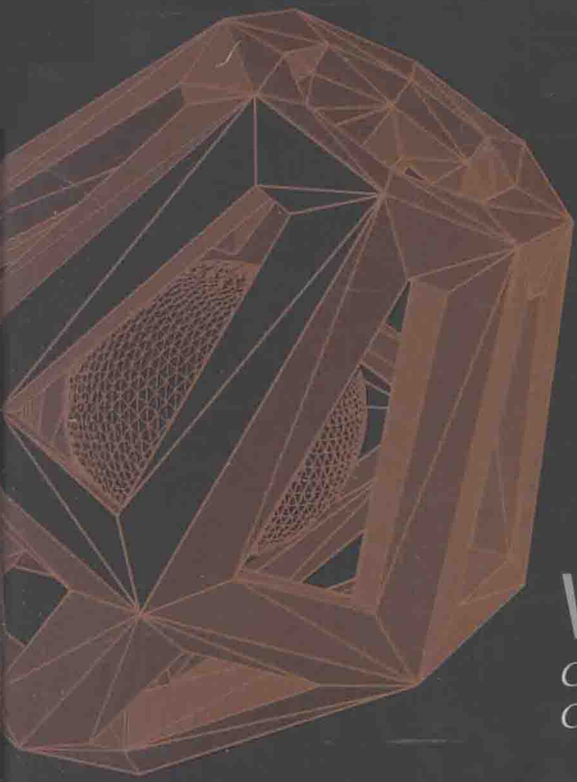


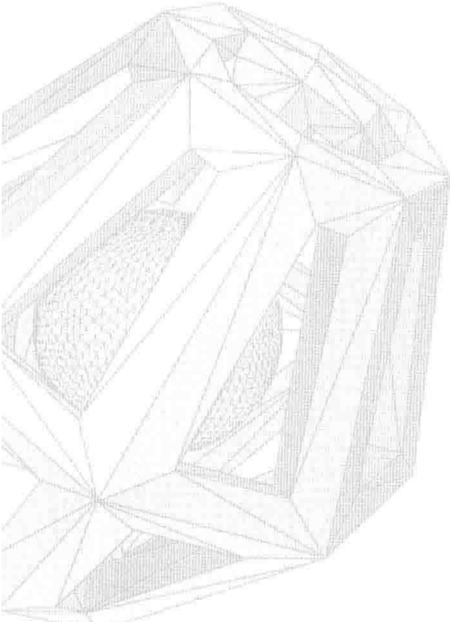
Vol. 4

Computer Aided Design /
Computer Aided Manufacturing (CAD/C

Computer Aided and Integrated Manufacturing Systems

A 5-Volume Set

Cornelius T Leondes



Vol. 4

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Preface

Computer Technology

This 5 volume MRW (Major Reference Work) is entitled "Computer Aided and Integrated Manufacturing Systems". A brief summary description of each of the 5 volumes will be noted in their respective PREFACES. An MRW is normally on a broad subject of major importance on the international scene. Because of the breadth of a major subject area, an MRW will normally consist of an integrated set of distinctly titled and well-integrated volumes each of which occupies a major role in the broad subject of the MRW. MRWs are normally required when a given major subject cannot be adequately treated in a single volume or, for that matter, by a single author or coauthors.

Normally, the individual chapter authors for the respective volumes of an MRW will be among the leading contributors on the international scene in the subject area of their chapter. The great breadth and significance of the subject of this MRW evidently calls for treatment by means of an MRW.

As will be noted later in this preface, the technology and techniques utilized in the methods of computer aided and integrated manufacturing systems have produced and will, no doubt, continue to produce significant annual improvement in productivity — the goods and services produced from each hour of work. In addition, as will be noted later in this preface, the positive economic implications of constant annual improvements in productivity have very positive implications for national economies as, in fact, might be expected.

Before getting into these matters, it is perhaps interesting to briefly touch on Moore's Law for integrated circuits because, while Moore's Law is in an entirely different area, some significant and somewhat interesting parallels can be seen. In 1965, Gordon Moore, cofounder of INTEL made the observation that the number of transistors per square inch on integrated circuits could be expected to double every year for the foreseeable future. In subsequent years, the pace slowed down a bit, but density has doubled approximately every 18 months, and this is the current definition of Moore's Law. Currently, experts, including Moore himself, expect Moore's Law to hold for at least another decade and a half. This is impressive with many significant implications in technology and economies on the international scene. With these observations in mind, we now turn our attention to the greatly significant and broad subject area of this MRW.

