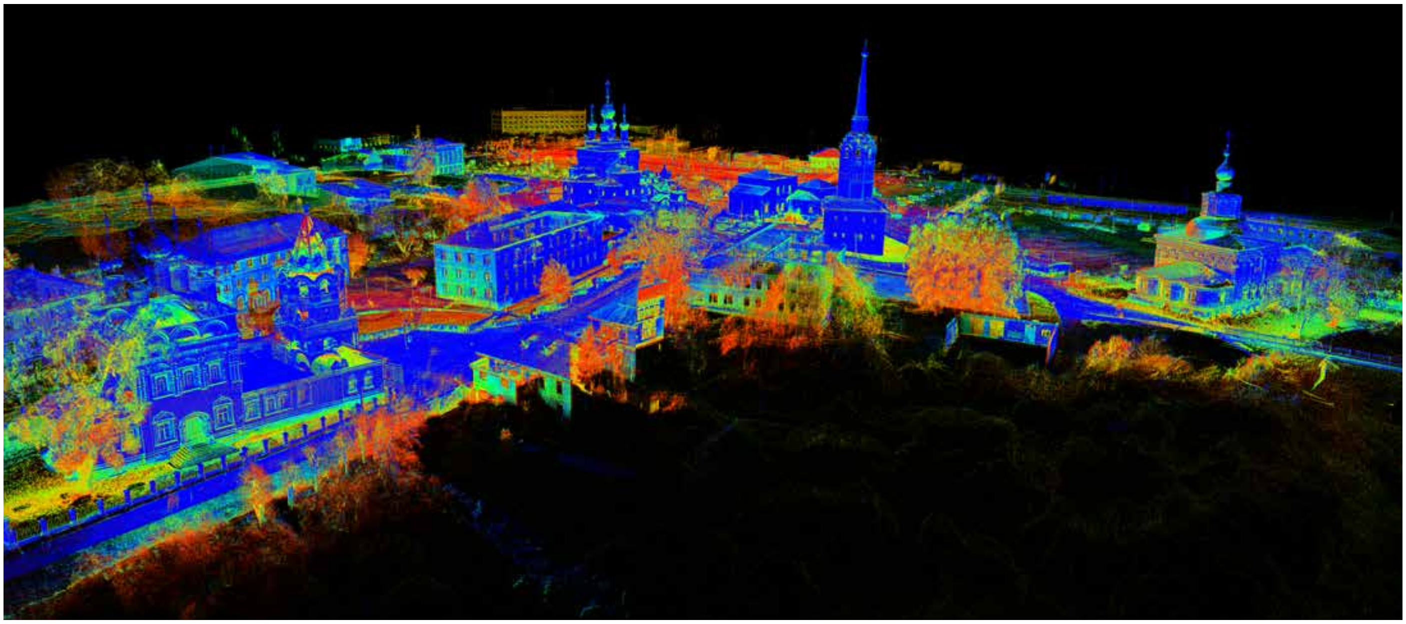
The morphological complexity of the area, combined with the need of a fast planning of the survey campaign[4], led to the development of a rigorous acquisition strategy aimed at ensuring consistent and high metric quality of the architectural data. This approach enabled a comprehensive and homogeneous understanding of the surveyed space through the integration of multiple digital survey and mapping technologies, including TLS (Terrestrial Laser Scanner), MLS (Mobile Laser Scanner), and UAV (Unmanned Aerial Vehicle).

The TLS-based survey campaign required the adoption of a dual acquisition strategy. In addition to a *distributed* acquisition along polygonal paths parallel to secondary urban fronts, a *targeted* acquisition was carried out for significant elements of the urban landscape, namely the main monuments. Large overlap margins (5–50 m) were ensured between datasets, allowing the survey to be conducted over multiple days while maintaining accurate registration and a uniform metric reliability (1–2 cm) in the final point cloud. Targeted acquisitions focused on buildings of highest historical and architectural relevance, primarily identifiable within the religious architecture of the historic centre.

Next page, Figs. 06-07
Integration of LiDAR acquisition databases on the historic center of Solikamsk
RGB point cloud from Terrestrial Laser Scanner and red-grade point cloud from Mobile Laser Scanner.

[4] Survey activities focused on testing fast survey strategies, following a strategy of documenting the route in a timeframe useful for data processing and intervention. In that regard, digital documentation of the Solikamsk ensemble was comprised of 4 days of fieldwork, during which operators conducted simultaneous multi-instrumental mapping of the area.





