3D acquisition and modeling for flint artefacts analysis

B. Loriot[a], Y. Fougerolle[a], C. Sestier[b], R.Seulin[a]
[a]Le2i Laboratory,12 rue de la fonderie, Le Creusot, FRANCE,
{b.loriot | y.fougerolle | r.seulin}@u-bourgogne.fr
[b]UMR-CNRS 5594, 9 Boulevard Gabriel, Dijon, FRANCE, sestier.flint@wanadoo.fr

ABSTRACT

In this paper, we are interested in accurate acquisition and modeling of flint artefacts. Archaeologists needs accurate geometry measurements to refine their understanding of the flint artefacts manufacturing process. Current techniques require several operations. First, a copy of a flint artefact is reproduced. The copy is then sliced. A picture is taken for each slice. Eventually, geometric information is manually determined from the pictures. Such a technique is very time consuming, and the processing applied to the original, as well as the reproduced object, induces several measurement errors (prototyping approximations, slicing, image acquisition, and measurement). By using 3D scanners, we significantly reduce the number of operations related to data acquisition and completely suppress the prototyping step to obtain an accurate 3D model. The 3D models are segmented into sliced parts that are then analyzed. Each slice is then automatically fitted by mathematical representation. Such a representation offers several interesting properties: geometric features can be characterized (e.g. shapes, curvature, sharp edges, etc), and a shape of the original piece of stone can be extrapolated. The contributions of this paper are an acquisition technique using 3D scanners that strongly reduces human intervention, acquisition time and measurement errors, and the representation of flint artefacts as mathematical 2D sections that enable accurate analysis.

Keywords: 3D acquisition, mathematical analysis, flint, archeology, 3d segmentation

1. INTRODUCTION

1.1 A way for understanding past human groups and their activities.

One of the main methods of production of tools by the prehistoric man is fracturing rocks like flint or material with similar properties. Fine grained, homogeneous and brittle rocks are selected for this purpose. Flint, a sedimentary material composed of microcrystalline and amorphous silica has been widely used worldwide [1], both for its availability (cretaceous sedimentary rocks yield huge amount of flint all around the world) and for its mechanical properties. Flint has a Mohs hardness around 7 and gives sharp cutting edges once fracturated. Contrasting with its hardness, its brittle properties makes fracturation easy to obtain by applying a shock or a pressure.

According to the modern school of archaeologists mainly rooted in French studies [2], the process of flintknapping is described as techniques and methods. Technique is related to the way by which fracturation of the flint is obtained (basic mechanism of fracturation may be described in term of "solid mechanics" [3]). Method of flintknapping refers to the sequence organization (organization in the time and a volume of the sequence) leading to a specific result.

1.2 How to study this "past knowledge" ?

This archaic (but complex) handcraft definitively disappeared at the onset of historical times. Briefly, manufacturing of rifle's-stone was still in use at the beginning of the 19th century and helped for the first understanding of past flintknapping techniques. Native American population still used flintknapping while ethnographers used the first cameras to immortalize them. Obsidian blade-making was still in use during the 14-15ième century when European Conquistadores destroyed the Maya civilization [4].

As a consequence, the modern art of flintknapping is a reconstructed knowledge.

Despite the fact that general principles of flintknapping are partly explainable by physical principles [3] and thus may be modelized by using modern tool of intensive calculus, such tools are not actually used in this field mainly due to their financial cost.

Experimental work (eg. Reproduction of flint objects and comparative study for testing hypothesis) in fact remains the obligate way to understand how tools were manufactured and used. Reproducing the process of use wear [5] and resharpening processes of the cutting edge is the way to mimic the production, use and consumption of prehistoric tools.

