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# Investigation into Surface Finish of Parts Built by the EnvisionTec PerFactory® Rapid Prototyping Process

P M Hackney, G K Chinnaswamy, A C Arulraj, B T Nair,  
School of Informatics, Engineering and Technology,  
Northumbria University, Newcastle upon Tyne, United Kingdom.  
E-mail: phil.hackney@unn.ac.uk

## ABSTRACT

The PerFactory® technique from Envisiontec is unique in its method of manufacturing parts in discrete voxels, compared to the technique of smooth laser contouring implemented in the traditional SLA process. This method of approximating the contours with “Voxels” (3 dimensional pixels) has a pronounced effect on surface finish of the finished part. This work investigates the effect of pixel size, and also build angle and build direction on surface finish of parts built on the Envisiontec RP machine. A high surface finish is important because, apart from offering surfaces of high quality, it also helps to reduce post-processing time and to increase accuracy.

**Keywords:** Perfactory process, Surface finish, Layer thickness, Orientation, Pixels.

## 1. INTRODUCTION

### 1.1 The PerFactory® part building process

The PerFactory® technique utilises the technology called Digital Light Processing (DLP™) developed by Texas Instruments [1]. The process uses a high-powered, precise light projector working on the DLP™ technology, to polymerise a photosensitive resin layer-by-layer [2]. This polymerization is similar to that happening in SLA, but the laser positioning galvanic mirrors used in SLA are replaced by a DLP™ projector [3] with a mercury lamp. The galvanic mirrors in SLA trace the exact contours of the cross section [4], but the PerFactory® system builds each mask in discrete Voxels, approximating the boundaries. An illustration of the PerFactory® machine is shown in Figure 1. The method by which the Perfactory® and SLA techniques build a layer is shown in Figure 2.

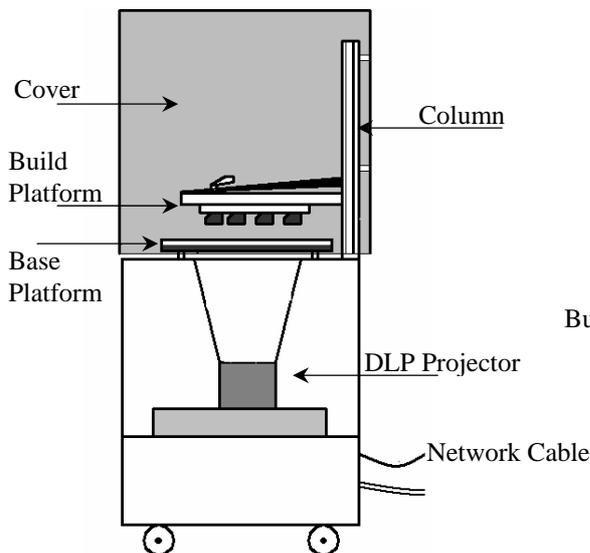


Figure 1 – The PerFactory® machine

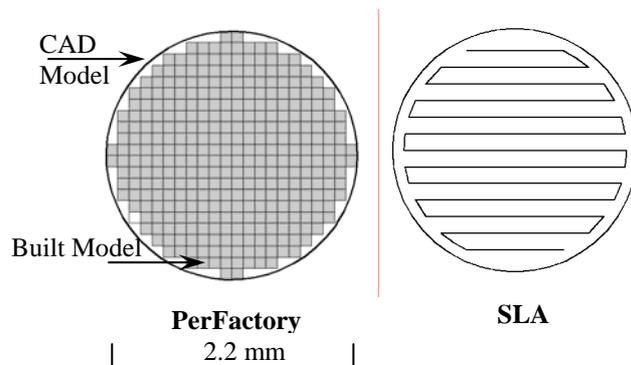


Figure 2 – Comparison of a layer built by the PerFactory® and SLA processes

The influence of build angle on the surface finish of a curved face that is built using “layer by layer” prototyping is shown in Figure 3.

