2023 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Rome, Italy, October 19-21, 2023

GP-NEP: a prototype of an assistant for non-experts in photogrammetric survey

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Abstract – **Photogrammetry is a widely used survey technique for creating digital replicas, but its application requires some expertise in survey planning and execution that sometimes can represent a challenge, especially for non-expert users. This paper presents GP-NEP, a prototype tool designed to address this task. GP-NEP aims to guide non-expert users through the intricacies of photogrammetric surveying, helping to understand the key factors that influence the quality of the final digital replica by employing an interactive questionnaire-based approach and general tips. GP-NEP assists users in selecting suitable equipment and optimizing the survey process based on the complexity of the object being captured. Through a comparative case study, concerning the 3D survey of two marble artifacts from the Roman river port of Seripola, the effectiveness of GP-NEP was tested.**

I. INTRODUCTION

In the last decade, photogrammetry has undergone a significant transformation, shifting from a specialized discipline to a widely accessible technique for both commercial and research purposes [**1**]. Within this panorama, the integration of photogrammetry and computer vision, along with the availability of low-cost image acquisition devices [**1**, **2**, **3**], has democratized the creation of 3D models using this specific survey technique [**4**]. Even if "mass photogrammetry" phenomenon has allowed non-specialists to engage in 3D survey [**5**], increasing the demand for user-friendly tools that enable non-experts to effectively capture complex real-world 3D scenarios [**6**], this advantage poses new challenges in ensuring quality and accuracy of the outputs [**2, 7**]. While the texture realism of photogrammetric meshes is remarkable and has contributed to their widespread use as digital objects valuable for game industries, commercial and dissemination purposes, it is important to critically consider two aspects. Firstly, the underlying metric accuracy of these digital replicas [**7, 8**] should be evaluated. Secondly, one must acknowledge the required skills to complete the entire photogrammetric pipeline, which includes data acquisition, data processing, and eventual use or dissemination.

In this regard, the transmission of photogrammetry knowledge not only to common users, such as enthusiasts and professionals, but also to users that belong to the research field of Cultural Heritage, such as museum workers, archaeologists, and aspiring students, poses an intriguing question. It raises the need to identify the most practical, efficient, and inclusive approach to engage this wide audience in photogrammetric practice yielding reliable results, allowing them to: understand the acquisition and the processing workflow according to the distinctive features of the object; estimate the final purpose of the survey (study, research, commercial needs); explore all available resources and references and choose the appropriate modeling techniques or acquisition instruments based on the analysis [**8**].

The surge in Online and Distance Learning (ODL), especially during the pandemic of the COVID-19, has prompted discussions and research on identifying the most effective e-Learning tools and methods to gain initial experience and knowledge in digital photogrammetry and remote sensing, specifically referring to non-expert users [**9**]. These efforts aim to create various learning scenarios that incorporate lectures, exercises, and software training [**9**]. In recent times, the International Society of Photogrammetry and Remote Sensing (ISPRS) has backed the "Education and training resources on digital photogrammetry" project, to explore and assess pedagogical web-based approaches that enhance education, training, and technology transfer in the areas of photogrammetry, remote sensing, and spatial information sciences [**7**]. The project is specifically tailored to engage non-expert users in the learning process and targets undergraduate students, professionals, trainers, and individuals without prior expertise who are seeking to acquire new knowledge [**7**]. By combining practical field work and classroom activities, supported by multimedia tools such as videos, games, tutorials, and MOOCs, the aim is to create engaging learning experiences. Various pedagogical approaches have been explored within these projects, including the Flipped Classroom (FC), Learning-by-doing (LBD), Collaborative Learning (CL), and Challenge-Based Learning (CBL). These approaches are enhanced by the integration of multimedia tools, which contribute to capacity-building and effective knowledge transfer [**7**].

In this regard, *D3Mobile*, a fully online international competition organized as part of the ISPRS initiative, stands out as one of the successful project experiences [**2**]. Implemented for over eight years and involving participants from across the globe, the project utilizes a project-based e-Learning approach to familiarize secondary school students (grades ISCED 1 and 2) with the realms of photogrammetry and metrology [**2**]. Notably, it adopts Challenge-Based Learning (CBL) as a means to provide students with practical, experiential learning opportunities [**2**]. However, it's important to note that Challenge-Based Learning (CBL) is just one of the available solutions. As emphasized by [**7**], combining different approaches can produce compelling and equally valid outcomes. Within this landscape, the lack of an interactive guided procedure (a wizard), which could help non-expert users to approach the photogrammetric survey, has been noticed.

