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Modeling the shape of additive manufactured parts

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Abstract. The additive manufactured parts can be made by the use of suitable layer thicknesses of the polymer in order to respect the requirements of a refined geometry and of a surface appearance of the physical object that should be as similar as possible to the original CAD model. An other important variable is the digital datum that can represent a key variable of the realization procedure. The methodology proposed and followed in the present investigation got the objective to get a physical model, through the information obtained by a 3D scanning device, taking into consideration not only the digital treatment but also the building direction to guide the FDM layer deposition in order to realize the required surface appearance. The profiles of the specimen in the digital environment were compared to each other before realizing. The physical object obtained after digital treatment was similar to the one obtained by the original CAD.

Introduction

The prototyping is very useful in the initial phases of the project in order to verify some important features of the object to be definitively realized. In particular those related to the concept, geometrical and ergonomic characteristics. Sometimes such prototypes in particular for polymers got also properties very similar to those obtained by other technologies. For example injection molding widely used in fields when too much resistance values are not required.

The quality of the manufactured component is a function of the technology utilized and, in the sector of the additive manufacturing, on the type of technique among FDM, SLA, polyjet, etc. In particular the layer thickness and the deposition strategy, also represented by the building direction, are the main variables of the manufacturing process.

In addition the digital information for model realization represents an other variable affecting the process. In general the information to the 3D PRINTER is given by the Computer Aided Design and the geometrical information translated into some working formats like those based on the Standard Triangulation Language initially applied on STereoLithography some tens of years ago. Such formats are used by some researchers [1] and by the authors in previous works [2]. But, the input information can be also supplied to the management software of the machine unit using directly control nodes of the realized elements such as curves, surfaces, solids and composition of them [3]. The problem is represented by the amount of information sent into the machine software to generate the control instructions. That means time consumption and queues in processing digital data with related errors in loading and redundant instruction generation.

For this reason the STL represents a simplification in terms of digital information due to the approximation of the surface of the object to be realized with a surface characterized by an elevated number of triangles connected to each other by their vertices or nodes. The solid appearance of the digital object is represented by the versus of surface normal of each triangle. The external versus means a solid object while the internal versus a cavity or hole. Under these conditions the file format and the approximation to the original digital geometry play a key role in the precision of the input file in terms of geometry and then on the physical object respect of requirements [2-4]. Of course smoother and more accurate is the surface of the object better the STL approximation is. The improvement can be in general obtained managing the approximation tolerance in terms of the distance between the surface of the triangle to the original surface of the object and/or in terms of the number of triangles of the approximating surface.

The problem is represented by the description of the approximating surface when the geometry is detected by some 3D SCANNERS or similar techniques by which is possible to acquire the entire surface of the physical object or part of that. The technique of acquisition naturally determines the quality of the digital information with some musts represented by reduced setup and detection times. Normally but not always the acquired information is represented by a cloud of nodes that can be translated in the different available formats [5]. STL is one of them able to represent with a generally low amount of storing memory the acquired surface of the physical object. Such technique is very useful when some digital archives need to be realized about already existing geometries or when the realized geometry needs to be compared with original one in the computer aided environment [6,7]. Such procedure is very useful when simple geometries are detected while still represents a newness for those geometries characterized by complicated structural elements such as double curvature surfaces [6]. In particular when they are connected with planar ones. When using the described tools some computing phases need to be performed before comparing the detected with the original ones. The level of computing must be of course as high as high is the building performance of the RP machine used [8]. In particular the building strategy represents the key variable to tune other than the layer thickness in order to get a physical model respecting given geometrical requirements.

Considering that a methodology is proposed in order to evaluate the building direction variable in obtaining a FDM physical object, starting from the digital data acquired by a 3D SCANNER on photopolymerized physical model, as similar as possible to that given by the same technique when using original information. A compact FDM machine was used for the purpose with a digital input supplied with the STL format. The digital model was treated in order to increase the quality of the geometry up to the one of the original STL. It was observed that different digital treats are required when different building directions are considered.

Methodology, Digital Treatments and Experiments

Methodology.

