

Raytracing Milling

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Abstract

This research will be about how to work with raster images and milling techniques in order to be able to interpret them accurately, and how to measure the same information from the initial input image and the final picture of the milled object in order to compare the image quality of the final object.

Keywords: RayTracing, Milling, Robot Arm, Computer Graphics, Digital Fabrication,

1. Introduction

The aim will be to take advantage of the use of a 6 axis machine in order to place reflection surfaces that will give us a rich range of brightness. allowing us to see emerging richer images from a low resolution grid.

Cnc machines have been used, apart from its industrial use, to render pictures into different materials. Mostly working with pure black and white, through halftones techniques.

“Halftone is the reprographic technique that simulates continuous-tone imagery through the use of dots, varying either in size or in spacing, thus generating a gradient-like effect.”

Our aim is to enrich an impoverished image through the accurate link between luminance and angle.

Whereas in a real color gradient the halftone will behave changing progressively the size of dots or the spacing, we will use same size of dot, but varying the reflexion angle in a continuous and controlled range of values.

The surprise effect of the viewer plays an important role, the image will only be rendered in its fully expression under certain circumstances, from a point of view, and receiving light from a certain source.

So we will not always see the image the same way, the conditions of the environment and our relationship to the observed object will change our experience.

2.State of Art

The work of Giles Miller Studio in UK, has been a keystone for this research, their work around material orientation meanwhile depicting images have been of great importance. Their work is often a high end, luxury installation, in which materials are used accurately to make images emerge from wall frames. Their work shows us how related light and fabrication are. There is a way to see different ranges of light if we orient reflective surfaces respectively to the lightsource and the viewer. This will be the material we will work with.



Fig 1: Where the mountains meet the river.

In Fig 1 we can see a whole wall as a frame for one of its works. We can see a whole image of some mountains that are emerging through the use of oriented metal plates. In this case the frame and the oriented surfaces are made from different materials, and fabricated with different techniques.

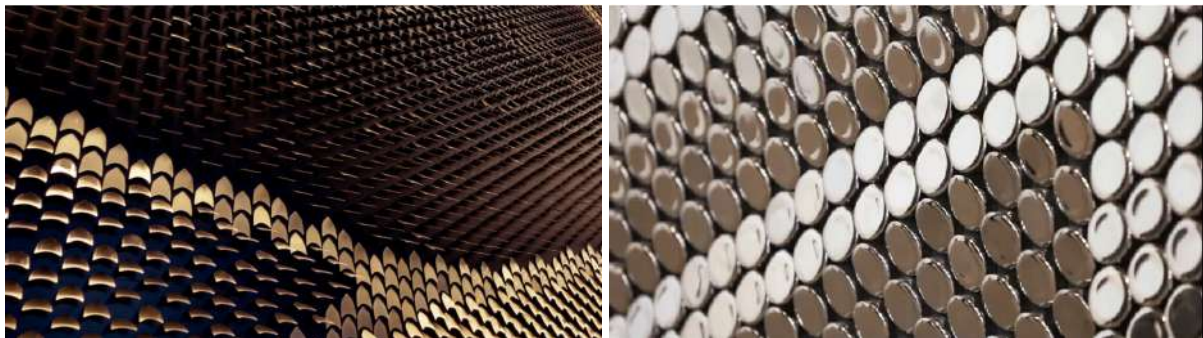


Fig 2: Where the mountains meet the river. Detail.

Fig 3: Ceramic penny.

In Fig 2 we can see how these metallic fish scales are oriented showing different reflexion intensities. We can see how the frame and the scales are made in different materials and different techniques. All the brightness information is coded into the frame.

In Fig 3 we can see a different technique with the same result. Oriented reflecting surfaces emerging from a frame.

3. Hypothesis

Working with oriented surfaces, structuring all the picture information into a range of different brightness values, and coding them into a complete set of milled areas in a homogeneous material will allow us to see a rich image emerge from a milled object.

Our main goal is to transform the brightness information from an image into a range of reflective surfaces. This transformation will finally be carved (drilled) into a solid homogeneous object in which we will be able to see an image emerge, this image will not be dependent on a hard contrasting operation for it to be recognizable. Instead a whole range of reflective surfaces will render the image.

Thanks to the translation from the whole set of grays to a continuous range of angles into which surfaces are oriented the quality of the image will suffer less than expected, and the image emerging will be richer and showing full spectrum of brightness under the right light and perspective circumstances.

As an important constraint, this research will finally be carried out on a single material and with a single mechanical operation.

4.Methodology

Our working method starts with the sampling Process, then finding an accurate link between the luminance and the angle orientation after that improving the image brightness and contrast, then simulating the results digitally using a raytracer engine. Afterwards going from digital to physical with the milling process and at the end compare the original photo to the digital output and the final photo using an error map, that will lead for the synthesis.

5.Image Sampling

A digital image's spatial resolution is defined by the image's spatial density and the optical resolution of the microscope used to create the image. The sampling interval, which is a function of the digitizing device's precision, is defined as the number of pixels in a digital image and the distance between each pixel.

For the image sampling we need to work on two major subjects, first explore different shapes and second search for how to get a most accurate color.

5.1 Grid

The work is done using geometrical grids the first is the square grid the second the hexagonal grid and the the third was the staggered grid.

5.1.1 Square Grid

The basic square grid, is a grid where the cells are done with squares which means that the centroids are orthogonal and equidistant. We are working with an Audrey Hepburn image and we are sampling with a very low resolution, to increase the difference between the grid and show the different properties.

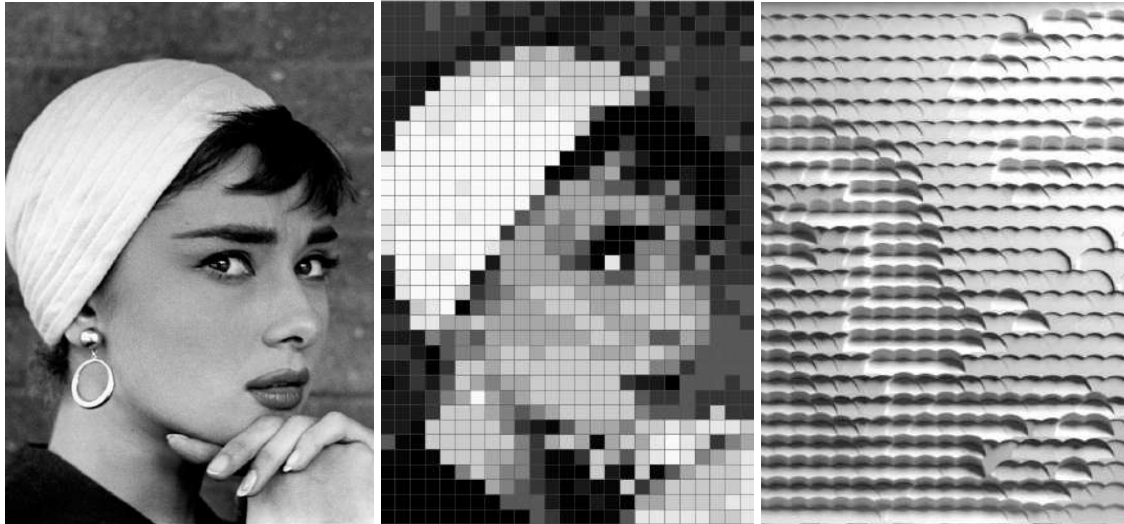


Fig 1: Photo of Audrey Hepburn 8 bit image.

Fig2: Square Grid sampling

Fig 3: Square grid rendered image to show the light and shadow

For the issues that we had faced using the square grid were the lines of lights and shadows that we got in the rendering, and the milled samples.

5.1.2 Hexagonal Grid

The basic hexagonal grid, is a grid where the cells are hexagons which means that the centroids have a sixty degrees rotation and equidistant one from the other. We are working with an Audrey Hepburn image and we are sampling with a very low resolution, to increase the difference between the grid and show the different properties.