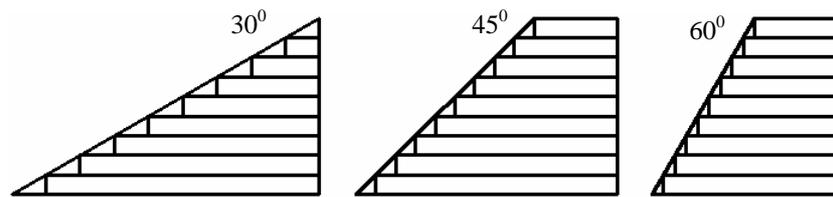


Figure 3 – Effect of build angle on surface finish

### 1.2 Need for good surface finish

Surface finish of rapid prototyped parts is a very important quality that is desired, be it a visual or a fit/function model. Poor surface finish results in poor accuracy and appearance. Certain prototyping techniques require manual post processing to impart acceptable levels of surface finish. But this practice is not advisable, since rapid prototyping is a time compression technique, and post processing would offset the gains made. Hence, the objective should be to impart acceptable level of surface finish as the part leaves the machine. The test sample that was built for surface finish measurements is shown in Figure 5.

### 1.3 Processes involved in formation of single layer

**Exposure:** This is the time for which the mask layer is projected onto the resin by the DLP™ projector.

**Peeling:** This refers to the action during which the base platform is pulled away from the newly formed layer, by a servomechanism. Peeling is achieved by pivoting the silicone base plate at the front, and pulling it down away from the build plate using a stepper motor driven mechanism.

**Waiting:** This is the period of time that the base platform waits at the bottom-most point, before returning to its original position.

**Levelling:** This refers to the action during which the base platform returns to its original position. This happens at a constant default velocity.

The above four processes are repeated for every layer.

#### Additional structures:

**Base Layers:** The build process starts by building a base layer, which acts as a foundation for the rest of the process. Default parameters are used for the base layer.

**Supports:** The building of supports is the next stage in the process. The supports are built with same parameters as that used the part.

## 2. SURFACE ROUGHNESS TESTS

The objective of these tests was to investigate the effect of pixel size, and also build angle and build direction on surface finish of parts built on the EnvisionTec RP machine. These terms are defined below, with the aid of the illustration in Figure 4.

**Pixel size:** This is the actual size of the pixels making up the mask, as projected by the DLP™ system. The smaller the build area, smaller will be the pixel size. Pixel size varies from 0.094mm to 0.148mm.

**Build angle:** This is the inclination of the face being built. In this work, all angles are measured with respect to the horizontal. Angles are marked by the symbol ‘ $\theta$ ’ in Figure 4.

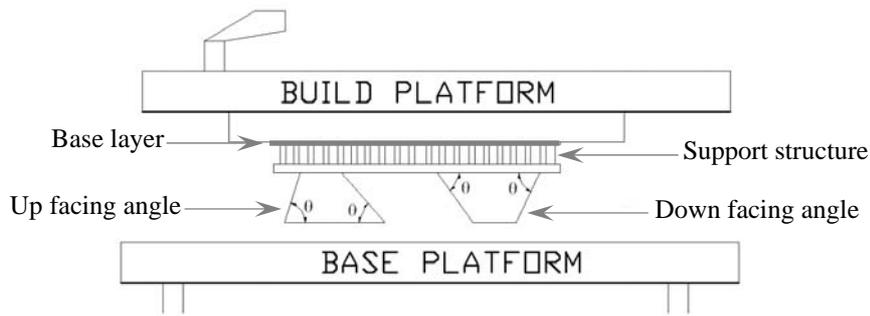


Figure 4 – Illustration of Up- and Down-facing angles

**Build direction:** This is the direction in which the angular face is being built. Direction can be classified as ‘Up’ or ‘Down’ facing. It has to be noted that parts are built upside down in the PerFactory® machine. In this work, all reference would be made to the direction that the angular face is oriented as it is being built on the platform.

### 2.1 Building the surface finish test parts

Simple test parts were built with 30, 45, 60 and 75 degree slopes on them, to study how the surface finish varied with angle. The parts were built with both up- and down-facing configurations of the afore-mentioned angles. They were built with a layer thickness of 0.05mm. Example of up and down-facing angles can be seen in Figure 4, and Figure 5 shows the model of the part that was built for the study.