"The Magic Elixir of Productivity" is the title of a significant editorial which appeared in the *Wall Street Journal.* While the focus in this editorial was on productivity trends in the United States and the significant positive implications for the economy in the United States, the issues addressed apply, in general, to developed economies on the international scene.

Economists split productivity growth into two components: Capital Deepening which refers to expenditures in capital equipment, particularly IT (Information Technology) equipment: and what is called Multifactor Productivity Growth, in which existing resources of capital and labor are utilized more effectively. It is observed by economists that Multifactor Productivity Growth is a better gauge of true productivity. In fact, computer aided and integrated manufacturing systems are, in essence, Multifactor Productivity Growth in the hugely important manufacturing sector of global economies. Finally, in the United States, although there are various estimates by economists on what the annual growth in productivity might be, Chairman of the Federal Reserve Board, Alan Greenspan — the one economist whose opinions actually count, remains an optimist that actual annual productivity gains can be expected to be close to 3% for the next 5 to 10 years. Further, the Treasure Secretary in the President's Cabinet is of the view that the potential for productivity gains in the US economy is higher than we realize. He observes that the penetration of good ideas suggests that we are still at the 20 to 30% level of what is possible.

The economic implications of significant annual growth in productivity are huge. A half-percentage point rise in annual productivity adds $1.2 trillion to the federal budget revenues over a period of ten years. This means, of course, that an annual growth rate of 2.5 to 3% in productivity over 10 years would generate anywhere from $6 to $7 trillion in federal budget revenues over that time period and, of course, that is hugely significant. Further, the faster productivity rises, the faster wages climb. That is obviously good for workers, but it also means more taxes flowing into social security. This, of course, strengthens the social security program. Further, the annual productivity growth rate is a significant factor in controlling the growth rate of inflation. This continuing annual growth in productivity can be compared with Moore's Law, both with huge implications for the economy.

The respective volumes of this MRW "Computer Aided and Integrated Manufacturing Systems" are entitled:

Volume 1: Computer Techniques
Volume 2: Intelligent Systems Technology
Volume 3: Optimization Methods
Volume 4: Computer Aided Design/Computer Aided Manufacturing (CAD/CAM)
Volume 5: Manufacturing Process

A description of the contents of each of the volumes is included in the PREFACE for that respective volume.

There is really very little doubt that all future manufacturing systems and processes will utilize the methods of CAD/CAM (Computer Aided Design/Computer Aided Manufacturing), and this is the subject of Volume 4. Key to the processes of CAD/CAM is the generation of three dimensional shapes, a subject treated at the beginning of this volume, 2D assembly drawings are what are generally utilized for conversion to 3D part drawings in the CAD process in order to generate three dimensional shapes for the CAM process, and this is treated in depth and rather comprehensively in this volume. The evolution of a design process and product is often referred to as an adaptive growth representation in the CAD process and this receives necessary treatment in this volume. Fixture designs for the manufacturing process utilize modular elements, and the CAD methods for this essential process are treated rather comprehensively in this volume. Finite element techniques are becoming a way of life for CADS and CAE (Computer Aided Engineering) and rather powerful optimization techniques for processes involved here are also treated in depth in this volume. Rapid prototyping techniques are now a way of life in manufacturing systems, and CAD techniques for this are presented in this volume. These and numerous other techniques are treated rather comprehensively in this volume.

As noted earlier, this MRW (Major Reference Work) on "Computer Aided and Integrated Manufacturing Systems" consists of 5 distinctly titled and well-integrated volumes. It is appropriate to mention that each of the volumes can be utilized individually. The significance and the potential pervasiveness of the very broad subject of this MRW certainly suggests the clear requirement of an MRW for a comprehensive treatment. All the contributors to this MRW are to be highly commended for their splendid contributions that will provide a significant and unique reference source for students, research workers, practitioners, computer scientists and others, as well as institutional libraries on the international scene for years to come.