The aim of this paper is to present a prototype version of GP-NEP, an assistant that can guide non-expert users to plan or verify a photogrammetric survey of artifacts. The prototype has been compared with the results of an existing photogrammetric dataset. The GP-NEP implementation consist of a set of inquiries, designed to define the descriptive attributes of the object earmarked for digitization, as well as the backdrop of the acquisition campaign. Additionally, GP-NEP engagement involves practical recommendations and precautions for the acquisition process.

In general, the paper is arranged as follows. **Sections II** and **III** present respectively the prototype and the case study. **Section IV** describes the main results, which are then discussed within **Section V**. Finally, conclusions are depicted in **Section VI**.

II. MATERIALS AND METHODS

A. GP-NEP, FROM A CONCEPT TO A FIRST PROTOTYPE

GP-NEP, which stands for Guided Procedure for Non-Experts in Photogrammetry, is a prototype version of a semi-automatic procedure which has been developed to assist non-expert users involved in photogrammetric surveys of artifacts [**10**]. Its concept stems from the master's thesis work in Digital Heritage and Multimedia, entitled '*A semi-automatic procedure for the 3D survey of cultural heritage objects: the case of the archaeological Dynamic Collections*' [**11**].

GP-NEP aims to focus on the most significant moments of critical reflection before starting a 3D photogrammetric survey. It stimulates especially non-expert operators to identify the complexity factors of a "model", and suggest how to deal with them. Through a supervised and interactive path, composed of approximately 14 questions and multiple answers (selected by the user), GP-NEP intends to: make non-expert users aware of the variables that can influence a 3D acquisition, offer some suggestions, and focus their attention on both the object of the survey and the dynamics of the campaign itself. Following the visualization of the final report, users receive an appendix containing recommended guidelines for conducting acquisitions. These include: camera settings (such as: Aperture, shutter speed, and ISO interplay), insights on lighting arrangement, camera height intervals, and artifact orientations.

B. HOW GP-NEP WORKS

GP-NEP, towards its semi-automatic procedure, induces the user to accurately observe both intrinsic and extrinsic parameters of the object to be digitally reproduced and the characteristics of the acquisition context. At the end of the process, GP-NEP proposes a report with some suggestions concerning the equipment to be used, according to the complexity of the "model" to be acquired and its physical and morphological characteristics.

In this regard, the guided process mainly focused on the complexity of the "model", rather than the inherent complexity of the object itself. This differentiation is crucial as the assessment of complexity holds significance solely within the framework of the photogrammetric acquisition campaign [**12**]. To reflect this perspective, the term "model complexity" will henceforth be used instead of "object complexity".

For the creation of GP-NEP's interactive route structure, Twine (version 2.6.1) [**13**] was employed. Twine was chosen for its user-friendly interface and its status as an open-source solution. Notably, Twine enables direct HTML publishing, simplifying the sharing of works on diverse platforms, without the need for coding. Additionally, it provides the flexibility to enhance stories with variables, conditional logic, images, CSS, and JavaScript, as desired.

At the moment, GP-NEP has been tested only for a limited range of artifacts, that is "small" (< 8 cm) and "very small" (8-35 cm) classes.

The interactive path addresses various macro areas (such as: Object description, Environment, Project purpose and definition) in order to guide non-expert users through a mindful analysis of the photogrammetric survey.

The path starts with a detailed description of the object, aiming to comprehend its shape and intricacy to capture it in 3D. GP-NEP provides guidance on how to roughly estimate the object's complexity by analyzing various factors, including the bounding box that contains the object, the desired quality of the model's resolution, the presence and topology of any cavities or holes within the object, as well as the surface and material properties.