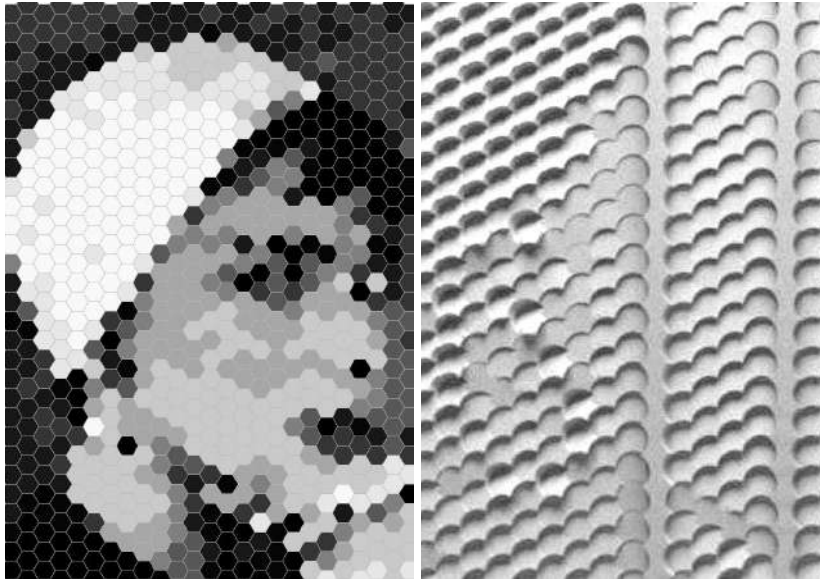


Fig3: Hexagonal Grid sampling

Fig 3: Hexagonal grid rendered image to show the light and shadow

For the issues that we had faced using the hexagonal grid, is that the centers are really far one from the other what needs a very high number of faces, a very high resolution, to recognize the image well.

5.1.3 Staggered Grid

Staggered grid is a collocated grid, where the cells pack well and have both properties from the square grid and the hexagonal grid, the centroids are well distributed and close one to each other which gives homogeneous layout.

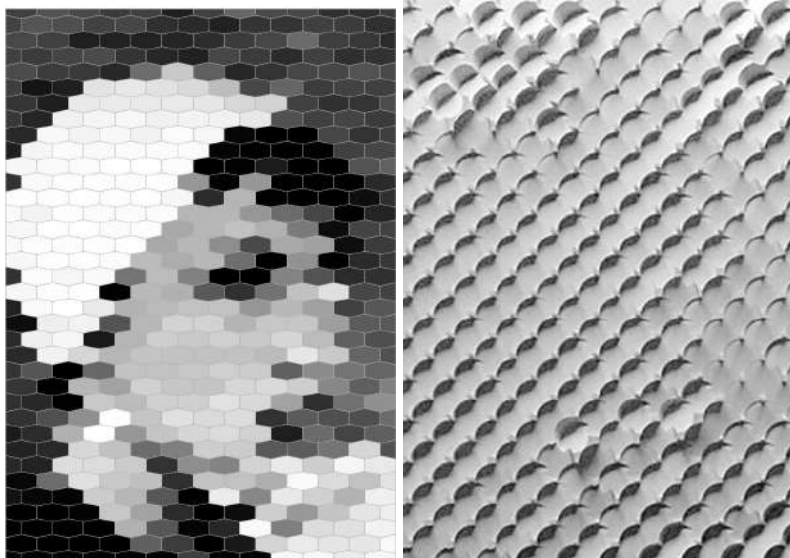


Fig4: Staggered Grid sampling

Fig 3: staggered grid rendered image to show the light and shadow

Here the three grids for the same image with a higher resolution. where we can simply look at how the details are changing with the different grids.



Fig 5 High resolution square(a) Hexagon(b) and staggered(c) grid sampling

5.2. Image Resampling

5.2.1 Resampling image using the image sampler

Image resampling, from the other side, occurs when the number of pixels in an image is practically changed. After working on the grid, the shape of the pixel, working on the color of the pixel is a must. First we just resampled the image using the image sampler.



Fig 1: Photo of Audrey Hepburn 8 bit image.

Fig 2: Image sampled using the image sampler.

5.2.2 Resampling image using the mean color

Resampling the image using the mean average of different grades of grey inside each cell.

For example, on the left we have a pixel with a zero value which does it mean black and it's done using the image sampler and at the right, using the mean, the value has changed to ten which is a very dark grey. So with the mean colors we have a more accurate information about the colours and as a result we get a more homogeneous image with better gradients.

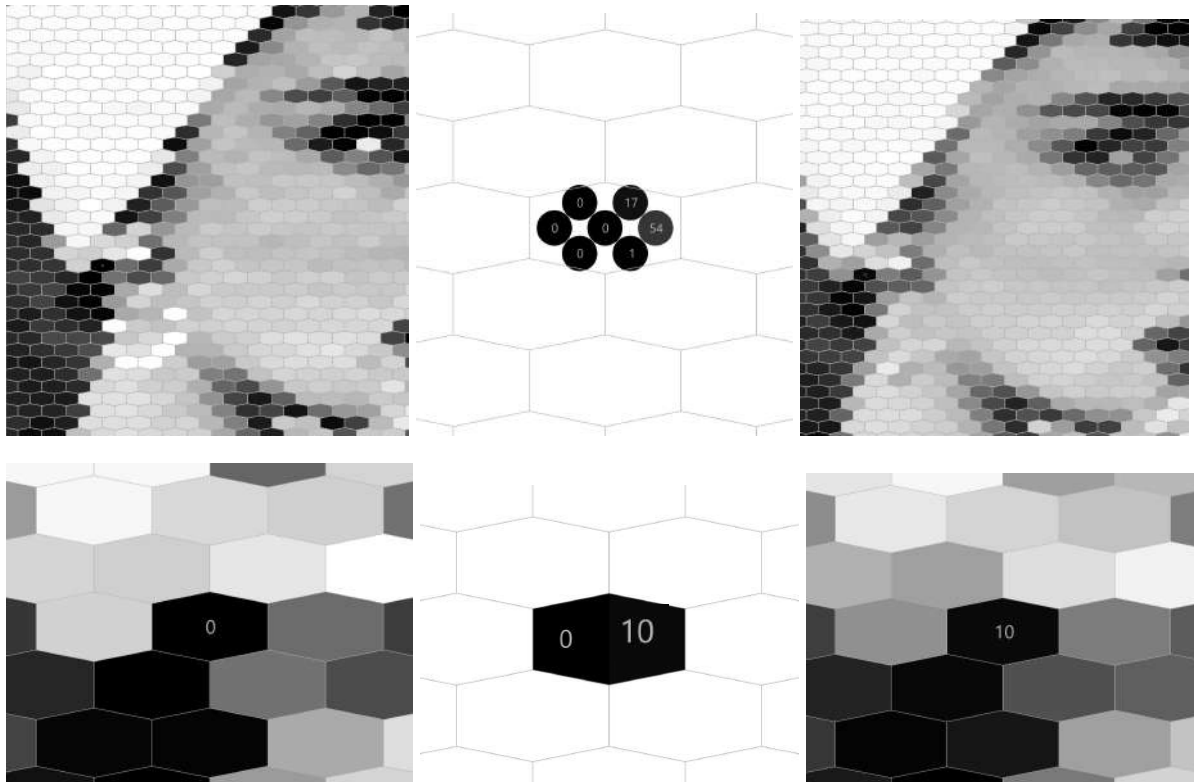


Fig 3:Resampling the image with the mean.

To get the mean for each pixel we divided the image on a smaller grid .Then we extracted the different values.For each Pixel we extracted 7 smaller values to resample the image in a more accurate way. so we have more shades of grey. For example the pixel shown above had a value of 0 using the image sampler, but 10 while using the mean average for the extracted dots.

Comparing both resampling techniques to the original image we can say that the resampled image using the image sampler has preserved 196 shades of grey from the original image compared to the mean image that has preserved 247 shades of grey from 252 shades that we got from the original image.



Fig1: Graphs showing the shades of grey that exist in each image respectively: Original image(a) the result from the image sampler(b) and the image sampled using the mean colors on each pixel(c)

6. Graytone Range Rotation and Orientation

Our work is going to be to study the relationship between the brightness measured in a picture, and its translation into a range of oriented surfaces. Two equal planes side by side under the same conditions will reflect the same amount of light. If we orient one of those planes differently we will be able to see a change in the reflection of light.

We are going to work changing the orientation of planes in order to get a full range of continuous reflection. Our assumption is that if we translate the whole brightness spectrum of an image to our new range of reflective oriented planes we are going to have the same bits of information that make possible to identify an image. Where we had black we'll have the least reflective plane. Where we had white we'll have the most reflective oriented surface. Now we have to choose our range of angles, that would be related directly to the tool we are using, how are we giving shape to those planes. With the machine we are using we think a safe range would be from 45° to 0° . 45° being the darkest and 0° the brightest. We are going to do two operations: first rotation of all the planes on the grid on its z axis. And the second, range of rotations in the x axis related to the brightness measured on the image.