Contents

CHAPTER 1

GENERATION OF THREE-DIMENSIONAL SHAPES IN CAD/CAM SYSTEMS USING ART-TO-PART TECHNIQUE

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In some industries, products have elements of complex engraving or low relief on them. Traditionally, such work is carried out by skilled engravers working from 2D artwork manually. This process is costly, open to unwanted misinterpretations and lengthens the design cycle. This research presents the Art-to-Part technique which relies on computers and automation from the scanning of 2D artwork, to 3D surface and relief generation, and finally to the fabrication of the model by rapid prototyping. The technique links design to manufacturing stages together and reduces the whole production time. Furthermore, the quality is increased and reproducibility and reliability are ensured, as demonstrated in the 3 case studies.

Keywords: 3D relief; Art-to-Part; CAD/CAM; rapid prototyping.

1. Introduction

There are presently numerous commercially-available software for product design for a particular range of industries which include ceramics, glassware, bottle making, both plastic and glass, jewelry, packaging and food processing for molded products and products produced from forming rolls, coins and badges, and embossing rollers.[1–3] All of these industries share a common problem: most of their products have elements of complex engraving or low relief on them.[4] Traditionally, such work is carried out by skilled engravers either in-house or more often by a third-party sub-contractor, working from 2D artwork. This process is costly, open to unwanted misinterpretation of the design by the engraver and most importantly, lengthens the time of the design cycle.

Advances in manufacturing technology allow many industries to upgrade and change their usual production practices from labor-intensive to automated and computerized methods. With these changes, the production cycle time and cost could be reduced tremendously with an improvement in the quality of the product. In recent years, computer-aided design and computer-aided manufacturing (CAD/CAM) have become very popular, especially in the manufacturing industries. It links the designing and manufacturing stages together and thus reduces the whole production time. It is a significant step toward the design of the factory of the future.[5]

2. Art-to-Part Process

The use of CAD/CAM and Stereolithography Apparatus (SLA) reduces the time required for design modifications and improvement of prototypes. The steps involved in the art-to-part process include the following:

1. Scanning of artwork
2. Generation of surfaces
3. Generation of 3D relief
4. Wrapping of relief on surfaces
5. Converting triangular mesh files to STL file
6. Building of model by the SLA.

The flow of this series of stages is illustrated using coin design as a case study. Figure 1 shows the steps involved in the art-to-part process.

2.1. *Scanning of artwork*

The function of scanning software is to create a 2D image from 2D artwork automatically or semi-automatically. It would normally be applied in cases where it would be too complicated and time consuming to model the part from a drawing using existing CAD techniques.

The 2D artwork is first read into ArtCAM, the CAD/CAM system used for the project, using a Sharp JX A4 scanner. Figure 2 shows the 2D artwork of a series of Chinese characters and a roaring dragon. This combination of hardware and software allows the direct production of a standard image from the artwork, which can be read directly into ArtCAM. The 2D artwork in such instances represent the designs to be used on the face of the coin.

In the ArtCAM environment, the scanned image is first reduced from a colour image to a monochrome image with the fully automatic "Gray Scale" function. Alternatively, the number of colours in the image can be reduced using the "Reduce Colour" function. A colour palette is provided for colour selection and the various areas of the images are coloured, either using different sizes or types of brushes or the automatic flood fill function. Figure 3 illustrates the touched-up image.