1.3 Production, use and consumption of flint blades :

This study has been carried out on flint blades. This object is an elongated flake of which the length is twice larger than the width. Section is roughly triangular or prismatic, and the blade is slightly curved along its long axis

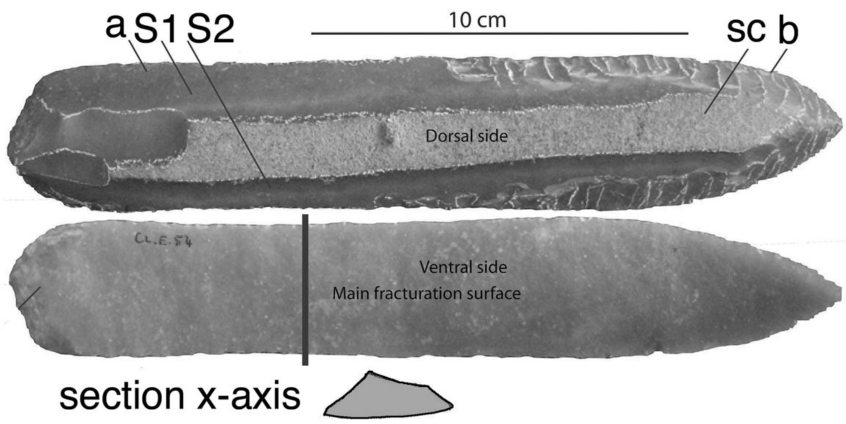


Fig.1 : A neolithic dagger made on a flint blade. A: unmodified side and natural cutting edge. S1 and S2 : negative of the fracturation surface leaved by detachment of previous blades. B: retouched edge (retouch is white underligned,for a shake of visibility). D=dorsal side, V=ventral side, positive main fracturation surface.

Production of blades requires elaborate strategies that allow to obtain a serial production : each blade leaves the flint core quite unmodified, allowing the process to be repeated again [6, 7].

Various techniques and methods were developed during the prehistoric period. Such production took place in Europe between IVth and IIIth millenary BC, sustaining both the development of commercial networks and the systematic and well organized exploitation of flint good quality [8].

The standardization of the laminar products thus makes them very useful to meet some specific needs such as long and linear cutting edge. For example, sickles or tribulum (plat-processing tools) are composed with segmented flint blades easy to replace [9] without modifying the hafting system, due to the standardized shape of the blades.

The blades we are referring to in this work were produced in the Grand-Pressigny area (Indre-et-Loire, France) during the late neolithic between 3200 and 2400 cal. BC. They are made out of a very specific flint (Upper Turonian). While some exceptional products were kept out the commercial flux (mainly as untransformed blades, [10]), the vast majority of the production was retouched to provide "daggers" (fig1), a term referring to the shape but not to the function. Implements were exported over the north eastern of Europe [11, 12, 13], and their initial shape showed progressive modifications which is subjected to our investigations.

1.4 Shape modification of flint implements, rejuvenation of the cutting edge

The shape of the flint "daggers" is initially standardized, and the gradual modification of their shape may be explained by sequential rejuvenation of the cutting edge, a process well described for all kinds of flint implements [14, 15]. Use wear studies of some of these flint "daggers" showed that they were mainly used for processing vegetal material [16, 17], probably explaining the need for a sharp cutting edge and its renewal by retouch.

1.5 Re-Building the initial shape of the flint blade

An important scientific goal for studying shape modification of these implements (due to cycles of rejuvenation of the cutting edge) is to know the actual shape of the blade before being transformed in dagger. Precise characterization of the blade's shape may also give significant informations on the method used production (each method of production may give have some characteristic signatures).

A geometrical modeling of the surfaces of the blade is thus necessary to obtain a three-dimensional reconstruction of the volume. Preliminary tests were first carried out on transversal sections of blades (2D section). Modeling of the 3D surface was further obtained with the aid of optical scanning and numeric modeling.

2. FLINT ARTEFACTS, SCANNING ISSUES

Flint implements : segment of blades (retouched or not) were found on "sites" in the area of Grand Pressigny (Indre-et-Loire, 37, France). Long blades were also produced using indirect percussion and dynamic immobilization of the core [18, 19, 20] and with the same flint (Upper turonian flint)

The fracturation of a homogeneous flint produces a regular surface : the initial portion of the fracture has an elongated conical shape (derived from a Hertz cone), which gradually transform into a quasi plane surface. Typically, the dorsal side of a flint blade is shaped by the intersection of two or three regular curves (portion of the negatives surfaces leaved by the detachment of previous blades). The ventral side is also regularly curved, the fracturation surface is complete. This fact suggests that modelization of this volume may be quite easy.

