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HARMONIZING PHOTOGRAMMETRIC APPROACHES FOR CULTURAL HERITAGE PRESERVATION: A METHODOLOGICAL FRAMEWORK AND COMPARATIVE ANALYSIS

1. Introduction

Digital imaging technologies have transformed archaeological documentation and analysis, necessitating interdisciplinary collaboration to merge archaeological and digital imaging methods (Barrile *et al.* 2022). In particular, photogrammetry, which reconstructs 3D models from photos, requires the combined efforts of archaeologists and surveyors (Chatzigrigoriou *et al.* 2021). This method processes images, executes measurements, and reconstructs archaeological sites and artifacts, generating significant raw data due to its multi-component nature involving cameras, computations, and modeling (Remondino 2011; Kaneda *et al.* 2022). The integration aims to balance archaeological objectives with technical choices for effective model creation. Achieving an effective symbiosis between archaeological research and technical implementation in 3D modeling naturally leads to the critical role of metadata organization in managing the large volumes of data generated.

The organization of large volumes of data relies on a careful design of metadata. The consistency of metadata across acquisition, processing (e.g., the algorithm in use), and modeling (e.g., the choice of mesh sections to delete) is crucial for data integrity and interoperability (Carboni *et al.* 2016). Contemporary archaeology depends on data sharing and reinterpretation across contexts. Yaworsky *et al.* (2020) exemplify this through predictive models reconstructing historical use phases of Grand Staircase-Escalante National Monument (USA), drawing from diverse campaign data and areas. Kansa, Whitcher Kansa (2022) have shown that producing data annotated with shared formats or vocabularies leads to new discoveries and validations of previous interpretations. Despite the increasing use of photogrammetry in acquisition, Klehm (2023) notes a lack of shared metadata, resulting in many unvalidated 3D models. Protocols have emerged since the 2010s, but interexchangeability remains unresolved. Literature often presents closed protocols, hindering integration (e.g. Cerasoni *et al.* 2022). Efforts like cross-evaluation (Goodbody *et al.* 2021) and guideline development (Douglass *et al.* 2015; Di Giulio *et al.* 2017; Homburg 2019) aim to address this issue.

This paper presents the FOPPA (Functional Ontology Protocol for Photogrammetric Acquisition) acquisition protocol, aiming for effectiveness in surveys and improving interoperability. It employs standard ontologies and modular structure, bridging humanistic and surveyor perspectives. Grounded in Digital Data Curation framework (Miksa *et al.* 2019) and CIDOC-CRM ontological model (Bruseker *et al.* 2017), it standardizes processes and metadata, ensuring formal encoding. The protocol is compared with other interoperable methods in the literature, addressing the need for standardized photogrammetric approaches.

2. State of the art

In photogrammetric acquisition protocols, metadata is vital. Quantin *et al.* 2015 highlight metadata's role in understanding and correctly using 3D models. However, scholars lack consensus on metadata management and selection. Faniel *et al.* 2013 stresses standard metadata formats and contextualization for data reuse. Ahmadi and Ebadi (2009) propose GIS metadata structuring and Goodbody *et al.* 2021 suggests evaluation benchmarks for aerial photogrammetry.

Photogrammetric protocols aim to abstract acquisition processes, addressing interdisciplinary needs in archaeological contexts and guiding survey conduct through standardized phases that produce coherent metadata (Douglass *et al.* 2015; Di Giulio *et al.* 2017; Homburg 2019). Khalil and Stravoravdis (2022) argue that standardizing processes and formats is crucial for unifying digital archaeological data, enhancing interoperability and enabling advanced analysis. However, implementing these standards requires consensus within the archaeological community. Di Giulio *et al.* 2017 developed an abstract photogrammetric methodology to integrate diverse projects, though it remains largely theoretical. Rodríguez-Martín and Rodríguez-Gonzálvez (2020) applied these concepts practically but focused on specific object categories.

Our research posits that existing protocols, with shared ontologies, can facilitate effective communication beyond specific projects or contexts through proper data and metadata organization in 3D model generation.

