

# A Case Study of Reverse Engineering Integrated in an Automated Design Process

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**Abstract.** This paper presents a design methodology which automates the generation of curves extracted from the point clouds that have been obtained by digitizing the physical objects. The methodology is described on a product belonging to the industry of consumables, respectively a footwear type product that has a complex shape with many curves. The final result is the automated generation of wrapping curves, surfaces and solids according to the characteristics of the customer's foot, and to the preferences for the chosen model, which leads to the development of customized products.

## 1. Introduction

It is well known that the current trends on the product markets refer to shortening the launch cycle of products on the market [1]. This cycle takes into account the conceiving, designing, prototyping and manufacturing of the product. Nevertheless, if the aim is to develop new products starting only from the physical model, new technologies allow major flexibility and bring high profits. Despite the fact that in the beginning, the Reverse Engineering (RE) technique has not been considered a time saving technology that could shorten the time before the output of new products [1] on the market, it has gradually been proved to be an extremely useful connection between designing and manufacturing [2]. The RE technique can be used in the product quality evaluation process or in the redesigning process of products for which no documentation is available [2].

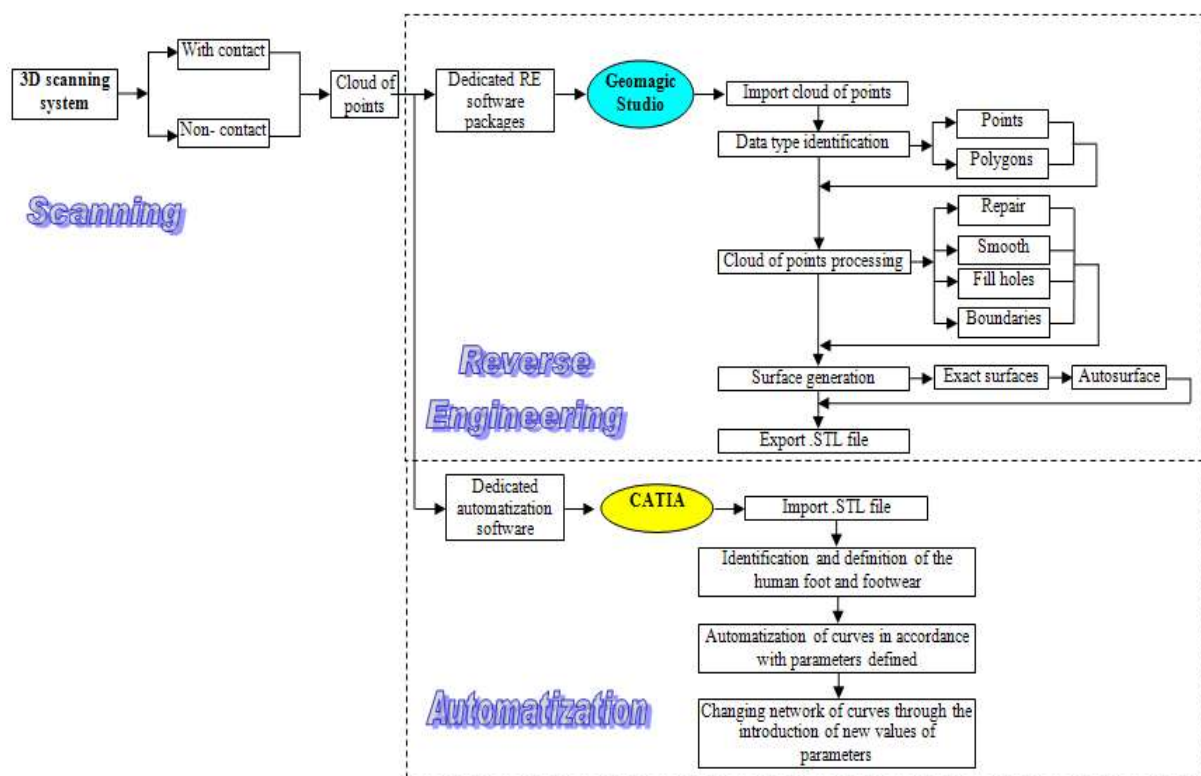
The development of the product digitization technology has led to the emergence of a various range of 3D scanners. Scanners have been divided in two categories: with contact or without (non-contact) [3]. The choice of the scanner type is made according to the object surfaces; a scanner that has contact is thus preferred for surfaces that contain edges, spikes or holes, while scanners without contact are chosen for surfaces that contain details. However, the scanners without contact have proved to be more useful due to their portability, high speed of data capturing and high precision.