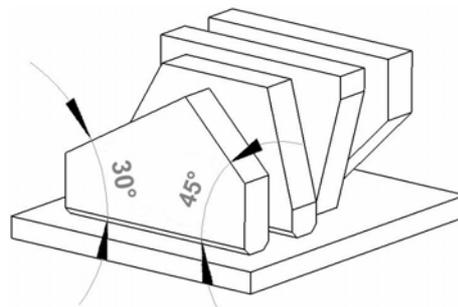


Figure 5 – The surface finish test sample

### 2.2 Testing the surface finish

The surface finish was measured with a Taylor Hobson Talysurf, for a cut-off length of 0.80mm for each measurement. The test set-up is shown in Figure 6. The results obtained are shown in Figure 7.

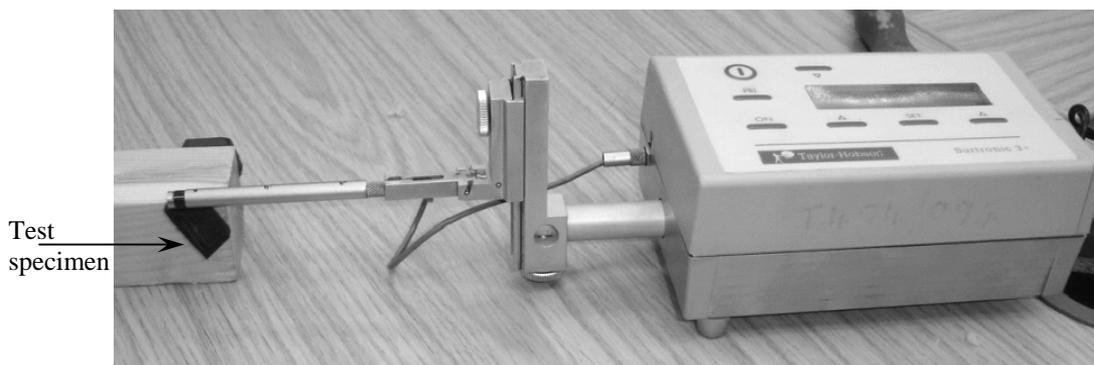


Figure 6 – Testing surface finish with a Taylor Hobson Talysurf

## 2.3 Results of the Surface Roughness test

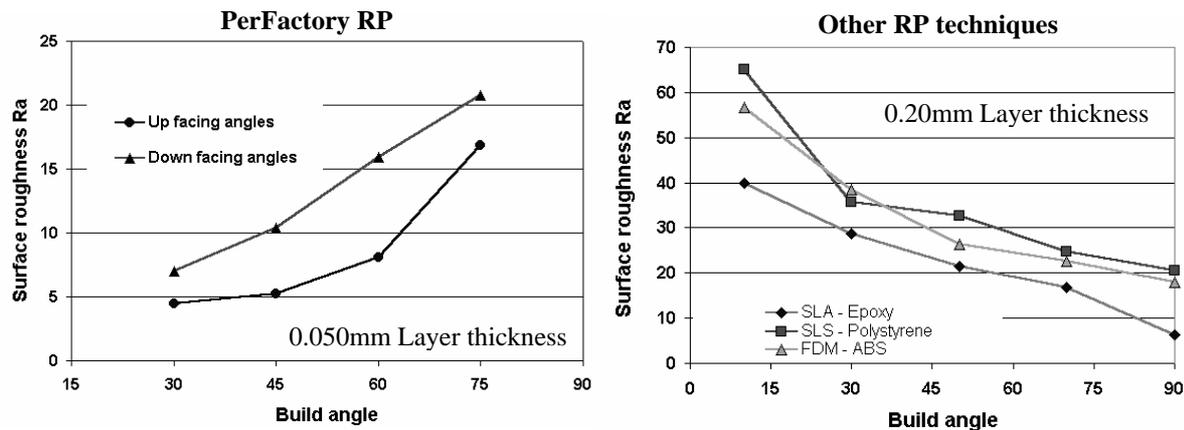


Figure 7 – Effect of build angle on RP part finish – Comparison

The results of the surface finish test are graphically represented in Figure 7a. It is observed that building in the Up facing direction consistently produced better results than in the Down direction, for the same parameters, layer thickness and build angles.