3. Abstract models and the application to photogrammetry

Abstraction facilitates digital data archive management, ensuring standardized methodologies for compatibility and coherence across projects, promoting data reuse. Despite early hopes for centralized archives and standardized formats (Koller *et al.* 2009), achieving unified or interoperable protocols remains a challenge. Reffat and Nofal (2013) emphasize the need for a multimodal protocol, while Napolitano *et al.* 2017 proposes meticulous documentation for protocol deciphering. Douglass *et al.* 2015 and Pocobelli *et al.* 2018 outline key stages in the acquisition process, addressing challenges like surface reconstruction and accuracy testing. Compliance with EU guidelines is essential, covering factors affecting digitization quality and relevant formats and benchmarks.

3.1 *Digital data curation*

To meet the organizational and methodological needs in Cultural Heritage, we utilized Digital Data Curation structures. This practice involves managing, preserving, and enhancing digital data, ensuring secure storage and adherence to ethical standards. Despite its importance, few photogrammetry projects reference Digital Data Curation, limiting its use in the field, as addressed by Fernandez (2019) and Lauro and Lombardo (2023a), among the few examples, we can cite Garozzo *et al.* 2017. Considering this, our photogrammetric acquisition protocol aligns with Digital Data Curation concepts, aiming for broader applicability in humanities research.

3.2 *Ontologies and vocabularies: CIDOC-CRM*

Ontologies and thesauri are pivotal in shaping shared terminological vocabularies for digital databases, notably in cultural heritage. These structured tools enable efficient information retrieval across domains, fostering interoperability. The EU-funded CrossCult project exemplifies semantic technologies' application, redefining historical appraisal (Vlachidis *et al.* 2017). Freire and Valk (2019) explore ontologies' usability in web crawlers. It must be placed in this research context the creation of the CIDOC Conceptual Reference Model (CRM) that has emerged as the main reference ontology for the management of databases and information in cultural heritage. While previous applications in archaeology and photogrammetry exist, they often focus narrowly on specific cases, limiting broader theoretical application (Bruseker *et al.* 2017). Despite its theoretical relevance to cultural heritage, research on CIDOC-CRM's practical implementation in photogrammetry remains sparse.

4. Photogrammetric workflow and CIDOC-CRM encoding

Our approach yielded the BeAPG protocol (Lauro, Lombardo 2023b), evolving into the FOPPA protocol, designed for heritage object photogrammetric surveying within the BeArchaeo project. FOPPA integrates Digital Data Curation and CIDOC-CRM, ensuring data management and ontology-based entity definition during digital clone generation. It aligns acquisition processes with CIDOC-CRM phases, enhancing standardization. The protocol expands sub-phases to encompass broader techniques, aiming for a precise glossary and comprehensive representation. We align photogrammetric processes with cultural heritage discoveries, codifying actions into CIDOC-CRM classes