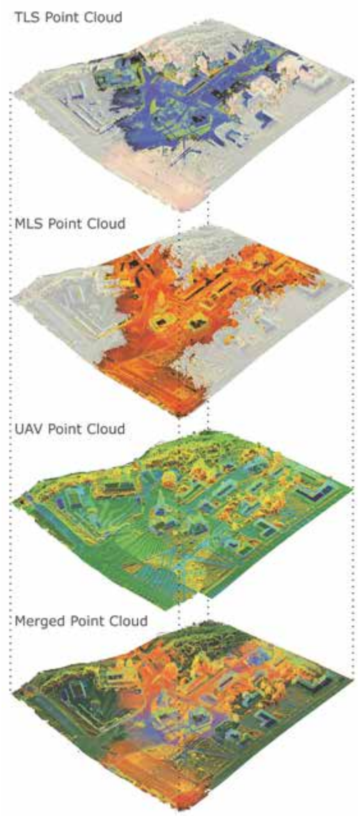
The use of closed polygonal trajectories to support TLS sensors during the acquisition phase, together with the predominant adoption of cloud-to-cloud registration methods in the post-processing phase, enabled effective error compensation without the need for ground control targets, thus facilitating the rapid execution of the survey. The metric accuracy and resolution of TLS data proved suitable for documentation purposes, supporting the analysis of architectural features from both geometric and chromatic perspectives[5]. These aspects are particularly relevant in the investigation of decorative elements on church façades, as well as in the mapping of decay phenomena and conservation conditions.

However, TLS acquisition presented some operational limitations. The duration of individual scans (3–8 minutes), combined with the time required for instrument repositioning (1–3 minutes), partially constrained the efficiency of rapid survey workflows.

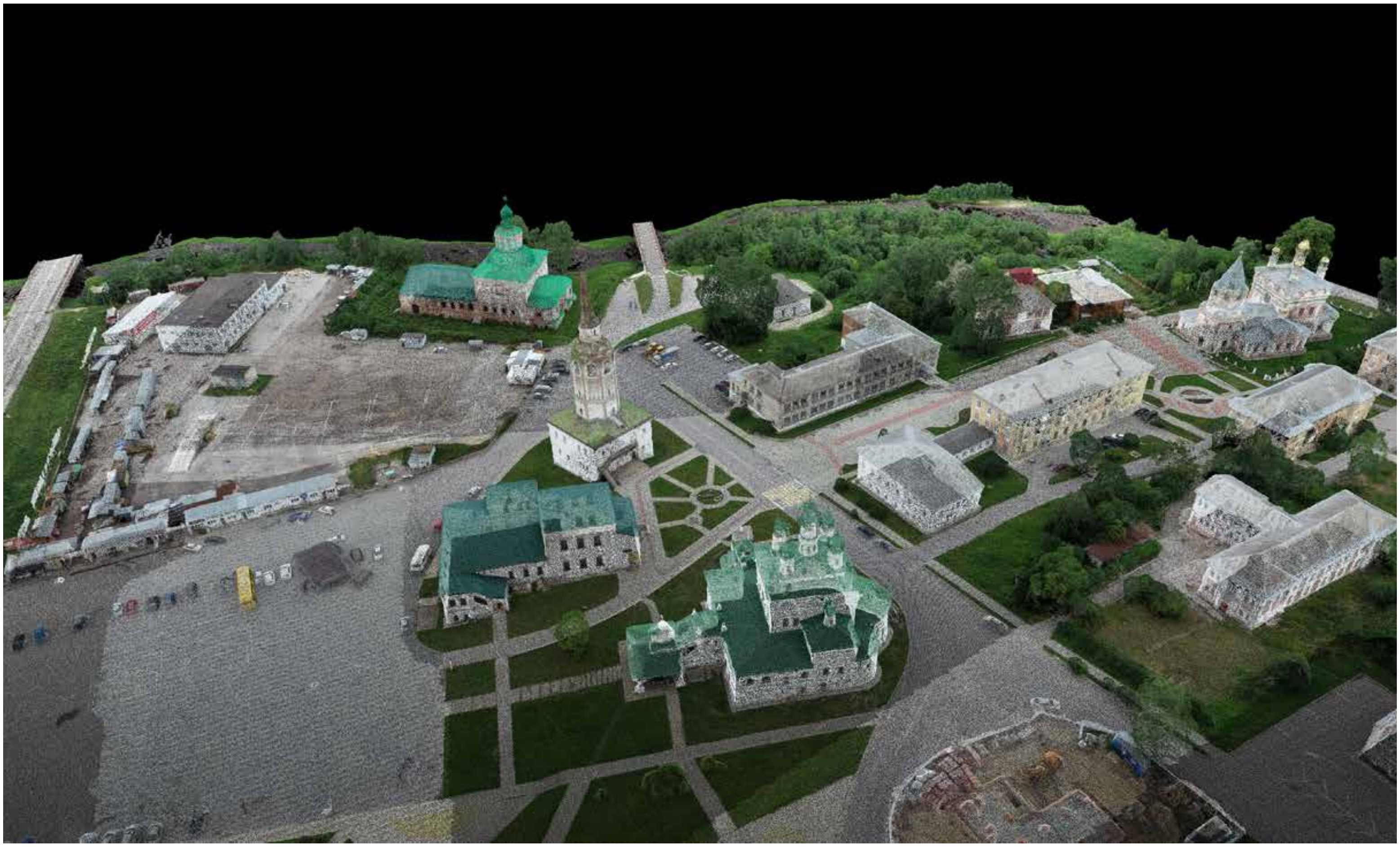
Furthermore, TLS systems are limited in capturing inaccessible areas, such as elevated architectural components (roofs, domes, decorative elements) and densely vegetated zones, necessitating the integration of aerial photogrammetry.