7. Contrast and Brightness Improvements

The average behaviour to work with this techniques would normally be to contrast the input image in order to increase the amount of pure blacks and whites, so impoverishing the image in order for the results to be more clear. What this research is going to do is to work with the whole range of grays from pure black to pure white. What the research is trying to prove is that it is possible to render the whole image with this milling technique. So the only impoverishing operation on the picture will be the data loss regarding the pixelization, the reduction of resolution related to the size of the final mill-end tool.

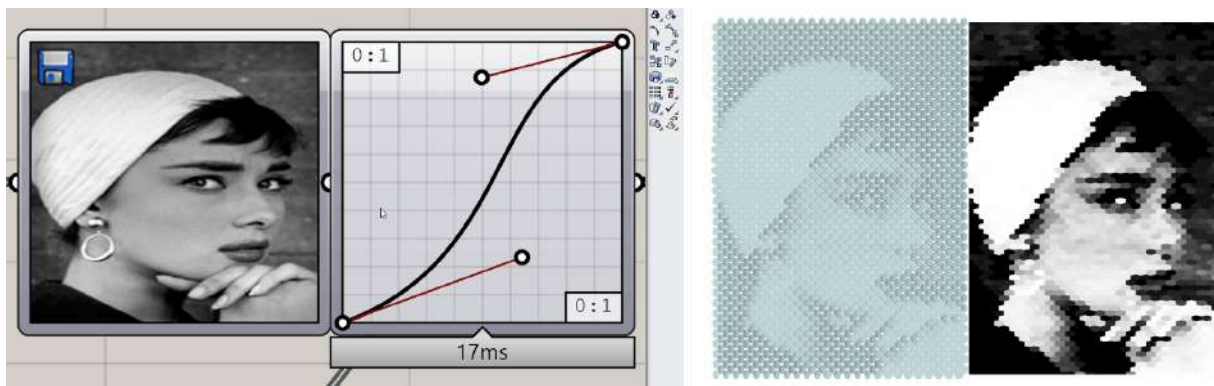


Fig1: Link between image sampler, coloured mesh and circle surfaces both with same resolution and range of brightness/amount of grays/rotation angles

Nonetheless, to prove our ideas and compare results we have linked the information from the image sampler to these two ways of directly visualizing and comparing the results, rhino custom display mode, and coloured mesh.

8. Ray Tracing Simulations

Our scene was similar to a light box where the light is coming from the top and diffused in different directions. Then we added one rectangular light similar to a studio light condition. Also we worked with 8 similar rectangular light distributed on a circle to enhance our lighting scenario and at the end we changed the hue of the lights to see how it can affect our model if we were working with a reflective material

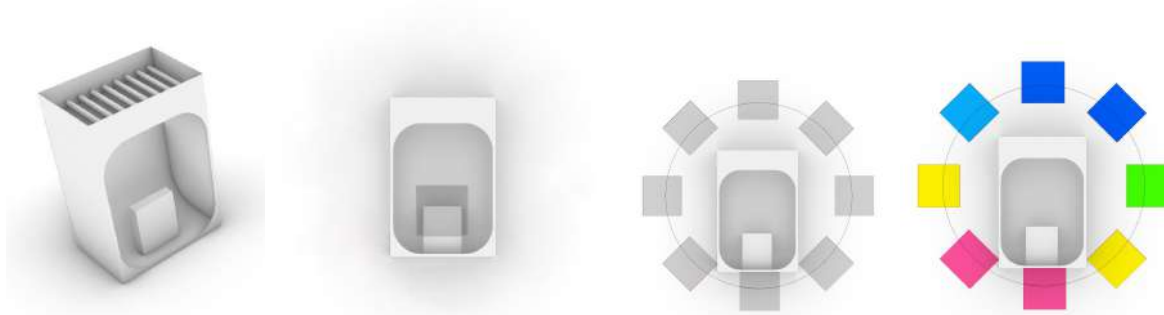


Fig1: Light Box To diffuse the light(a) One Rectangular light(b)8 Rectangular light(c)8 Rectangular light with different hue(d)

We are working on a Mohamad Ali image and by simply comparing the image with one light and 8 lights we can see that the one with 8 lights can show us more details than the one with a single light.

Rendering the same image with a more dark and reflective material can show more details.

Rendering the same image with eight different coloured lights

By definition The illuminance is defined as the total light flux incident on a surface per unit area in photometry. It is a wavelength-weighted measure of how much incident light illuminates the surface, which correlates with human brightness perception. On the other hand, Luminance is a photometric measurement of luminous intensity per unit area of light traveling in a specific direction. It refers to the amount of light that passes through, is emitted from, or is reflected from a given solid angle.

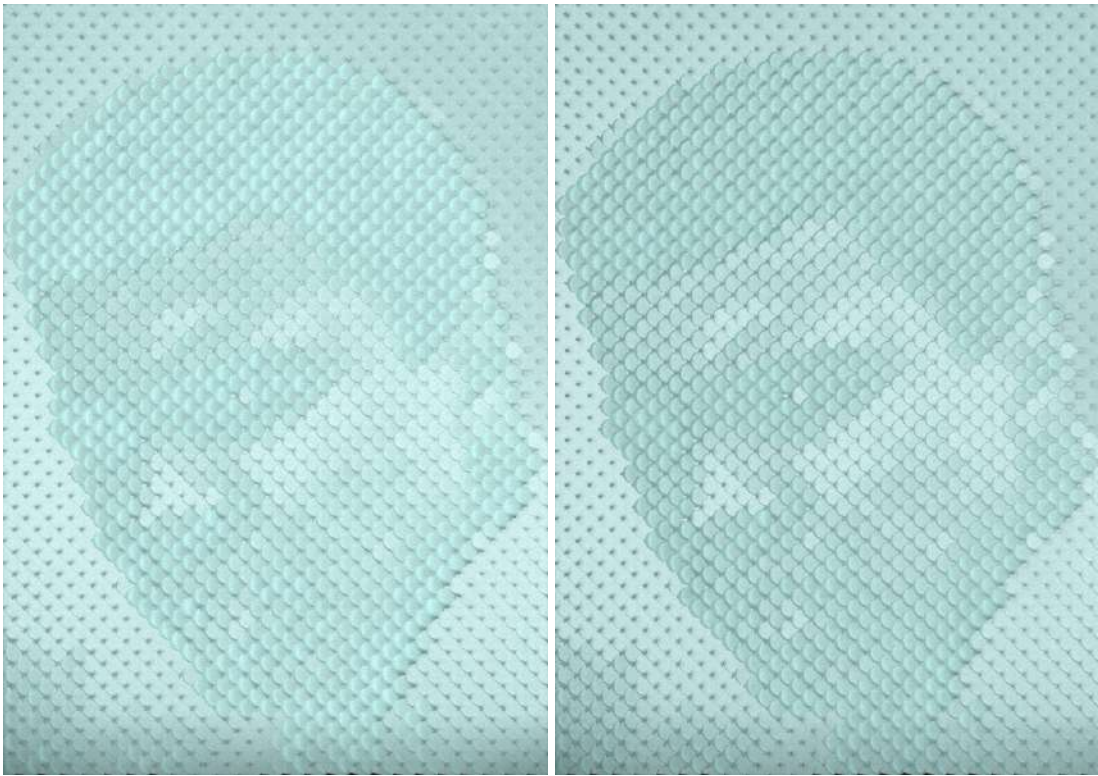


Fig1: One Light Source(a) 8 Light Sources(b)

This is why we were interested more in the luminance output.

Comparing the mean of the 3 images that we worked with, Audrey Hepburn portrait, Muhamad Ali Clay portrait and Humphrey Bogart, we will stick on our study on Muhamad ali Clay portrait because the mean average value is 148 which is more close to a fifty percent grey in the midtones.