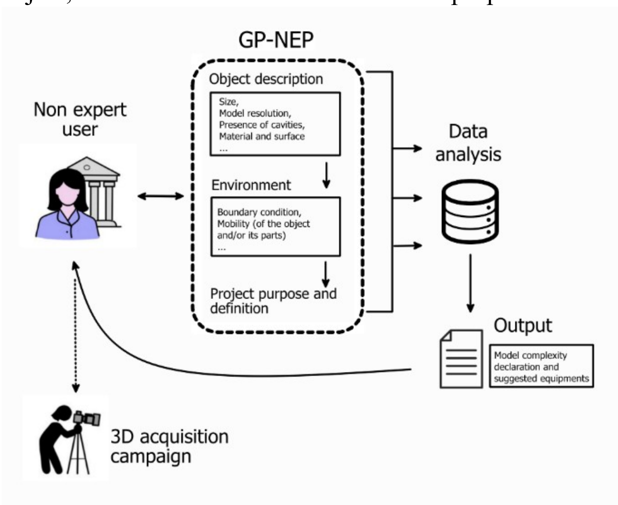

Fig. 1. Diagram describing how the GP-NEP concept works.

Furthermore, attention is given to the environment where the artifact is stored, including considerations about the object's boundary conditions and the delicacy of any movable parts. Lastly, the user is prompted to reflect upon the ultimate purpose of the model, differentiating between personal and professional uses such as display, commerce, study, and research.

At the end, a tailored report represents the final result of a simple question and answer process that, due to every response, has the possibility to define the degree of complexity of the object to be acquired and, also, alter the necessary equipment to be used (**Fig. 1**).

In order to assess the complexity of the object of the survey, GP-NEP follows the example of previous experiments [**3, 14**] by proposing a complexity index assessment. Based on these studies, generally the main aspects which influenced both the object complexity and the instrumental choices are structural characteristics, surface and material features. Therefore, GP-NEP queries the user on: object size, desired resolution model, presence of cavities and cavity type (Cavity Ratio), materials and surface, spatial distribution, presence of holes and blind holes, boundary conditions, mobility of the object or part of the object, acquisition goal. For instance, GP-NEP asks the user to approximately estimate the Cavity Ratio (CR), which serves as a metric value to assess the feasibility of digitally capturing certain areas of an object during the surveying process (**Fig. 2**).

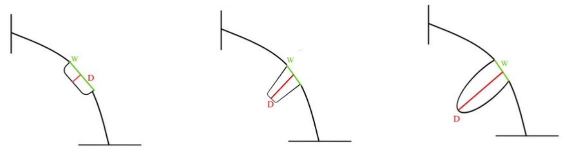

Fig. 2. The intrinsic feature of Cavity Ratio (CR).

This value is calculated by determining the ratio of the depth (D) to the width (W) of a cavity, considering the specific surveying approach and instrument utilized [**3**]. Planning the survey becomes relatively linear when CR values range between 0 and 1. However, as the CR values exceed 1, the surveying process becomes progressively more challenging. As already mentioned the second mission of GP-NEP has been developed to support the user during the actual photogrammetric acquisition phase. Within this section, the prototype tool does not interact with the users, instead it includes sheets with theoretical "concepts" and images that can be useful for the survey.

III. The 3D Survey of the Artifacts from the Archaeological Site of Seripola

The final report of GP-NEP was compared with two photogrammetric datasets relating to a couple of marble artifacts, a fragmented male bust and a female head, which were found during the excavation at the Roman river port of Seripola [**15, 16**]. These two artifacts, now part of the archaeological collection of the Museo Civico Archeologico of Orte, constitute the case study of a Master's thesis in Law and new technologies for the protection and enhancement of Cultural Heritage.

The thesis aims to highlight the importance of creating a digital replicas with photogrammetry that can be useful for archaeological research (such as: the reconstruction of the archaeological context relating to the artifacts, a possible stylistic analysis, images from specific point of view), enhancement purposes (online sharing through digital galleries and Virtual Museums), and, if necessary, projects of virtual restoration. By following these aims the project underlines the relevance of using 3D models as research products to be shared as Open Data objects through Creative Commons licenses.

The results of the workflows were published on Zenodo [**17**], a long-lasting repository for the preservation and management of data, including datasets. The platform of Zenodo was launched in May 2013 by CERN to support Open Data and Open Access for scientific research. The scientific community deals with these standards and principles as an opportunity to experiment new and alternative contents, available and reusable to everyone [**18**]. The publication of the digital replicas on Zenodo observed the guidelines of the metadata operative manual for Cultural Heritage datasets [**19**].