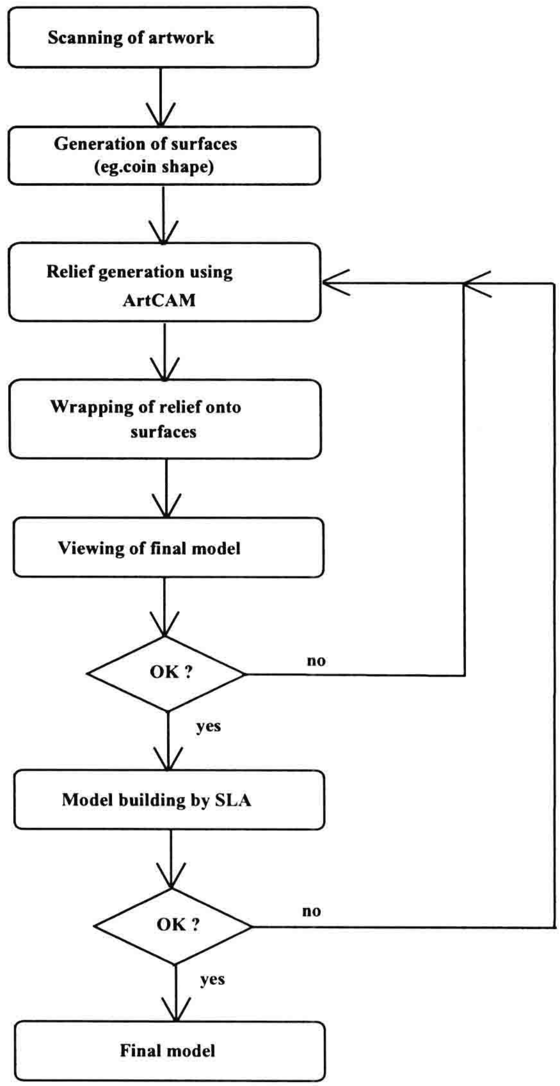

Fig. 1. Steps involved in the Art-to-Part process.

2.2. *Generation of surfaces*

The shape of a coin is generated to the required size in the CAD system for model building. Figure 4 shows the shape of a coin model generated. A triangular mesh file is produced automatically from the 3D model. This is used as a base onto which the relief data is wrapped and later combined with the relief model to form the finished part.

Fig. 2. 2D artwork.

Fig. 3. Touched-up image.

2.3. *Generation of 3D relief*

The next stage in creating the 3D relief is to assign each colour in the image a shape profile. There are various fields which control the shape profile of the selected coloured region, namely, the overall general shape for the region, the curvatures of

Fig. 4. Shape of a coin model.

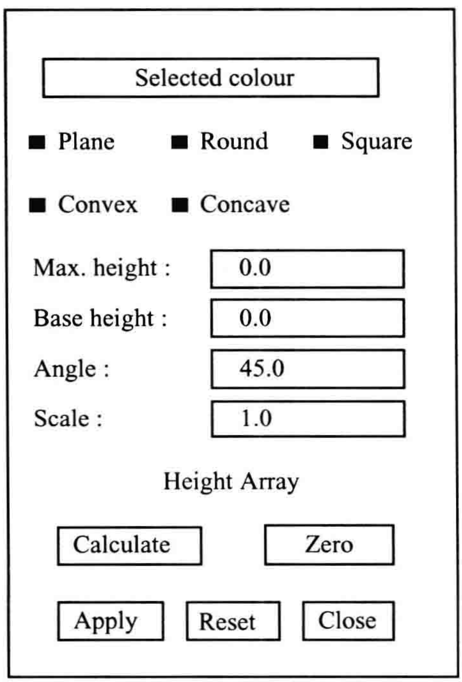

Fig. 5. Control panel for the shape profile.

the profile (convex or concave), the maximum height, base height, angle and scale. Figure 5 shows the control panel for the shape profile.

There are three possibilities for the overall general shape; a plane shape profile will appear completely flat, whereas a round shape profile will have a rounded cross section and lastly, the square shape profile will have straight angled sides. Figure 6 illustrates the various shapes of the 3D reliefs. For each of these shapes, there is an option to define the profile as either convex or concave.

The square and round profiles can be given a maximum height. If the specified shape reaches this height, it will 'plateau' out at this height giving in effect a flat region with rounded or angled corners, depending on whether a round or square shape was selected for the overall profile respectively (see Fig. 6).

The overall profile height, which covers the respective region, can be controlled by specifying the required angle of the profile which represents the tangent angle of the curve at the edge of the region. Figure 7 further illustrates the concept of the overall profile height. An alternative to control the overall profile height is to use the 'scale' function to flatten out or elevate the height of the shape profile

