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Product Design, Reverse Engineering, Rapid Prototyping - a Case Study in Cutlery Production

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Abstract

Reverse Engineering and Rapid Prototyping are consolidated practices in the industrial product design process. In any case, best practices should be set up according to the type of product and of objectives. This paper presents the results of a product re-engineering application in the field of high quality stainless steel cutlery. This activity included a re-modeling of a basis-shape that reproduces at best the original shape of a cutlery set designed in the Thirties for Alessi, which is still considered to be very fashionable. The shape of the manufactured physical pieces of cutlery has changed in time in respect to the original design, mainly because of some problems related to their manufacturing, which has been transferred from the central plant to other branches. We have obtained the digital model of the pieces of cutlery on the basis of the analysis of the available original 2D drawings, and of the laser scanning and subsequent re-engineering design of the available manufactured objects. Particularly complex activity was the removal of the shapes deviations due to the different forming techniques used in the various production factories. At the end of the reconstruction activity, physical prototypes of the new models were produced by means of a sintering process in order to evaluate and compare them to the original ones.

Categories and Subject Descriptors (according to ACM CCS): J.6 [Computer Aided Engineering]: Reverse Engineering, Computer Aided Prototyping.

1. Introduction

The Reverse Engineering (RE) and Rapid Prototyping (RP) techniques are nowadays employed in the industrial product design process. The first technique is effectively used for the analysis and modification of existing products, and the second for the design and evaluation of new products. Based on a fully digital 3D model representation, these technologies allow users to analyze conceptual products before their final production, to evaluate their consistency, to verify formal deficiencies and functional errors, to suggest possible changes. These are aspects that are not always identified easily and completely on a 2D drawing. Therefore, the use of RE and RP techniques improves the efficiency and quality of the overall design process.

RE is a fundamental activity in the final product quality control, because it assures the similarity with the original object, and it can show the difference between the manufactured object and the reference model, the changes due to undocumented modifications that were made after the design phase, or errors due to the production manufacturing process [VMC97].

The reconstruction of a free-form object into a three-dimensional CAD digital model, which defines for each point the object geometry and topology, is obtained by measurements acquired through scanning, which produce a clouds of 3D points that correspond to points on the surface of the object being re-engineered [CBS00] [SP01]. These real-scale data sets are usually used to create CAD models for subsequent revisions and manufacturing of the objects [Fud06]. Physical prototypes developed through RP are effectively used in several phases of the design process: to test the product shape, its dimensions and functionality whenever required, to visually control the product and to make comparisons between different concept maquettes [FSMC06].

An interesting case study concerns the use of these technologies applied in field of high-range home products and accessories, qualified for their "design excellence" applied to the whole product development, typical aspect of Alessi Italian Factory. The company manufactured precious cutlery sets designed by some very famous designers in the Thirties. At that time, designers provided sketches and technical drawings with little information. Modelers had the task of interpreting the drawings and producing the physical prototypes. The designers had little and no direct control over the final object shapes. Nowadays, designers have more powerful tools which allow them to directly participate in the design, production, evaluation and quality control phases of product development. The re-engineering activity described in this paper allowed Alessi to acquire information about the design intent of old designers. This activity was complicated by the fact that the available artifacts are old, worn out, and consequently different from the originals: as a result, the models coming from the reconstruction activity were not unique. In order to decide the final shape RE experts worked with Alessi's designers: the focus was put on aspects like stylistic coherence, and on the identification of those characterizing style features which had to be maintained in the all shapes of the cutlery pieces, as opposed to considering precision aspects alone.

2. Alessi cutlery case study

2.1. The Company

Alessi, one of the most important "Factories of Italian Design", is based in Crusinallo, close to Omegna, on Lake Orta (http://www.alessi.it). Founded in the 20s, in a region historically devoted to the household goods production, since the 50s Alessi specializes itself in stainless steel manufacturing.

Alessi is recognized as an advanced research laboratory operating in the field of applied design, with great attention to product quality. Recently, the company has reclassified the entire product range under three different brands. The "Officina Alessi" collection is one of them and it includes the most sophisticated design products that have never actually gone out of fashion, such as the cutlery set designed in 1938 by Luigi Caccia Dominioni, perhaps one of the most historical and famous Alessi cutlery set.