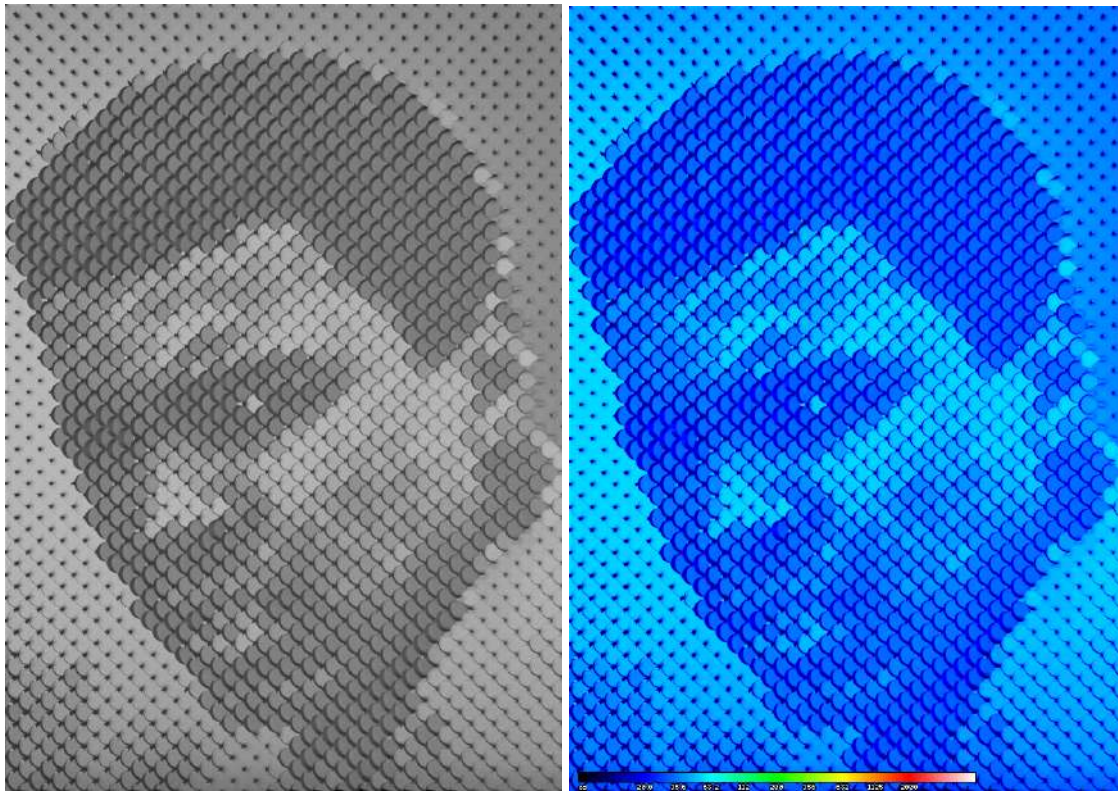


Fig1: Luminance Output (a) Illuminance output(b)



Fig1: Dark Reflective material -8 Light Sources(a) Coloured Lighting-8 light Source(b)

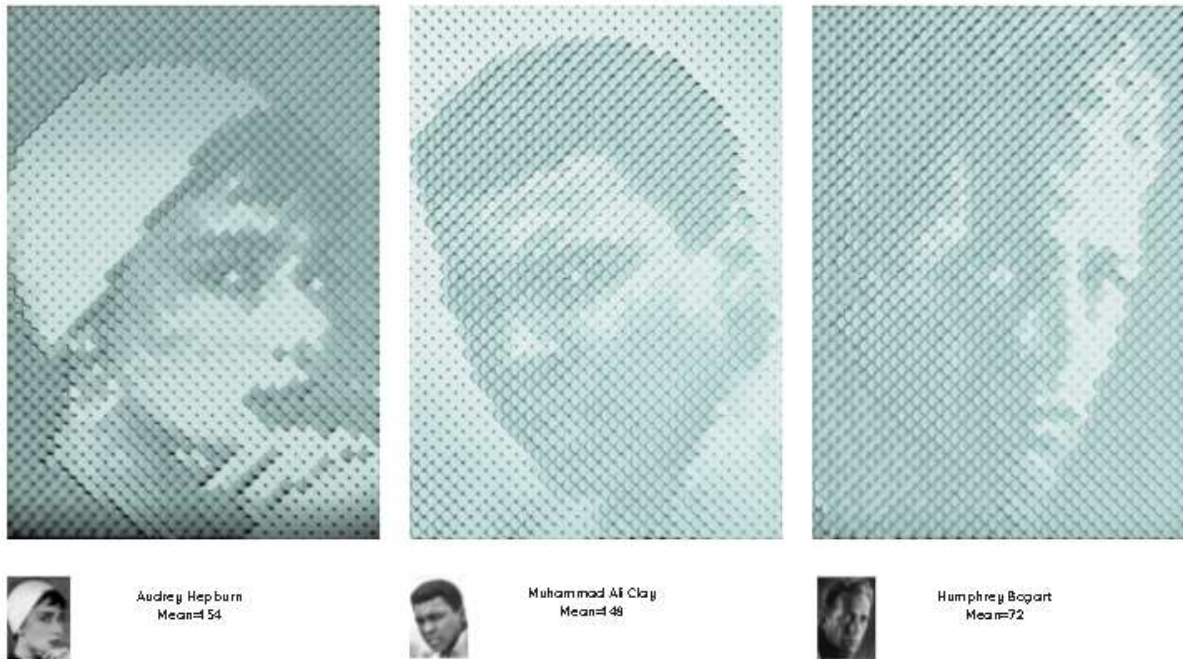


Fig1: Rendered Images with the mean values, respectively, Audrey Hepburn(a), Mohamad Ali (b), Humphrey Bogart(c).

The standard deviation is a measure of how much variation (such as spread, dispersion, and spread) there is from the mean. The standard deviation denotes a variation from the mean that is “typical.” Because it returns to the data set's original units of measure, it is a common measure of variability.

Standard Deviation Formula

The population standard deviation formula is given as:

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (X_i - \mu)^2}$$

If the data points are close to the mean, there is a tiny variation, similar to the variance, however if they are far from the mean, there is a large variation. If the data points are close to the mean, there is a modest variation, however if the data points are widely scattered from the mean, there is a large variance.

The standard deviation determines how far the numbers deviate from the average. The most generally used measure of dispersion, Standard Deviation, is based on all values. As a result, even a small change in one value has an impact on the standard deviation. It is scale-independent but not origin-independent. It can also help with some advanced statistical difficulties.



Fig1: Showing the standard deviation values for different images.

So the standard deviation shows how much variation do we have in an image and comparing the mean image to the luminance of the rendered images we can see that the standard deviation of the rendered image with 8 lights having a 45 as a value for the standard deviation is higher than the one rendered with one light that has 30.7 as a value. which means that it has more variance and therefore more shades of greys and better gradients.

Standard deviation = $\sqrt{\text{variance}}$

After showing how much difference we have in the image. comparing each cell to its neighbours is essential to measure the gradient quality.

Variance Formula:

The population variance formula is given by:

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^N (X_i - \mu)^2$$

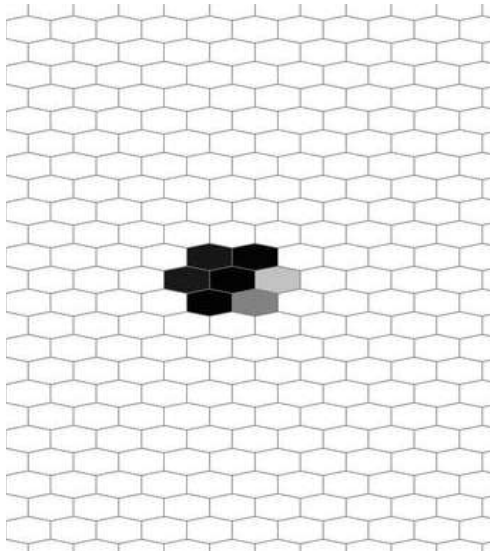


Fig1: the variance is comparing each pixel to its neighbours.

For that we need the variance which is very related to the standard deviation.

The term "variance" refers to the degree to which a set of data is dispersed. If all of the data values are the same, then the variance is 0. Positive variances are defined as those that are not zero. A low variance implies that the data points are close to the mean and to one another, whereas a large variance shows that the data points are far apart from the mean and from one another. In the fewest possible words, variance is the average of the squared distance between each point and the mean.