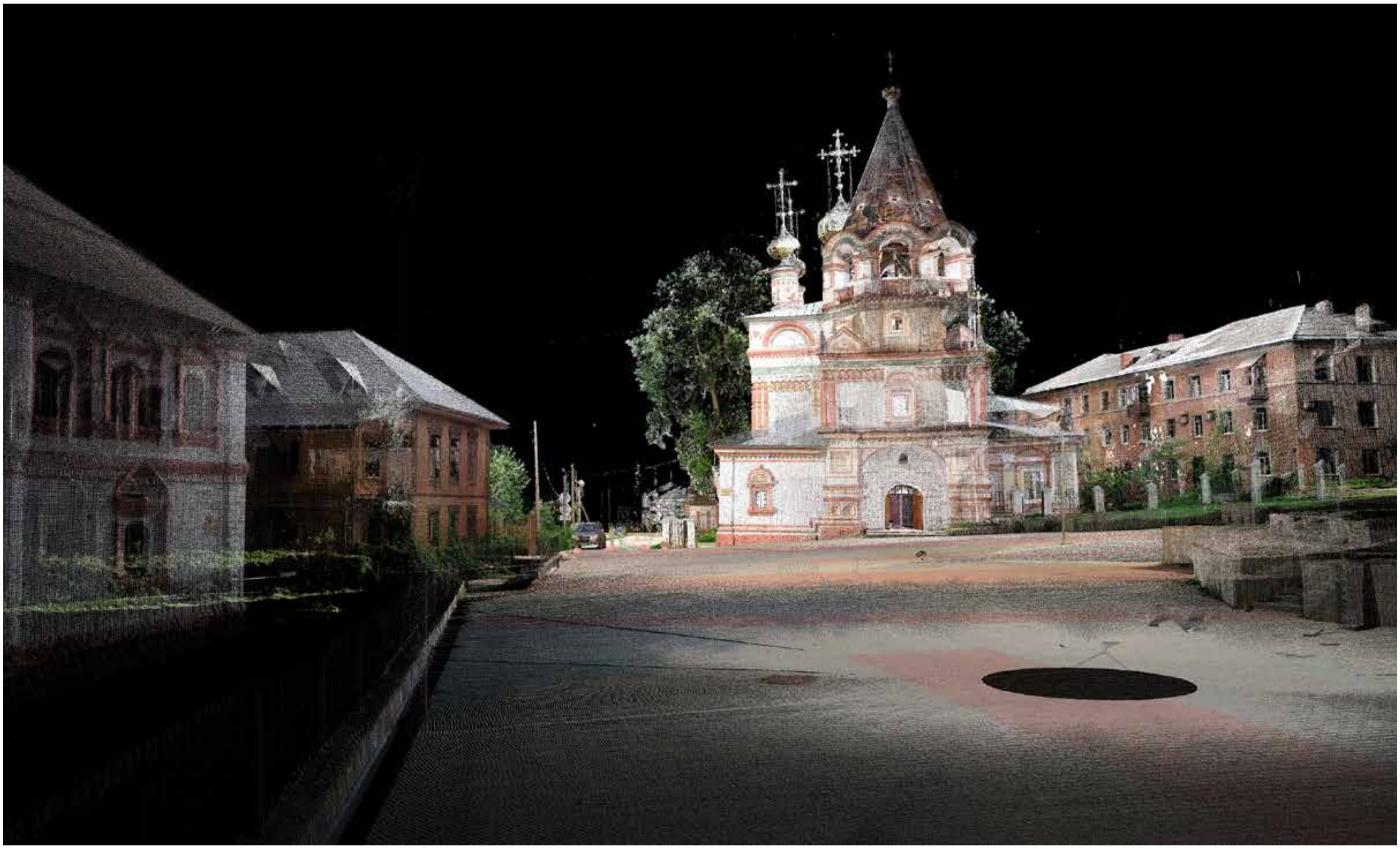
The SfM acquisition process was structured into multiple flight plans[6]. An initial phase involved planar mapping flights covering the entire urban area, providing a comprehensive overview of the site. The resulting data proved effective for large-scale spatial analysis, offering a coherent representation of landscape morphology enriched by colour information. However, due to the distance between the UAV and individual buildings, the morphological resolution of specific architectural elements remained limited.

