

The reverse engineering of a blade runner geometry through photogrammetry

D Nedelcu¹, S L Bogdan¹ and I Pădurean²

¹“Eftimie Murgu” University of Reșița, The Faculty of Engineering and Management, Department of Mechanical Engineering and Management, Traian Vuia square, no.1-4, 320085, Reșița, Romania

²Politehnica University of Timișoara, Romania, Mechanical Faculty, Mechanical Machines, Equipments and Transportations Department, “Mihai Viteazu” street, 300222, Timișoara, Romania

E-mail: d.nedelcu@uem.ro

Abstract. The paper illustrates the reverse engineering process of a blade, from a Kaplan runner with a diameter of 5400 mm, using the following software packages: Agisoft Photoscan and Geomagic Design X (formerly Rapidform XOR); the next step was to generate the solid geometry of the blade using the SolidWorks software. The last step was to compare, using GOM Inspect software, the geometry of the designed blade with the corresponding geometry obtained using Photogrammetry and finally answer the question if this technique can be used in the mechanical field to get a precise 3D reconstruction of large objects with complex geometries.

1. Introduction

The reverse engineering technology based on Photogrammetry is used for GIS applications, aerial imagery processing, mining and quarrying, precision agriculture and environmental management, archeology, architecture and cultural heritage documentation and visual effects production [1]. The application references of Photogrammetry in the mechanical field are not so widespread in literature; still we can exemplify the following papers [2], [3], [4], [5], [6]. Photogrammetry is the technique used to extract geometric information from two-dimensional images or videos, by taking multiple overlapping photos and obtaining measurements from them in order to create 3D models of objects or scenes. The name „*Photogrammetry*” derives from the following Greek words: „*photos*” – light; „*gramma*” – letter; „*metrein*” - to measure. Photogrammetry needs multiple photos, because only the X, Y coordinates can be extracted from one photo. However, from several photos of the same object that are taken from different positions, a third coordinate Z can be extracted. The required condition is for every point to be visible in at least two photos. This way, the extracted information from photos, regarding the points, can be used to reconstruct lines, distances, areas and volumes of space.

Using the reverse engineering technology, the geometry of a Kaplan blade turbine with a 5400 mm diameter will be reconstructed and compared with the blade geometry design (Figure 1), by following the next steps:

- 3D scanning of the blade using Photogrammetry and the Agisoft Photoscan software;
- blade reconstruction using the Geomagic Design X and SolidWorks software packages.



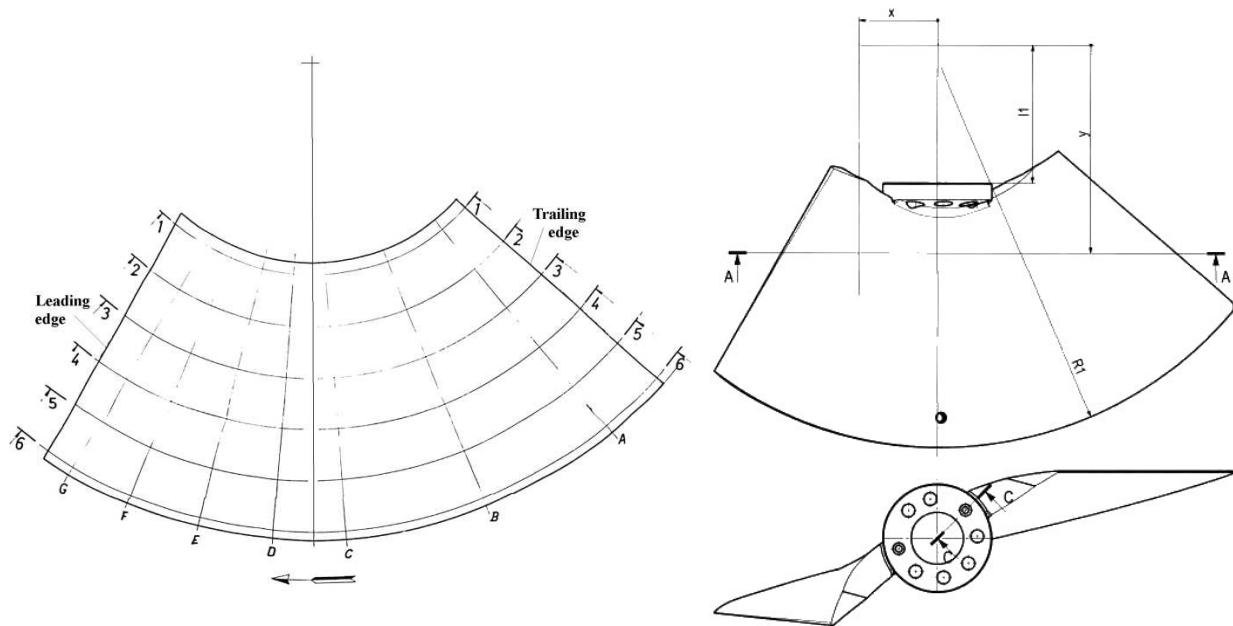


Figure 1. The geometry of the design blade.