The variety of shapes in the point clouds obtained from the scanning process, led to the emergence and development of dedicated RE software systems such as: Geomagic [4], Rapid Form [5], CATIA [6] and so on. These software systems allow the conversion of point clouds into parametric surfaces by taking into account the following steps: processing the point clouds, designing the curves and generating the surfaces.

However, the parametric surface obtained by means of dedicated RE software systems represent “a lot of patches” [7] which is the virtual model of the physical product, a model that is frozen [8], that



does not allow their automatic modification. Even if the generation of curves/surfaces over point cloud is performed automatically, using the dedicated functions, the development of a customized model cannot be implicitly performed [9]. In terms of designing, a customized model actually means a product which automatically updates once the parameters have been established at the beginning, thus leading to create a model entirely adapted to the customer needs. In order to outline the customized products the authors have used [10] the RE technique for assemblies that contain parts with simple configuration. Based on customer needs have developed a series of algorithms to automate the creation of products dedicated to human [11].



**Figure 1.** Stages of design methodology

The design methodology proposed by the authors (figure 1) starts with the specific stages of RE technique, namely: digitization of the product, processing the point clouds, conceiving of the curves over the finished point cloud. Its originality consists in the curves automation by introducing the parameters corresponding to the human component and to the product. These parameters stand at the basis of defining the characteristic points of the product and they allow the creation of new curves. All these curves will be entirely parametric, but above all they will be customized. The paper presents how the methodology is used for a complex customizable product.

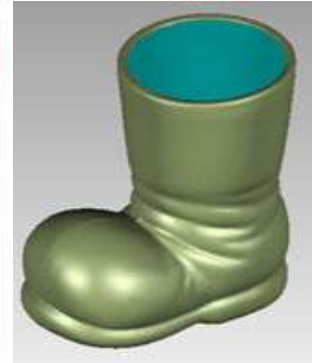
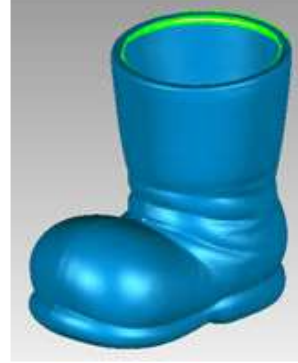
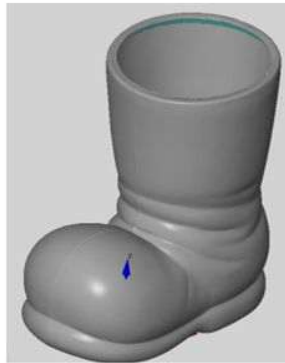
## 2. Data Acquisition

The digitization stage of the product was achieved using a solution from Steinbichler Company with the non - contact scanner named COMET L3D with blue light [12].

The dedicated software package of this scanner is Comet Plus and it provides a series of specific tools for object digitization, alignment the point clouds, processing the point clouds, creating and editing of the mesh. The result of scanning process (figure 2) is a file in STL format.

### 3. Processing of Cloud Points

The Geomagic Studio software dedicated to the RE technique is used to process the point cloud. Firstly, in order to obtain a quality of the point cloud, the types of data that make it up have to be identified [13]: ordered points, unordered points or polygons. In this case the point cloud consists of polygons (figure 3). In order to achieve a high quality mesh, the point cloud is being analyzed (e.g. non-manifold edges, self-intersections, highly creased edges, spikes, small tunnels, and small holes) and the issues occurring during the object scanning are removed.