The fragmented bust (**Fig. 3**) represents a male figure (dimensions: 10,3x13x7 cm) which presents encrustations of the surface on its back and near some of its fractures [20]. The head (**Fig. 4**), instead, represents a female figure with a wreath (dimensions: 21x13x8,5 cm) [21]. Both the artifacts are in marble and currently under study.

The 3D survey was carried out with a Canon EOS 6D, equipped with a EF50mm f/1.4 USM (50 mm) lens, and a LightBox, to manage light interaction with the object during the survey. The whole dataset counts 138 images (5488x3662 and 3662x5488), 62 for the bust and 76 for the head.

At the end of the survey, two digital replicas of the artifacts were obtained. Both the 3D meshes were scaled using a scale bar, then a colored texture (8192x8192) was processed. After a cleaning step, the mesh of the bust presented 364.313 faces and 182.165 vertices and the one of the head counted 815.171 faces and 408.072 vertices.

Fig. 3. Image of the fragmented bust during the acquisition.

Fig. 4. Image of female figure's head with a wreath during the acquisition.

IV. Results

The contribution of GP-NEP consists in presenting a guided procedure, which is still in its prototype version, not only with the intent of submitting questions to the user, in order to assist the planning of a 3D survey, but also presenting a final report at the end of the whole interactive process. Through a series of questions GP-NEP guides users towards a sequence of relevant considerations to bear in mind during a 3D survey campaign, regardless of the object being replicated and analyzed. On one hand, during the guided process, in order to plan and realize a 3D acquisition, the operator will recognize that evaluating an item entails analyzing different types of features, such as: size, topological complexity, constituent materials, spatial position, and final purpose of the survey. On the other hand, the final report indicates a list of potentially useful instruments with which to manage the 3D acquisition. The recommendations outlined in the report can be further enriched with a set of theoretical and practical guidelines aimed at improving the data acquisition setup during the survey.

By comparing the final report made by GP-NEP with the 3D survey of Seripola, it emerges that only five elements out of nine (i.e., the 50 mm lens, scale bar, and resizable light box structure) were shared by both procedures (**Table 1**).

	The case study of Seripola	**GP-NEP**
DSLR camera		X
Full frame camera	X	
50 mm lens	X	X
Tripod		X
Turntable		X
Scale bar	X	X
Static lighting set		X
Resizable light box structure	X	X
Curtain of matte surface	X	X
Rubber pads		X

Table 1. Comparison of the two approaches

V. Discussions

At the moment, every step of the guided procedure presents detailed and intuitive questions, occasionally supported by images, that allow users to independently answer, according to the characteristics of the artifact to be acquired. This semi-automatic procedure not only focuses users' attention on the dynamics of the photogrammetric method, but, with the final report, it also proposes a list of technical suggestions that can be used to accomplish the purpose of the 3D survey.

From the experienced case study of Seripola, it emerges that GP-NEP is useful when both the subject and the context of the survey are well known. In this case, it's noted that the information about the artifact to be acquired is necessary to properly answer the questions that GP-NEP poses (i.e., intrinsic and extrinsic features of the object, survey goal etc.).

The photogrammetric acquisition of the case study was carried out with a reflex full frame, equipped with a 50 mm lens. For this step of the workflow, GP-NEP suggested a DSLR camera, equipped with a 50 mm lens. However, based on the second part of the tool, a wider angle lens could have been more useful for the acquisition of both the artifacts. In such circumstances, the difference between GP-NEP and the case study are modest (DSLR vs Full Frame), this difference could be overcome by considering a different set of answers that the procedure could suggest (for example: based on the final resolution of the 3D model that could be crucial in the choice of the camera).

Due to some logistic issues both the datasets were acquired without using a tripod. As a consequence, in some cases low quality images have been acquired, 58 out of 62 were used for the photogrammetric process of the bust and 64 out of 76 for the head (in this case, the "estimate image quality" tool of Agisoft Metashape [**22**] was used to verify the quality value).

The size of the lightbox did not allow the use of a turntable, therefore the artifacts were manually rotated. Since a light was already included within the lightbox, it was not necessary to employ an external light during the photogrammetric acquisition.