2.1 Is flint surface's fracturation generated by "simple" curves ?

The contour line of the section of a flint blade (retouched or not, N=75) was manually fitted with segments of different families of curves (polynomial and conical surfaces). This was done by using a commercial Software (Adobe Photoshop®). Preliminary results showed that best fit was obtained by using segment of elliptic curve. Fig.2 shows a typical example of this. Moreover, true reconstruction of missing parts (where 50% of the initial section is "lost") shows typical error of 8-10% in the estimated width of the section (ws), a result which would allow the reconstruction of the initial shape of neolithic daggers.

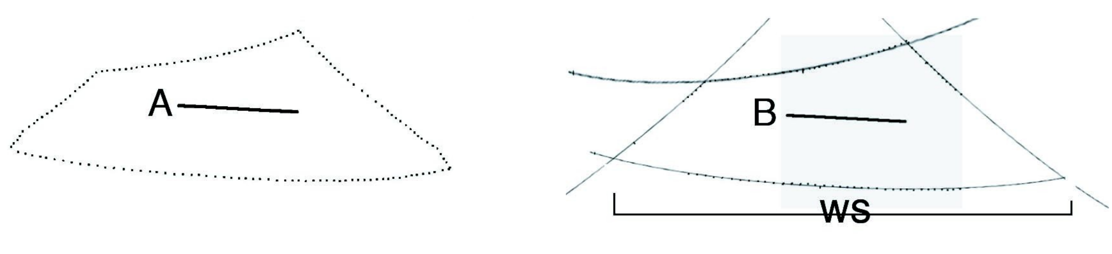


Fig.2. A : contour plot of the transversal section of a flint blade (Fig.1). B : fitting contour plot with elliptic curve segments.

2.2 From 2D to 3D reconstruction

3D modeling of complex shapes is obtained by two different strategies. The firsts involve shape decomposition and reconstruction by using algorithms containing no implicit hypothesis about the nature of the shape. Another way is to obtain a reconstruction driven by strong hypothesis about the shape and its true geometric nature. In our case, the fact that 2D reconstruction of section works well with segment of elliptic curves probably has a great signification. This result ultimately helps in the choice of algorithms or mathematical models to exploit rough data obtained after 3D optical scanning of flint blades or flakes.

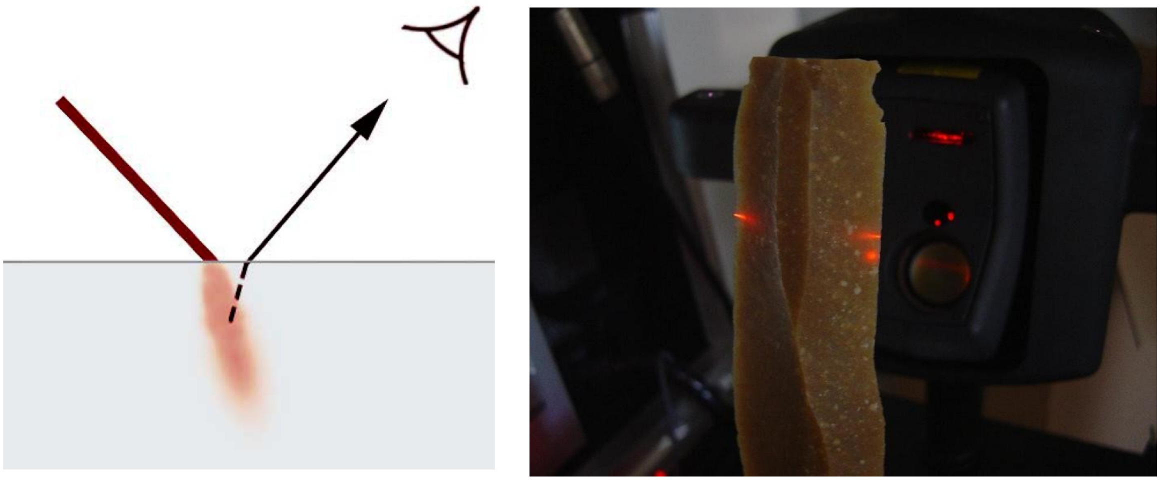
The first step is to test the efficiency of 3D optical methods for scanning flint [21]. In a first approximation, flints artefacts present an optically cooperative surface: light-colored, diffuse (mostly), and with a consistent minimum feature size imposed by the strength of the material. As such, their shape can be digitized using a variety of noncontact rangefinding technologies including photogrammetry and structured-light triangulation.