2. The 3D scanning of the blade

The 3D scanning of the blade requires the following stages [7]:

- *Acquire photos* - with a high quality camera; the input data was captured from the platform where the blade was placed; a number of 43 photos were taken with a CANON EOS 500D camera from a ≈ 4.5 m mean distance; the mean ISO-value for each photo is 400 by shutter 1/30; some images of the blade are presented in (Figure 2);
- *Import Photos* - loads all the raw images into the Agisoft Photoscan interface (Figure 3);
- *Photo's inspection* – the quality of the images must be a minimum of 0.5, 0.7 is recommended; the *Quality* factor is calculated by the Agisoft Photoscan software.
- *Align Photos and build sparse cloud* - this processing step compares the pixels in the photos to find matches and build a 3D geometry from them; a sparse point cloud of 3491 points is generated (Figure 4); the software tries to identify common points between pairs of images and estimate camera locations; (Figure 5) shows the points correspondence between “img_0008.tif” and “img_0013.tif”, where from a total of 438 points, 217 are valid (with blue color) and 221 are not valid (with red color); (Figure 6) shows the points correspondence between “img_0008.tif” and “img_00141.tif”, where from a total of 36 points, 8 are valid (with blue color) and 28 are not valid (with red color);
- *Build Dense Cloud* - once satisfied with the alignment, the sparse point cloud (a mere fraction of the total data) is processed into a dense cloud, with 10965040 points, where each matchable pixel will get its own X, Y, Z location in 3D space (Figure 7);
- *Build Mesh* - this step connects each set of three adjacent points into a triangular face, which combine seamlessly to produce a continuous mesh over the surface of the model; this step is optional, because the mesh was generated using Geomagic Design X software;
- *Build Texture* - in this step, the original images are combined into a texture map and wrapped around the mesh, resulting in a photorealistic model of the original object; this step is optional;
- *Scale the geometry* – based on a known distance in the photos; the geometry was scaled based on 3 distances between three markers (Figure 8);
- *Export the geometry* – export the dense point cloud to Geomagic Design X software.

