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REVERSE GEOMETRIC MODELLING AS A PART OF REVERSE ENGINEERING - ACCURACY OF FITTING CYLINDER

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Abstract: *This research investigates reverse geometric modelling in CAD software PowerShape for reconstructing polygonal 3D models. The process utilises specialised functions for reverse modelling to create 3D CAD models. Integral to this is integrating 3D digitisation data, with a sample part digitised using the METROTOM 1500 industrial computer tomograph. The study applies the fitting method to a polygonal cylindrical mesh, employing techniques like point reduction, smoothing, and fitting surface diameter based on points cloud. Notably, the number of points on the cylinder's mesh directly impacts the resulting diameter. Reducing points increases the diameter; for instance, 26,934 points cloud a 29.898 mm diameter, while a 90% reduction to 2,385 points results in a 30.001 mm diameter. The research highlights the effect of polygon mesh smoothing, with values of 0.2 and 0.5 significantly reducing the reconstructed cylindrical surface's diameter. However, further smoothing does not alter the diameter.*
Keywords: *reverse geometric modelling, 3D CAD model, computed tomography, geometric parameters, fitting elements.*

1. INTRODUCTION

Engineering is designing, manufacturing, assembling, and maintaining products and systems. Forward and reverse engineering are two types of engineering activities known [1], [2]. Reverse geometric modelling is used in the engineering, energy, aerospace, biomedicine, archaeology, and art industries. One of the most challenging goals in reverse geometric modelling is creating high-quality surface models from the obtained data with minimal user assistance [3]. The computer-assisted design/computer-assisted manufacturing (CAD / CAM) approach to reverse engineering processes includes duplicating parts in the process chain: digitization-CAD modelling-CNC machines. Each process specific to the CAD modelling part of the reverse engineering chain requires time and resources, resulting in specific errors leading to problems with geometry differences between the existing part and the resulting CAD model [4]. The colour deviation map is used to assess the quality of the reconstructed model, which arose from a point cloud or polygonal model. The authors used a colour deviation map to evaluate the quality of a reconstructed CAD model [5], [6], [7], [8], [9]. The colour deviation map overlaps the reconstructed model with the polygonal model.

Authors Page et al. [10] and Raja and Fernandes [1] introduced a new acronym in the field of computer-aided CARE (Computer Aided Reverse Engineering). Wang et al. [7] describe a process of reverse geometric modelling that can potentially solve technical problems with rapid prototyping and shape analysis. He further states that the reconstruction of a geometric model from a polygonal mesh of an existing physical model consists of four steps: smoothing the polygonal model, dividing the polygonal mesh into segments - segmentation, solid and surface reconstruction, and finally, solid modelling (Boolean operations). The CAD software PowerShape used three ways of fit direction, illustrated in Figure 1 [11]. The influence of fitting a geometric element to a polygonal 3D model or a polygonal mesh is of fundamental importance on the geometric parameters of the created geometric element to the polygonal mesh. In Figure 1, the small green dots represent the point's cloud and the detail of the fitting of the cylindrical surface with respect to the cloud of points.

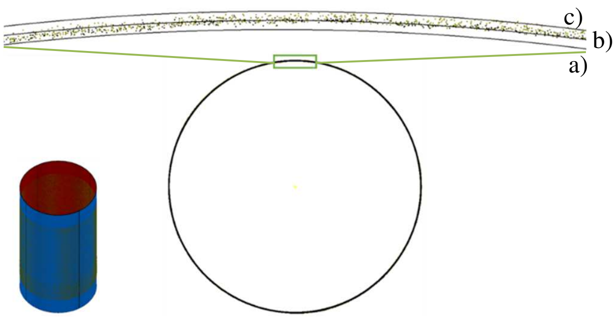


Fig. 1 Detail of the fitting of the cylindrical surface with respect to the cloud of points
a) fit inside
b) fit middle
c) fit outside

2. MATERIALS AND METHODS

Figure 2 shows the workflow for the influence of reverse engineering on the accuracy of the 3D model. The number of points in the cloud of points is decisive for the reverse geometrical modelling. There are three ways to get a certain number of points. The first way is a 3D digitalisation and parameters of the digitalisation devices. 3D digitalisation is also essential. The second way is with respect to the polygonisation parameters.

