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Paper ID

Automating photogrammetry-GIS integration: Scalable solutions for spatially-linked 3D data in submerged cultural heritage

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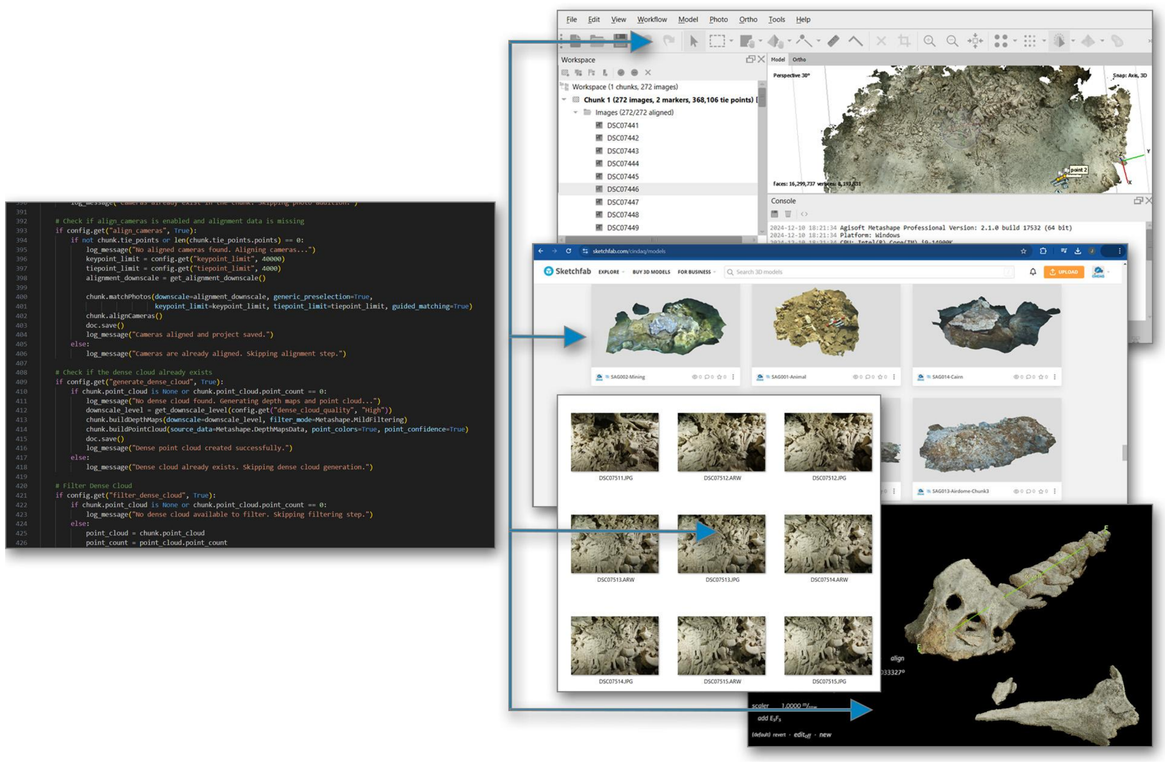
Background

Mexico's Yucatan Peninsula is a karstic region with extensive submerged cave networks accessible through cenotes. These sites contain significant biological, cultural, and archaeological materials, including human remains, Maya artifacts, and ancient mines. CINDAQ has spent over two decades documenting these underwater sites using scientific diving and geospatial technologies to support research and preservation. Efficient photogrammetric data processing and seamless integration with Geographic Information Systems (GIS) are crucial for this large-scale digital heritage and scientific research. By leveraging pre-documented processes, CINDAQ developed an automated photogrammetry workflow designed to enhance efficiency while ensuring consistent data quality. This system not only streamlines image-to-model processing but also integrates directly with a GIS-based Single Source of Truth (SSOT), enabling real-time spatial data updates and improved metadata management. By automating model generation, linking photogrammetric datasets to spatial layers, and enforcing standardized metadata structures, we have significantly reduced processing time and enhanced data accessibility for researchers. Additionally, the system lowers the technical barriers to entry, allowing non-specialists to engage with photogrammetry tools, thereby democratizing access to 3D modeling and spatial analysis. By simplifying workflows and reducing manual effort, this approach enables large-scale model production, increasing scientific collaboration and accelerating discoveries. The findings highlight a scalable, reproducible strategy for bridging photogrammetry and GIS, ultimately providing a structured, efficient, and inclusive digital archive for subterranean and underwater research, which can be replicated to other study areas.

Process standardization & Data Management

The development of CINDAQ's automated photogrammetry workflow in 2024 was the result of a multi-year effort to standardize, document, and refine model generation. Before automation, the team established detailed procedural guidelines through an in-house wiki, ensuring methodological consistency. By 2023, these steps were consolidated into a comprehensive workflow, including necessary steps and suggested parameters, covering image alignment, point cloud generation, noise filtering, mesh model generation, scaling, export to other viewing or analysis platforms, streamlining both training and execution.

