2019 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Florence, Italy, December 4-6, 2019

A 3D information framework for automated archaeological pottery archival

Di Angelo L.[1], Di Stefano P.[1], Guardiani E.[1], Morabito A.E.[2]

[1] *Department of Industrial and Information Engineering, and of Economics – University of L'Aquila, via Piazzale Pontieri 1, L'Aquila, Italy, {luca.diangelo,paolo.distefano, }@univaq.it, emanuele.guardiani@graduate.univaq.it*

[2] *Department of Engineering for Innovation – University of Salento, via per Monteroni, Lecce, Italy, annaeva.morabito@unisalento.it*

***Abstract* – The classification of ceramic archaeological fragments is based on shape, dimensions, decorations, technological elements, color and material. Nowadays, all of these features are still recognized and analyzed by a skilled operator. It follows that the resulting characterization of shape and sizes of archaeological fragments is poorly reproducible and repeatable. With a view to overcome these limitations, a computer-based methodology, able to extract automatically several quantitative information from high-density discrete geometric models acquired by the laser scanning of archaeological fragments, was proposed. In this paper, the set of quantitative information obtainable is furtherly broadened, by including the segmentation of some types of morphological features, the identification of the fragment shape type, the evaluation of the longitudinal profile and the estimation of a larger set of dimensional features. Finally, a new 3D information framework is proposed to store the large variety of quantitative information extracted.**

I. INTRODUCTION

Large quantities of pottery finds, usually in the form of fragments, are discovered during archaeological excavations. These artefacts contain important information on the history, economy, and art of a site so that it would be desirable to fully document and process them.

The classification of ceramic material is based on shape, dimensions, decorations, technological elements, color and material. Nowadays, all of these features are recognized and analyzed by a skilled operator. Some of them, such as decorations, technological elements and color, are investigated by a visual analysis. The shape and dimensions characterization are largely based on the graphical representation of findings [1]. Since ceramic materials are typically found in fragments, the previous operations are even more complex to be performed.

In a previous paper [2], the authors stressed the non-reproducibility and non-repeatability of the traditional method for the characterization of shape and sizes of archaeological fragments. The traditional method is not only poorly reproducible and repeatable, but also has the following limitations:

- it is time consuming: according to [3], a talented and trained operator needs in average 90 minutes for a drawing;
- only the indicative fragments (i.e. those for which, due to the presence of a piece of rim, base or grooves, an acceptable estimation of the axis is possible), are analyzed.

It follows that only a little part of all finds are analyzed with great uncertainties and most of the knowledge detectable from excavations is lost.

The traditional analysis of fragments based on manual methods conveys the information acquired through drawing. The operator, by visual comparison between the hand-sketched profile and those on printed catalogues with known classifications, assigns the analyzed sherd to a specific ceramic class. In the last years, however, with the aim to standardize many repeated tasks encountered during the recording of archaeological and ceramic data in an efficient framework and to support for classification and interpretation especially in post-excavation analyses, the Relational Databases Management Systems (RDBMS) have been proposed. The storage and retrieval of archaeological data within computer databases are actually becoming important requirements for modern archaeological research. The RDBMS, in particular, are increasingly being used in archaeology to register and to document archaeological excavations, including information that describe the historical, stratigraphic, urban and topographic context, with a focus on pottery.

By analyzing, particularly, the databases relative to finds' shape and morphology, which are currently present in the literature, it can be seen that they mostly contain the digitization of out-of-print fascicules ([4], http://www.beazley.ox.ac .uk / pottery / default.htm) or information obtained from qualified operators [5]. The databases built starting from 3D scanned archaeological fragments are still very few and rather limited in the variety of quantitative information, relative to dimensions and morphology, which can be extracted from discrete geometric models. In Pottery Informatics Query Database (PIQD), for example, the morphology of the ceramic vessel (captured both from 2D scans of illustrated ceramics profile and 3D acquisitions) is converted only in measurements of radii, tangent and curvature of its representative profile (longitudinal profile) as a function of arc-length [6].

