

# The Voxel Workflow

A guide to bitmap and voxel management  
for hi-resolution multi-property 3D printing

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Victoria University of Wellington

SUPPORTED BY:  
MedTech CoRE  
Product Accelerator

ISBN 978-0-473-60936-8

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## Introduction

**The Voxel Workflow** is a handbook for creating files in a format that allows complex colour mixing and the specification of material properties for polyjet 3D printing.

You may be conversant with mesh-based modelling and the output of .stl file formats which typically follow the convention of parts in an assembly. For example, a .stl file is a 3-dimensional mesh that describes a shape, it can only have one colour with one material property. To afford greater colour and/or material properties the mesh must be cut and divided, a time consuming and intensive method.

The voxel workflow differs by approaching the creation of parts at a droplet level. Rather than creating a 3 dimensional mesh this method is layer or slice based. Imagine a 3D shape as a stack of very thin slices with each slice being an image. Looking closer you would see the image is made up of micro squares of colour, known as pixels. As each of these pixels are volumetric, they are referred to as a voxel, and thus is a very small 'part' of the overall model.

To explore how this new method works **The Voxel Workflow** is broken into two guides. First, **The Guide To Voxel** where imagery can become 3 dimensional and 3D printed. Second, **The Guide To Bitmap** where the use of medical DICOM data is explained.

**The Voxel Workflow** is step based and following each step is imperative. You may find anomalies or failures when creating files, which may be due to missed steps, incorrect formatting, or programme updates.

Programmes required are GrabCAD Voxel Print Utility available in the GrabCAD research package, Adobe Photoshop, 3D Slicer.

Enjoy.

This guidebook was created by Ana Morris, Izzy Robb, and Bernard Guy and contributed to by Charlotte Horder ©2021

## Ana Morris

Ana Morris is an Industrial Designer currently based in Auckland, New Zealand. Ana recently completed her Master of Design Innovation, specialising in multi-property and highly realistic 3D-printed medical modelling. Her thesis “Beneath the Skin: Emulating human physiology using a novel bitmap-based (voxel) additive manufacturing workflow” promoted the need to create this guide.



**Izzy Robb**

Izzy Robb is currently studying towards her Masters of Design Innovation. Izzy's thesis explores the value of medical data as an object. Flowing data into an object can only be achieved using a voxel approach and the need for a 'recipe' enthused Izzy to contribute to this guide.

**Charlotte Horder**

During the final evaluation of the Voxel Workflow Charlotte Horder tested the procedure as a novice. Charlotte applied the workflow to cross sectional photography of fruit and vegetables, successfully 3D printing The 'Cuisine' jewel collection is Summer, Spring, Winter, and Autumn earrings, each expressed through a 74 layered three dimensional form.





STEP BY STEP

# Guide to VOXEL

## OVERVIEW

# *Key Terms and Definitions*

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### **3D PRINTING**

a type of additive manufacturing (AM) that builds a physical object out of a digital blueprint by depositing sequential two-dimensional (2D) layers of material in order to create a three-dimensional (3D) form (Bastawrous et al., 2018, p. 2809).

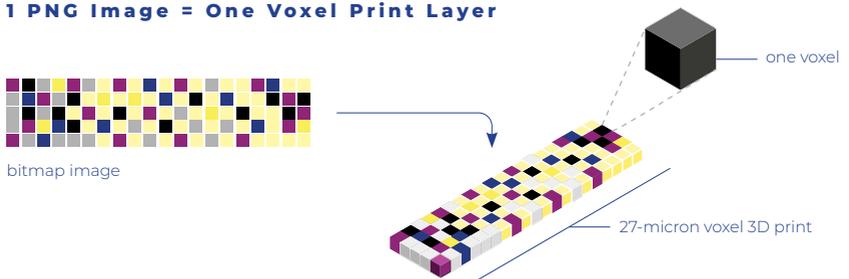
### **BITMAP**

a type of image (e.g. PNG or JPEG file formats) that is made up of squares, or 'pixels', that form a grid making up a full image. The smaller the squares that make up an image, the higher the quality (resolution) of the image. Each pixel holds colour data.