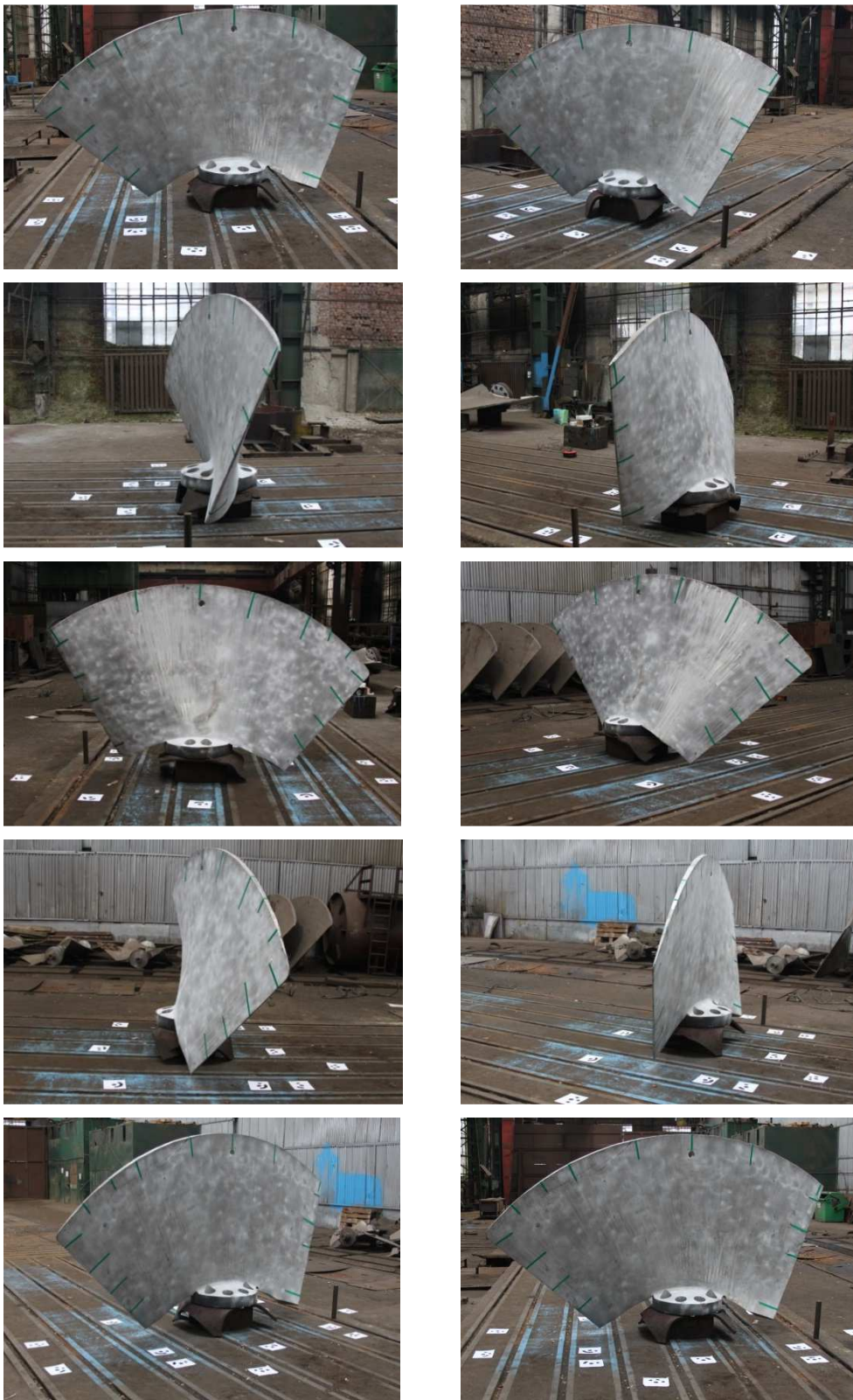
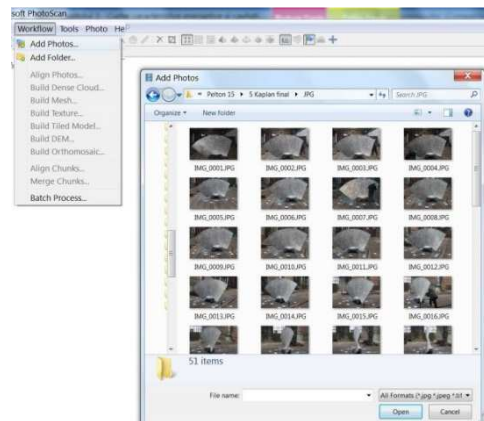
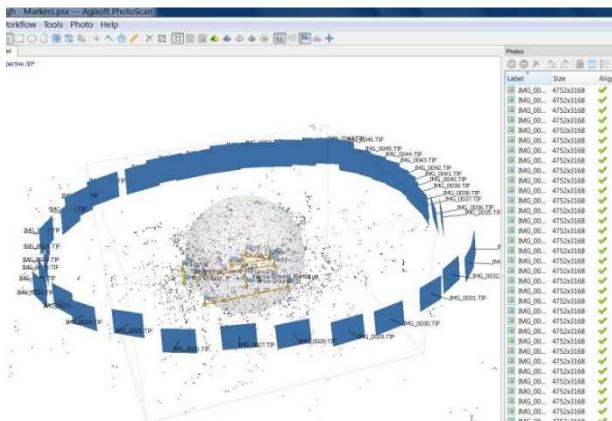
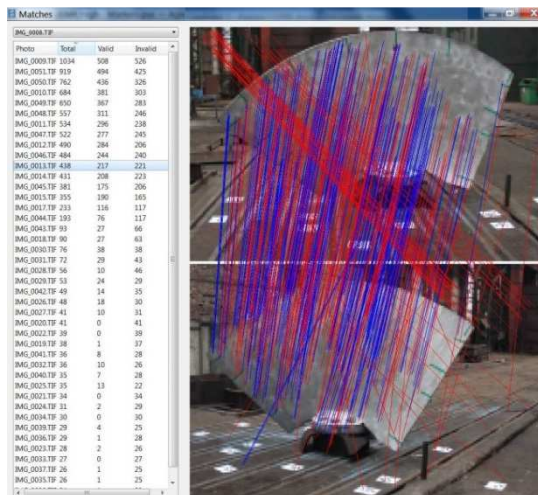
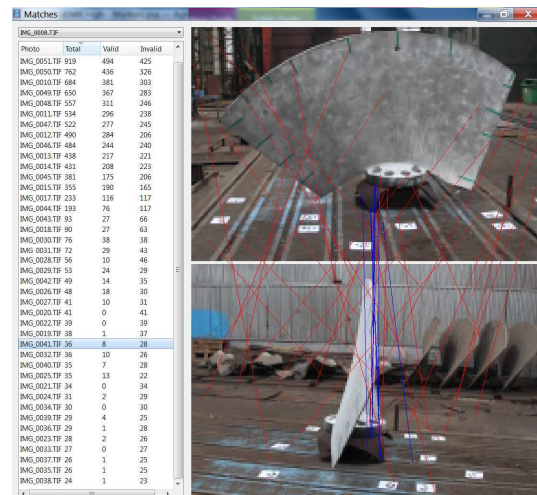
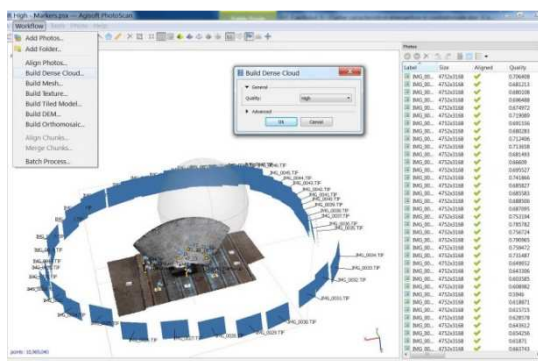