One of the most important scanning issues is the low thickness of flints artefacts. Most of scanners need several views from different positions to construct a complete 3D model. Each 3D view is acquired in a different coordinate system and must be registered to obtain the final 3D object. Several registration algorithms have been proposed in literature, such as ICP [22], or more elaborate techniques using Gaussian fields [23]. Unfortunately, for fine and sharp objects such as flint artefacts, ICP algorithm does not provide good results because the faces of the object are too close, almost parallel, and may sometimes be considered as the same face, and Gaussian fields techniques are not yet available in commercial products.

Fortunately, some handheld scanners with portable CMM allow working in one coordinate system, which avoids complex registration and merge algorithms. Two systems of acquisition are available to the laboratory :

- a system KScan, manufactured by Metris: a handheld scanning solution combined with the LC50 scanner and the K610 optical portable CMM
- a articulating arm INFINITE (CimCore) with the MMZ scanner from 3dScanner

The goal is to quickly and accurately capture the shape and the dimensions of the flint artefacts. We are more especially interested into the detection of marks of blows. We decided to use Kscan system because its resolution and field of view are more adapted to flint artefacts acquisition. This system has a width of view of 50mm, a depth of view of 50mm and a stand off distance of 70mm.



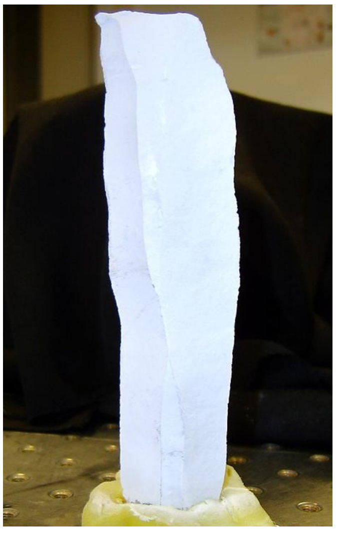
(a) (b)

Fig. 3. Dispersion of the laser beam, (a) volume of scattered light in sharp edges (b) Photograph of a flint artifact in the course of 3D acquisition

2.3 How optically cooperative is flint artefact?

Although flints are light-colored and usually diffuse, their sharp edges are extremely fine, which involves an important dispersion effect of the laser beam crossing the surface. Figure 3 shows the interaction of a laser beam with a flint artefact : Figure 3a) illustrates the physical phenomenon and Figure 3b) illustrates that the material is very translucent. Such a subsurface scattering effects has one major implication: it strongly degrades the quality of our range data, especially near sharp edges.

When a laser beam crosses a sharp edge, it creates a volume of scattered light, whose apparent centroid is below the flint surface, as shown in Figure 3a), which has two effects. First, the reflected spot seen by the range camera is shifted away from the laser source. Since most laser triangulation scanners operate by detecting the center of this spot, the shift causes a systematic bias in derived depth. The magnitude of this bias depends on angle of incidence, angle of view and laser power. To solve this problem, flints artefacts are covered by a fine layer of white powder as illustrated on Figure 4.



(a)

(b)

Fig. 4. Flint artefact with and without powder. (a) powdered flint, b) genuine flint)

2.4 Scanning procedure and post-processing

With KScan scanner, scanning procedure is rather simple. Flint artefacts are positioned vertically, so that their largest two faces are quite visible. Nevertheless, a second position is necessary to scan the bottom of the flint artefact. To increase accuracy, each face is scanned several times in a cross way, as illustrated on Figure 5.