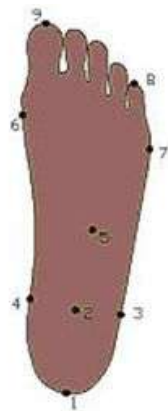


**Figure 2.** COMET L3D and scanning result. **Figure 3.** Default cloud of points. **Figure 4.** Patch surfaces

Decimation (reducing the number of polygons) is performed in order to facilitate working with point cloud. The following operations: cleaning the disconnected triangles of point cloud, noise reductions, spike removal, filling of holes, are done automatically, using the predefined functions. If the result of the cleaning operations and the editing of point cloud are satisfactory, the type patch surfaces are performed (figure 4). The obtained result is saved using the STL extension in order to import them into the CATIA environment.

### 4. Automated Product Design

The idea of automating the resulted curves over the point cloud is the first step to be taken in order to obtain customized products. This stage can be done in CAD environment such as CATIA, PRO-Engineer, Solid WORKS, by means of dedicated tools. The CATIA software package contains these specific tools in the Shape module [14].



**Figure 5.** Anthropometric points of human foot [15]

**Table 1.** Anatomical points of human foot.

<i>Point name</i>	<i>Number of point</i>
Anterior ankle point	1
Heel centre	2
Center of lateral malleolus	3
Center of medial malleolus	4
Bending point of foot	5
1st Metatarsophalangeal Joint	6
5th Metatarsophalangeal Joint	7
Extreme anterior point of the 5th toe	8
Extreme anterior point of the foot	9

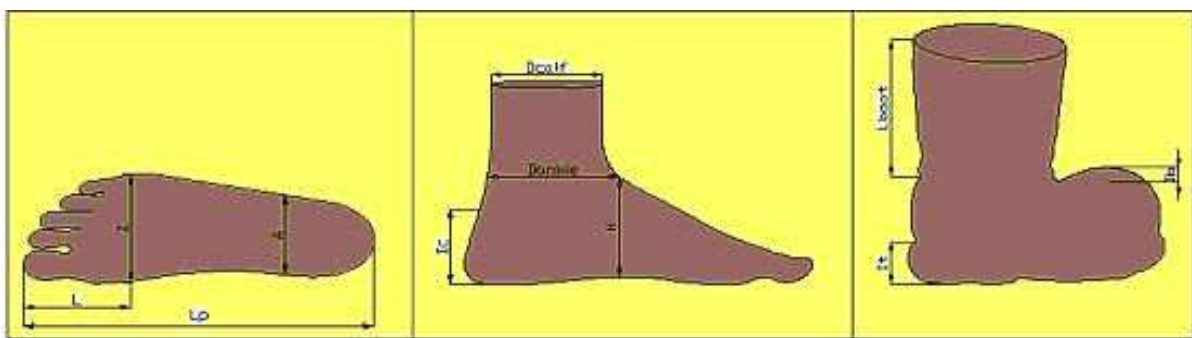
The tools of the Digitized Shape Editor toolbar allow the creation of sections (in blue on the point cloud) and curves (in white on the point cloud). Both sections and curves can be achieved by means of automatic and/or manual method. The sections are generally obtained by intersecting the point cloud with working planes, while the curves emphasize details of the object.

Firstly, before obtaining the sections over the point cloud, the working planes must be defined using the functions on the Wireframe and Design toolbar. These tools allow the defining of points, lines, working plans, circles, spline curves, projection of points on the curves, intersection of curves, using various methods.

#### 4.1. Human Foot Parameters

The anthropometry applied in shoe industry targets the measuring of the human foot dimensions. The dimensions are measured between landmarks known as anthropometrical points or characteristic points of the human foot [15].

In figure 5 and table 1 [16] are presented the anthropometrical points needed to define the main dimensions used to characterize the human foot, respectively for designing the footwear. The parameters of the human foot have been defined in accordance with the anthropometrical points shown in figure 6 and table 2.