Additionally, original model imagery as well as generated outputs (point cloud files, projects, orthomosaics) and contextual information (site videos, assessments by scientific partners) is organized in a standardized manner by using the same folder template for every documented site. Data is primarily stored on a NAS, which is itself both backed up in the cloud and mirrored on an off-site emergency NAS.



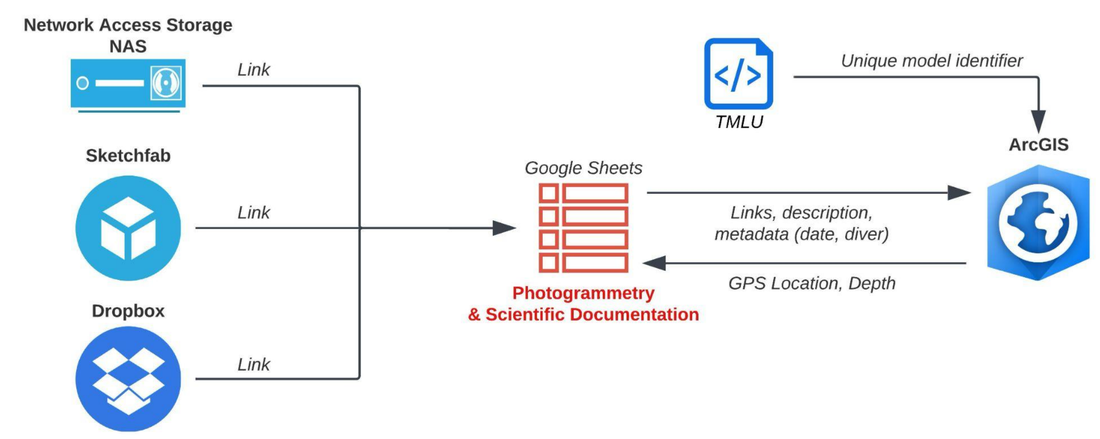
Photogrammetry Workflow Automation

Feeding the workflow documentation to an AI to accelerate the development process, we generated a series of scripts to automate each step of the photogrammetry process. Implemented on a high-performance workstation, it cut processing time fivefold, transforming image datasets into fully processed models with minimal intervention. Additionally, the system lowers technical barriers, enabling non-specialists to engage with photogrammetry tools and expanding access to 3D modeling. This automation has not only boosted efficiency but also enhanced the reproducibility and scalability of photogrammetry for scientific research and heritage preservation.

Furthermore, the system is designed to preserve the original imagery, allowing users to manually reprocess data when needed. It also supports re-running any step of the workflow with different parameters, without discarding the results of previous steps, while systematically logging all parameters used during each run to ensure full traceability.