Another interesting trend can be observed when figures 7a and 7b are compared. It is seen that surface finish gets worse with increasing angle in the PerFactory® part, whereas the trend is exactly opposite for parts built on SLA, SLS and FDM [4]. The sensitivity of surface finish to build angle, for parts built on SLA, SLS, FDM and LOM techniques was also illustrated in Figure 3. The observation of this unique trend in the PerFactory® technique called for further analysis of the built specimen, as it seemed that the surface finish was not influenced by layer thickness and build angle alone, but also by some other additional factor.

Micrographs of the experimental parts were made, to study this behaviour further. The micrographs are shown in figure 8. This would also help us to understand how the steps were formed, in building the angular face. It would be beneficial to define certain terms at this stage, for better understanding.

**i. Layer thickness:** This is the thickness of the build layer as specified by the user. The build platform moves upwards by this value, for each layer. It is marked by the letter “L” in the figure 10. In this experiment, a layer thickness of 0.05mm (50 microns) was used.

**ii. Step thickness:** Steps are formed when angular faces are built layer by layer. The step size is influenced by layer thickness and build angle. Step thickness has two components: Along the direction of build and perpendicular to it.

- **Thickness along the build direction:** This is always more than the layer thickness and is a multiple of it. It is indicated by the letter “Y” in Figure 8.

- **Thickness perpendicular to build direction:** It is indicated by the letter “X” in Figure 8.

## 2.4 Magnified views of different Up and Down facing angles

The part shown in Figure 5 was built using default process settings, and the various up and down facing angles were studied under the optical microscope, and micrographs obtained. All the micrographs are shown in figure 8. The solid line at the top of each image represents the build platform, and the block arrow signifies the direction in which the layers are added progressively.