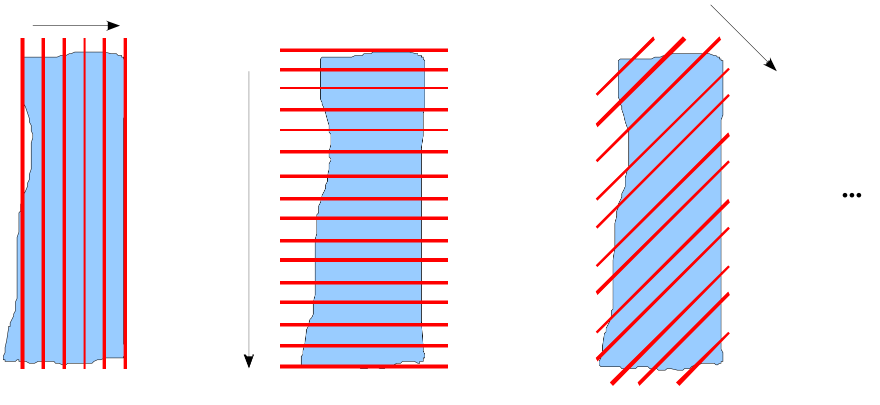


Fig. 5. Scanning directions of flint artifacts, in a cross away

We obtain two point clouds that are filtered to remove incorrectly measured vertices and to reduce the number of vertices due to large overlap (redundancy). Then, the point clouds are triangulated to obtain a 3D mesh. 3D models are manually cleaned to remove abnormals faces (non-manifold faces, crossing faces, spikes ...). Eventually, the 3D meshes are registered and merged to form the final 3D model as illustrated on Figure 6.

Fig. 6. Final 3D model of a flint artefact

3. DATA ANALYSIS

The main data preprocessing presented in this paper concerns 3D segmentation. There exist several 3D segmentation algorithms [24, 25], but most of them are rather difficult to implement or require complex computations that are not necessary in our case. A recent comparative study of 3D segmentation techniques has been presented in [26]. For our current needs, a manual segmentation is acceptable and provide us a ground truth. We focus in this section on simple and efficient methods to automate the segmentation process.

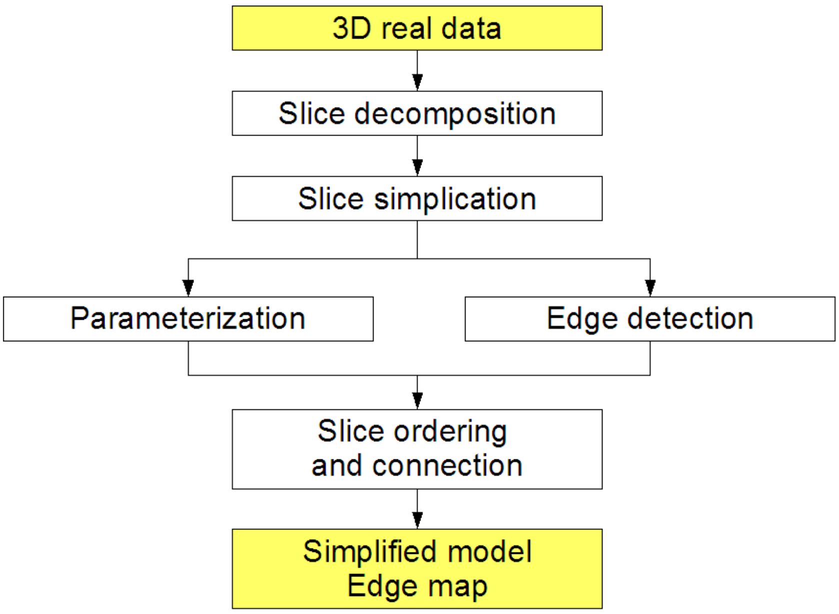


Fig 7. Flint artefact processing pipeline

We are especially interested into detecting the sharp edges of the flints in order to, in future work, represent the flint faces by mathematical representations such as Bézier surfaces, conics, or more elaborate primitives such as superquadrics or Gielis surfaces. Such mathematical representations will allow for fast and efficient volume computations that are critical to determine the way the flints had been manufactured. Furthermore, we want the data processing to stay as similar as possible from the manual approach previously used, *i.e.* we want to conserve an analysis of 2D slices of the virtual object. Additionally, due to their simple shape, we can parameterize the 3D models to obtain simplified, still accurate, 3D models of the flint artifacts that are going to be used for accelerating and automating the segmentation process. The whole processing pipeline is presented in Figure 7.