The data structure proposed in [7] is richer and includes the following information:

- general layout (represented in the plane y-z, where z-axis coincides with the axis of symmetry of the fragment);
- overall form of the selected profile (containing information for further fragment classification, e.g., rim, foot, handles, distance measurements, volume estimation, maximum sector angle);
- graphical outputs (fragment rendering in linear, photorealistic or shaded modes);
- pottery symmetry and irregularities (evaluated respectively as distance between model points and axis or model points and the 3d object obtained by rotating the profile around the axis);
- 3D reconstruction (the 3d object obtained by rotating the profile around the axis);
- illustration exportation (archeological illustrations, 3D reconstruction).

There is not yet a common structure universally adopted by researchers for pottery database, but it is usually defined depending on the context and the archaeological site. Ceramic data are organized in small databases developed for individual analytical studies. The exchange of data among researchers is often difficult because of the use of commonly diverse database formats. In addition, the available databases store information that the methods, to which they refer, are able to extract automatically: the analysis of the literature currently shows that this information is mostly of a qualitative kind.

With a view to overcome these limitations, some important knowledge elements, used by the archeologists to study the ceramic materials, have been codified by implementing them in a new computer-based methodology [2]. Starting from a laser-scanned sherd, the methodology, automatically segments the geometrical and morphological features and, then, evaluates the most important dimensional features. In this paper, the information related to sherd's shape and dimensions are furtherly broadened, including:

- Segmentation of morphological features;
- Segmentation of axially-symmetric (or geometric) features;
- Identification of the fragment shape type;
- Evaluation of the longitudinal profile;
- Estimation of dimensional features.

To overcome the limitations of the existing computer databases, a new system is proposed to manage the large set of quantitative information that can be automatically extracted from the archaeological fragment.

II. SHORT DESCRIPTION OF THE METHODOLOGY

The main phases of the methodology, implemented to feed the 3D informative database proposed here, are depicted in the flow chart of figure 1. Starting from a real fragment, a skilled operator extracts by 3D laser scanning a discrete geometric description of the surface, in the form of a manifold triangular model. The automatic extraction of high-level information to store into the database requires the preliminary estimation of geometrical differential properties, such as normals (medial quadric method [8]) and principal curvatures (the 5-coefficients paraboloid fitting method [9]) at each vertex of the mesh. Since the surface geometry of a ceramic fragment is generally of axisymmetric type and the axis is an important *intrinsic reference* for this type of surfaces [10], another important pre-requisite, for the automatic extraction of knowledge elements from these high-density triangular models, is the axis preliminary identification. Since the quality of axis estimation affects the quality of the measurements, which will be performed, it is important to use a reliable algorithm to identify the axis of symmetry. Several methods for axis estimation can be implemented, which differ in the use of different geometric properties of the axisymmetric surface. In [11-17] the main implementations of these methodologies are reported. Unfortunately, the surface of an archaeological sherd is only approximately axisymmetric: it may include several features, referred to as *morphological features*, such as handles, decorations, inscriptions, lugs, feet and fractured surfaces that obviously are not axially symmetric. A preliminary recognition of the axially symmetric portion of the vessel/fragment surface is carried out here by identifying the widest portions of the surface characterized by a uniform sign of the mean curvature H. In this way, the widest convex and concave patches are coarsely recognized. A first axis is estimated from these portions by using by the thickness versor intersection-based method [14]. This estimation can be further improved by refining the axially symmetric patches identification. This refinement is performed based on a specific index d_i measuring the minimum distances between the normal lines and the estimated axis. Thanks to this distance, the *i-th* point is considered axially symmetric if d_i is lower than a threshold value. By a region growing algorithm connecting the adjacent axially-symmetric points, the archaeological fragment is segmented into an *axially symmetric* and a *non-axially symmetric portion*. Two kinds of features can be retrieved respectively from these surface portions: morphological features and geometric features.

A. Morphological Features Segmentation

The non-axially symmetric surface portion of a fragment may include several types of morphological features. A complete automatic segmentation of all these features is still not possible at present, although, for some types of these features, decisive steps have been taken.

Recently, Di Angelo et al. [19] proposed a new computer-based methodology suited to recognize automatically morphological features characterized by an approximately constant circular transverse section (such as embossed decorations). The methodology, by investigating the principal curvature maximum in absolute value at the points of discrete models, identified the nodes attributable to these features of constant radius. To overcome the limits of a recognition affected by uncertainties (i.e. high variability of the principal curvatures), the rule for the feature segmentation has been implemented by a fuzzy approach. Based on the subsequent dimensional analysis of these detail features of constant radius, some interesting indications on technologies used to manufacture them can be obtained. A first analysis of this type can be found in [20], where the tools used for manufacturing some decorative ribs, automatically segmented from the vessel surface by the afore-mentioned methodology, have been identified due to the repeatable track they leave.