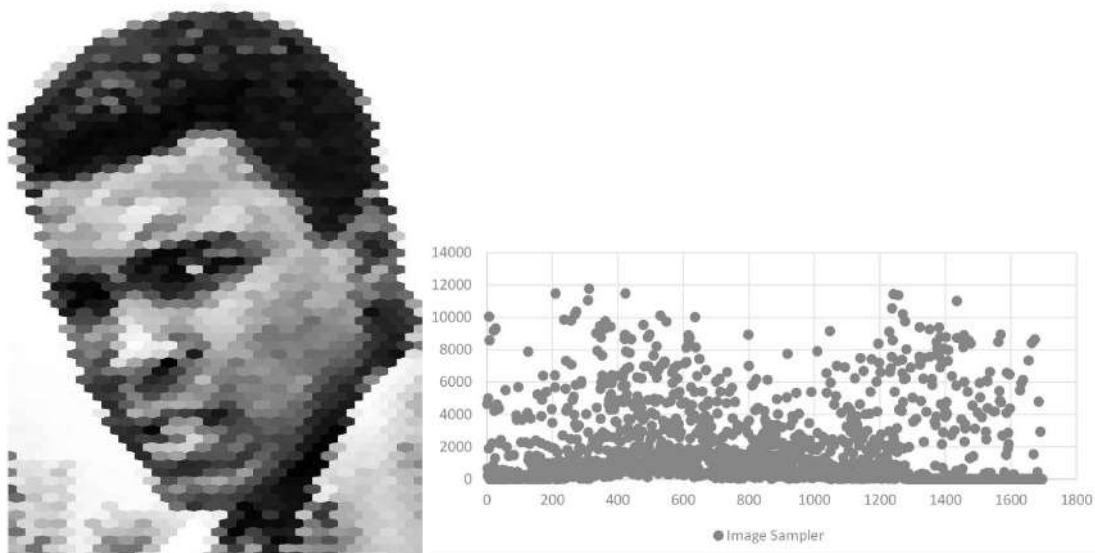


Fig1: Image done using the image sampler (a) Graph showing the variance(b)

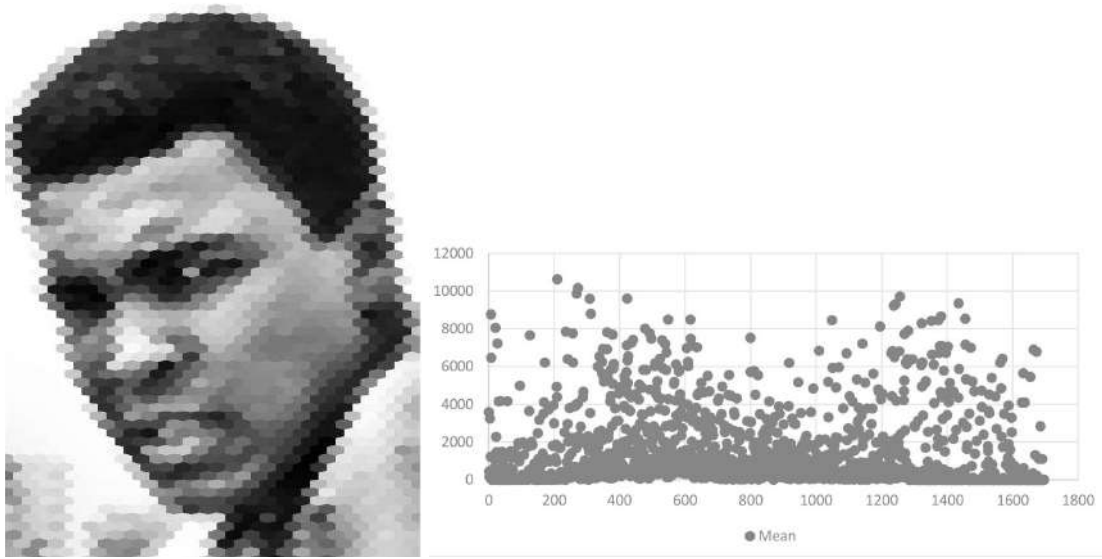


Fig1: Image resampled using the mean(a) Graph showing the variance(b)

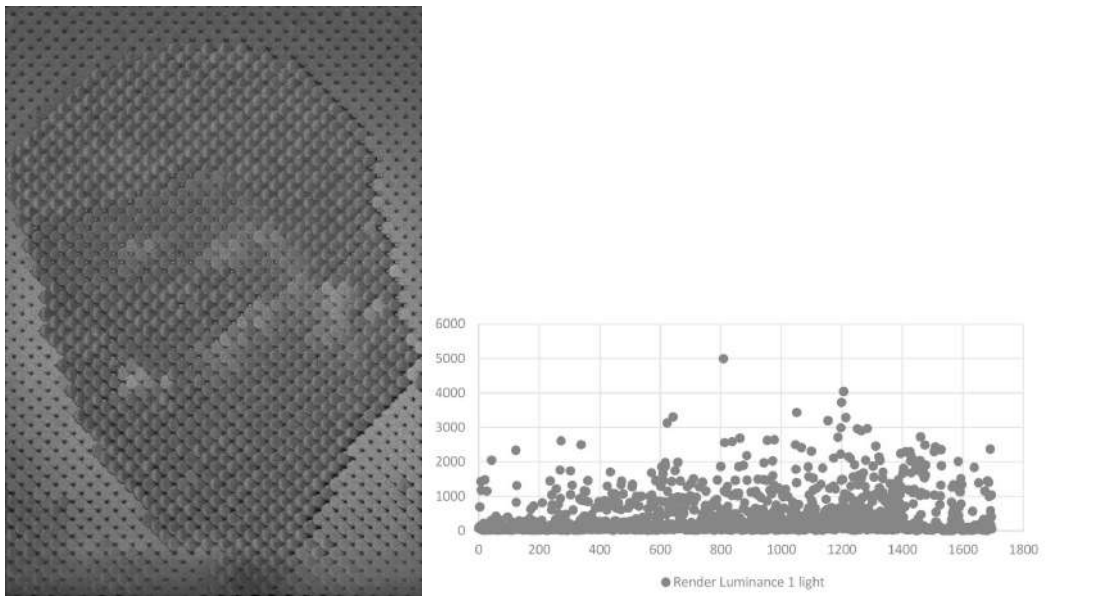


Fig1:rendered image with one source of light using the mean(a) Graph showing the variance(b)

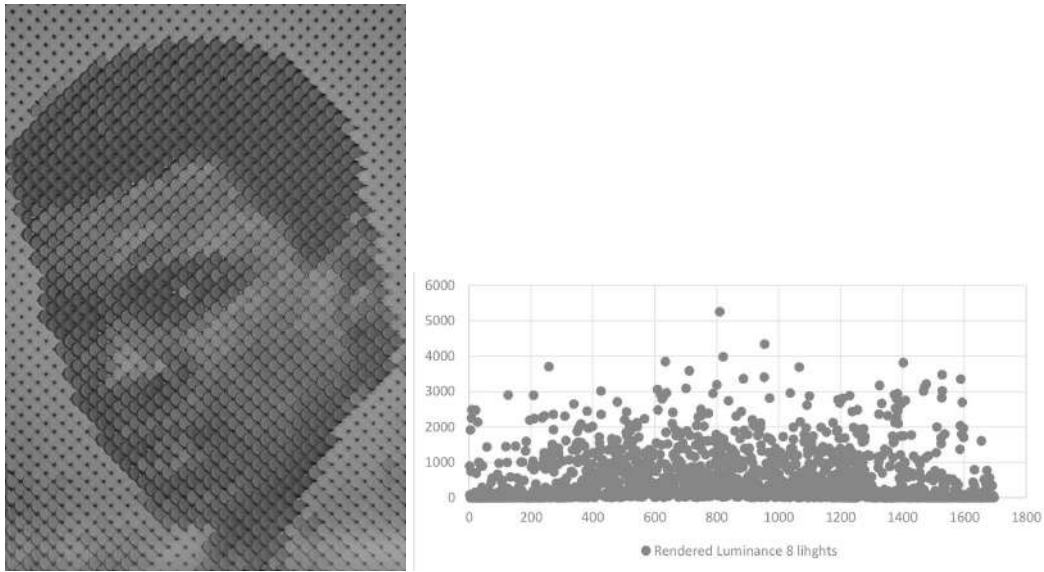


Fig1:rendered image with eight sources of light using the mean(a) Graph showing the variance(b)