Model Utility & Scientific Applications

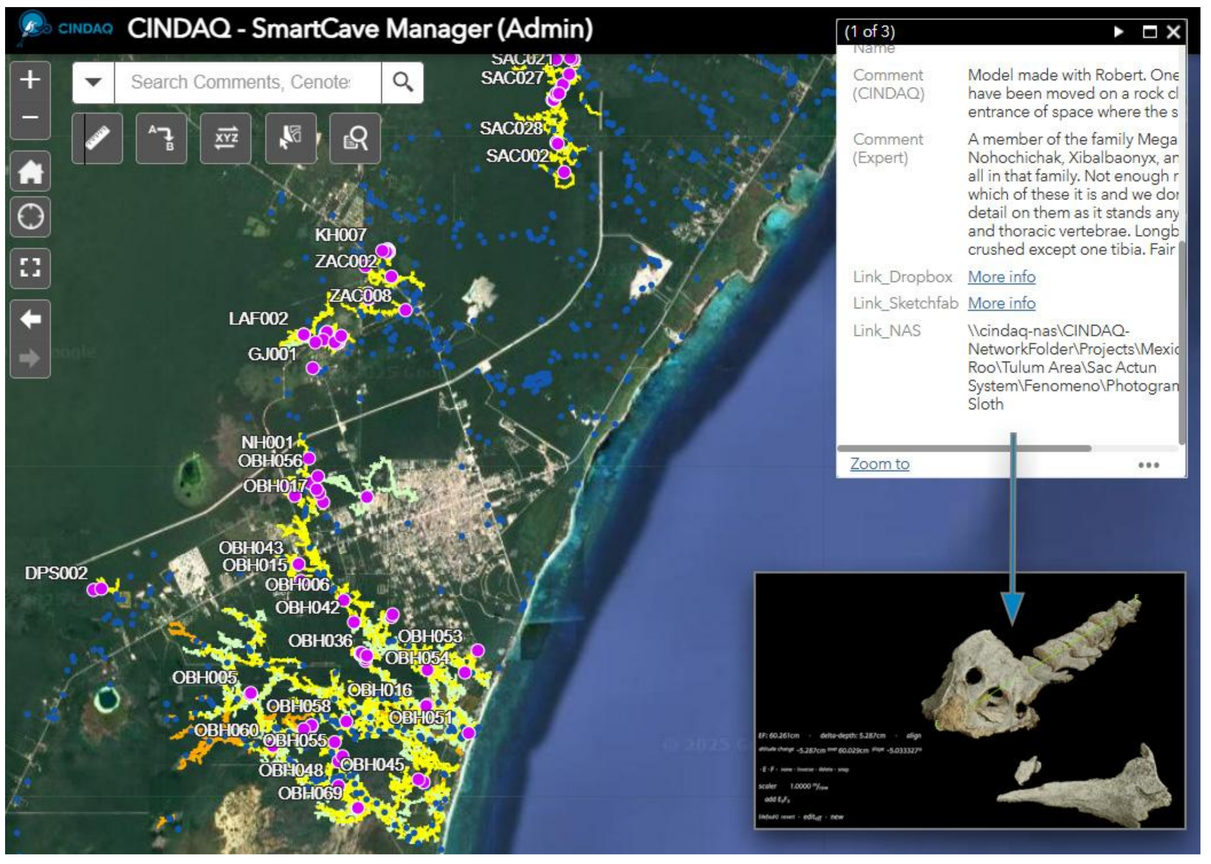
While textured meshes are shared via platforms like Sketchfab for rapid reference or public engagement, the core scientific value lies in the dense point clouds produced by this workflow. These high-resolution datasets support digital twin synthesis and feed into visual analytics pipelines that enable accurate segmentation, annotation, and measurement. Domain specialists can virtually manipulate point data to isolate key elements, take measurements, assess spatial distribution, or overlay imagery for contextual interpretation. Our workflow allows us to generate, store and organize all original data as well as the point clouds for scientific analysis and the textured mesh models for quick online visualization.



Single-Source-of-Truth Approach to GIS Linking

Ensuring seamless integration between photogrammetric datasets and Geographic Information Systems (GIS) is crucial for maintaining data consistency, accessibility, and long-term usability. CINDAQ adopted a Single Source of Truth (SSOT) approach to centralize metadata, linking records across NAS storage, Dropbox, Sketchfab, and GIS layers. Previously, data was fragmented, requiring manual effort to resolve discrepancies. By formalizing the SSOT within a Google Sheet linked to GIS, we created a real-time, two-way synchronization pipeline, automating updates of key metadata like model creation date, expert assessments, and spatial coordinates.

Beyond improving integration, this has revealed data inconsistencies, driving a virtuous cycle of refinement. By visualizing gaps and misaligned records, researchers can identify missing or erroneous data, enhancing data quality. This feedback loop has resulted in a 200% increase in the number of models that can be spatially linked in the CINDAQ database. The modular nature of this system also allows for future scalability, enabling adaptation to alternative database formats such as SQL tables or feature layers within GIS platforms.



Preliminary results

Since 2021, the introduction of a compact photogrammetry setup has steadily improved model processing efficiency. However, the most significant boost came after automation was implemented on November 17, 2024. Before automation, an average of 0.141 models per day were processed, increasing to 0.238 per day after automation —a 69.2% improvement. This suggests that automation streamlined workflows, reduced bottlenecks, and improved scalability. The combination of standardized procedures from 2021 and the automated workflow of 2024 has significantly enhanced productivity while maintaining data consistency.

Beyond efficiency, automation has also led to a more equitable distribution of workload among contributors. To assess this, we calculated the number of models each contributor processed and derived two statistical indicators: the standard deviation and the coefficient of variation (CV), both measured in percentage of total contribution. These values reflect the spread of individual contributions relative to the group. Before automation, the standard deviation was 13.62 and the CV 68.10%, indicating highly uneven distribution. After automation, these dropped to 5.07 and 25.34%, respectively, reflecting a more balanced and sustainable process. This shift ensures that no single contributor is disproportionately responsible for model production, making the overall workflow more scalable, resilient, and accessible to a wider team.

Additionally, integrating photogrammetry models into GIS visualization is already yielding scientific benefits. Researchers can now spatially analyze model locations, allowing them to spot emerging patterns in archaeological, geological, and paleontological data. By overlaying models with other survey data like cave topography and aerial imagery with embedded geographic metadata, scientists can correlate findings more effectively, identifying site clusters, geological formations, or previously unnoticed relationships. This integration enhances interpretability and facilitates data-driven discoveries, demonstrating the power of GIS-linked photogrammetry for large-scale research initiatives.