Figure 2. Some captured images of the blade.

**Figure 3.** Insert images in Agisoft Photoscan.**Figure 4.** Images aligned and the sparse cloud.**Figure 5.** The correspondence between “img_0008.tif” and “img_0013.tif”.**Figure 6.** The correspondence between “img_0008.tif” and “img_0041.tif”.**Figure 7.** The dense cloud with 10965040 points.

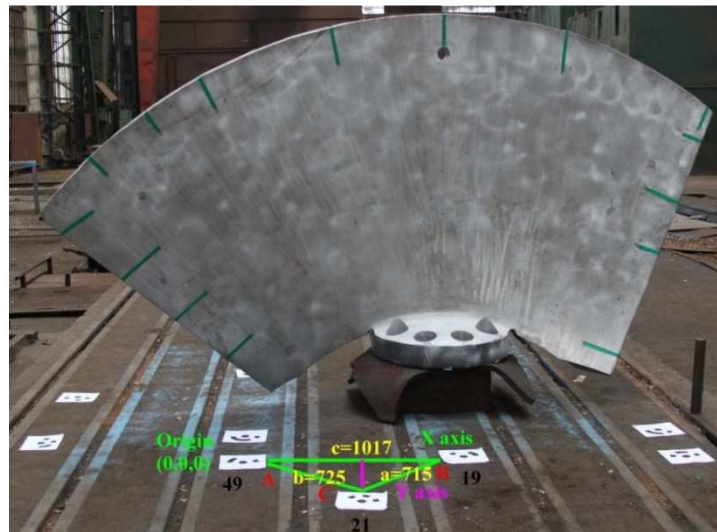


Figure 8. Scale the geometry using Agisoft Photoscan software.

3. The blade reconstruction

The aim of this stage was to generate the blade geometry as a solid format, by following the next steps:

- import the dense point cloud into Geomagic Design X software (Figure 9);
- generate the mesh based on a dense point cloud; the software creates a network with 241577 triangles similar to the mesh from the finite element software (Figure 10);
- generate the blade surface and the trunnion cylinder (Figure 11);
- generate the 3D curves (profiles) that result from the blade intersection with cylinders (Figure 12);
- export the profiles to the SolidWorks software;
- generate the geometry of the blade as a solid format in the SolidWorks software (Figure 13).

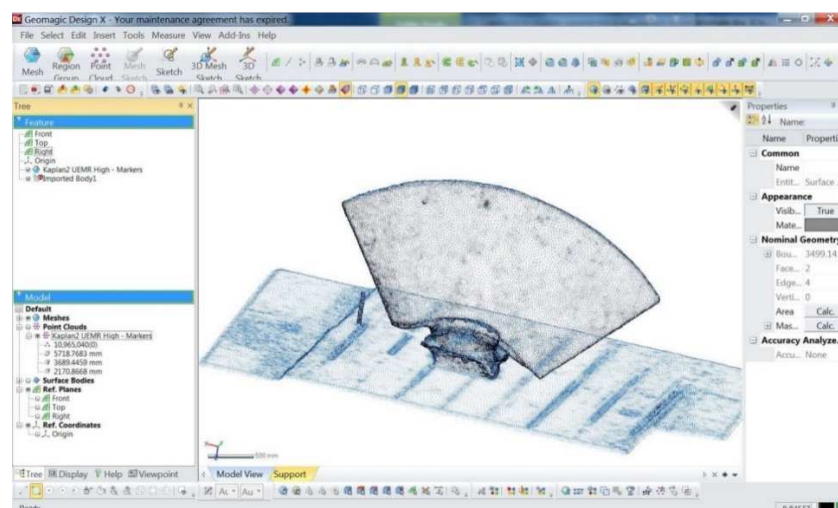


Figure 9. The dense point cloud imported into Geomagic Design X software.