Fig. 08
Overlapping scheme
Integration and complementarity between the databases of point clouds acquired by multiple instrumental applications of digital survey.



[5] The scans using TLS instrumentation were set up with colorimetric data capturing, this extends the acquisition time however allows for a better understanding of the elements and context.
[6] For each flight plan, it was chosen a favourable viewpoint to control the drone, in order to ensure complete and constant visibility, to be constantly in control over the drone's trajectory and to modify it in case of malfunction.





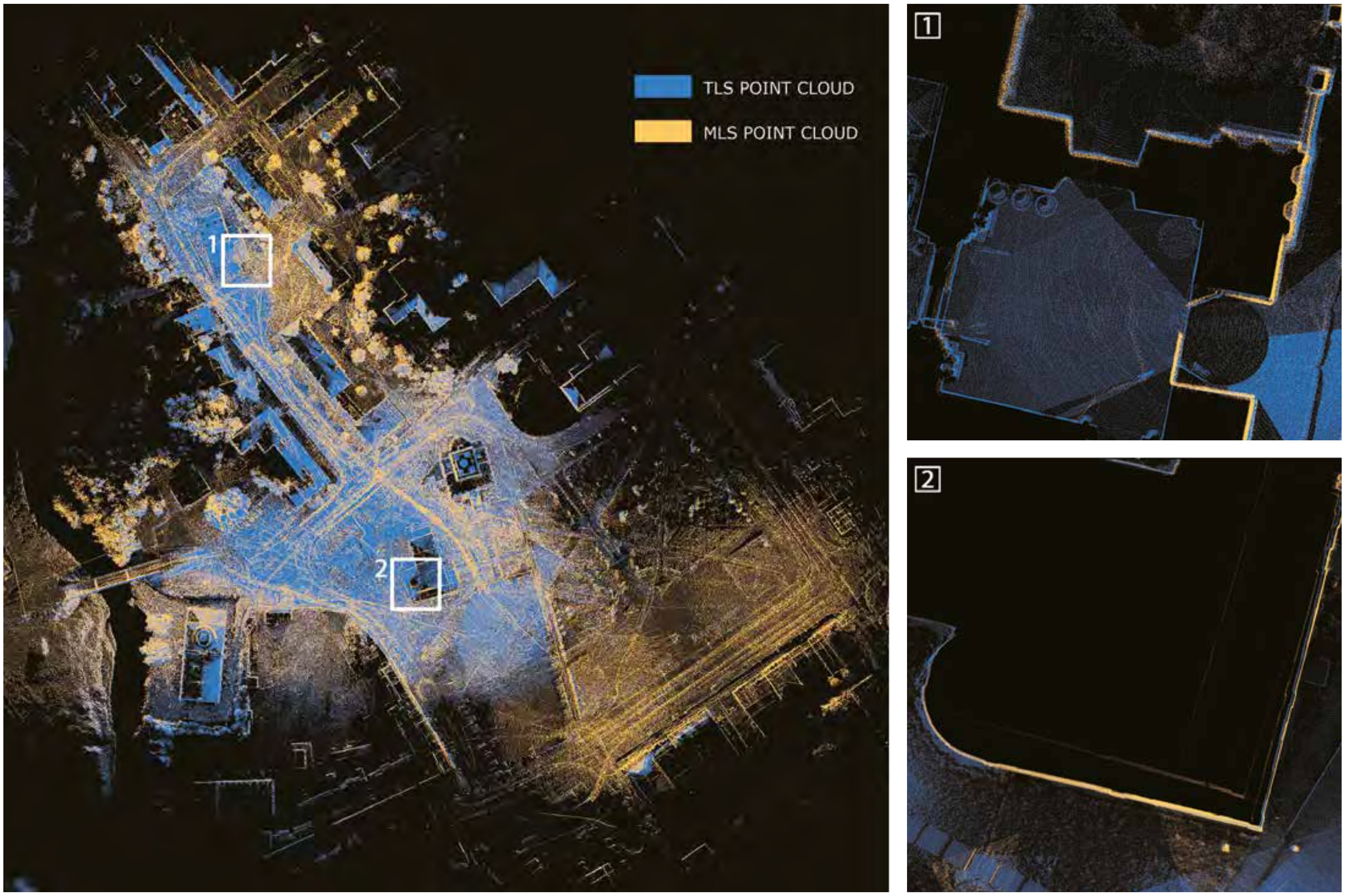


Fig. 11
TLS and MLS point clouds
Overlapping and complementarity between TLS and MLS point clouds (left) and morphometric comparison of data obtained from the measurement systems across two specific sections of the churches (right).

To address this, a second phase focused on detailed acquisition through point-of-interest-based flight plans. These involved concentric, multi-altitude trajectories around individual buildings, significantly improving the geometric definition and clarity of the resulting models.

The use of Mobile Laser Scanner (MLS) systems based on SLAM technology enabled rapid data acquisition over extensive areas. Each acquisition generated point cloud datasets within a radius of approximately 50 m, covering segments between 150 and 500 m along the operator's trajectory. Point density and resolution were influenced by movement speed and by the system's ability to recognise stable morphological features within the urban environment. The resulting datasets include reflectance-based colour information but may exhibit geometric distortions (e.g., drift or mirroring effects), requiring post-processing corrections.

Processing of digital data and final 3D products

During post-processing, TLS and MLS datasets were aligned to produce two comparable 3D point clouds. This enabled a comparative evaluation of the morphometric data at both urban and territorial scales, allowing an overall assessment of the documentation quality achieved through the two acquisition systems. The data registration process from the TLS survey was carried out by using visual