**Figure 6.** Parameters of human foot and of boot

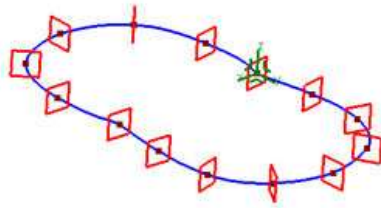
**Table 2.** Characteristic parameters of human foot and of product

<i>Parameters of human foot</i>
A – specific length for narrowing of foot
<b>Lp</b> –length of foot
Z – specific length for width of foot
L –length from top of foot up to section where width of foot is known
<b>H</b> –height of foot
<b>Ic</b> –height of heel of foot
<b>Dankle</b> –diameter specific for ankle of foot
<b>Dcalf</b> –diameter specific for calf of foot
<i>Parameters of product</i>
<b>It</b> –height of boot heel
<b>Ib</b> –height of boot toe cap
<b>Lboot</b> –height of boot

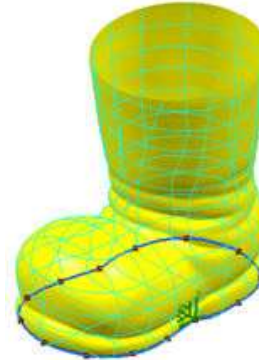
#### 4.2. Identification of Wrapping Curves

The process of automatization starts with identifying the base curve (which is obtained by intersecting the point cloud with the default XOY plane). On the curve shown in figure 7 are defined the following: the origin of the own coordinate system (the point corresponding to the narrow part of the

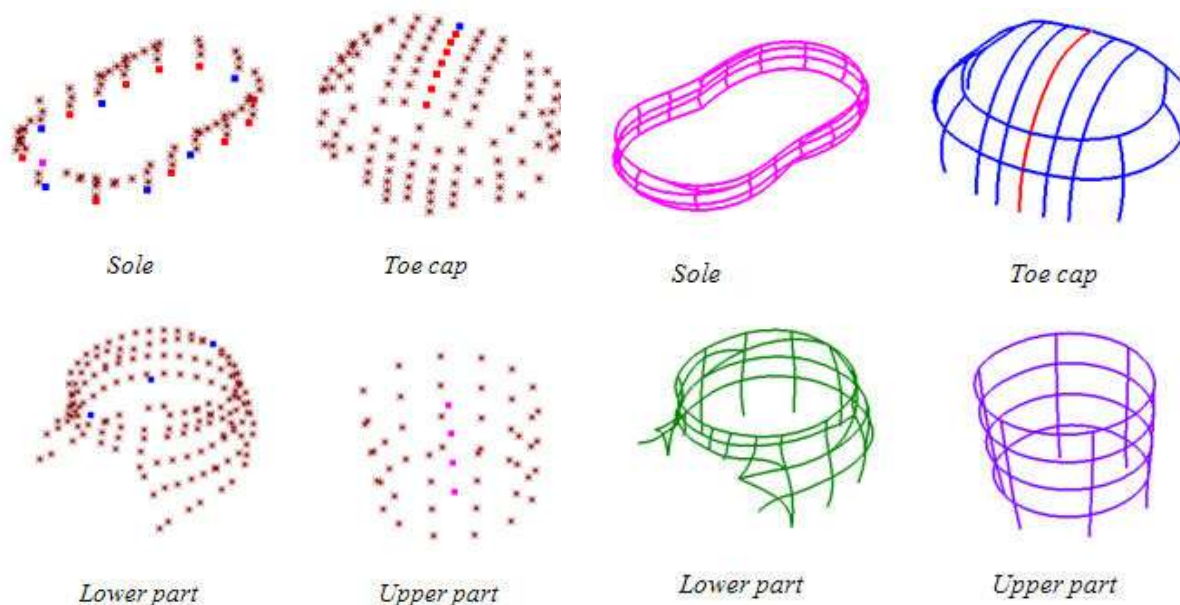
foot), the support points of the object (defined in accordance with the point origin and parameters of the foot) and the auxiliary points (which allow keeping the curve shape). Each point, previously defined, will have a working plane that will become the basis for the other points.



**Figure 7.** Necessary points



**Figure 8.** Network of wrapping curves



**Figure 9.** Parametric points of boot components

**Figure 10.** Automated network of curves

The previously defined working planes are used to intersect the point cloud in order to obtain the sections and the curves that define the object. The result of this operation (figure 8) is a network of wrapping curves.

#### 4.3. Automated Generating of Wrapping Curves

The points that represent the basis for defining the wrapping curves are introduced according to: a point of origin (default or chosen by the user), a series of lengths corresponding to the human foot and to the approached product type. All these points are gathered from the generated curves, on the finished point cloud (figure 8), using manual or automatic methods.

