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When meshes Lie: Tracing Flaws and Extracting Knowledge from Expert Intervention in CH Mesh Processing

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Abstract

In the digital acquisition of Cultural Heritage artefacts, surface corrections are routinely performed by expert operators to eliminate defects in reconstructed 3D models. Yet these interventions, though essential, are rarely documented or formalised. This work proposes a method to capture and structure them: corrections are semantically tagged during the mesh cleaning phase and retroprojected onto the pre-cleaned model, transforming both meshes into a dual-layer system of interpretive paradata. By treating correction as a moment of knowledge production rather than mere refinement, the framework enables the construction of a taxonomy of flaws grounded in morphological traits and geometric indicators. The result is a reproducible and extensible system for flaw recognition that supports both expert practice and future analytical generalisation.

CCS Concepts
• Computing methodologies → Mesh models; • Human-cantered computing → Visualisation; Applied computing

1.Motivation and context

3D models generated through SfM/MVS pipelines often exhibit geometric inconsistencies with respect to the physical object. Unlike gaps, noise, or connectivity errors, these defects do not belong to standard categories: they are not formally characterised and typically escape conventional detection and correction methods. As a result, their identification and resolution rely on expert judgement, applied through critical and localised interventions.

Yet, in the absence of structured annotation, these actions remain opaque, as the cleaned model may be visually coherent, but the logic behind its refinement is lost undermining its value as a trustworthy representation of the physical object.

This opacity is particularly critical because many surface configurations are morphologically ambiguous: the same geometry may represent either a Feature (a legitimate detail of the object) or a Flaw (a defect introduced by reconstruction artefacts) (Figure 1). In the absence of contextual cues and formal descriptors, such disambiguation is not reliably automatable.

While texture information may assist in distinguishing Flaws from genuine Features, its integration as a systematic indicator would rely on advanced image recognition techniques that are neither standardised nor readily applicable within current mesh-processing pipelines. A robust approach should therefore rely primarily on geometry, which also ensures applicability across different acquisition methods.

Such need for disambiguation and traceability resonates and aligns with long-standing calls for methodological rigour in digital heritage. The London Charter [Lon09] and the Seville Principles [Ico17] have both emphasised that digital representations must be accountable, transparent, and grounded in documented interpretive processes. In this perspective, paradata, as defined by Bentkowska-Kafel et al. [BDB12], become the primary vehicle for making decisions explicit and reproducible.

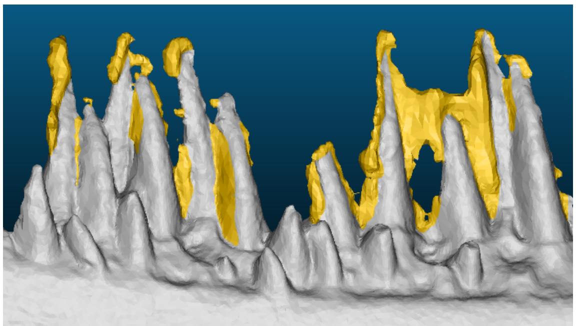

Figure 1: *Segmented acquisition artefacts on a mesh.*

Yet despite their conceptual uptake, few technical frameworks have operationalised paradata in early-stage

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3D mesh workflows. This gap is further highlighted by the VIGIE 2020/654 study commissioned by the European Commission [PRR*21], which underlines the lack of shared standards in 3D digitisation and the urgent need to bridge expert practice and formal documentation.

The present framework directly addresses this need by embedding structured paradata into the corrective phase, turning implicit knowledge into a reproducible semantic layer.

2. Method overview

The proposed framework operates within a four-stage pipeline for 3D digitisation of Cultural Heritage assets, articulated as RAW → RAWp → DCHO → DCHOo, as formalised in the pipeline defined by the CHANGES - Spoke 4 group in [BBC*24], of which the author is a member. This structure separates data acquisition, initial filtering, expert correction, and optimisation for dissemination. While RAW refers to the unprocessed output from the acquisition system, and DCHOo to the final optimised model ready for delivery, the method focuses on the intermediate transition between RAWp and DCHO—the critical phase where unsystematic surface flaws are addressed manually.

In this configuration, RAWp denotes the automatically filtered mesh, where generic high-frequency artefacts (e.g., noise, outliers, open borders) are removed through standard procedures, but localised morphological defects remain embedded. DCHO, in contrast, is the expert-corrected mesh: complete, readable, and visually coherent, but traditionally lacking an explicit record of the interpretive actions applied during cleaning.