The CAQ (Computer Aided Quality) software includes polygonisation parameters used to reduce the number of point clouds. CAQ software ZEISS Inspection Pro and VG STUDIO MAX includes polygonisation parameter.

The CAQ software has default polygonisation parameters. ZEISS Inspection Pro has four default polygonisation parameters: Less Details, Standard, High Quality and Raw data. The main polygonisation parameters in GOM Inspect are Smoothing (Filter Radius, Detail Sharpness, Surface Tolerance), Thinning (Surface tolerance, Maximum edge length) and Patch Removal (maximum number of points). VG STUDIO Max has nine methods of exporting polygonal 3D models: Quick, Very Fast (only points cloud), Fast, Normal, Normal with Simplification, Precise, Precise with simplification, Super precise and Super precise with simplification.

The third option for reducing points and triangles is directly within CARE (Computer Aided Reverse Engineering) and CAD (Computer Aided Design) software.

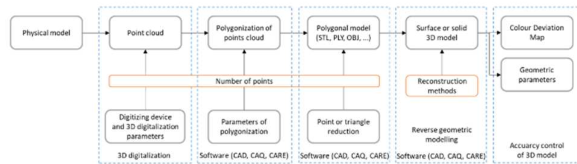


Fig. 2. Workflow for the influence of reverse engineering on the accuracy of the 3D model (Number of Points and Reconstruction Methods)

2.1 Sample part

The sample part was made by MultiJet Printing (MJP). Figure 3 shows the 3D-printed part. The sample part contains geometrical elements, four spheres (S1 – S4) with different diameters and positions. The next object is a cylinder (C) with a hole. The wall (W) includes holes with different diameters. All geometrical elements are connected to the rectangular base element (B). The dimension of the 3D printed part is 100 x 100 x 40 mm.

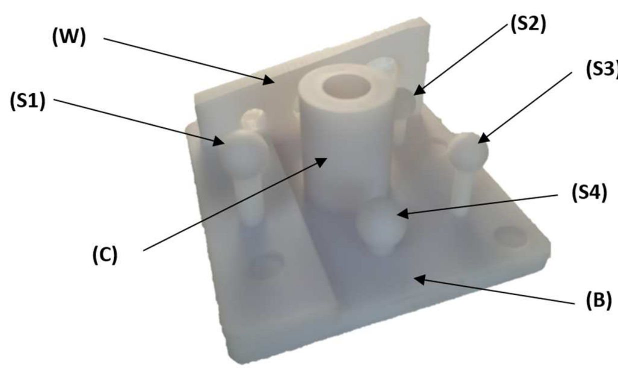


Fig. 3. 3D printed part by MJP technology.

2.2 Parameters of 3D Digitising

Metrotom 1500 was used for data acquisition of 3D printed part. Metrotom 1500 is an industrial computed tomography. Table 1 shows the parameters of the data acquired.

Table 1

Parameters of data acquired by industrial computed tomography

The parameters	Value	Unit
Current	700	μA
Voltage	140	kV
Integration time	667	ms
Resolution of Detector	1K (1024x1024)	Px
Filter	0,5	mm
Voxel size	151	mm
Measurement method	VAST	[-]
Number of Images	900	[-]

Figure 3 shows a polygonal 3D model of the 3D printed part. The number of points was 297 246, and number of triangles was 594 500.