### **BITMAP-BASED "VOXEL" 3D PRINTING**

a method of AM that can translate information from various types of bitmap datasets into heterogeneous physical entities by converting on-screen pixels into multi-material droplets. These micro-droplets are also referred to as 'voxels' (Bader et al., 2018, p. 2).

### **1 PNG Image = One Voxel Print Layer**



**VOXEL**

a term used to describe a '3D-printed pixel', a 14-micron or 27-micron material droplet.

**THE STRATASYS J750™ 3D PRINTER**

a full-colour and multi-material Polyjet 3D-printer manufactured by Stratasys and supplied by the Victoria University of Wellington. School of Design Innovation.

**AGILUS30™**

a rubber-like PolyJet photopolymer material that can flex and bend.

**VERO™**

a rigid PolyJet photopolymer material available in many colours.

## OVERVIEW

# *Bitmap to Voxel Process*

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## **HOW DOES VOXEL 3D PRINTING WORK?**

A bitmap-based 3D-printing workflow allows image files to be sent directly to some multi-material 3D-printers, such as the Stratasys J850™ 3D-Printer for the production of physical forms.

The Stratasys J750™ 3D-Printer can 3D-print one image on top of another. When images are deposited sequentially on top of each other, the 3D-printer can construct a tangible 3D model. Each image sent to the 3D-printer contains a pixel matrix inspired by error-diffusion algorithms from 2D-printing.

Due to the limited amount of 3D-printer primary colours, additively manufactured shades and gradients can only be produced through 2D-printing Halftoning principles. So, just like a printed photograph which is comprised of many pixels, a 3D-print made up of many voxels can be observed as a homogenous area with blended materials.

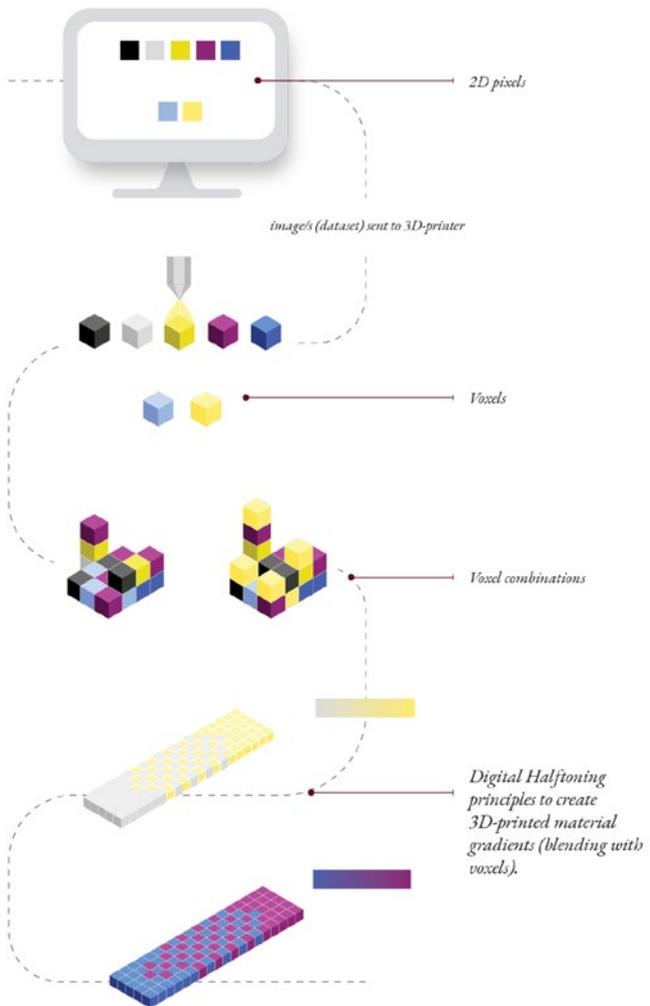
### **Part-based 3D Printing**

Usually, one part (STL, OBJ, Mesh) = One material

### **Voxel Printing**

One material droplet = One material

(printing enables the fabrication of parts with complex material distribution, such as a gradient or a sophisticated pattern)