This method builds upon, extends, and systematises two complementary mechanisms already conceptualised within our research group. First, during mesh correction, operators annotate interventions, such as gap-filling, sculpting, or geometric reconstruction, by tagging affected regions [BCF*25]. This transforms DCHO into a dual artefact: a cleaned mesh and a container of structured paradata. Second, these tagged regions are retroprojected onto RAWp, establishing a spatial correspondence between the cleaned and uncorrected meshes and transferring the segmentation onto the pre-corrected model [ABC*25].

In this work, the retroprojection is further refined and structurally supported by a set of mesh-derived indicators including curvature proxies, edge length, and confidence, allowing the process to operate not only as a spatial match but as a morphologically informed re-mapping of flaws (Figure 2).

This combination transforms RAWp into a diagnostic surface enriched with semantic traces of the operator's interpretive action. Rather than altering the established pipeline, this framework enhances it by formalising the corrective phase.

Through this two-way mapping, operator knowledge is made explicit, and a typological structure grounded in real-world interventions begins to emerge, enabling structured reuse, analytical development, and critical validation of the mesh cleaning process.

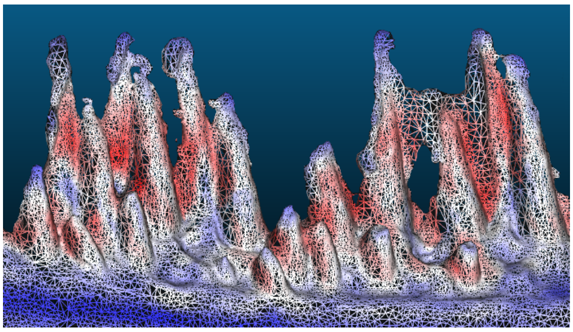

Figure 2: *Colour-mapped curvature proxy on the mesh*

3. Dual use of the method

This dual-layer structure supports a twofold function. In its current exploratory phase, the feedback loop from DCHO to RAWp serves as a knowledge extraction device, enabling the retroactive formalisation of tacit operator expertise through semantically tagged corrections. This configuration plays a foundational role: it reveals recurring flaw patterns, supports their morphological and analytical characterisation, and underpins the development of a transferable taxonomy.

As this taxonomy becomes more robust—anchored in reproducible indicators and validated classifications—the process will evolve. At that stage, flaw identification can be performed directly on RAWp, with the feedback loop remaining as an open channel for refining and expanding the typology. This design ensures that the system remains both operationally grounded and methodologically extensible, capable of supporting day-to-day mesh inspection while continuously integrating new knowledge into a shared semantic structure.

4. Flaw taxonomy and identification

Flaws are characterised through a dual perspective: by their morphological appearance and by quantitative indicators derived from the mesh. The former includes geometric patterns such as blobs, folds, bridging, or duplications; the latter includes Mean curvature, computed at three spatial scales, to capture surface behaviour across frequency bands; Edge length, as a proxy for local sampling density; Confidence values, reflecting photogrammetric stability or reconstruction reliability.

This combination supports the disambiguation between Features and Flaws by making surface anomalies legible within their geometric context. While currently interpreted under expert supervision, these descriptors provide a stable foundation for future analytical workflows, including threshold-based classification or assisted cleaning.

5. Scope and future development

Originally developed during the digitisation of the Ulisse Aldrovandi collection as part of CHANGES (Spoke 4, WP 3/4), the method integrates with broader group research while consolidating a field-derived approach to mesh correction and documentation [BBB*24].

By operating between RAWp and DCHO, it remains agnostic to the acquisition technique. It assumes only that RAWp has been filtered to remove systematic high-frequency noise, and that DCHO reflects expert-led correction. The workflow is unaltered: the method observes it, turning unrecorded intervention into structured information.

Future developments will formalise the link between flaw descriptors and analytical thresholds, enabling reproducible classification. Segmentations would then be aligned with CIDOC-compliant schemas and may support training datasets for diagnostic tools, including Deep Learning approaches.

Rather than introducing new tools, the method formalises what experts already do, turning embodied knowledge into a sharable, extensible system. At full maturity, it would support a dual function: as a structured memory of past corrections, and as a diagnostic aid for identifying flaws in need of future intervention.

6. Aknowledgements

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