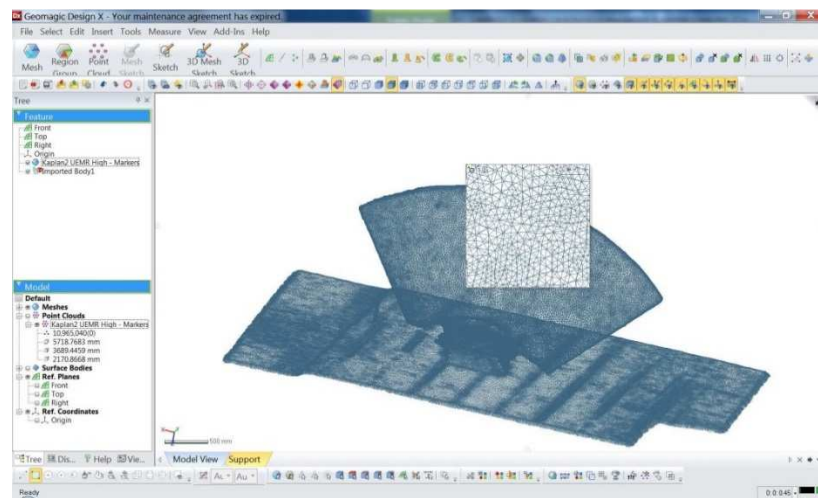


Figure 10. The mesh created using Geomagic Design X software.



Figure 11. The blade surface and the trunnion cylinder.

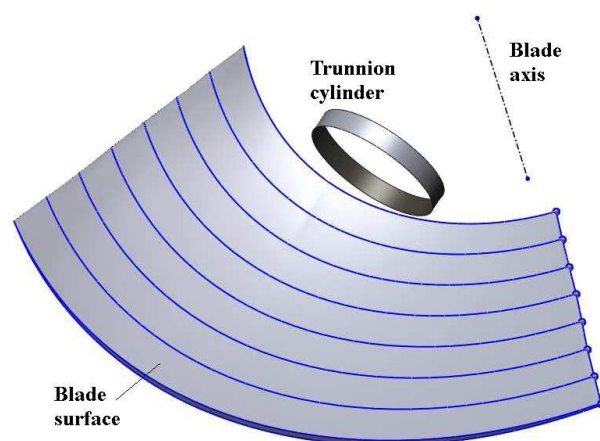


Figure 12. The profiles that result from the blade intersection with cylinders.

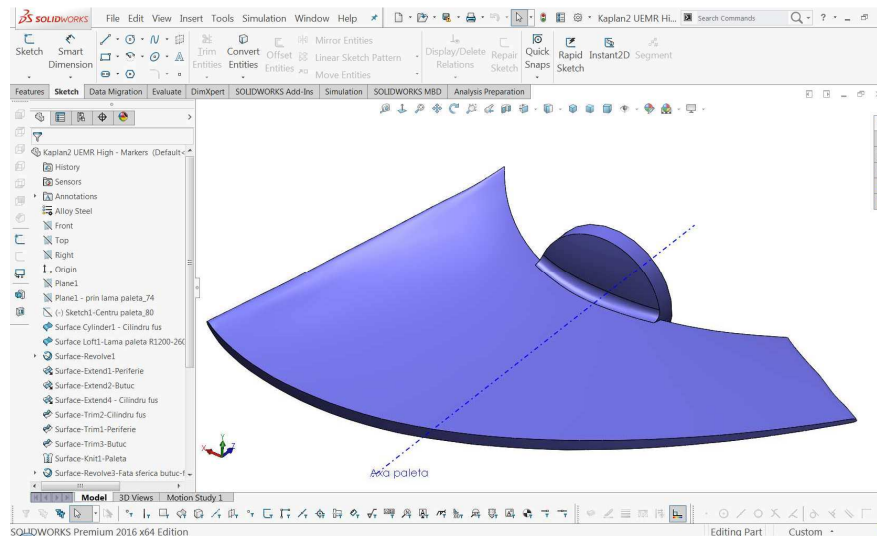


Figure 13. The solid format of the blade.

4. The blade comparison

According to the CEI code [8] “the blade profiles shall be measured on at least three sections along the entire profile (either along cylindrical or plane sections), on both the pressure and suction sides of the blade or randomly on the whole surface (Figure 14)”. The geometry of the reference blade from the project (Figure 15) design was compared, for 6 profiles generated by blade intersection with 6 cylinders, with 6 profiles from the reconstructed blade (Figure 16) obtained at the same radius. The blade profile tolerance was imposed from CEI code: $\pm 0.1\% D = \pm 0.1\% \times 5400 \text{ mm} = \pm 5.4 \text{ mm}$. The geometry of the blade was imported to GOM Inspect software and aligned through automatic best-fit alignment.