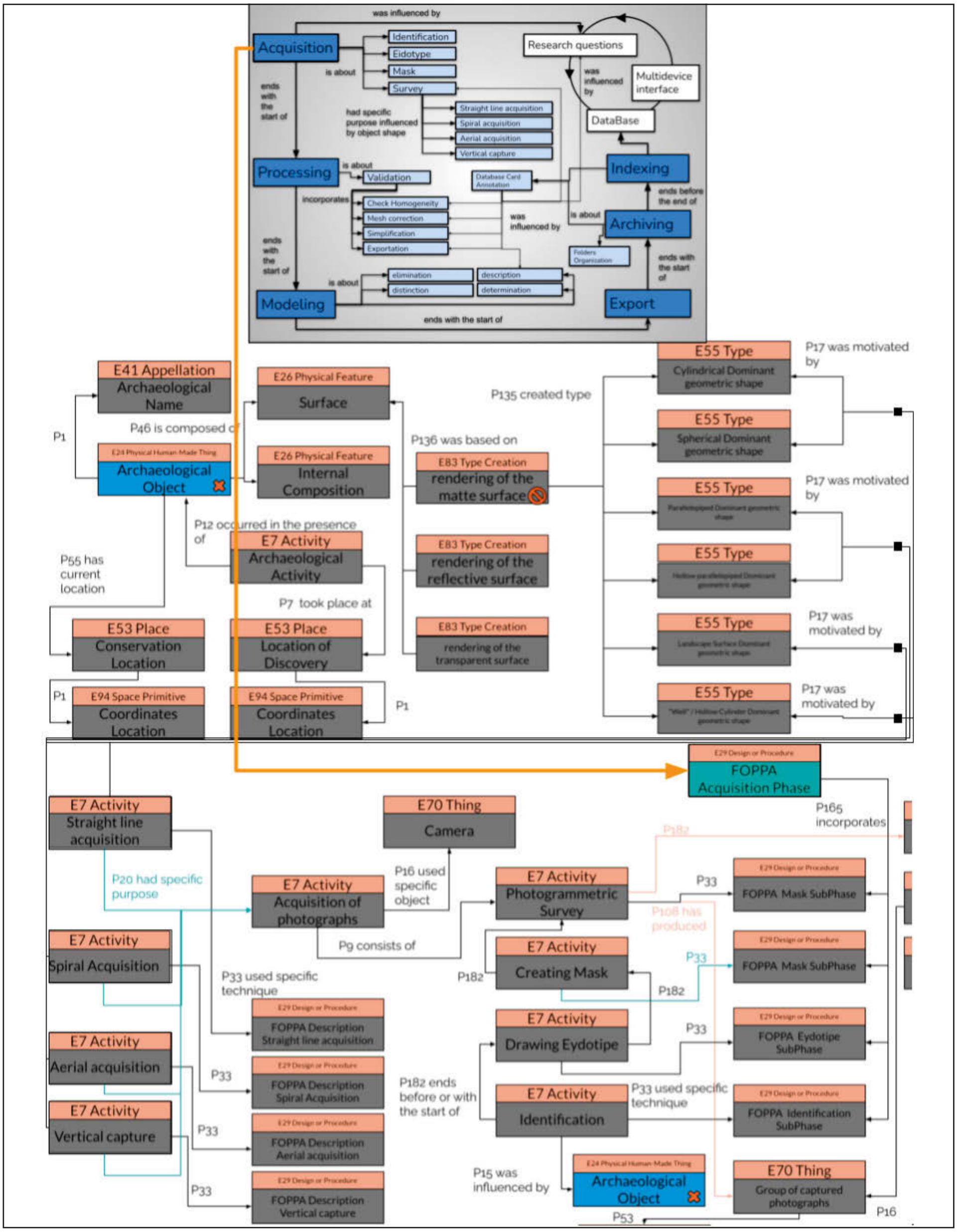

Fig. 1 – The diagram shows the summarized and simplified version of the protocol: in the upper part there is a detailed version where each single step has been codified and defined by a class relating to the generative activity of the model; in the lower part there is a detailed view of the constituent classes of the model Acquisition Phase.

for interoperability. The protocol delineates phases: acquisition, processing, modeling, exporting, archiving, and indexing, each represented by corresponding classes, facilitating meticulous process description and universal understanding (Fig. 1).

4.1 *From BeAPG to FOPPA, towards the implementation of other protocols*

The FOPPA protocol reconstructs the photogrammetric creation processes starting from pre-existing projects in a manner not dissimilar to how CIDOC-CRM is used today to reconstruct and organize information, data and metadata in relation to historical events that may have led to the creation of specific Cultural Heritage objects. As a reference example we bring the case of three protocols that will be subjected to direct comparison with this method. The aim is therefore to use the FOPPA protocol to collect these other acquisition protocols, identify their work phases and thanks to our protocol make them coincide with the ontological classes of the CIDOC-CRM, thus allowing communication between the data and the metadata produced by various projects even transversally among themselves once this conversion has been completed and therefore ensure correct storage and transmission of the 3D model metadata.

4.2 *Inception Protocols*

The Inception Protocol, introduced by Di Giulio *et al.* (2017), streamlines 3D semantic model creation for Cultural Heritage sites. It focuses on cost-effective data acquisition, balancing quality and resources. Phases, called in Inception Protocol 'Action', cover planning, technology selection, data acquisition, processing, and validation, ensuring comprehensive site coverage. The protocol promotes model sharing and interoperability through common file formats. Ontological alignment between Inception and FOPPA phases facilitates CIDOC adaptability, enhancing database integration.

The FOPPA protocol complements Inception by aligning with its interpretative phases (Action 1) and enhancing find recognition (Action 2). It also streamlines 3D model management and justifies operational choices (Action 3), ensuring comprehensive archaeological data collection and processing. These adaptations provide clearer insights into site characteristics and acquisition techniques. Action 1 corresponds to FOPPA's initial Acquisition phase, organizing metadata and activities while considering space, time, and typology. Action 2 merges with FOPPA's data capturing, managing survey phases and metadata. Action 3 precedes semantic model creation, guiding data manipulation and modeling. Finally, Action 4 aligns with CIDOC-CRM principles, facilitating database communication, while Action 5 integrates deployment and valorization in the archiving phase (Fig. 2).