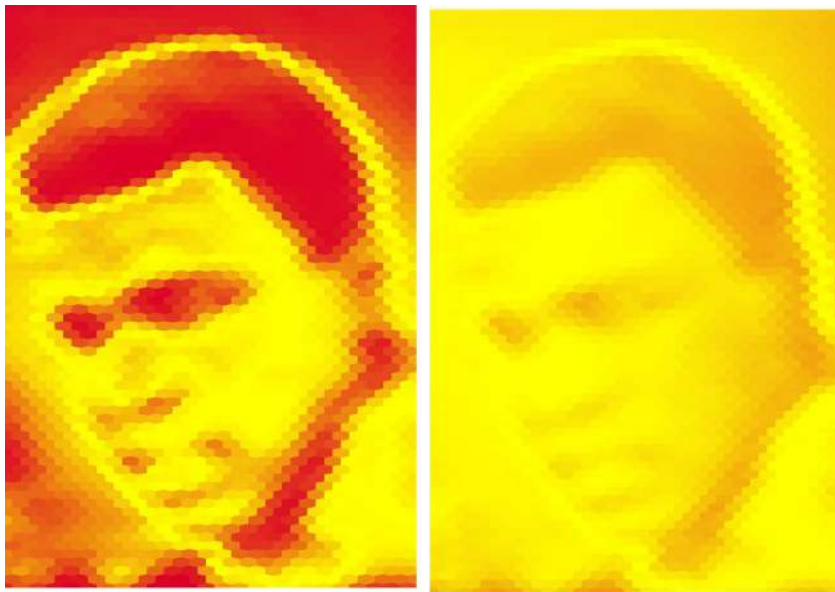


Fig1: Error Map for the rendered image with the one light.- we are working using the luminance as a render output.

Fig1:Error Map for the rendered image with the 8 lights.- we are working using the luminance as a render output.

9. Robot Milling

At EXarchitects facilities we have been able to use an ABB IRB 120 6 axis industrial robot. It has been the first time this robot is used for milling, so we have been able to design the whole setup, from the file to the hardware of the tool.

9.1 The Robot

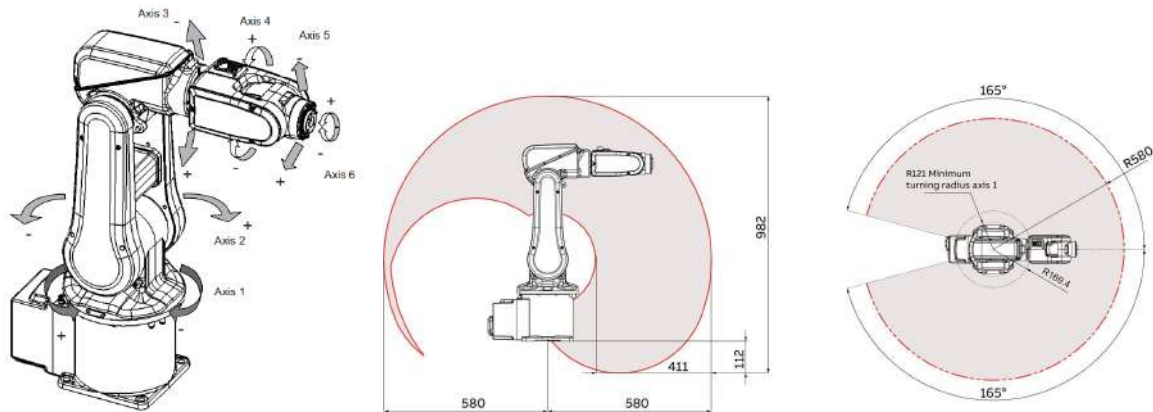


Fig1: ABB IRB 120 6 axis industrial robot.

Fig2: Work range of action of ABB IRB 120.

This 6 axis industrial robot has a payload of 3kg. With this system we can get with the tip of the tool oriented to places that would be impossible with a 3 axis or even 5 axis cnc machines.

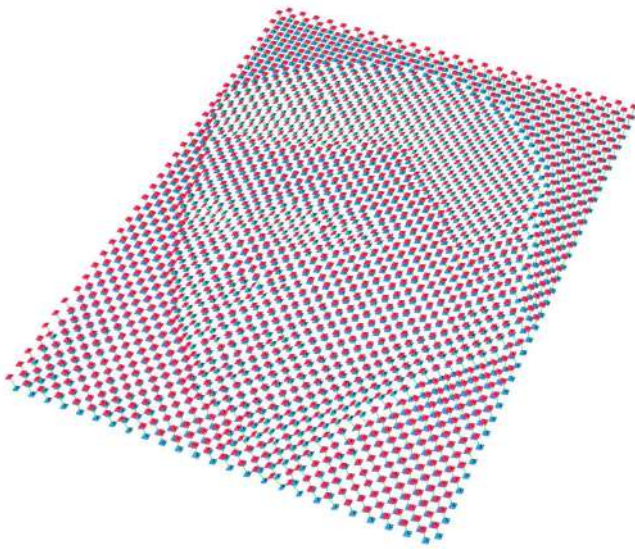
We are going to take advantage of this to be able to reach orientations that will allow us to render images with a great range of brightness thanks to the oriented reflection planes that will be drilled.

9.2 The Plugin

To control the trajectories of the robot, our custom tool path, we have used this “[robots](#)” plug-in. It will allow us to locate the tip of the tool on the robot to whichever plane we want, and control its movements, trajectories, speed or accuracy.

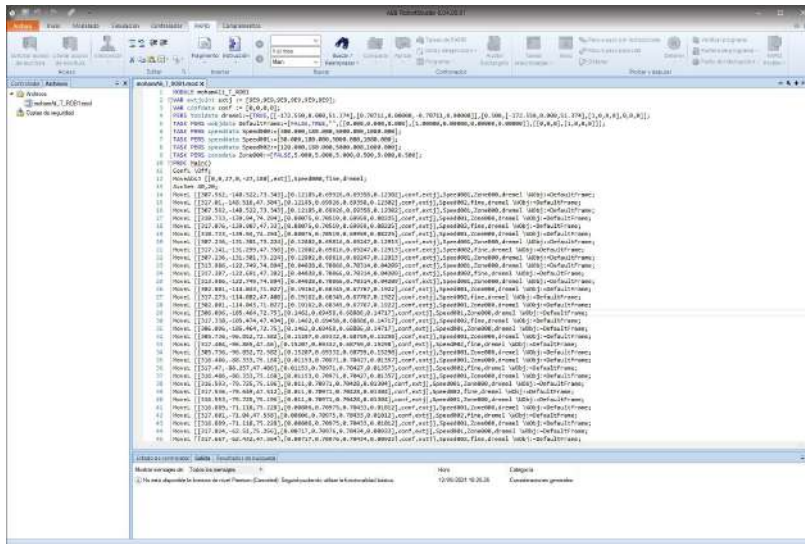
One direct link between gh and the robot. The author of the plugin is Vicente Soler.

9.3 Control planes



To control the robot is to control the planes of our geometry. We want the tip of the tool to get to a certain location at a certain angle, for this we will match the plane located at the tip of the tool with our target plane. As to control the trajectory, in this case, drilling along a straight line. We will offset the target plane into somewhere outside of the stock material. This way the robot will go before and after the final target to these offsetted targets, orient there, and then drill into the stock material.

9.4 Robot Studio



Our computer will be connected to the robot arm through an ethernet cable. Once online, we can control the robot arm and send programs. We see here how the tool we are working on grasshopper is present on the code, same as the speed variables declared are the same we imputed to the targets. same as the zones. The rest of the code is the list of targets and orientations, coded into coordinates and quaternions.

9.5 The Tool



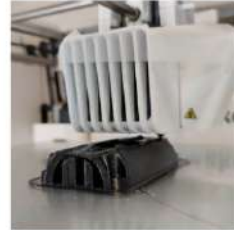
Dremel rotary tool + flex shaft



PU-70 quick release plate



3d model of every tool element



Nylon 12 GF 3d print



Quick release plate + bottom part



Lateral view holder-flex shaft



Top view holder-flex shaft



End mill vs. drill bit



End mill vs. drill bit



Tool assembled to the robot

It is the first time this robot is used for milling, so we have to design a tool that fulfills our requirements, we'll look for the best way to straight drill on a foam material with the flattest possible result. The robot is useless without a tool, we could use a gripper to grab something, a hot wire to cut styrofoam, a 3d printer extruder... In this case, we want to drill, so we use a dremel rotary tool, this will be our humble spindle, with the right rpm it will drill foam as required. We have decided to use the flex shaft to be attached to the robot, it'll be light and compact, the total weight of the tool will be 500g.