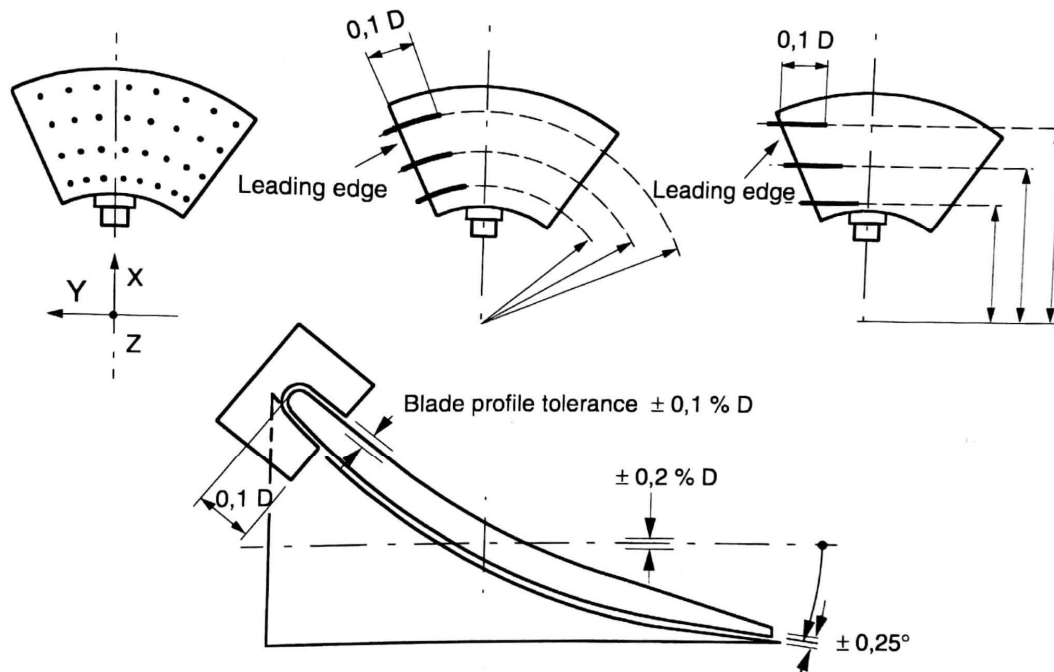


Figure 14. The CEI code recommendations.

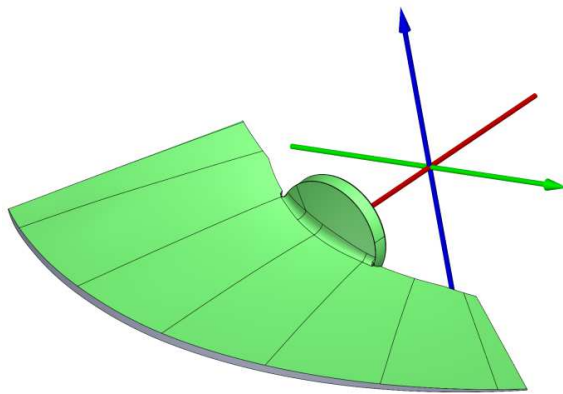


Figure 15. The geometry of the reference blade.

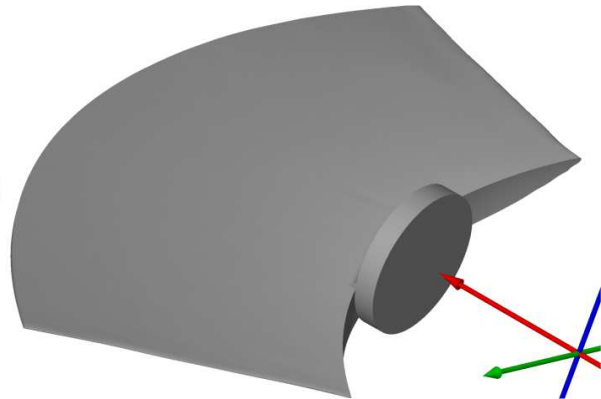


Figure 16. The reconstructed blade.

The following comparisons were made based on this alignment:

- the surface comparison, which shows that the deviations are in the tolerance domain, except for two points located at the hub and one point located at the blade periphery, with +6.69, +9.79 and +8.99 mm deviations, (Figure 17).
- the profiles comparison; the six profiles were obtained with plane sections of the two blades (Figure 18); from 88 measured points, 68 points (77.27%) are in the tolerance domain and 20 points (23.81%) are out of the tolerance domain, of which: 7 points (7.95%) exceed the permissible deviation by 1 mm, 5 points (5.68%) exceed the permissible deviation by 3 mm, 5 points (5.68%) exceed the permissible deviation by 6 mm and 3 points (3.41%) exceed the permissible deviation by more than 6 mm. The inspection points and deviations are presented in (Figure 19) for section 1 and in (Figure 20) for section 5.