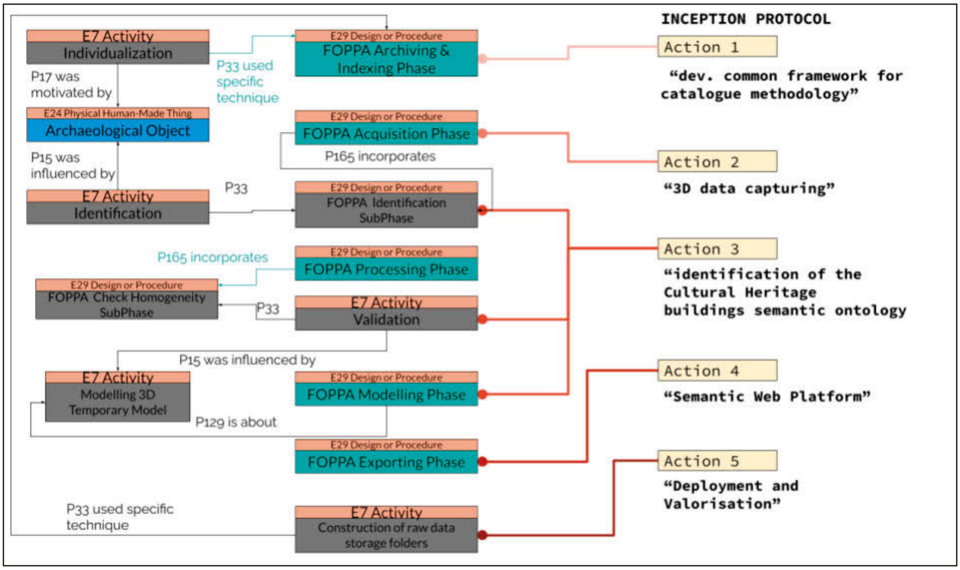

Fig. 2 – Schematic representation of the ontological coincidence between the main phases marked according to the FOPPA protocol and the ‘Actions’ which constitute the operational phases of the Inception protocol.

4.3 *Another method compared: the Douglass case*

In comparing our methodology with Douglass’s research (Douglass *et al.* 2015) on photogrammetry in archaeological pedestrian surveys, similarities and differences emerge. Both methodologies share operational phases, enabling cross-validation and enhancing photogrammetry’s utility in archaeological research. Our five-phase approach (acquisition, processing, modelling, export, and archiving) offers a structured framework for digital documentation, preservation, and dissemination of cultural heritage assets. Douglass’s methodology aligns conceptually, with phases like image capture, processing, and model verification. While both prioritize efficient data processing, Douglass emphasizes fieldwork and rapid documentation, contrasting our broader cultural heritage focus. Regarding the step of choosing photo capture strategies, it involves selecting the acquisition technique and recording it in the form database. This process includes ‘image collection and inconsistent image discard’ and the subsequent recording of the number of photos acquired and those discarded. This information is noted in the ‘validation information’ section of the archive card.

The ‘matching processing, point cloud, and surface reconstruction, densification and texturing’ phase falls perfectly within the processing of