In the following sections, we explain in details each of the pipeline operation.

3.1 Slice decomposition

Data obtained from 3D scanner are dense, may sometime be noisy, may contain cracks or present ill-defined or degenerated faces, even after a manual data cleaning using dedicated 3D softwares. It is important to keep in mind that another objective of this work is to strongly reduce human intervention during acquisition, data cleaning and preprocessing, and measurements. Furthermore, as previously mentioned, we also want to keep the analysis as similar as possible from the one previously used. Therefore, for a width noted w, slice decomposition allows us to express part of the original 3D data as a cloud of points, to evacuate incorrect topological information (wrong faces, non triangular faces, etc), thus to reduce the data to geometric information, as illustrated in Figure 8. The points within a given slice (in blue on Figure 9 are then projected onto the average plane to obtain a 2D cloud of points (in red).

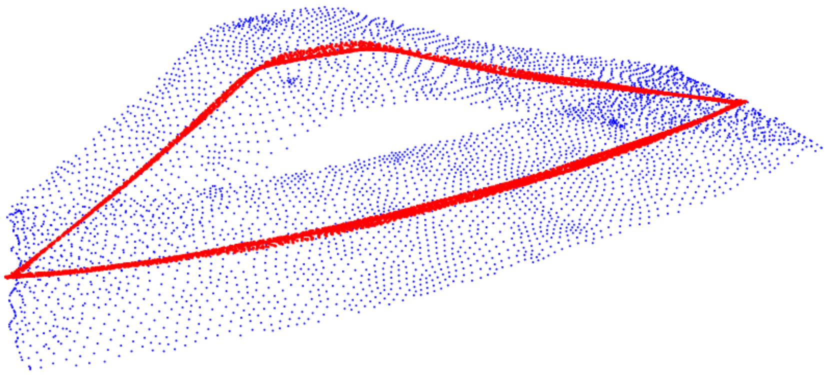


Fig. 8. Slice Decomposition : vertices within a slice of width w are projected onto its average plane. In blue : orginal data. In red, projected points.

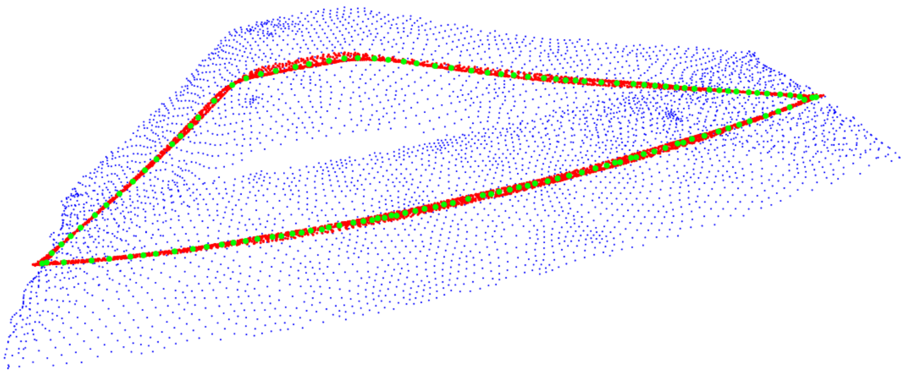


Fig. 9. Epsilon simplification. In green : new points representing the red dots of the projected slice

3.2 Slice simplification

Once the 3D points are projected onto a slice average plane, the problem becomes a simpler 2D problem. The next processing step is a simplification step : the points that belong to a same ε-ball are replaced by their center of mass, as illustrates Figure 9 (in our example, ε=0.5 mm). Notice the new points representing the data are accurately positioned over the real original surface

3.3 Parameterization and edge detection

Among the several parameterizations available, one of the most simple and adapted is the angular parameterization. The dots representing a slice are expressed in polar coordinates and are ordered according to their angular values. Once the dots are ordered, the angle at a point can be directly evaluated using the dot product of the vectors of its 1-neighborhood (or weighted dot products of its k-neighborhood to reduce noise influence if needed).