The present investigation aims at proposing and applying a methodology to manage the digital data points given by a 3D scanning of an high quality complex surface made in a UV photopolymer shown in Fig.1. In order to use those as input for realizing a physical object with a surface as similar as possible to the one of the original. The acquired geometry was refined in its surface and in the connection between the complex part of that and the planar one. This acting on lines and surface elements and on the number and typology of triangles composing the approximating STL. The main variable of the investigation is represented by the building direction when reproducing by FDM the digital models with and without treatments. The methodology is reported in Fig. 2.

Digital treatments.

The data cloud obtained by the 3D scanner using LED-CMOS systems in order to get the shape of the physical object were computed by CAD in different ways, some of them reported in a previous research of the authors [2] in order to solve the problem of the connection between the complex part of the component represented by the dome and the planar part of that represented by the basis. Fig. 3 shows the particulars of the photopolymer model acquired as digital information. The digital treat was made considering a planar basis of 5.5 mm in order to include the defective scanned zone of the component and then rebuilding completely the basis with a thickness of 5.2 mm. After that the digital model was treated in the STL format improving the number of triangles approximating the CAD surface and applying some smoothing sequences using the Materialise software.

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Fig. 1. Photopolymer model utilized to get the digital information by 3D SCANNING.

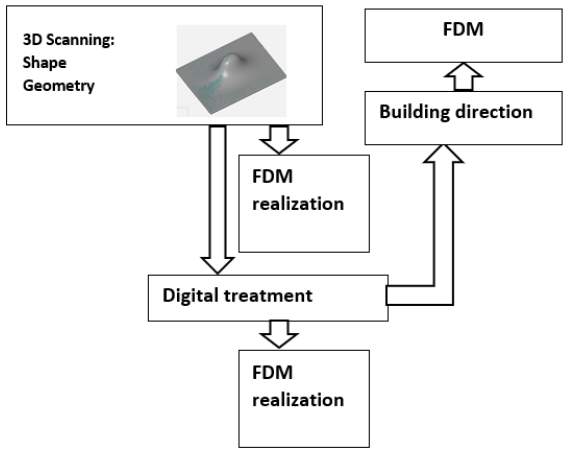
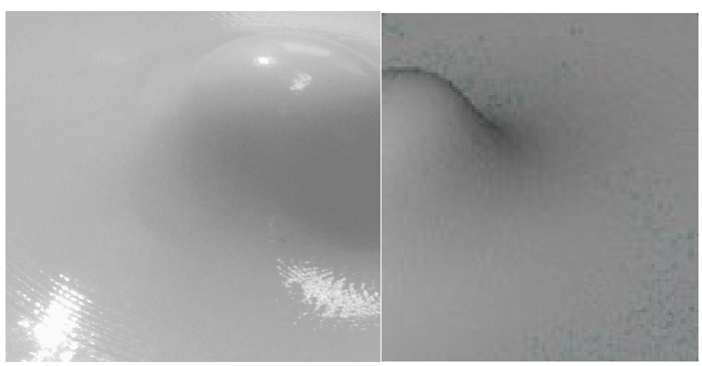


Fig. 2. Methodology.



a) b)

Fig. 3. Particulars of the physical photopolymer (a) model and of the STL (b) obtained by the scanning device.

CAD profiles of the shape.

The profiles captured on the original shape in the CAD environment were reported by two equations.

The equation of the profile of the original CAD model in the longest direction:

$$y = -8E\text{-}07x^6 + 6E\text{-}05x^5 - 0.0012x^4 - 0.0091x^3 + 0.4423x^2 - 0.8688x + 0.549 \quad (1)$$

and the equation of the profile in the shortest direction:

$$y = 2E\text{-}08x^6 - 4E\text{-}06x^5 + 0.0002x^4 - 0.003x^3 - 0.0234x^2 + 0.0015x + 24.554 \quad (2)$$

where y represents the axis along the height of the dome and x the one on the basis in the longest and in the shortest directions respectively.

All of the digital models were realized by FDM after the comparison of the original CAD profiles with STL like shown in Table 1.

Table 1. CAD and STL main profiles.

CAD	STL
Original profiles by Eq. (1) and Eq. (2).	Profiles given by CAD. Profiles given before digital treatment. Profiles given after final digital treatment.