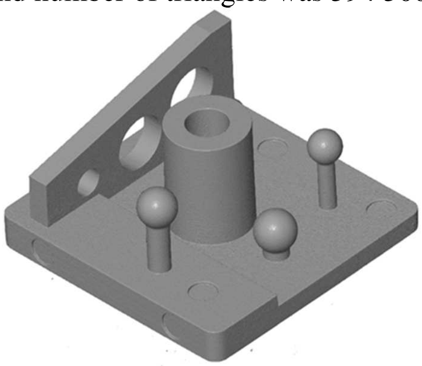
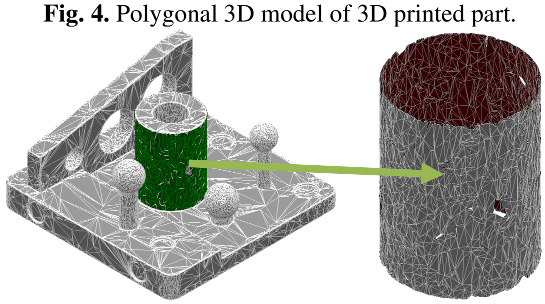


Fig. 4. Polygonal 3D model of 3D printed part.



a) *b)*

Fig.5. Polygonal surface of polygonal 3D model with 90% of points reduction
a) Polygonal 3D model with selected triangles of cylindrical surface (297 246 points)
*b)*Detail of the cylindrical surface detail (2 385 points)

A part of the polygonal mesh (Fig. 5.) was separated from the sample model. The geometric element "cylinder" was fitted using the manual function with the middle-fit parameter, the most common method of fitting geometric elements to a mesh.

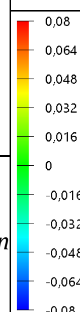
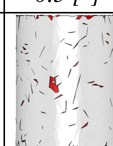
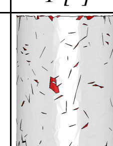
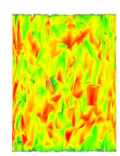
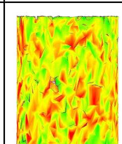
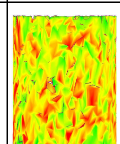
3. RESULTS AND DISCUSSIONS

3.1 The impact of smoothing of a polygonal 3D model on geometric parameters of a 3D CAD model

Polygon mesh smoothing of a polygonal 3D model is a frequently used function to eliminate the noise of a polygonal mesh or a polygonal 3D model. Since it involves the smoothing of a polygonal mesh, this process during the reconstruction has a certain influence on the geometric parameters of the 3D CAD model. The smoothing tolerance value is set in CAD, CARE, and CAQ software. The smoothing tolerance was applied to the unreduced and reduced (90%) cylindrical polygon mesh shown in Table 2 and Table 3. The unreduced mesh contained 26.934 points and 53.026 triangles. The reduced polygon mesh had 2.385 points and 4.218 triangles.

Table 2

Colour deviation map for smoothing tolerance 0.2; 0.5; 1 – 2.385 number of points

	Tolerance [mm]	*Smoothing Tolerance – PowerShape*		
		0.2 [-]	*0.5 [-]*	*1 [-]*
				
Color deviation maps				
Number of points	*2 385*			

Tables 2 and 3 show a colour deviation map for the smoothing process of cylindrical polygons with smoothing tolerances of 0.2, 0.5, and 1. The polygonal mesh shown in grey is an unsmooth mesh translated by a smoothing mesh (shown in black, visible in Table 3). The colour map of the deviations shows that with a smoothing tolerance of 0.5 [-), the colour distribution of the deviations on the colour map does not change. In contrast, the range of deviations is set within the tolerance range of 0.08 to -0.08 mm.

Table 3

Colour deviation map for smoothing tolerance: 0.2; 0.5; 1 – 26 934 number of points

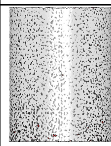
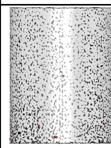
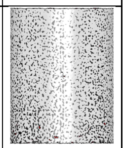
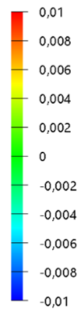
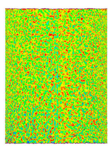
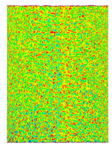
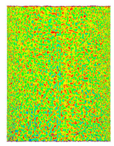
	Tolerance [mm]	*Smoothing Tolerance - PowerShape*		
		0.2 [-]	*0.5 [-]*	*1 [-]*
				
Colour deviation maps				
Number of points	*26 934*			

Figure 6 shows a graph that characterises the influence of the smoothing tolerance on the dimension of the selected geometric element. The selected element was a cylindrical polygon mesh, according to Figure 4. The smoothing tolerance was set to 0, 0.2, 0.5, 1, 2, 5, 10, 20.