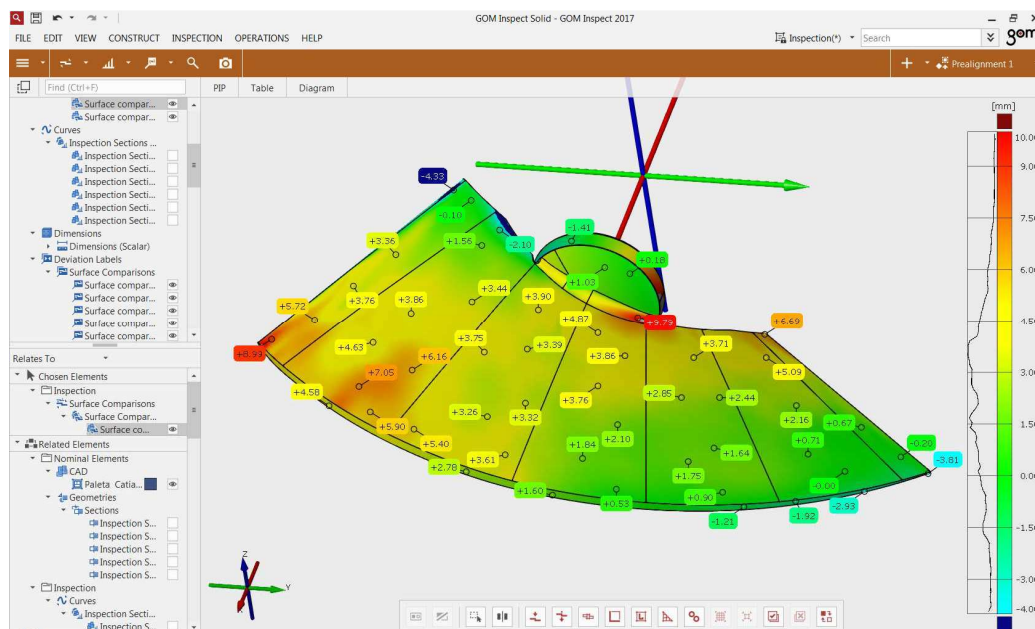


Figure 17. The surface comparison.

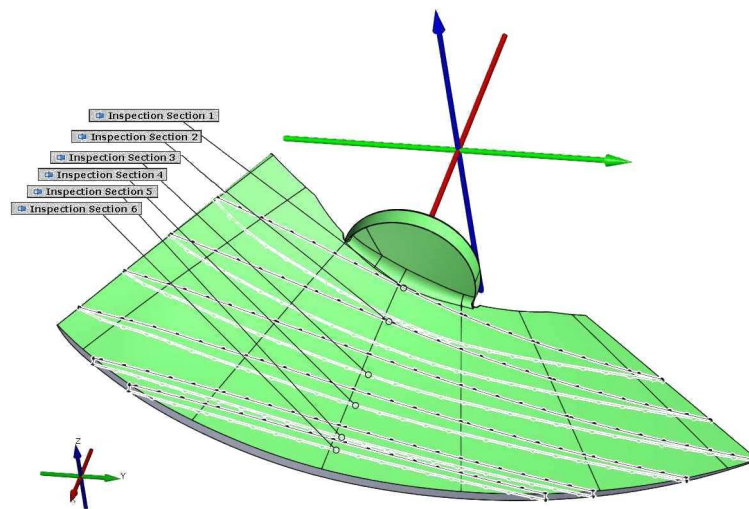


Figure 18. The inspection sections.

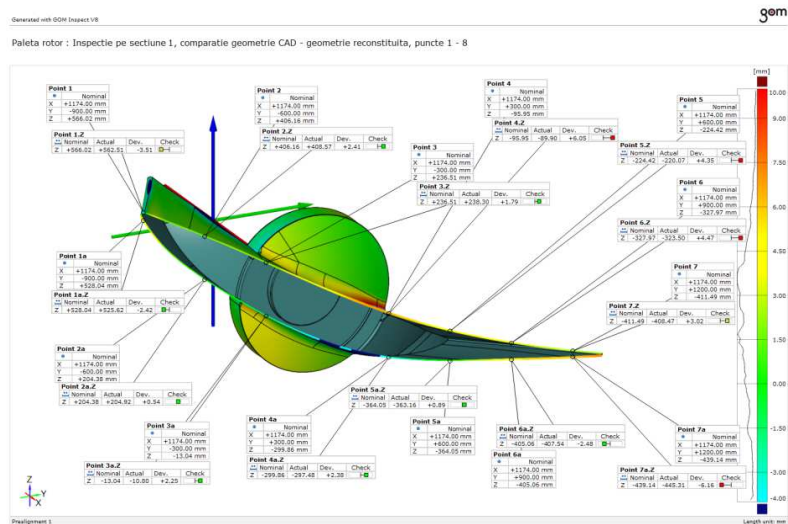


Figure 19. The inspection for section 1.