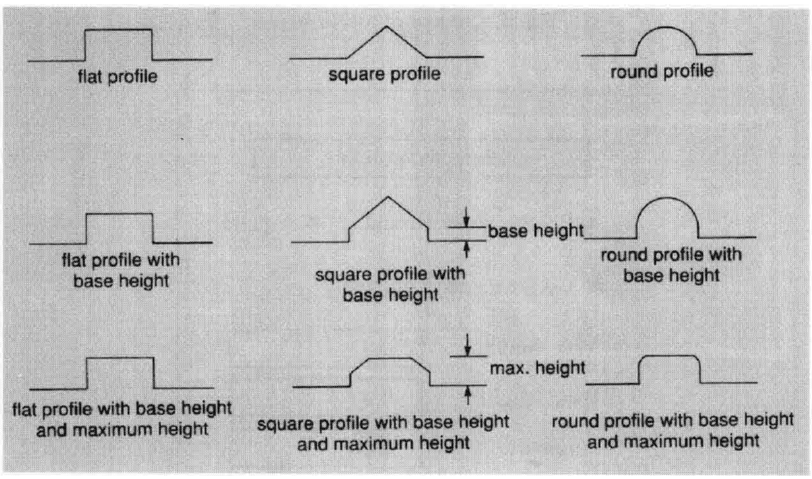

Fig. 6. Various shapes of the 3D relief.

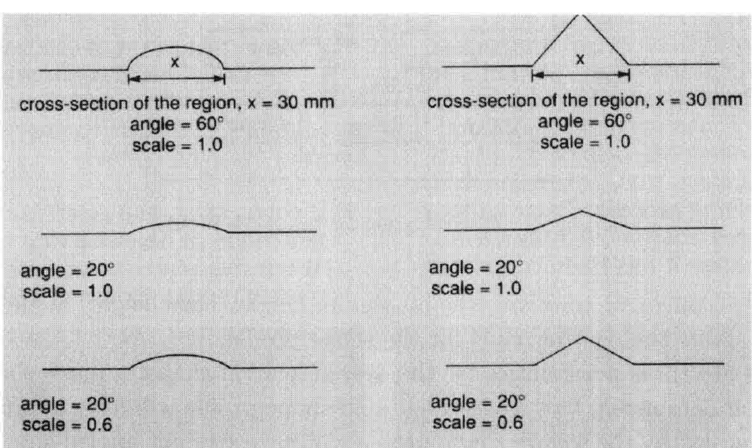

Fig. 7. An illustration of the overall profile height.

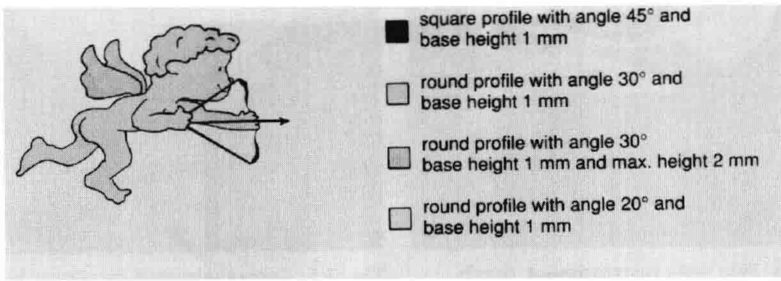

Fig. 8. An illustration of the definition of shape profiles on different regions.

Fig. 9. 3D relief of an artwork.

(see Fig. 7). The relief detail can be examined in a dynamic Graphic Window within the ArtCAM environment itself. Figure 8 shows an illustration of the definition of shape profiles on different regions. Figure 9 illustrates the 3D relief of an artwork.

2.4. *Wrapping of relief on surfaces*

The 3D relief is next wrapped onto the triangular mesh file generated from the coin surfaces using the command Wrap (see Fig. 10). This is a true surface wrap and not a simple projection. The wrapped relief is also converted into triangular mesh files (see Fig. 11). The triangular mesh files can be used to produce a 3D model suitable for colour shading and machining. The two sets of triangular mesh files, of the relief and the coin shape, are automatically combined (see Fig. 12). The resultant model file can be colour-shaded and used by the SLA to build the prototype (see Fig. 13).

2.5. *Converting of triangular mesh file into STL file*

The STL format is originated by 3D System Inc. as the input format to the SLA, and has since been accepted as the *de facto* standard of input for Rapid Prototyping

Fig. 10. 3D relief wrapped onto coin surface.

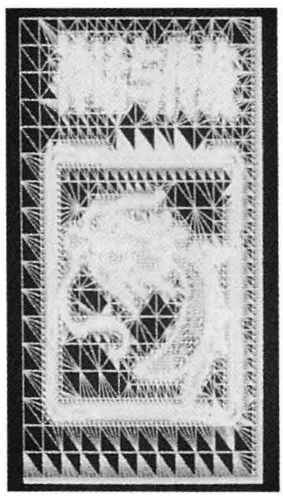

Fig. 11. Wrapped relief converted into triangular mesh files.