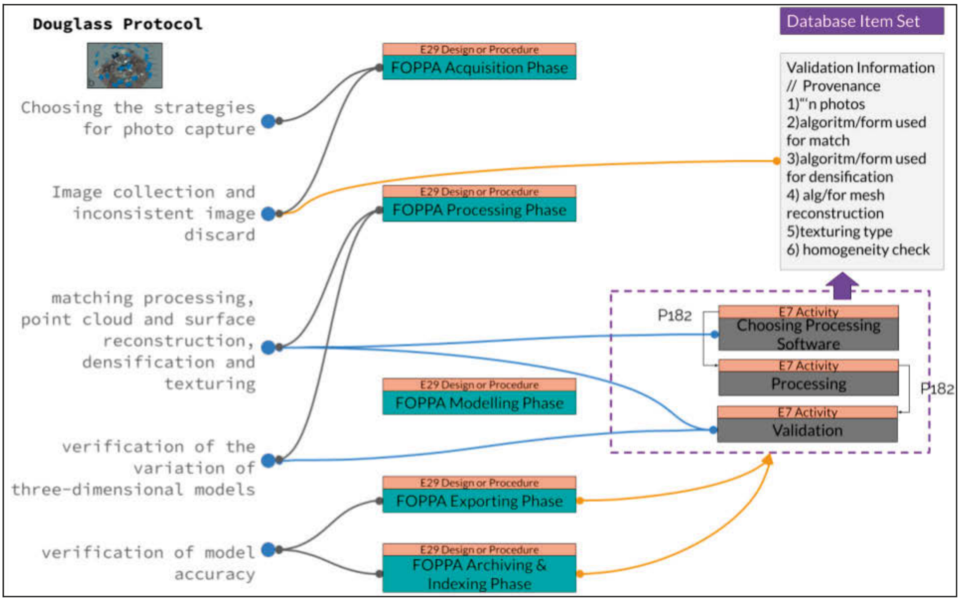

Fig. 3 – Schematic and essential comparison between our protocol and that of Douglas *et al.* 2017.

which each phase is recorded, and in the case of a process already carried out, reconstructed and destructured, into the coinciding CIDOC-CRM classes and consequent recordings in the form of database, where however the validation is brought forward in the processing phase coinciding with its final sub-phase. In this way the final phase of the Douglass protocol 'verification of model accuracy' is not an operation to be carried out in post-production but the natural result of the final export and archiving executions (Fig. 3).

4.4 *Another method compared: the Homburg case*

In comparing Homburg (2019) ontology model with our FOPPA methodology, parallels emerge in structured data processing and metadata's significance. Homburg's workflow, akin to FOPPA's phases, encompasses acquisition, processing, modelling, export, and archiving, supported by an ontology categorizing entities and activities. Both methodologies acknowledge agents' roles and algorithms' importance, albeit with different levels of abstraction. While Homburg's method focuses on enriching 3D model information, FOPPA prioritizes data acquisition and documentation, facilitating interoperability with diverse protocols. Both underscore software tools' integration and metadata management, albeit with distinct approaches. Homburg's detailed protocol suits systematic data recording, while FOPPA

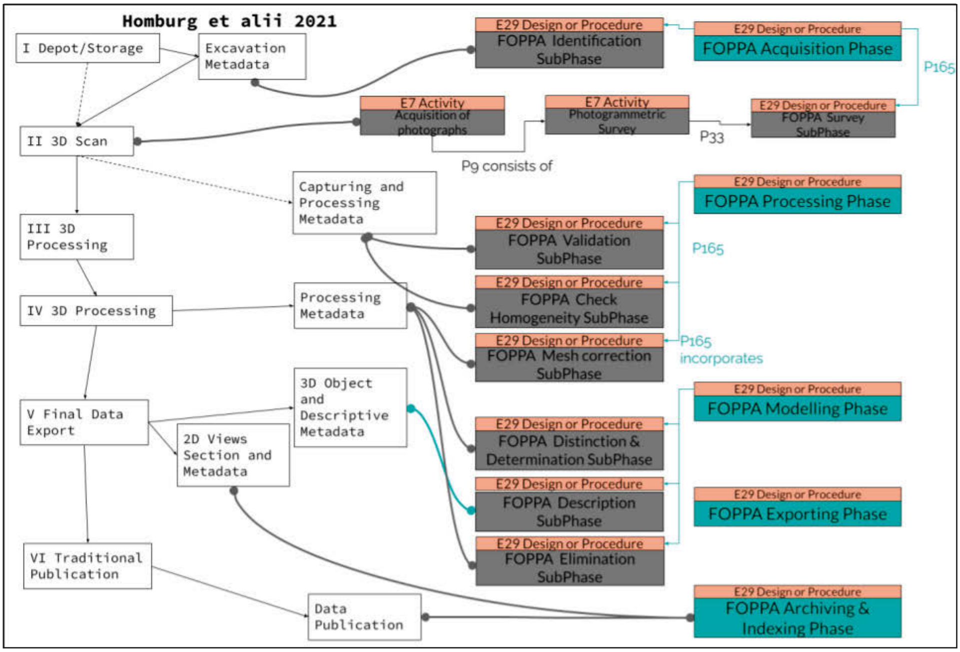

Fig. 4 – Schematic and essential comparison between our protocol and the Homburg one.