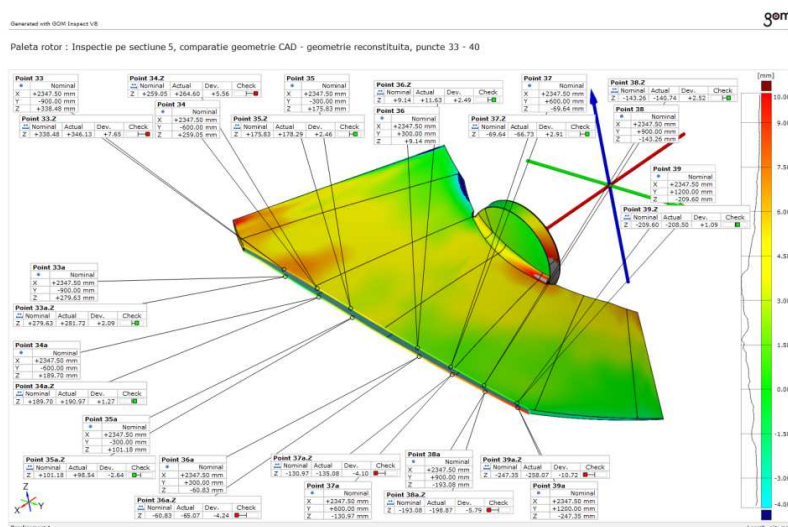


Figure 20. The inspection for section 5.

5. Conclusions

The geometry of the scanned blade is not perfect, because it's a manufactured one which must fit a tolerance domain imposed by the design drawings. It's also affected by execution errors, so it is not identical to the geometry of the project. The scanning process itself is also affected by scanning errors that occur in any measurement process.

However, the comparisons presented in the paper use a theoretical blade as a reference which does not correspond 100% to the real blade that was scanned. These differences also include the camera quality and shooting settings, the number and quality of the photos, the light around the blade, the settings imposed on the Agisoft Photoscan software, the accuracy of alignment geometries made for comparison using the GOM Inspect application, and the configuration of the computer. Reducing differences can be done by increasing the number of purchased pictures, using a professional camera with superior technical characteristics, enriching the experience with the use of photogrammetry, as well as the associated information processing programs.

In our opinion, the answer to the question if the Photogrammetry technique can be used in the mechanical field to get a precise 3D reconstruction of large objects with complex geometries is YES and Agisoft Photoscan is required software among others that exist on the market.

Acknowledgments

This paper was supported by “Eftimie Murgu” University of Reșița, “Traian Vuia” Square, No. 1-4, 320085, Caraș-Severin county, Reșița, Romania.

References

- [1] Agisoft LLC 2017 *PhotoScan, Fully automated professional photogrammetric kit*, www.agisoft.com
- [2] Agisoft PhotoScan, *Point Cloud accuracy in close range configuration*, www.koppel-engineering.de/
- [3] Curtis S K, Harston S P and Mattson C A 2011 The Fundamentals of Barriers to Reverse Engineering and Their Implementation into Mechanical Components, *Research in Engineering Design* **22**(4) 245-261
- [4] Mohaghegh K, Sadeghi M H and Abdullah A 2006 Reverse Engineering of Turbine Blades Based on Design Intent, *The International Journal of Advanced Manufacturing Technology* **32**(9-10) 1009-1020
- [5] Zhang D H, Jiang R S, Li J L, Wang W H and Bu K 2009 Cavity Optimization for Investment Casting Die of Turbine Blade Based on Reverse Engineering, *The International Journal of Advanced Manufacturing Technology* **48**(9-12) 839-846
- [6] Kumar A, Jain P K and Pathak P M 2014 *Machine Element Reconstruction using Integrated Reverse Engineering and Rapid Prototyping Approach*, 5th International and 26th All India Manufacturing Technology, Design and Research Conference AIMTDR, Assam, India, December 12-14, pp. 123-1–123-5
- [7] Agisoft 2018, *User Manual: Professional Edition*, www.agisoft.com/pdf/photoscan-pro_1_4_en.pdf
- [8] CEI IEC 1999, *International Standard, Hydraulic turbines, Storage Pumps and Pump-Turbines – Model Acceptance Tests*, Reference no. CEI/IEC 60193-1999