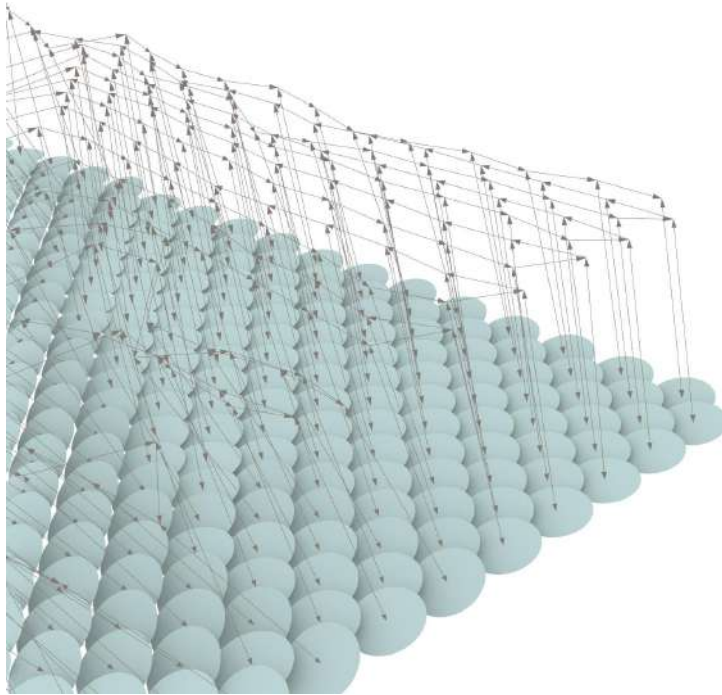
9.6 The Material



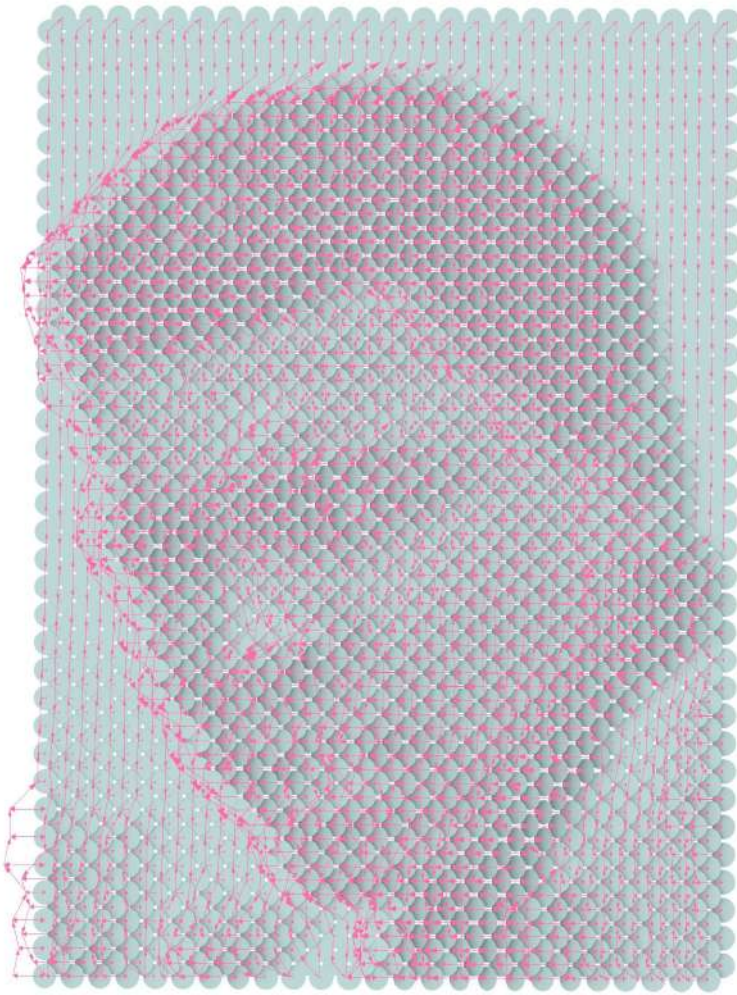
For the best results we have chosen High Density Polyurethane Foam. This will allow us to be accurate. The finish will be more homogeneous, and milling will require not a great effort for the robot. The dremel as the spindle with an adequate number of rpms is a proper setup to drill with the robot. We have done some trials with another material, XPS or Extruded Polystyrene. Cheaper material, but less homogeneous, as well as bendable when stored, and the finish is less appealing. As the drilling is happening the material melts and leaves hard debris difficult to remove.

9.6 The Data Tree

The data structure of the set of targets is the way to control the order of milling, to plan a trajectory, as we have seen its mandatory to be able to drill along a straight axis (with the longitudinal axis of the drill bit oriented in the same axis) so we will set the order of the data structure to mill side by side, from a plane to the adjacent one. Meaning that from one plane to the next the tooltip will do all of the designed motions in order. We design the toolpath.



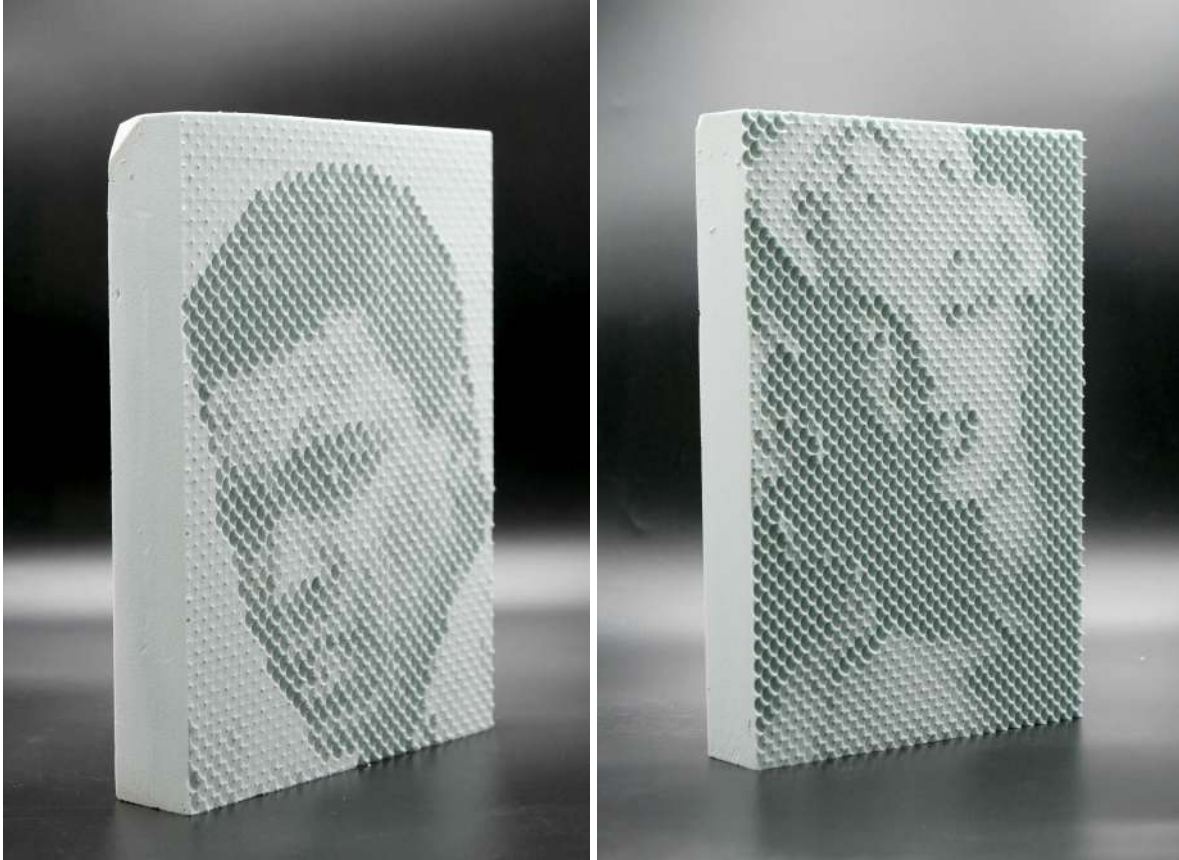
The toolpath has been ordered and linked to the data tree structure, continuity is achieved. The order in which we are going to drill has a great impact on the performance, speed, collisions, time, and possible erratic motions of the robot. The continuity helps us build a feasible, and consistent work.