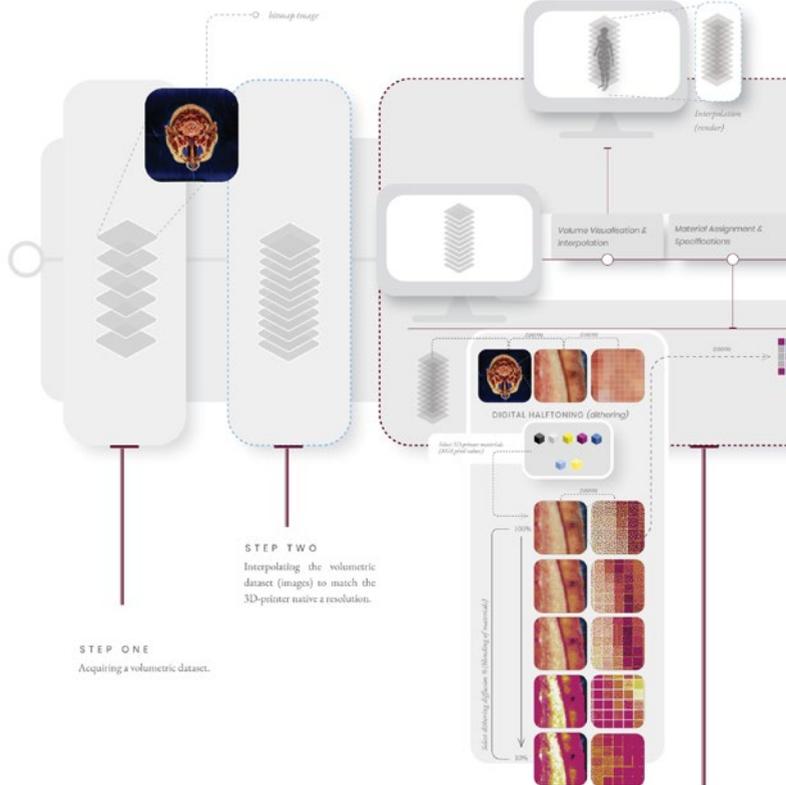
OVERVIEW

# An Example of a Voxel Printing Workflow

Looks kind of complicated right? Turn the page for a step by step tutorial.

1 Data Acquisition

2 Primarily Automated Digital Workflow



STEP ONE  
Acquiring a volumetric dataset.

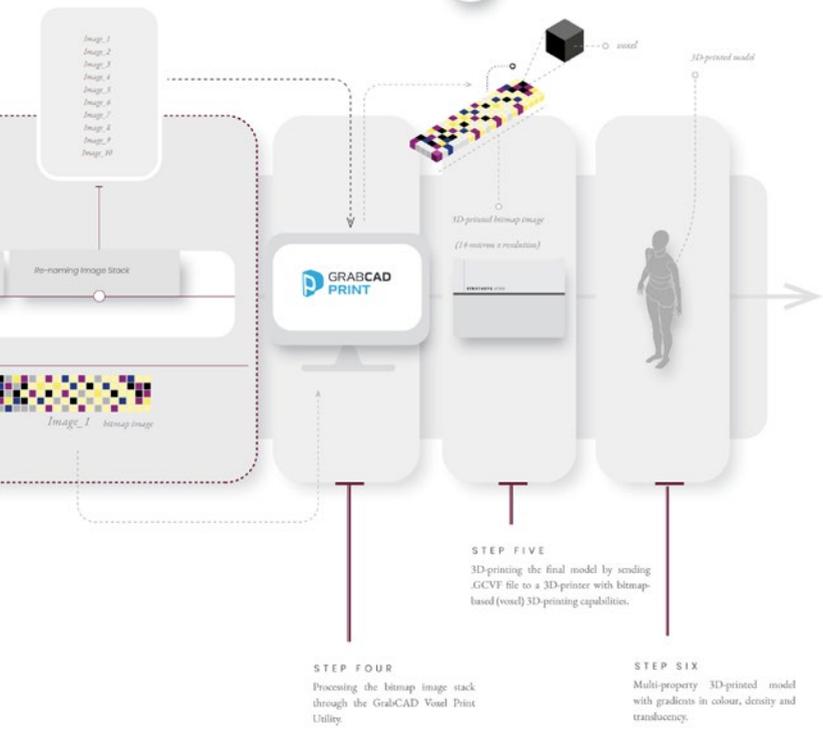
STEP TWO  
Interpolating the volumetric dataset (images) to match the 3D-printer native z-resolution.