Micrographs of different build angles and directions

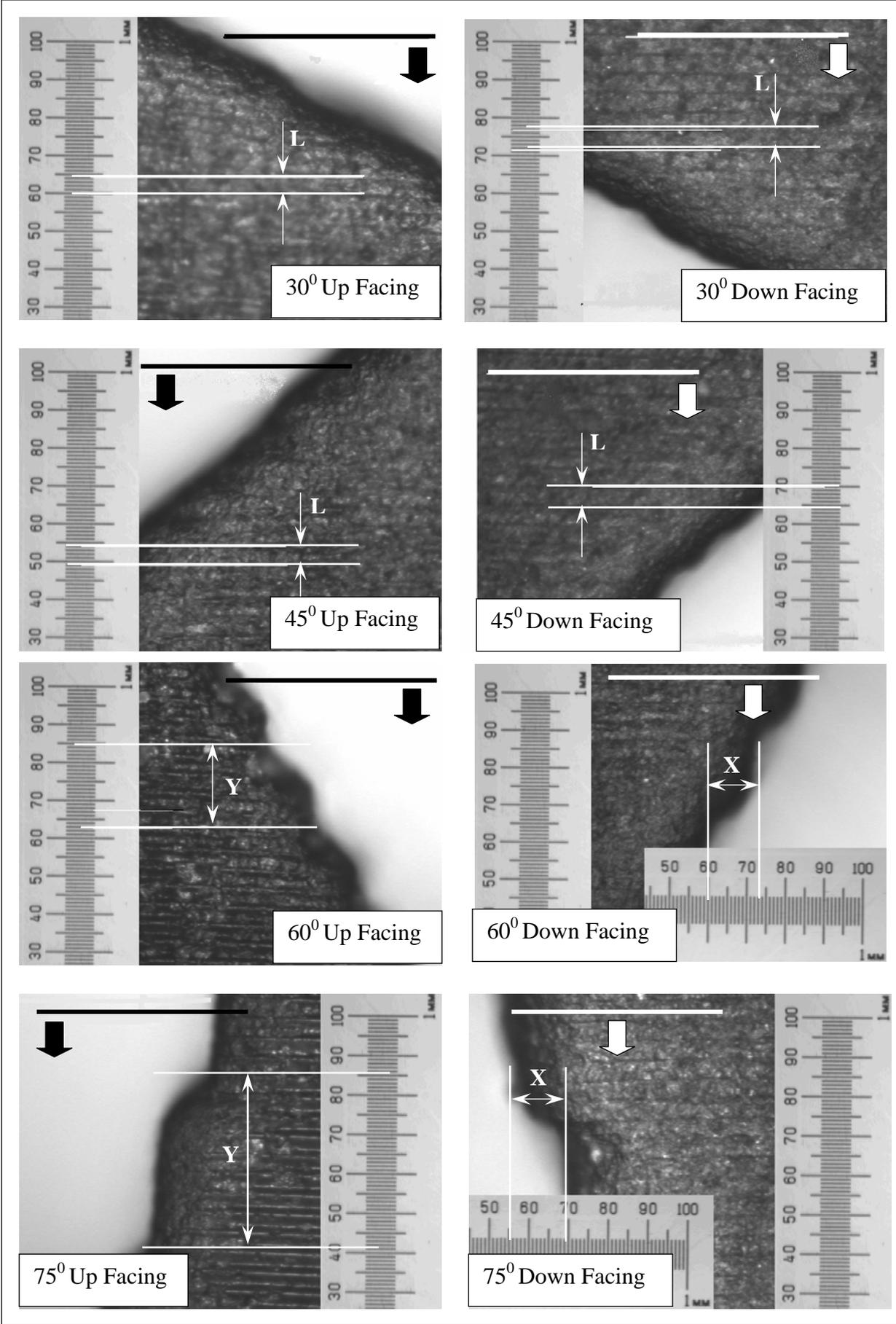


Figure 8 – Different build angles and directions

## 2.5 Reason for better surface finish in the ‘Up’ direction

From the figure, it can be seen that the dimension “X” closely matches with the pixel size setting used for this build, 0.15mm. Hence it can be deduced that the trend in surface finish was caused by Pixel size. It can also be observed that the dimension “Y” increases as the angle of the face increases.

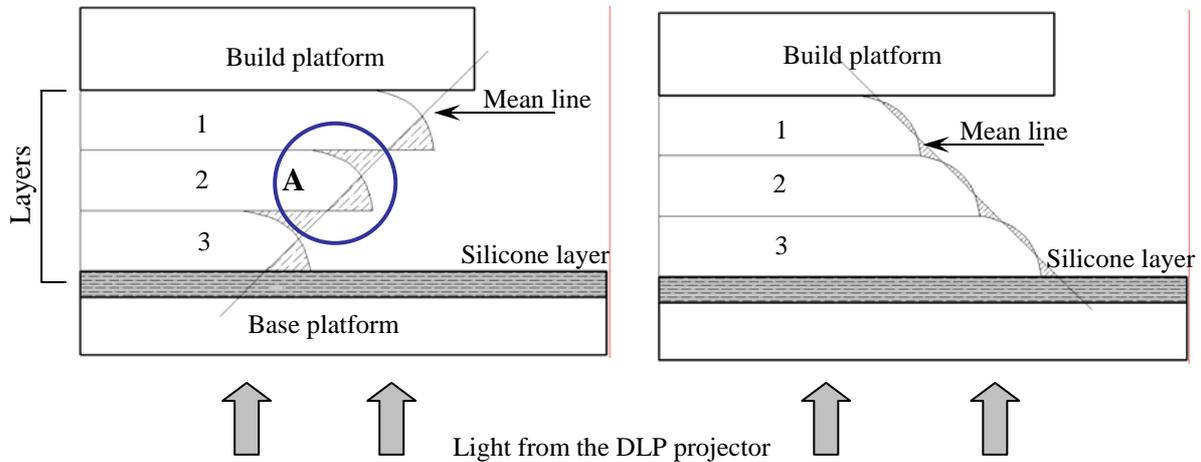


Figure 9a – Down facing build

Figure 9b – Up facing build

The parameter ‘Ra’ used to express surface finish is defined as the “universally recognised, and most used, international parameter of roughness. It is the arithmetic mean of the departures of the profile from the mean line.” [5]. The expression to derive Ra is as follows:

$$Ra = \frac{1}{L} \int_0^L |y(x)| dx$$

Effectively, it is the magnitude of the areas on either side of the mean line that dictate the Ra value – Higher the area, higher will be the value.