Realization of the physical objects.

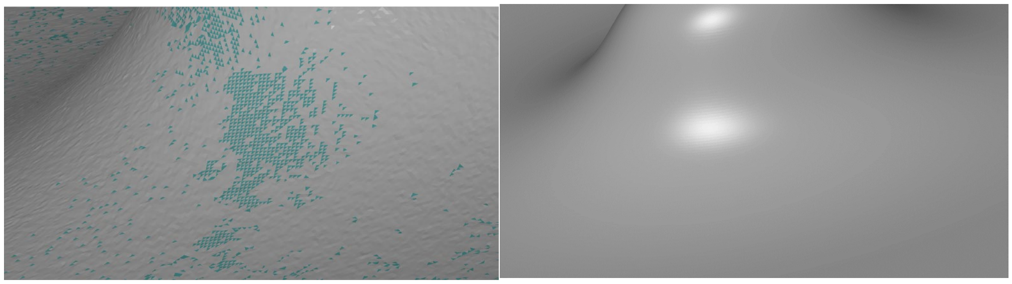
The manufactured components were realized by a FDM compact machine taking into consideration the building direction. In one specimen the building direction was parallel to dome axis of the model while in the other the building direction was perpendicular. A 0.2 mm thickness layer was used with a filament in PLA material and a temperature of the extruder between 215 and 220°C selected. The scanning velocity of the extruder was 100 mm/s during working and 150 mm/s in idle movements. The comparison among the different physical models realized was made taking into consideration the CAD information, that without and with digital treatment along different building directions.

Results and Discussion

Digital treatments.

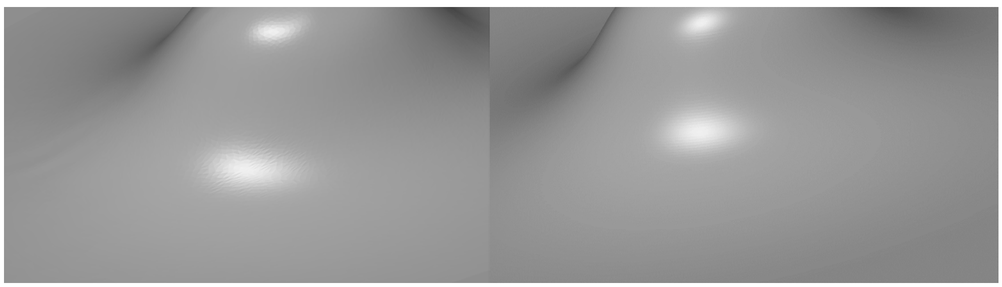
They were made in terms of the rebuilding of some reference nodes, lines and surfaces with related control points normally in the critical connections between the complex part of the model and the less complicated part represented by the planar basis. Such problem was already reported by the authors in a previous work of some of them [2]. Those are zones in which the building in the CAD environment requires the due attention and the digital data obtained by the scanning devices need to be always verified in order to be sure that the connections be always ensured. The lack means continuity solutions in the surface of the digital and subsequently of the physical models over those typical of scanning devices [8] and of the 3D printers [9].

Some of these problems may be corrected directly acting on the control points as described preserving the cloud points of the complex part when possible. The STL should be a subsequent way to simplify the problem by considering a surface alone able to approximate the whole mathematical elements of the model prior and after the treatments. The connection problems sometimes evidenced their effects in the physical realized models directly and in those realized by digital information obtained by the scanner. In Fig. 3a) the light waviness at basis of the photopolymerized model is evidenced and captured by the 3D scanning and sometimes amplified depending on the acquisition time, on the device and on some diffusive modes of the LED based light used by the SCANNER (fig. 3b). In Figs. 4a) and 4b) the comparison between 3D scanned STL after basis rebuilding and original STL is reported. After triangle refinement and smoothing the comparison can be observed in figs. 5a) and 5b). The improvement of the surface of the digital model was made using the Materialise software by which a further discretization of the triangulation representing the approximation to the cloud surface detected by the scanning device is made. In that way the dome surface is better described and the connection with the rebuilt plane improved.



a) b)

Fig. 4. STL 3D scanned surface (a) and the STL obtained directly by the original CAD (b).



a) b)

Fig. 5. STL 3D scanned surface after digital treatments (a) and STL obtained directly by the original CAD (b).