B. Geometric Features Segmentation and Fragments shape type classification

Various geometrical features can be automatically recognized from the axially symmetric portion of a fragment, such as internal wall, external wall, rim and base. The segmentation of these features is based here on a suitable analysis of the differential geometrical properties of the mesh (further details are found in [2]). A new and original classification of different types of sherd can be carried out by the methodology, based on the geometrical features segmented and on the following parameters:

- N_{ep}: number of recognised extremal parts;
- N_{fs}: number of recognised fractured surfaces;
- C_{as}: completeness of the azimuthal span;
- g: invariant identifying the number of holes through the object;
- g': maximum number of holes of the fractured surface [21].

C. Features Dimensional Evaluation

The dimensional features, such as the maximum diameter of a convex part or the thickness of the wall of a fragment, are significant parameters used by archaeologists to achieve a more accurate classification of archaeological sherds. The evaluation of these features needs the preliminary estimation of the longitudinal profile of the fragment and its following segmentation into convex and concave portions. In order to reduce the uncertainty of this evaluation, the profile has to be previously subject to a smoothing operation, where the generic point is substituted with the nearest one taken from the parabola approximating the neighborhood of the original point of given width. The segmentation of the profile is carried out taking as driving parameter the shape index s_i [22].

The quality of the data obtained by the automatic dimensional characterization of the fragment depends mainly on the robustness of the methodology implemented for geometrical and morphological features segmentation. An investigation performed here on hundreds of sherds pointed out only few critical cases where the sherd is characterized by a little angular spanning or it is so damaged that the information concerning its geometry cannot be adequately retrieved.

III. IMPLEMENTATION OF THE PROPOSED 3D INFORMATION SYSTEM

The whole methodology for the segmentation of the features and the subsequent dimensional characterization has been coded in MATLAB®. The main phases of the methodology, which feeds the 3D informative database proposed here, are shown in the flow chart of figure 1.

The methodology, in particular, has been applied to 168 pottery's fragments, excavated on the Alba Fucens site (Italy). All the fragments, of different dimensions and characterized by weathered and damaged surfaces, were scanned by a 3D laser scanner (FARO Edge, 9 ft (2.7m)), where the single point repeatability was less than 0.064 mm. The average point spacing of the point cloud was set to 0.15 mm. The high-density point clouds have been processed by using a commercial software (Geomagic®) in order to obtain a manifold triangular model of the fragment. Figure 1, in particular, shows the processing results for one of these sherds. The repeatability and reproducibility in the evaluation of dimensional features have been already investigated and demonstrated in [2].

The 3D information framework proposed here to store the high-level data automatically extracted by the methodology is a relational database management system based on a series of tables linked to each other and to different files. In figure 2, the structure of the entire 3d information system and its tables and files are recapped.

A table, in particular, is associated to a set of sherds excavated in a given site and at a certain date. Each table is a collection of related data entries, broken up into fields. Each field is a column of the table that is designed to maintain specific information on: presence or absence of morphological and geometric features, fragment types and related file names. These files specifically pertain to: the 3D model of the fragment segmented into a set of features (each feature is identified both as a region of points and as a region of triangles), the longitudinal profile of the fragment described in cylindrical coordinates, the dimensional features and the thickness data expressed in terms of curvilinear abscissa along the profile. In order to ease the management of the 3D information system, a GUI has been also coded in MatLAB®, as shown in figure 1.