The automatization stage begins by defining the previously presented parameters (section 4.1) and continues with calculating the point coordinates, defining them by means of parameters and formulas. In order to keep a better control over the product shape, the product has been divided in components

[17]. For this product the following four components are used (figure 9 and figure 10): (1) sole, (2) toe cap, (3) lower part and (4) upper part of the product.

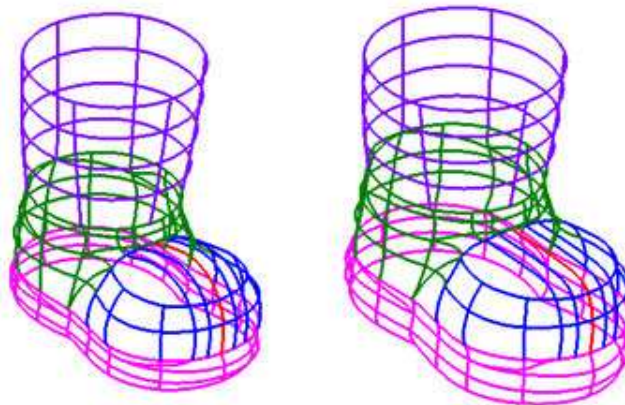
The first component, the boot sole, contains the base curve of the wrapping curves network and is made up of the supporting points, respectively of the auxiliary points. The supporting points are defined, to the following parameters:  $A$  –specific length for foot narrowing;  $L_p$  –length of foot;  $Z$  –specific length for foot width;  $L$  –length from the top of the foot up to the section where the foot width is known. In figure 9 are shown all the points necessary for the automated design of the boot sole.

In what concerns the second component, the toe cap, the operation starts by defining the points on the middle curve of the toe cap. The reference point for this component is coloured in blue (figure 9) and is defined according to the origin point and to the parameters that are necessary for the automated design of the component:  $H$  –height of foot and  $I_b$  –height of boot toe cap.

For the automated modelling of the third component, the lower part, of the boot are defined three points related to the point corresponding to the leg bending centre and to the parameters  $H$  –height of foot and  $D_{ankle}$  - specific diameter for foot ankle. To keep a symmetrical distance from the diameter of the ankle, a lot of supplementary points have been defined to allow maintaining the boot shape up to the heel height. The points that were automatically generated for the lower part in figure 9 are shown.

The upper part of the boot is influenced by two parameters, namely:  $L_{boot}$  –height of boot and  $D_{calf}$  –specific diameter for foot calf. The upper part component is divided into many levels along the boot height. A new centre has been defined for each level (colour magenta as shown in figure 9). This centre was defined in relation to the point considered to be the boot centre, and also related to the following parameters:  $L_{boot}$ ,  $D_{calf}$  and  $D_{ankle}$  (figure 9).

If it is considered the previously defined points to be control vertices then the curves network can be defined by means of the Spline curves (figure 10). In figure 11 are shown two footwear products of the boot type, the first is obtained using the default parameter values and the second is automatically generated with modified values.



**Figure 11.** 3D wireframe model obtained using automatically generated curve networks

#### 4.4. Automated Generating of Surfaces

The surfaces for each component of the footwear type product were developed, based on the wrapping curves network. Due to the fact that the surfaces which define the product are not of the primitive type, there were used complex type surfaces Loft and Fill type. Another factor that led to the choice of these types of surfaces is that only they allow automatization, once their parameter values have been modified. Figure 12 shows the surfaces based on wrapping curves that were generated for each boot component.

If the result is satisfactory, a specific thickness is applied throughout the entire product, resulting in a customized solid. The final result is presented in the figure 13.



**Figure 12.** Boot components obtained using automatically generated curve networks



**Figure 13.** Final parametric boot

## 5. Conclusion

In this paper, the authors have presented a methodology and associated algorithm used for the automated design of products with high level of customization for which no documentation is available. The algorithm underlying that the methodology contains the stages through which an existent object passes, in order to have its automated design: digitization, processing point cloud, designing the wrapping curves over the point cloud, the automation in correlation with parameters of the human component and product. For the studied footwear product a network of Spline curves is generated and based on it, networks of surfaces / solids are designed, the final result being a parametric CAD model.

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