(RP) systems.[6–8] Upon conversion to STL, the object's surfaces are triangulated, which means that the STL format essentially consists of a description of inter-joining triangles that enclose the object's volume. The triangular mesh files are also triangulated surfaces, however, of a slightly different format (see Fig. 14). Therefore, an interface programme written in Turbo-C language was developed for the purpose of conversion. The converted triangular file adheres to the standard STL format as in Fig. 15. It has the capability of handling triangular files of huge memory size.

2.6. *Building of model by SLA*

Californian company 3D System Inc. pioneered the Rapid Prototyping (RP) technology when they released their commercial RP system in December 1988 — the

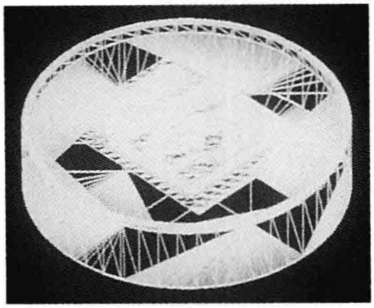

Fig. 12. 2 sets of triangular mesh files – relief and coin shapes are automatically combined.

Fig. 13. Colour-shaded resultant model file.

SLA-250 model of their Stereolithography Apparatus (SLA).[6,7] Stereolithography technology was first developed by Chuck Hall, 3D's founding president, in 1982. Stereolithography works by using a low-power Helium–Cadmium laser or an Argon laser to scan the surface of a vat of liquid photopolymer which solidifies when struck by a laser beam.

The SLA process chamber consists of a vat containing liquid photopolymer resin, a platform on which the object is to be built and whose height is controlled by an elevator mechanism, a re-coating blade wiper and a Helium–Cadmium or Argon laser subsystem. At the start of the object building process, the platform is positioned at a depth of one layer's thickness below the resin level. The laser will trace over areas of the resin surface defined by vectors as the cross-section of the first layer. The area where the resin is struck by the laser beam solidifies to form the first layer of the object. Subsequently, the platform is lowered by a distance equal to the layer thickness, pauses for about 15 seconds to allow the resin level to settle and the re-coating blade wipes over the resin surface to prepare the construction of the next layer as the process repeats itself. When the object has been completely built, the platform is raised above the vat of the resin to drain off the excess liquid resin that has adhered to the object. Figure 16 illustrates the building of prototype using the SLA.

```
DUCT 5.2 TRIANGLE BLOCK  P  18 AUG 1993 21.43.28
*
  1
 @1
1
GREEN
Paint Duct @1
    1      0      4      2      0
      0.00000     10.00000     0.00000     20.00000
      0.00000      0.00000     0.00000      0.00000
      0.00000      0.00000     1.00000      1.00000
      0.00000      1.00000     0.00000      1.00000
    0      0      0      0
      0.00000      0.00000     0.00000      0.00000
      0.00000      0.00000     0.00000      0.00000
      0.00000      0.00000     0.00000
      0.00000      0.00000     0.00000      0.00000
      0.00000      1.00000     0.00000      0.00000
     10.00000      0.00000     0.00000      0.00000
      0.00000      1.00000     0.00000      0.00000
      0.00000     20.00000     0.00000      0.00000
      0.00000      1.00000     0.00000      0.00000
     10.00000     20.00000     0.00000      0.00000
      0.00000      1.00000     0.00000      0.00000
        3          1          4
```

Fig. 14. The original triangular file format.

```
solid print
 facet normal -0.00000e+00  2.00000e+02  -0.00000e+00
  outer loop
   vertex  0.00000e+00  0.00000e+00  2.00000e+01
   vertex  0.00000e+00  0.00000e+00  0.00000e+00
   vertex  1.00000e+01  0.00000e+00  2.00000e+01
  endloop
 endfacet
 facet normal 0.00000e+00  2.00000e+02  0.00000e+00
  outer loop
   vertex  1.00000e+01  0.00000e+00  2.00000e+01
   vertex  0.00000e+00  0.00000e+00  0.00000e+00
   vertex  1.00000e+01  0.00000e+00  0.00000e+00
  endloop
 endfacet
```

Fig. 15. The converted triangular file to follow the STL format.