IV. CONCLUSIONS

Nowadays, the study and classification of large quantities

of ancient pottery are performed by the traditional method. Consequently, the information about shape and morphology are uncertain and incomplete, because only a portion of the sherds found in a site is fully studied.
In this paper, the highlights of a new methodology, aimed at extracting automatically a large set of quantitative information from discrete models of archaeological sherds, are reported together with the management system of all the gathered information. The main functionalities of the 3D information system have been tested in storage of data obtained analyzing 168 ancient Roman archaeological sherds, excavated on the Alba Fucens site (Italy).
Future efforts will be addressed to the extension of information that can be extracted from the finds, such as the characterization of the color of the fragment. Furthermore, specifically designed queries will be implemented to support a new automatic procedure for the pottery classification and reconstruction of ancient ceramics. This operation is currently performed manually by the operator with a trial and error strategy among wide sets of candidates. It is therefore a complex procedure both for fragments amount that has to be tested and for the possible lacks of pieces. The 3D information system proposed here can be interrogated to group the fragments recognized as similar based on size and/or morphological similarity of the longitudinal profile.

REFERENCES

[1] Martinez Carrillo A. L.: Computer Application in Archaeological Pottery: a Review and New Perspective. In: On the Road to Reconstructing the Past. Proceeding of the 36th Computer Application and Quantitative Method in Archaeology Conference. Budapest April 2-6 2008, pp. 397-401.

[2] Di Angelo, L., Di Stefano, P., & Pane, C. (2017). Automatic dimensional characterisation of pottery. Journal of Cultural Heritage.

[3] Politis, D., & Politis, D. (2008). E-learning methodologies and computer applications in archaeology. Information Science Reference.

[4] Anichini, F., Fabiani, F., Gattiglia, G., & Gualandi, M. L. (2012). A database for archaeological data recording and analysis. MapPapers. 1en-II, 21-38.

[5] Verga, F., and F. Fabbri. "Un approccio globale, archeologico, archeometrico, informatico, alla schedatura della ceramica a vernice nera della Valle del Tevere." Archeologia e Calcolatori 22 (2011): 51-65.

[6] Smith, N. G., Karasik, A., Narayanan, T., Olson, E. S., Smilansky, U., & Levy, T. E. (2014). The pottery informatics query database: A new method for mathematic and quantitative analyses of large regional ceramic datasets. Journal of Archaeological Method and Theory, 21(1), 212-250.

[7] J. Wilczek, F. Monna, A. Jébrane, C.L. Chazal, N. Navarro, S. Couette, C.C. Smith: Computer-Assisted Orientation and Drawing of Archaeological Pottery. Journal on Computing and Cultural Heritage (JOCCH), 11(4), 22 (2018).

[8] Di Angelo L., Di Stefano P., “Experimental comparison of methods for differential geometric properties evaluation in triangular meshes”. Computer – Aided Design and Applications, vol. 8 (2), 2011, p. 193-210, ISSN: 1686-4360.

[9] Di Angelo L., Di Stefano P., Morabito A., Secondary features segmentation from high-density tessellated surfaces. International Journal on Interactive Design and Manufacturing, 12 (3), pp. 801-809. (2018).

[10] L. Di Angelo, P. Di Stefano, A.E. Morabito, The RGM data structure: A nominal interpretation of an acquired high point density model for automatic tolerance inspection (2012). International Journal of Production Research, 50 (12), pp. 3416-3433.

[11] Pottmann H, Peternell M, Ravani B. An introduction to line geometry with applications. Computer Aided Design 1999;31:13–6.

[12] Y. Cao , D. Mumford, Geometric structure estimation of axially symmetric pots from small fragments, Signal Processing, Pattern Recognition, and Applications, IASTED International Conference, 2002 .

[13] L. Di Angelo, P. Di Stefano, A.E. Morabito, A robust method for axis identification, Precision Engineering, 39 (2015) 194–203.

[14] L. Di Angelo, P. Di Stefano, Axis estimation of thin-walled axially symmetric solids 2018. Pattern Recognition Letters, 106, pp. 47-52.

[15] Halir R. An automatic estimation of the axis of rotation of fragments of archaeological pottery: a multi-step model-based approach. In: Proceedings of the seventh international conference in central Europe on computer graphics. Visualization and interactive digital media (WSCG’99). 1999.

[16] Lao YZ, Leong HW, Preparata FP, Singh G. Accurate cylindricity evaluation with axis-estimation preprocessing. Precis Eng 2003; 27:429–37

[17] Han D, Hahn HS. Axis estimation and grouping of rotationally symmetric object segments. Pattern Recogn 2014;47(1):296–312.