STEP THREE

Processing the images to create a bitmapped 3D-printing file (defining 3D-print parameters and materials). This step may replace traditional segmentation processes.

Interpolation can happen at different stages in the process. These stages are highlighted in blue.

3 3D-Printing



## *Before you Begin: Considerations*

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### **a. WHICH MATERIALS ARE ON THE 3D PRINTER?**

You can only have 7 materials on the 3D Printer at a time.

Materials most commonly on the 3D Printer are:

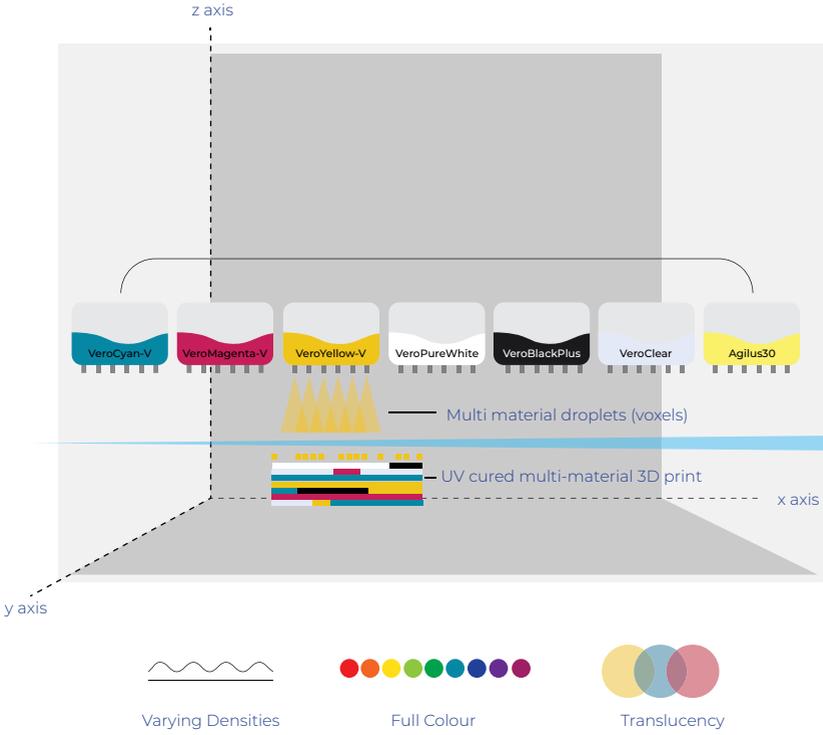
-  VeroCyan-V™
-  VeroMagentaV™
-  VeroYellow-V™
-  VeroBlackPlus™
-  VeroPureWhite™
-  VeroClear™ (hard, clear material)
-  Agilus30™ (clear-ish bendy material)

However, the following materials can be added if required;

-  VeroUltraClear™ (a new material, super clear, not common)
-  Clenser (liquid)

Material changes come with added costs and printing requirements, please check with the printing technician before creating models with these materials.

If you want to see if there is a planned material change, check the Stratasys J850 Google calendar (ask how you can see this or email the 3D print technician for access).