For the 3D acquisition of both the artifacts, the curtain of matte surface and the rubber pads suggested by GP-NEP were not employed since the lightbox has been equipped with a white background and a skid-proof surface. In addition, the skid-proof surface within the lightbox and the shape of both the artifacts allowed them to be placed firmly without the use of rubber pads.

In conclusion, the final report made by GP-NEP illustrated some analogies compared with the acquisition instruments employed for the case study of Seripola. Nevertheless, not all the advice suggested by GP-NEP has been considered effective for the 3D acquisition of the two artifacts. The additional tools offered by the guided process cannot be considered an error of judgment; instead, this information underscores the key role of the context in which the 3D survey is conducted and the complexity of the artifacts to be acquired.

VI. Conclusions

The GP-NEP concept demonstrates potential usefulness for the intended user segment of the project. However, the prototype tool assessed in this study would benefit from further improvements.

It is important to note that GP-NEP actually only considers a limited number of cases, as the focus on "medium-sized" and "large" objects is mentioned but not extensively developed. These aspects of the procedure will be faced in updated releases.

For future development of the prototype, it is recommended to incorporate more complex and less ideal scenarios, considering factors such as unknown acquisition contexts and object complexity.

From an aesthetic and usability standpoint, improvements can be made to enhance GP-NEP's user experience, such as adopting a less technical language, implementing a more intuitive and user-friendly interface, and embedding a greater number of images.

Regarding the choice of using Twine as a tool for structuring GP-NEP, while it proved beneficial for creating the prototype, it could be replaced in the future with a more automated approach for developing the branches leading to the final report. It is plausible to envision a programming-based structure for the tool, eliminating the need for manual configuration.

Moreover, considering that the second part of GP-NEP encompasses a variety of theoretical and practical elements, such as advice on artifact orientation, camera and lighting positioning, and trajectory, a future version of the tool could potentially feature a more interactive framework. This framework could be designed to be responsive to the user's input in the initial section, allowing for a more dynamic user experience.

VII. Acknowledgments

L.A. would like to thank Dr. Sofia Pescarin (CNR-ISPC), Dr. Diego Ronchi (CNR-ISPC) and Prof. Nicolò Dell'Unto (Lund University) for sharing their knowledge as tutors. B.M., E.D. and S.B. would like to thank Dr. Carlotta Schwarz (functionary of the Soprintendenza Archeologia, Belle Arti e Paesaggio per la Provincia di Viterbo e per l'Etruria Meridionale) and Dr. Matteo Zagarola (director of the Museo Civico Archeologico of Orte) for the authorization for the 3D surveys of the artifacts from Seripola, and Dr. Eleonora Scopinaro (CNR-ISPC) for her support during the 3D survey.

VIII. References

[1] M.Caine, M.Magen, "Low Cost Heritage Imaging Techniques Compared", Proceedings of the Electronic Visualisation and the Arts, London, UK, 11-13 July, 2017.

[2] J.Ortiz-Sanz, M.Gil-Docampo, T.Rego-Sanmartín, M.Arza-García, G.Tucci, "A PBeL for Training Non-experts in Mobile-based Photogrammetry and Accurate 3-D Recording of Small-size/Non-complex Objects", Measurement, 178, 109338, 2021, pp. 1-12 (doi.org/10.1016/j.measurement.2021.109338).

[3] F.I.Apollonio, F.Fantini, S.Garagnani, M.Gaiani, "A Photogrammetry-Based Workflow for the Accurate 3D Construction and Visualization of Museums

Assets", Remote Sensing, 13, No. 3, 486, 2021, pp. 1-39 (doi.org/10.3390/rs13030486).

[4] F.Ekengren, M.Callieri, D.Dininno, Å.Berggren, S.MacHeridis, N.Dell'Unto. 2021. "Dynamic Collections: A 3D Web Infrastructure for Artifact Engagement", Open Archaeology, 7(1), pp. 337-352 (doi.org/10.1515/opar-2020-0139).

[5] S.I.Granshaw, "Imaging Technology 1430–2015: Old Masters to Mass Photogrammetry", Photogramm. Rec. 30, 151, 2015, pp. 255–260 (doi.org/10.1111/phor.12112).