Profiling.

The different profiles were computed in the CAD environment supported by image analysis techniques and then compared. The equations of the two semi-profiles are reported in the previous paragraph.

The comparison between the STL profile obtained directly by the CAD original model, the profile plot of points of the original CAD model and the STL obtained by the digital rebuilt model is made in the Fig. 6. An excellent approximation to the original profile is obtained in the STL standard.

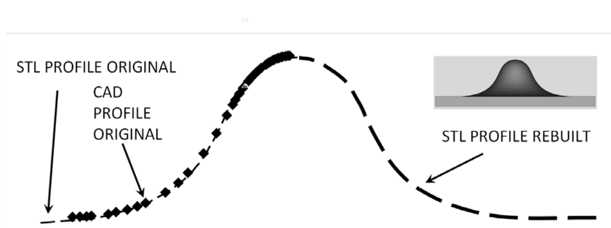
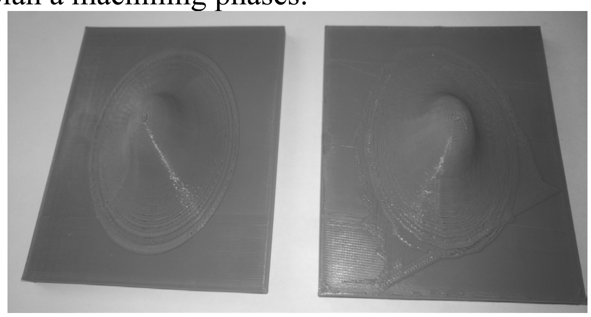


Fig. 6. Comparison between different profiles obtained along one direction of the object: CAD, STL and STL after digital rebuilding.

Realization of the FDM physical objects.

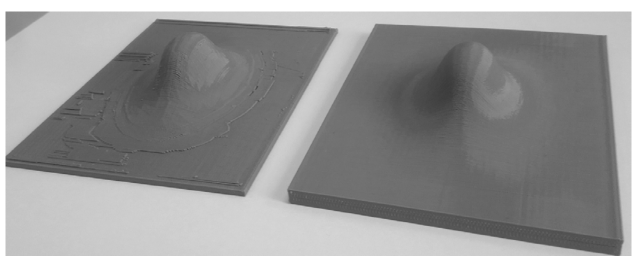
In Fig. 7 the comparison between the FDM models realized directly by the original CAD and that generated by the scanning device with the building direction parallel to the dome axis is shown. The problem at the basis is clearly observed. When the building direction is perpendicular to the dome axis the FDM produces its best performance and then the continuity solutions appear evidenced and the difference highlighted as in Fig. 8. In both the cases the waviness detected by the 3D SCANNER is copied on the FDM model reporting not only the original information of the model geometry but also that of the physical photopolymer model from which the digital data were initially acquired. The connection problem to the basis due to the difficulty to catch at the same time the complex part of the model and plan part exists in that phase.

In Fig. 9 the FDM physical objects were realized from digital information detected by the 3D SCANNER after some reported treatments in order to allow the connection between the dome and the planar surface. By such operation the planar level is improved and the connection rebuilt. Such improvement appears able to describe the physical model when the building direction is parallel to the dome axis. But some continuity solutions still persist when the building direction perpendicular to the dome axis is applied as can be seen in Fig. 10. It means that the configuration perpendicular to the building axis requires further digital treatments in order to get a geometry as similar as possible to the one obtained when the original CAD is considered. Further corrections of the geometrical elements, the increase in the triangulation density as well as the smoothing of the STL surface permit the increase in the quality of the surface appearance of the FDM physical object like shown in Fig. 11. In other words the profiles of Fig. 6 are correctly reproduced on the realized models. In this way the FDM physical object appears similar to the surface of the original FDM without the need to plan a machining phases.