2.2. The product

The first production of Caccia cutlery set, designed together with Livio and Pier Giacomo Castiglioni, was done back in 1938, and it included the collection in silver and the pewter set. From the original designer's 2D drawings, obviously on paper, stamps were created and the production was done by the silversmith company Miracoli in Milan.

The same product was re-designed in 1990 when the drawings were acquired by Alessi: this is the reference model for today's production. During the company development, the production was moved to many plants, initially located in Italy, and later in foreign countries. The different production systems, the transfer of technical information among several plants, the residual manual operations performed in the finishing phase of the cutlery production, all caused variations of the original shape. Although these variations are included in a nearly imperceptible range for the final user, Alessi does not accept them, because of its well-known and renowned high quality production.

Therefore, Alessi decided to re-engineer the currently available cutlery sets to help recover and to obtain the original cutlery shape, characterized by the lightening and tapering forms, with their elegance and functionality, and by the three pronged forks.

Figure 1: *"Caccia" cutlery set (ref. Officina Alessi).*

For the more, the aim for re-engineering the cutlery sets was to obtain a 3D digital model finally fixed as the reference model for the production henceforward. The cutlery set has two productions, the stainless steel set and the most precious 925‰ silver set.

3. Cutlery set re-engineering

3.1. Acquisition phase

Regarding the reconstruction of the digital models we received some strict requirements from Alessi. They mainly concern both shapes and dimensions:

- The shape features which distinguish the cutlery, especially the handle's bottom with its particular roundedness, need to be maintained.
- Some fixed dimensions, related to pre-defined sections which are taken as a reference for the following production, should be preserved.

Another strict request from the company is to maintain the dimensional tolerances within 0.2 mm, which is the maximum value the company accepts during the manufacturing control quality.

The acquisitions of the cutlery pieces were carried out at the HAPRE Lab of Department of Mechanical Engineering of Politecnico di Milano (http://www.kaemart.it/labs/hapre). We used the non-contact 3D laser digitizer VI-9i KonicaMinolta™ (http://konicaminolta.com), equipped with a tele-lens, using the *focal distance* f = 25 mm

and the *depth of view*:

dov = 600 mm (±50 mm)

in order to keep the measurements within the standard instrument's field and to guarantee laser acquisition accuracy. To eliminate the material reflection, the objects have been made opaque using Rocol powder before the acquisition phase. The range maps were aligned and edited using the software Geomagic Studio v. 7.0 ™ (http://www.geomagic.com), being the standard deviation of the models alignments:

σ = 0.028 mm (±0,01 mm)

Figure 2 shows the visual analysis of the deviation between the range maps.

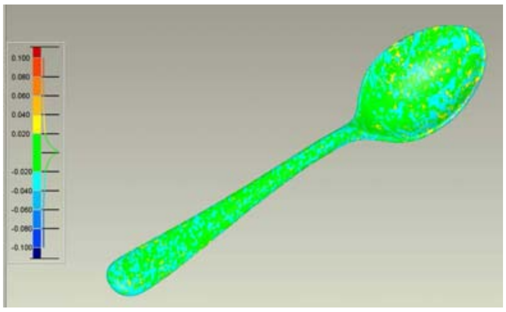

Figure 2: *Coffee spoon: global registration.*

The triangulated digital model is measured to control its similarity with the given reference measures provided by Alessi. The patches on the model are calculated by increasing the stiffness of the surfaces to eliminate the residual defects of the model, remained after the editing operations. Particular attention is paid to checking the surfaces on the cup of the spoons and on the prongs of the forks, because of the very thin thickness of these specific parts.

3.2. 3D modeling

When the object shape is acquired, the corresponding 3D digital model has to be created so as to make it easily modified with the use of a CAD system. The reconstruction process starts from the triangular mesh and provides surfaces perfectly connected and continuous between them and included within the required tolerances. We used the 3D modelling software thinkiD DesignXpressions™ (http://www.think3.com) for importing the patch-model, correcting its flexibility, and modifying its degree and/or continuity in both parametric directions, without changing its shape or position in space. Subsequently, we extracted some curves from the model on the following main sections: the silhouettes projected on the principal 3D orthogonal planes and the sections on the reference planes, where there are fixed measures. Figure 3 shows the curve network obtained by referring to the symmetry plane of the object.