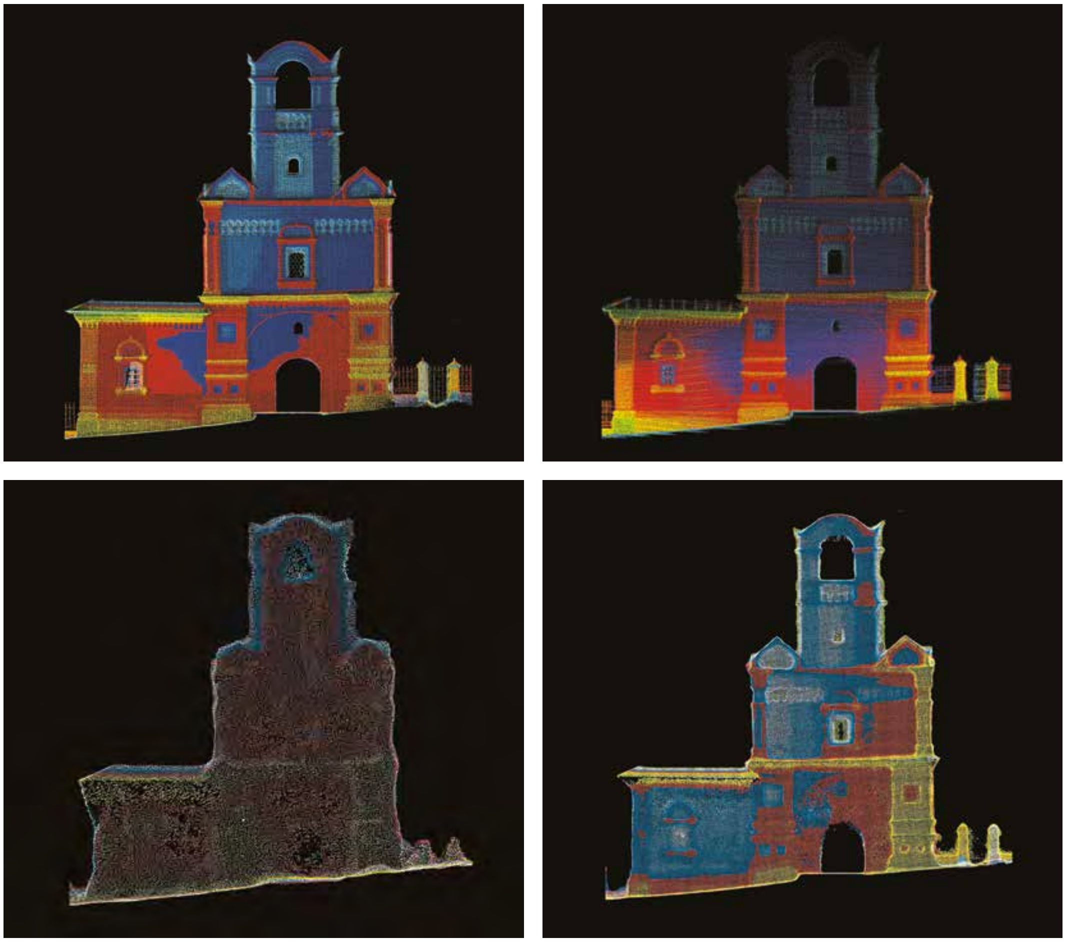


Fig. 12
Comparison of point clouds quality adopting elevation maps
The difference in resolution and geometric quality of the dataset is visible, considering the TLS density (above, left), the MLS vertical limit (above, right), the UAV resolution (below, left) and the terrestrial photogrammetric resolution (below, right).

matching systems based on cloud-to-cloud calculation algorithms, which allowed a registration match between data without the need of control targets. Monumental buildings, surveyed through closed polygonal scans, were processed as independent clusters (FARO Scene software) to ensure reliable cloud-to-cloud registration.

The integration of MLS datasets was carried out through the identification of homologous points within the urban morphology, which were subsequently used to merge TLS and MLS point clouds. Within the registration framework (Leica Cyclone software), these homologous targets were distributed to form a network of triangulated control geometries, ensuring a balanced and homogeneous error compensation across the dataset.[7]

The result is a point cloud with high metric reliability and resolution of the street level, whose missing portions of data are integrated with the aerial SfM data. The resulting integrated point cloud achieves high metric reliability and resolution at street level, while missing portions of data are supplemented through SfM photogrammetric acquisition. The photogrammetric point cloud was elaborated in Agisoft Metashape following image alignment and dense reconstruction processes.

[7] Due to the size of the area and in order to have as little overlapping error as possible, there were identified approximately 90 morphological targets.

The dataset was organised into separate chunks corresponding to the distributed survey and to targeted acquisitions on specific architectural elements; these were subsequently aligned and merged into a unified model. The resulting point cloud was then exported and aligned within a common coordinate framework derived from TLS data by identifying morphological reference points and assigning their coordinates accordingly.