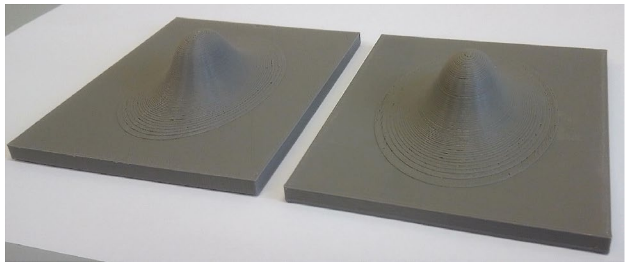
a) b)

Fig. 7. Comparison between FDM physical object realized by the CAD original data (a) and that directly obtained by the 3D scanning device information (b) with building direction parallel to the dome axis.



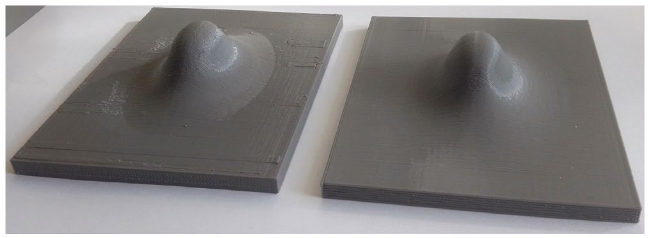
a) b)

Fig. 8. Comparison between the physical object obtained by the digital data directly given by the 3D scanning device (a) and model made by FDM considering the original CAD data (b) with building direction perpendicular to the dome axis.



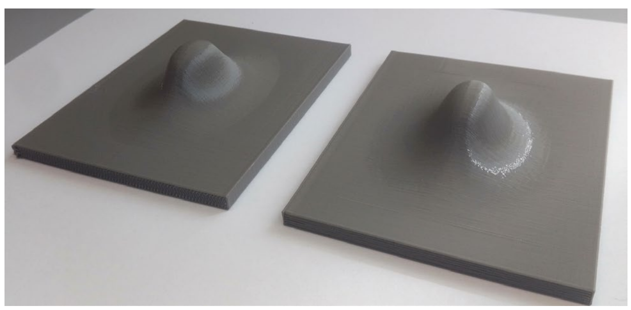
a) b)

Fig. 9. Comparison between the FDM model obtained after digital treatments (a) and that given by the original CAD (b) with the building direction parallel to the dome axis.



a) b)

Fig. 10. Comparison between the FDM model obtained after the digital treatment (a) and that given by the original CAD (b) with the building direction perpendicular to the dome axis.



a) b)

Fig. 11. Comparison between the FDM model obtained after further digital treatment (a) and that given by the original CAD (b) with the building direction perpendicular to the dome axis.

The results can be reported in terms of the dome height. In particular the realized FDM object obtained by the 3D SCANNING device with the building direction perpendicular to that gives an height of 20.52 mm with a thickness basis of 2.63 mm. The rebuilt model without the final digital treatment is about 23.68 mm while the one obtained after is about 23.6 mm. The original data get a FDM model with a dome height of about 23.79 mm.

Such results are very useful in particular when these methodologies, as already reported by other authors [10,11], need to be applied in a manufacturing system.

Summary

The investigation aims at defining the best profile shape of the STL model under given conditions taking the dome reference from a 3D SCANNED one and by applying different digital treatments in the computer aided environment in order to get a physical result as similar as possible to that obtained by the original CAD information. In the realization of the FDM models the building direction variable is considered.

First of all the basis of the STL model was rebuilt and the connection with dome properly managed. But such digital treatment was able only to permit the realization of a FDM physical model with a building direction parallel to the dome axis. With a further treatment consisting mainly in a heavy refinement of the triangles approximating the cloud points a smoother surface of the dome than before was obtained. The final treatment got a profile very close to the STL of the original CAD model as shown by the comparison of them and to the original CAD information described by two equations obtained through the longest and shortest sides of the model.

Finally, the comparison between the two main FDM physical models, in particular the one obtained directly by the original CAD and the other one given after the digital treatment of 3D scanned data allows to state that they are similar to each other. Under the conditions of the present investigation when treating polymers the building direction represents the key variable for the obtaining physical surfaces respecting requirements. To do that many digital treatments are required.

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