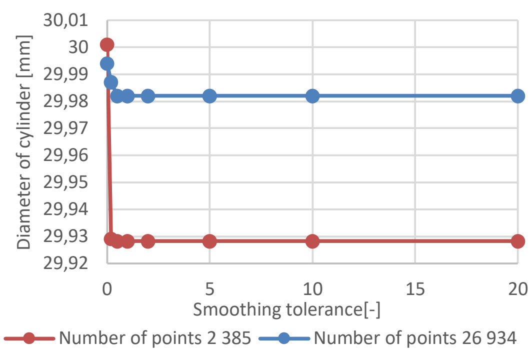


Fig. 6. Impact of smoothing tolerance on the diameter of the cylindrical surface

The number of points that make up the polygon mesh (polygonal 3D model) does not change when using the smoothing tolerance. As can be seen from the graph, the diameter of the clamped cylindrical surface does not change from the smoothing tolerance of 0.5 to the smoothing tolerance of 20 is linear. From the results, it can be concluded that the effect of smoothing can be significant, especially in the case of a large noise of the polygonal mesh of the polygonal 3D model.

3.2 The impact of points reduction on geometric parameters in a 3D CAD model

Reducing the number of points (triangles) is implemented to reduce the number of points, as some software can only load a limited number of points. From the point of view of reverse geometric modelling, reducing the number of points has an important meaning.

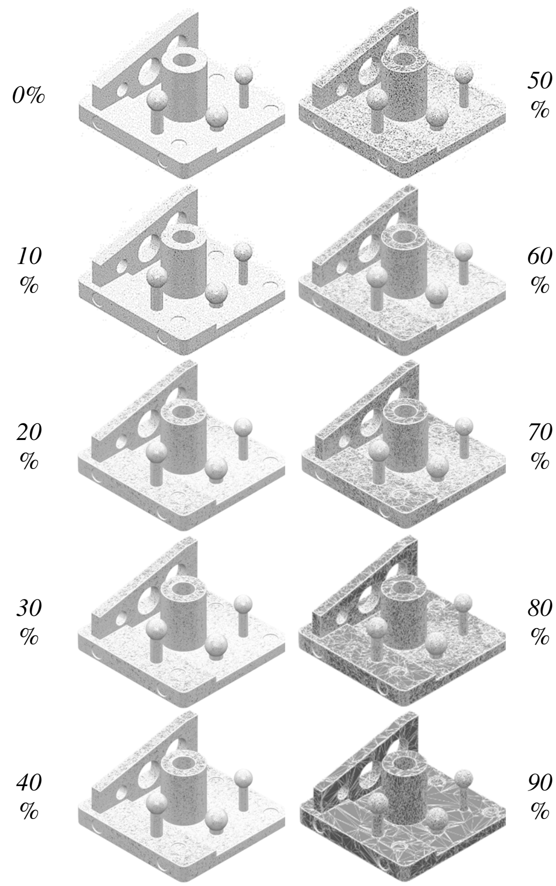


Fig. 7. Polygonal mesh after reducing the number of triangles (points) in the PowerShape CAD software

Figure 7 shows the reduction of the polygonal 3D model of the sample part. The reduction was realised in the CAD software PowerShape. Percentage reduction of triangles was used. The percentages shown in Figure 6 represent the percentage by which the number of triangles on the polygonal 3D model has been reduced. Reducing the number of triangles affects the number of points located in the polygonal 3D model. A reduction of 0% means that the number of points (triangles) has not been reduced on the polygonal 3D model. A reduction of 90% means that the triangles have been reduced on the polygonal 3D model, and only 10% of all the triangles that make up the polygonal 3D model have remained. Triangle reduction was performed on the entire polygonal 3D model with reduction values of 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%.