With information gained from the micrographs in Figure 8, the effect of build direction on surface finish are clearly illustrated in figures 9a and 9b. The shaded areas on either side of the mean line for the part built in the ‘down’ direction are much higher than that of the ‘up’ direction. This explains the lower Ra values of angular faces built in the ‘up’ direction.

The area “A” highlighted by the circle in Figure 9a shows how the edges of a layer are formed in the PerFactory technique. This effect is the same for both up and down direction builds. This could be due to refraction of light at the edges of the mask, as it passes through the glass and silicone layers of the base platform.

## 2.6 Illustration of part building using Voxels

Since it has been found that the Pixel size has a very pronounced effect on the step thickness and hence, surface roughness, a thorough understanding has to be gained as to how the RP part is built up using 3 Dimensional pixels (Voxels). This is illustrated clearly in Figure 10, along with the method of calculation of pixel size for any given work area setting.

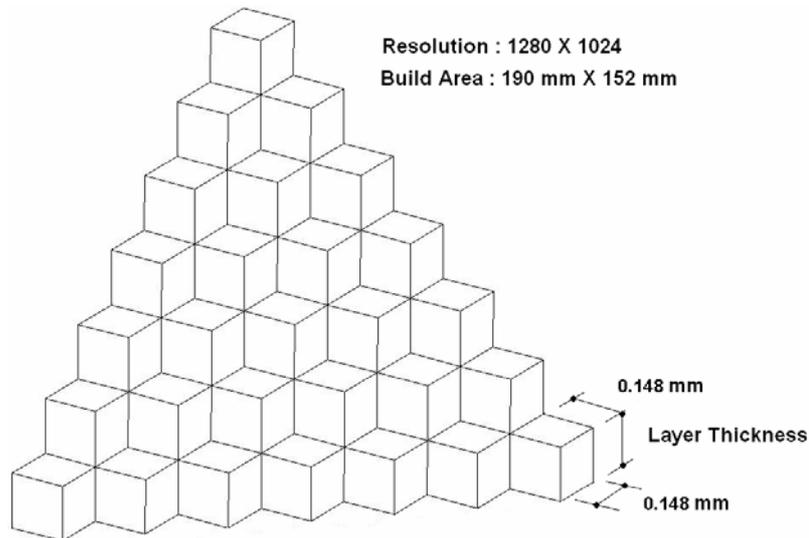


Figure 10 – Perfactory part building with Voxels

### 2.6.1 Calculation of Pixel size

Projector resolution =  $1280 \times 1024$

- Therefore, total number of Pixels = 1,310,720

Work area selected = 190mm x 152mm (Maximum)

- Therefore, total work area =  $28880 \text{ mm}^2$

Area per pixel =  $28880 / 1310720 = 0.0220 \text{ mm}^2$

Since a pixel is square in XY Plane, side of pixel =  $\sqrt{0.0220} = 0.148 \text{ mm}$

- Hence, the resolution of the machine at maximum work area setting is 0.148mm.

Volume of a voxel for different layer thickness (at 190 x 152 Build area):

$V_{30\mu\text{m}} = .0006 \text{ mm}^3$ ,  $V_{50\mu\text{m}} = .0010 \text{ mm}^3$ ,  $V_{100\mu\text{m}} = .0020 \text{ mm}^3$

### 3. CONCLUSIONS AND FUTURE WORK

The results of the surface finish study show that the roughness increases with increasing inclination with respect to the horizontal. This trend is exactly opposite to that exhibited by other established techniques like SLA, FDM and SLS. On further investigation it was found that this was caused by selection of work area settings, and therefore by the pixel size used for the build.

It was also found that building in the up facing direction consistently produces better results than that of the down facing direction, for the same process parameters, layer thickness and build angle.

Future research has to be conducted in the following areas:

- Since it was found that pixel size has a pronounced effect on surface finish, and the technique itself is based on polymerisation of discrete 3 dimensional pixels, more research has to go into areas like pixel shifting, pixel size optimisation, etc.
- Influence of process parameters like waiting time, exposure time, X-Y orientation and peeling velocity on surface finish, using partial factorial design.

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