[6] H.Rahaman, E.Champion, "To 3D or Not 3D: Choosing a Photogrammetry Workflow for Cultural Heritage Groups". Heritage, vol. 2, no. 3, 2019, pp. 1835-1851 (doi.org/10.3390/heritage2030112).

[7] G.Tucci, E.I.Parisi, V.Bonora, L.Fiorini, A.Conti, M.Corongiu, J.P.Ortiz-Sanz, M.Gil-Docampo, T.Rego-Sanmartín, M.Arza-García, "Improving Quality and Inclusive Education on Photogrammetry: New Teaching Approaches and Multimedia Supporting Materials", Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLIII-B5-2020, pp. 257–264 (doi.org/10.5194/isprs-archives-XLIII-B5-2020-257-2020).

[8] N.Dell'Unto, "3D models and knowledge production", in Y. Huvila (Ed.), Archaeology and Archaeological Information in the Digital Society, London, 2018, pp. 54–69 (doi.org/10.4324/9781315225272-4).

[9] E.Gülch, N.Alghorani, B.Quedenfeldt, J.Braun, "Evaluation and development of e-learning tools and methods in digital photogrammetry and remote sensing for non experts from academia and industry", ISPRS, XXXIX-B6, 1-6, 2012 (doi.org/10.5194/isprsarchives-XXXIX-B6-1-2012).

[10] https://luisammi.github.io/Digital-Heritage-and-Multimedia-Thesis/main.html.

[11] L.Ammirati, "A semi-automatic procedure for the 3D survey of cultural heritage objects: the case of the archaeological Dynamic Collections", Master Thesis in Digital Humanities and Digital Knowledge of University of Bologna Alma Mater Studiorum, Digital Heritage and Multimedia Thesis, 2023 (https://github.com/LuisAmmi/Digital-Heritage-and-Multimedia-Thesis).

[12] European Commission, "Study on Quality in 3D Digitisation of Tangible Cultural Heritage: Mapping Parameters, Formats, Standards, Benchmarks, Methodologies, and Guidelines", VIGIE 2020/654 Final Study Report, Luxembourg, Publications Office of the European Union, 2022.

[13] https://twinery.org/.

[14] H.D.S.Budiono, F.A.Hadiwardoyo, "Development of Product Complexity Index in 3D Models Using a Hybrid Feature Recognition Method with Rule-Based and Graph-Based Methods", Eastern-European Journal of Enterprise Technologies, 3, 1, 111, 2021, pp. 47–61. (doi.org/10.15587/1729-4061.2021.227848).

[15] M.A.De Lucia Brolli, L.Suaria, "Il territorio: il porto fluviale in località Seripola", Orte (Viterbo) e il suo territorio. Scavi e ricerche in Etruria Meridionale fra Antichità e Medioevo, 2006, pp. 135-149.

[16] C.Schwarz, V.Asta, S.Del Lungo, M.Fantucci, L.Tessicini, M.Zagarola, "Seripola (Orte): spunti di riflessione e nuove prospettive di ricerca", Fra tutela e ricerca. Indagini archeologiche in territorio amerino, 2022, pp. 201-213.

[17] www.zenodo.org (accessed on 29 May 2023).

[18] M.Arizza, A.Caravale, A.Piergrossi, "Accessibilità e disseminazione dei dati nell'esperienza dell'ISMA", Archeologia e Calcolatori, 29, 2018, pp. 101-109.

[19] A.Bucciero, E.Demetrescu, "Manuale operativo di metadatazione dei dataset per Zenodo nei Beni Culturali", 2022, pp. 1-15 (www.zenodo.org/record/6138586#.ZFjKLKDP1PZ accessed on 29 may 2023).

[20] B.Magliocchetti, E.Demetrescu, S.Berto, E.Scopinaro, "Museo Civico Archeologico di Orte: frammento di un busto maschile. Rilievo fotogrammetrico" (1.0), 2023, Dataset, Zenodo (https://doi.org/10.5281/zenodo.7905394).

[21] B.Magliocchetti, E.Demetrescu, S.Berto, E.Scopinaro, "Museo Civico Archeologico di Orte: testa di una figura femminile. Rilievo fotogrammetrico" (1.0), 2023, Dataset, Zenodo (https://doi.org/10.5281/zenodo.7905398).

[22] https://www.agisoft.com (accessed on 29 May 2023).