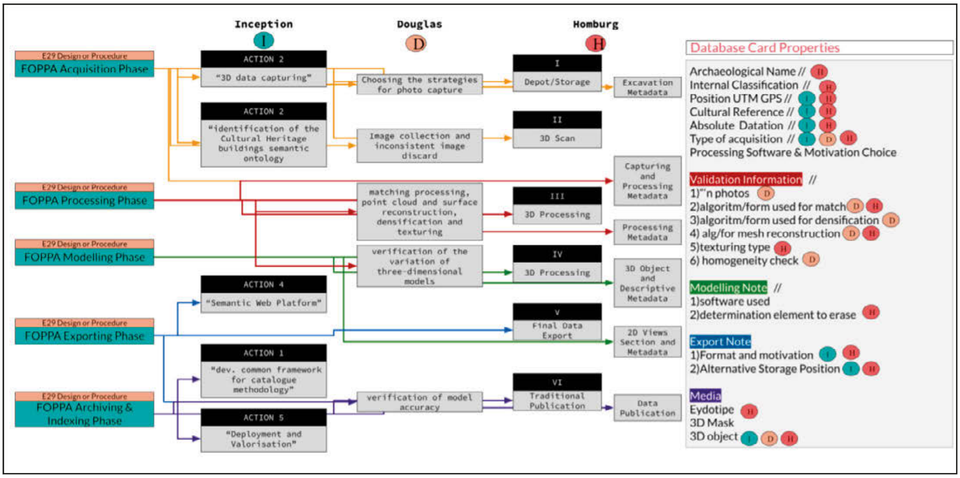

Fig. 5 – The adoption of a mediation protocol allows the comparative compilation of a database form of a three-dimensional finding coming from one of the three protocols analyzed.

offers interpretive flexibility for humanistic heritage contexts and protocol interoperability (Fig. 4).

4.5 *Procedural semantics in progress*

The database card captures metadata generated during 3D model creation, aligning with CIDOC-CRM phases. What were defined as Phases in the FOPPA are described in the Inception Protocol as Actions and the table was compiled by looking for coherence (and dissonance) between Phases and Actions. Required items include: archaeological name, internal classification, gps position, cultural reference, acquisition type, processing software, validation info, and export notes. Each item is linked to specific activities in its respective phase. Modeling notes detail model modifications, while export notes record procedural decisions. Additional MEDIA files store related data in the database, ensuring comprehensive documentation and organization of 3D models and associated information (Fig. 5).

4.6 *The need for comparison for exhaustive proof*

To comprehensively assess the FOPPA Protocol's capability to interpret data produced in the Inception Protocol, Douglass Protocol and Homburg Protocol, access to a 3D model generated in one of those protocols would be indispensable. By examining how the FOPPA Protocol handles the data-rich 3D model, researchers can evaluate its effectiveness in managing and processing complex photogrammetric datasets. This comparative analysis would not only highlight the strengths and limitations of the FOPPA Protocol but also provide insights into its interoperability with other photogrammetric methodologies.

5. Conclusions

In summary, this study proposes a methodological framework aimed at standardizing photogrammetric approaches in cultural heritage preservation. By leveraging principles from Digital Data Curation and CIDOC-CRM, the framework offers a structured approach to data acquisition and management, facilitating interoperability and consistency across diverse projects. However, to fully validate the effectiveness of this framework, practical applications across various cultural heritage contexts are essential. Through rigorous validation and refinement processes, our framework aims to contribute to the establishment of best practices in photogrammetric data acquisition for cultural heritage preservation, ultimately enhancing the accessibility, accuracy, and longevity of digital heritage records.

Vittorio Lauro
Università degli Studi di Torino
vittorio.lauro@unito.it

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ABSTRACT

This study addresses the standardization of methodologies and data formats used in photogrammetric projects related to archaeology. The application of photogrammetry in recording and safeguarding cultural artifacts proves invaluable in various domains. However, the lack of a standardized method makes effective sharing of experiences and knowledge among practitioners difficult. This paper presents a methodological framework for photogrammetric data acquisition in the context of cultural heritage. This framework transcends the constraint of specific technical tools, embracing instead a level of abstraction consistent with the general principles of the Digital Data Curation paradigm and ontological encoding through the CIDOC-CRM model. Eventually, we provide a comparison between the FOPPA protocol with other three main acquisition protocols in order to test the interlingua that can enhance the communication between protocols. The overall goal of our research is to support systematic and methodical structured acquisition path, as well as systematic classification of metadata, facilitating the effective implementation of the methodology in new projects and promoting effective communication among existing projects.