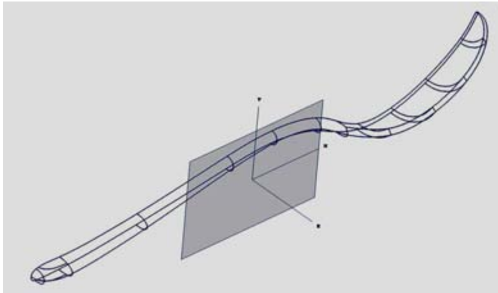

Figure 3: *The base-grid with the symmetry plane.*

These curves are then fitted to maintain the shape while at the same improving its quality. For example, sharp angles are eliminated by operating on their flexibility in terms of degree and continuity. The differences between curves calculated with the symmetry reference plane are shown in Figure 4.

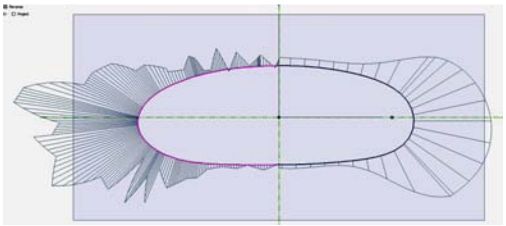

Figure 4: *Original curve (left) vs. fitted curve (right): curvature analysis.*

These curves are considered as base-grid for the re-engineering design of the cutlery. The curves are:

- approximated with a constant degree to control contour conditions;
- reconstructed considering symmetry, thus rectifying production defects presented in the acquired model, depending on the forming and finishing operations.

The subsequent step, to obtain the final NURBS surfaces based on the base-grid, is particularly critical [Far93]. We reconstructed a targeted surface based on the curves and then, using the Global Shape Modeling (GSM) technique provided by the think3 software, we modified the surface so as to pass through the fixed curve on the re-defined grid [Bar84].

To be able to check the final digital model we analyzed:

- the curvature map by using the reflection lines to observe the visual effect of the shape, and also to detect surface normal vector deviations and surface discontinuities. As shown in Figure 5, the isophotes, displayed as lines of constant illumination, look very smooth;

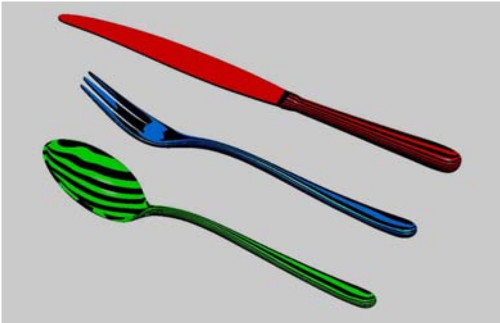

Figure 5: *Isophotes on the final models.*

- the deviation between the final model and the original acquired model, for highlighting the satisfaction of tolerances. The major differences are detected in those zones where re-engineering design eliminated the production imperfections, that is on fork prongs and along the handle where symmetry is imposed, as shown in Figure 6.

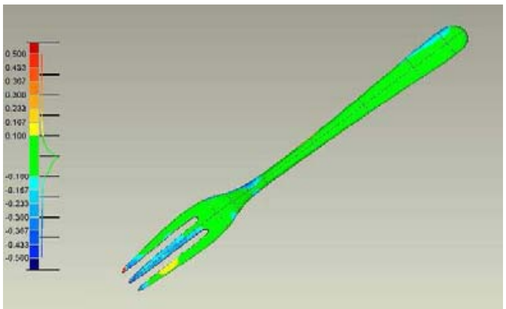

Figure 6: *Comparison stl-Nurbs model- table fork.*

4. RP of the new models

The physical prototypes of the re-engineered models were manufactured at Alessi by means of rapid prototyping system, the Invision si^2 3D printer™ (http://www.3Dsystem.com), using a VisiJet® SR 200 material, an acrylic polymeric resin.

The prototypes were evaluated by Alessi' designers as to verify the quality of the new cutlery set (Figure 7). In particular, shapes were compared to the original ones, as well as tolerance dimensions. The new physical prototypes satisfied the quality control.

5. Conclusions

This works describes how the identification of style features should be obtained through the integration of RE-RP-CAD systems to improve the design and production process. It has been demonstrated that designers today have the possibility to fully and easily apply and control the use of the same style features to a set of objects, thanks to available technologies and instruments.

Figure 7: *Physical prototypes of the new models.*

6. Acknowledgements

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