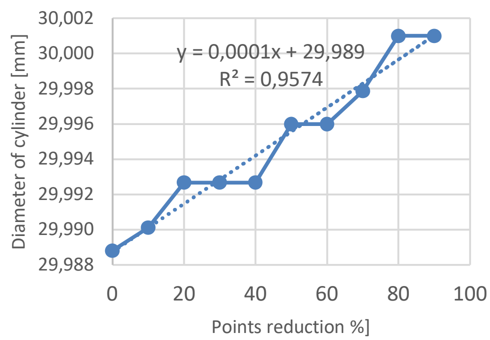


Fig. 8. The impact of reducing the number of points on the diameter of a cylinder

To verify the impact of the number of points on the accuracy of the attached element, a cylindrical surface, according to Figure 6, was used. Figure 8 shows a graph that shows the diameter of the cylindrical surface (mm) depending on the reduction (%) of the cylindrical polygonal mesh. The cylindrical polygon mesh has been reduced similarly to the polygonal 3D model from 90% to 0%. The same parameters were always used to attach the cylindrical surface to the polygonal mesh (middle attachment, all points were selected). After creating the cylindrical surface, the diameter of the cylindrical surface was obtained through the dialogue window of the corresponding 3D object. The number of points that make up the polygonal mesh of a polygonal 3D model is important when reducing triangles and subsequently creating an attached geometric element.

5. CONCLUSION

Reverse geometric modelling is carried out in CAD software with an appropriate RE module or in CARE software, where the reconstruction of a polygonal 3D model uses functions that facilitate the reverse creation of a 3D CAD model. An important role in the reconstruction of a polygonal 3D model is played by the data obtained by 3D digitisation. The sample part used in the experimental work was digitised by an industrial computer tomograph METROTOM 1500. The most common method in reverse geometry modelling is to fit elements to a polygonal mesh based on the shape of the elements composing the 3D model. This fitting method was applied to a polygonal cylindrical mesh using various techniques such as point reduction, smoothing, and attachment surface diameter determination based on point number. Reducing the number of points on the polygonal mesh of the cylinder increases the resulting diameter. The impact of altering the number of points can be seen in the diameter values of the reconstructed cylindrical surface. When using the full set of 26934 points of a polygonal mesh of cylinder, the diameter was measured at 29.898 mm. However, when the number of points was reduced by 90% to 2385, the diameter increased to 30.001mm. When utilising the polygon mesh smoothing feature, it is worth noting that the values of 0.2 and 0.5 are particularly noteworthy as they result in a significant reduction in the diameter of the reconstructed cylindrical surface. However, as the smoothing value increases, the reconstructed surface's diameter remains constant.

6. ACKNOWLEDGEMENT

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MODELARE GEOMETRICĂ INVERSĂ CA PARTE A REVERSE ENGINEERING - PRECIZIA DE APROXIMARE A UNUI CILINDRU

Rezumat: Această cercetare investighează modelarea geometrică inversă în software-ul CAD PowerShape pentru reconstrucția modelelor 3D poligonale. Procesul utilizează funcții specializate pentru modelarea inversă în crearea modelelor CAD 3D. Parte integrantă a acestui proces este integrarea datelor de digitalizare 3D, cu o piesă de eșantion digitalizată folosind computerul tomograf industrial METROTOM 1500. Studiul aplică metoda de aproximare la o rețea cilindrică poligonală, folosind tehnici precum reducerea punctelor, netezirea și ajustarea diametrului suprafeței bazată pe norul de puncte. Este de remarcat că numărul de puncte de pe rețeaua cilindrului influențează direct diametrul rezultat. Reducerea punctelor mărește diametrul; de exemplu, 26.934 de puncte creează un diametru de 29.898 mm, în timp ce o reducere de 90% la 2.385 de puncte rezultă într-un diametru de 30.001 mm. Cercetarea evidențiază efectul netezirii rețelei poligonale, cu valori de 0,2 și 0,5 reducând semnificativ diametrul suprafeței cilindrice reconstruite. Cu toate acestea, o netezire ulterioară nu modifică diametrul.

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