[18] Di Angelo, L., Di Stefano, P., Morabito, A.E., 2014. Comparison of methods for axis detection of high-density acquired axially-symmetric surfaces. International Journal on Interactive Design and Manufacturing (IJIDeM) 8, 199–208.

[19] Di Angelo, L., Di Stefano, P., Morabito, A.E., Pane, C. Constant radius geometric features segmentation in archeological pottery, (2019) IMEKO International Conference on Metrology for Archaeology and Cultural Heritage, MetroArchaeo 2017, pp. 69-74.

[20] Di Angelo, L., Di Stefano, P., Morabito, A.E., Pane, C. Measurement of constant radius geometric

features in archaeological pottery (2018) Measurement: Journal of the International Measurement Confederation, 124, pp. 138-146.
[21] Di Angelo, L., Di Stefano, P., Pane, C. An automatic method for pottery fragments analysis (2018) Measurement: Journal of the International Measurement Confederation, 128, pp. 138-148.
[22] J.J. Koenderink, A.J. Van Doorn, Surface shape and curvature scales, Image and vision computing 10 (1992) 557–564].

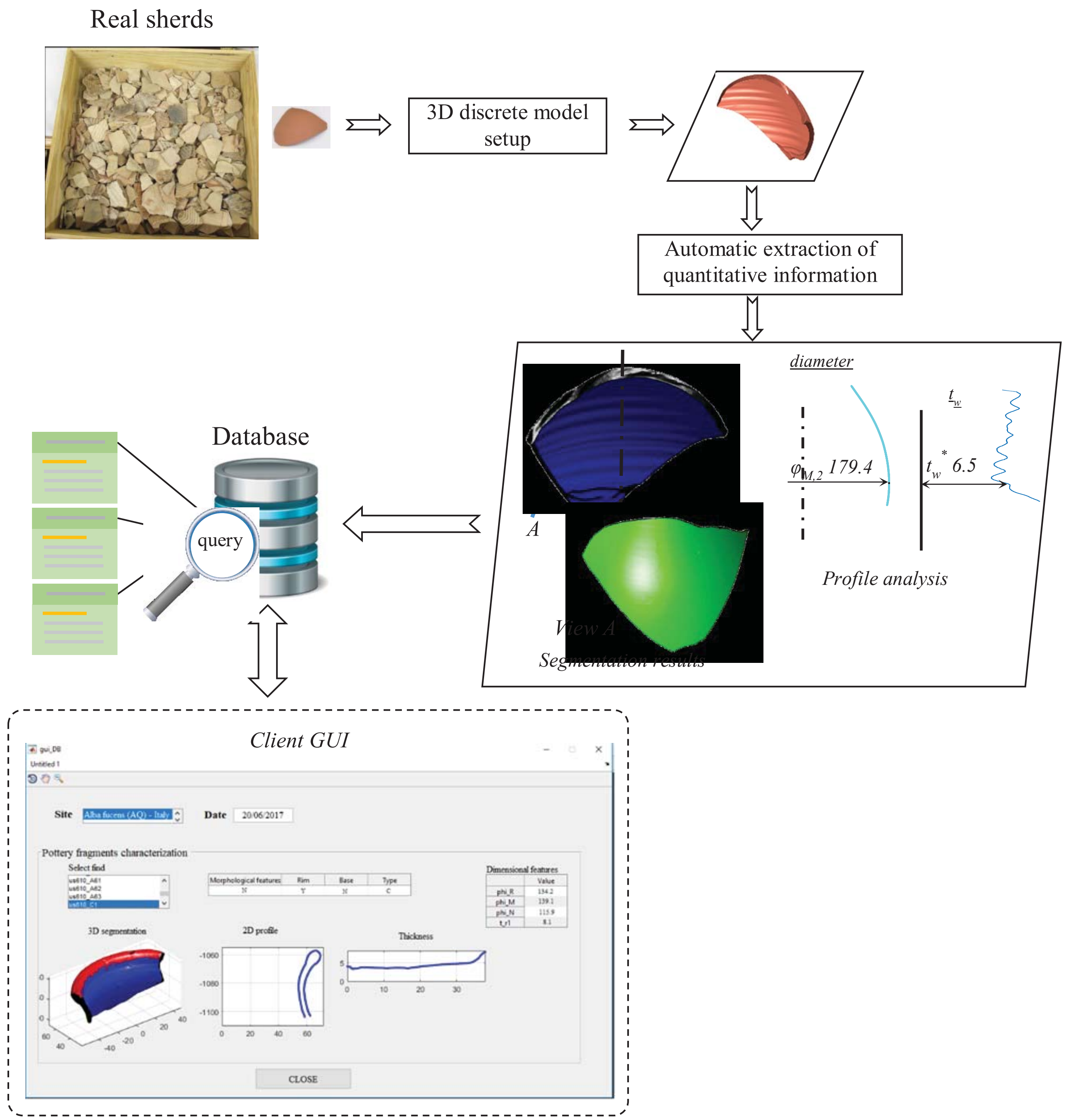

Figure 1. The flow-chart of the proposed methodology

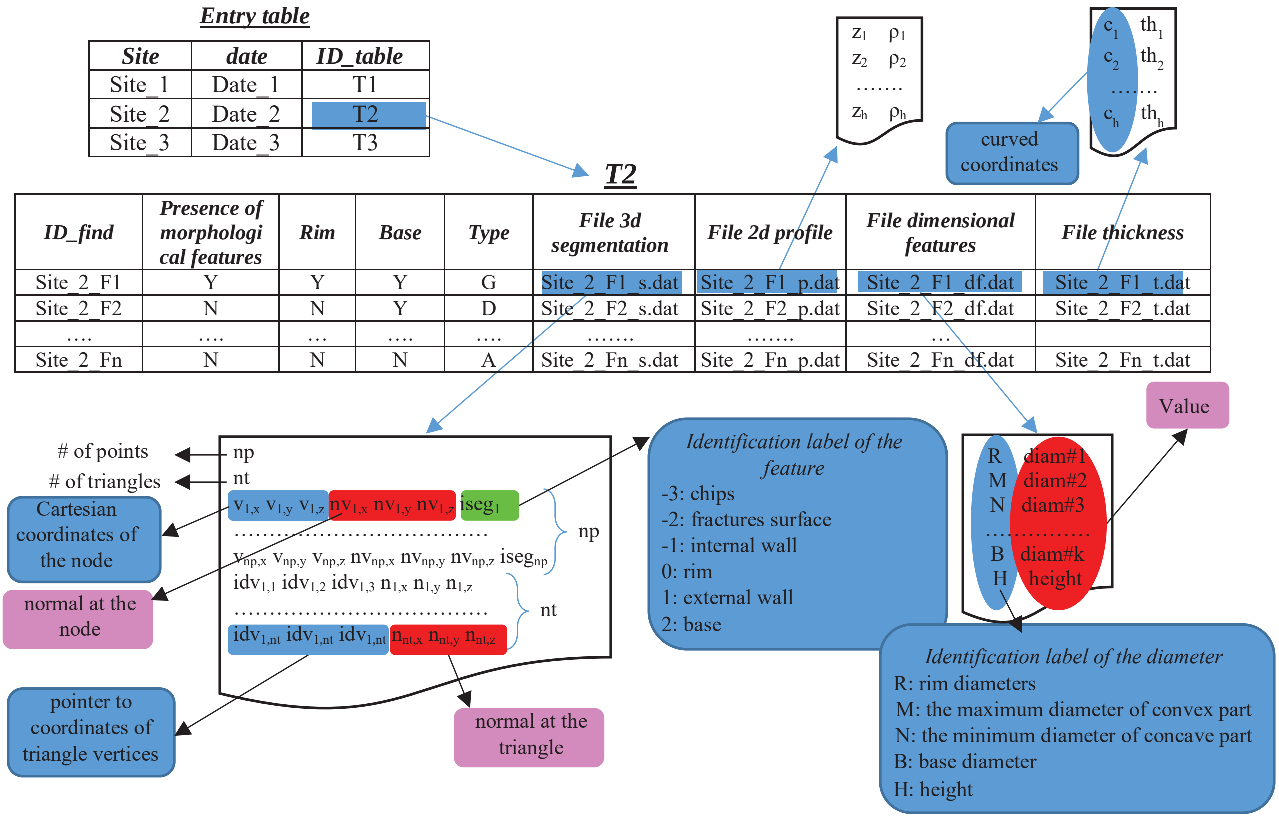

Fig. 2. The structure of the proposed 3d information system