As a final result, we obtain a simplified mesh, with a 2D parameterization, and associated angle values for each 3D point. Figure 10 illustrates the result of the processing. In blue are the simplified 3D points and in red the 3D points labeled as sharp corners.

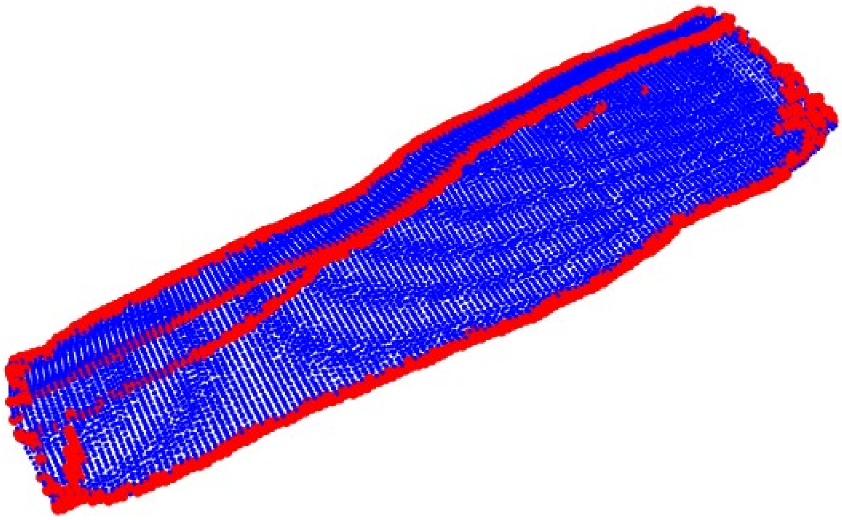


Fig. 10. Final result after slice reduction, data simplification, parameterization and edge detection. In red the points labeled as edge points

3.4 Discussion

Fracturation of flint produces a regular surface whose shape is mainly described by an ellipsoïd. Other family of curves have been tested and fit was not so good (polynomial regression was tested, best result was obtained for a second order polynomials. Ultimately an elliptic fit (a second order polynom both of x and y) of the section appeared to approach a correct numerical model. This observation may be explained by the fact fracture initiation is a portion of cone (a Hertz cône, [27],) that quickly transforms into a slightly curved surface. This surface must be described by a conical section, e.g. an ellipsoïd. Fitting surfaces by ellipsoïd may also be tested after optical scanning.

To obtain our results, we have used several properties of flints artefacts and made few assumptions that need to be discussed. The slice decomposition provides an accurate result as long as the slice width w is not too important. As an example, for the result presented in Figure 10, w=1 mm. Angular parameterization may be replaced by curviline absciss parameterization or more complex methods. Actually, angular parameterization works well in our case because, sharp edges on the border are efficiently detected, even with rough approximation, and the ones on the top of the flint benefit of a finer sampling, which allows for finer analysis in this area.

Nevertheless, there is still room for improvement, on the top right part of the flint, on Figure 10, one can see an edge is very partially detected. This comes from the several the angular threshold used to detect edges : there is a natural trade-off between localization and accuracy. Additionally, in the bottom the left and the top right, several edge points are detected. These points correspond to breaches in the real model

4. CONCLUSION

In this paper, an approach to obtain 3D model of flints with handled scanner was presented. Flint artefacts present an optically cooperative surface except for the sharp edges. With a fine layer of white powder, this problem is solve.

First results with 2D section suggest that blade's section may be accurately described by elliptic curves, leading to the hypothesis that its volume may be generated by intersecting ellipsoid surfaces. Thus real objects (flint blades) are irregular, this fact may be very helpful in constraining the numerical model used for the volume reconstruction and we suggests that this may help in solving the problems encountered at the sharp edges of the flint.

Geometric modeling of blade-derived objects are a good way to allow a virtual reconstruction of missing parts. Tests done with 2D section are very promising.

Reconstruction of missing volumes of a retouched flint blade is the first step to built-up a genetic typology (28) of such implements. True quantification of the degree of rejuvenation of retouched neolithic flint implements opens the way to study economic habits over territories. Such work take place in the study of emerging political and economic systems of neolithic groups (29), and the study of their side-effects on environment.

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