Starting from the TLS point cloud, which was assumed as most reliable basis, a comparative analysis of the global data obtained from the union was developed.

The SfM-derived point cloud provides extensive coverage and high overall overlap; however, it exhibits geometric inaccuracies near building edges, where volumes tend to appear smoothed or rounded, reducing the fidelity of architectural representation.

The MLS-derived point cloud, while characterised by lower geometric resolution and the absence of true colour information, offers acceptable morphological readability and efficient spatial coverage, with deviations (3–10 cm) compared to TLS data.

From a descriptive perspective, TLS data was prioritised for the representation of architectural morphology due to its superior resolution and metric precision. Conversely, SfM photogrammetry proved more effective at the urban and landscape scales, providing broader spatial coverage and enhanced colour information. MLS data, despite its lower precision, remains highly competitive in terms of acquisition speed, particularly for large-scale and time-sensitive survey scenarios.

The integrated dataset constitutes a comprehensive digital documentation system of the Solikamsk urban ensemble e from a morphometric perspective, supporting both detailed analysis of monumental architecture and broader investigations of urban structure, spatial organisation, and service networks.

The adoption of semi-automated semantic segmentation and annotation strategies further enables advanced interpretation of survey data, extending its application beyond conservation towards urban accessibility analysis and spatial redevelopment strategies within the framework of Cultural Heritage Routes.

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