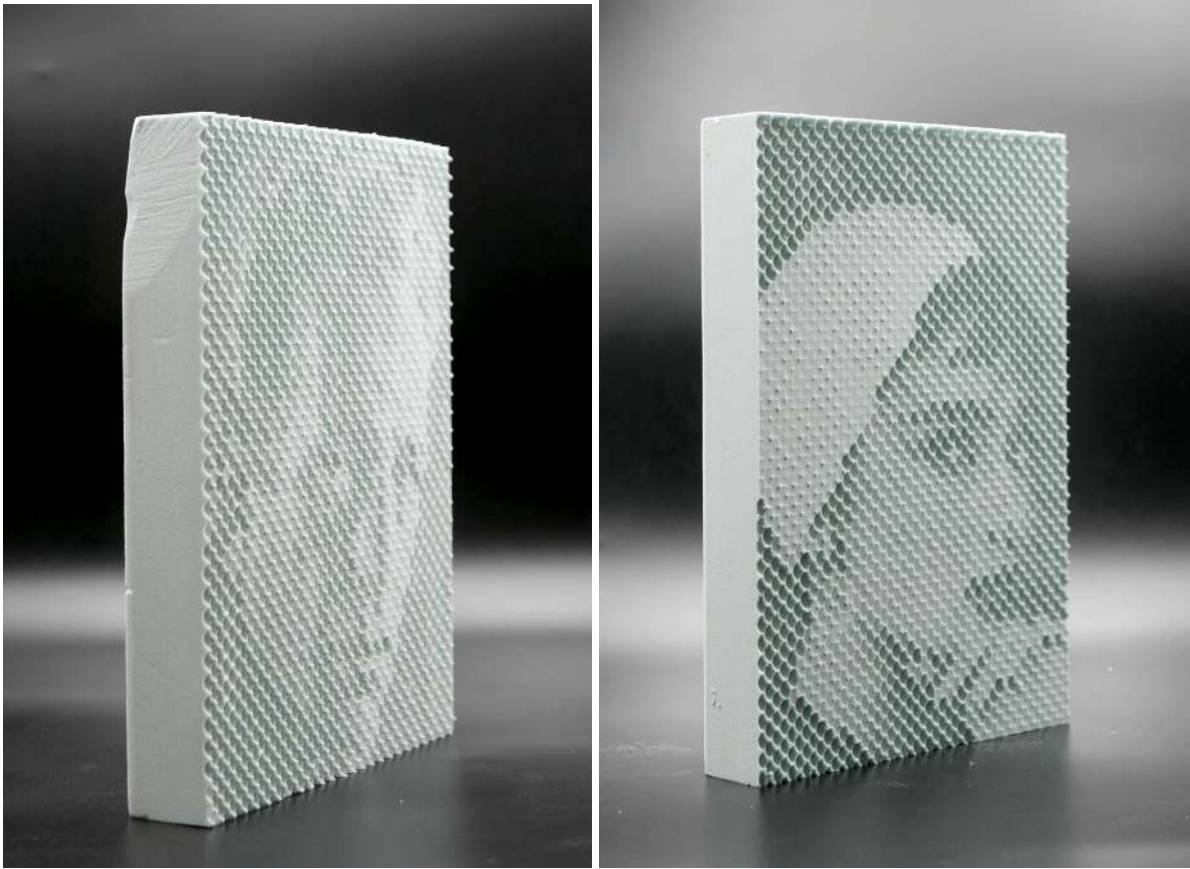


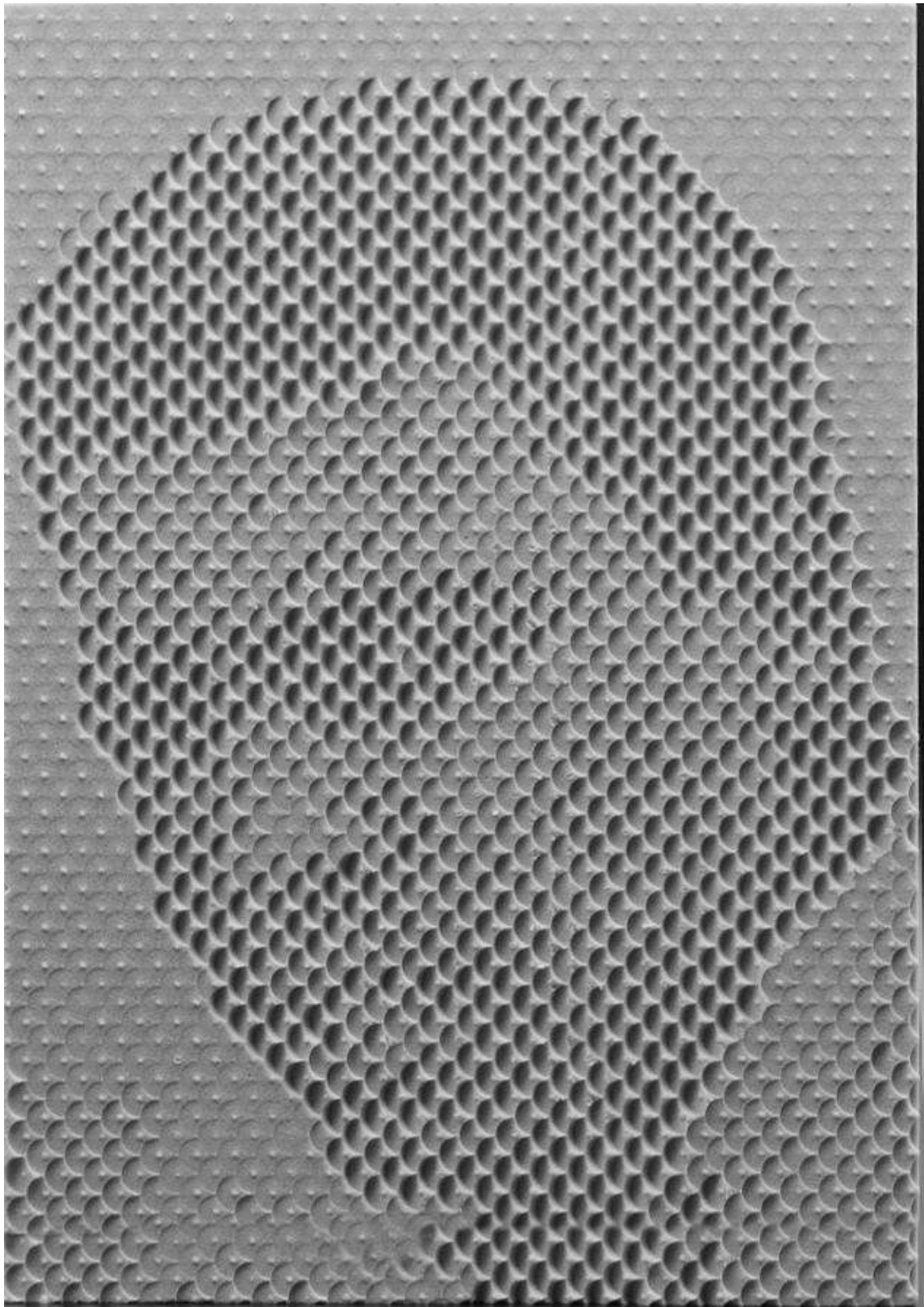
So, grafted or flattened lists will help us design continuous toolpaths and go out at the end of the row versus going-in drill and then out along the normal axis and get to the next target. so the tool is moving just linearly drilling straight.

During the experimentation we have understood how the best practice to visualise the real behaviour of the light and the oriented planes will be to render the boolean subtraction operation done between the stock material volume and the volume of theoretical pipes oriented on every plane. It is a heavy and slow operation but more reliable for this specific matter than the standard rhinoceros display modes over the oriented surfaces. At the end the orientation of the robot, each movement is related to the brightness from the first picture.

9.6 The Results







10. Conclusion.

This research has proven to be a tool, currently been developed, that will help us to improve the quality of the milled pictures as well as improve the system itself, after several iterations of measurements and mills, we should be able to reduce the error map, meaning that the final picture of the milled object will have less differences with the original input image thanks to several tweaks on the parameters we are currently working with.

Next to be researched will be to apply the system into a 3d surface, as well as combine different images and different perspectives.

Another field of study could be the design of an improved mill end in order to better flat drill each surface, getting rid of the centermark of the current tool.

Acknowledgements

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References

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