## *Before you Begin: Considerations*

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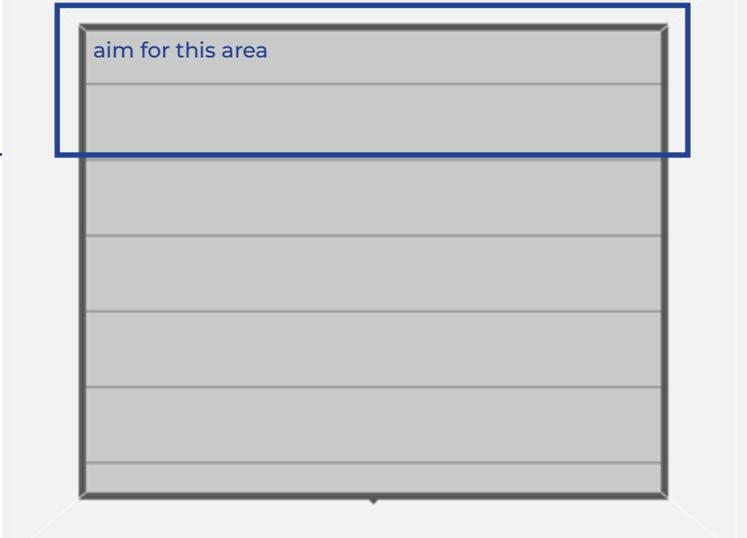
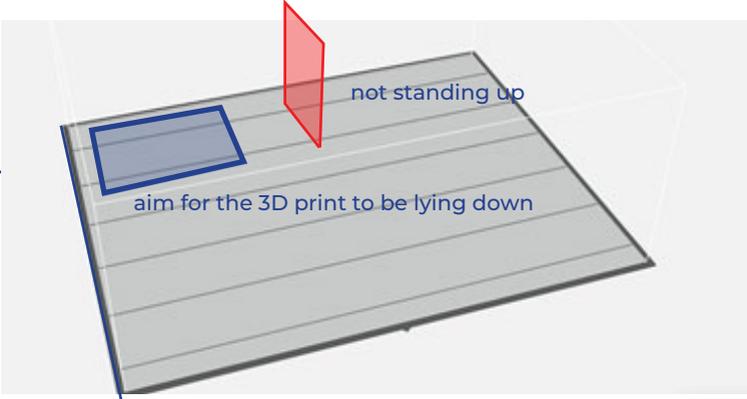
### **b. WHAT IS THE CHEAPEST ORIENTATION?**

The taller your 3D print is on the bed, the more expensive your 3D print will be. This means further up the z axis will mean the 3D print is more expensive. You want your 3D print to be lying down.

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If you're looking down on the 3D Printer bed, you want your 3D print to lie in the upper left corner, towards the top of the bed (further up the y axis).

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Tutorial

# *1. Data Acquisition*

## WHAT DATASET ARE YOU USING?

Before 2D halftoning and assigning materials to your voxel 3D print, you need a dataset (stack of images). These images must be in a folder on your computer. The end goal is to have a folder full of images on your computer to process.

### To get a dataset you can begin with:



eg. Lungs  
(.stl file)

#### A FORM

(in another program, such as Matlab or Slicer3D, you can slice the model and generate a set of .PNG image files).



Image Stack  
(eg. CT scan)

#### A STACK OF IMAGES

(eg. Images that you curate yourself, an MRI scan, or a CT scan).

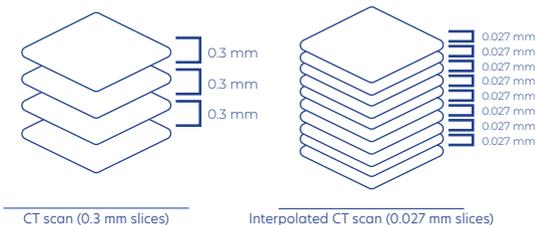
### Layer Height (space between images)

It is recommended that the layer thickness of the slices you prepare match the printed layer thickness. The printer layer thickness is:

- 0.027 mm = High Speed & High Mix

Each image will be 3D printed at 0.027 mm in height (z resolution).

Some files (such as a CT scan will be spaced further apart), which means that an interpolation function is need to 'fill in the gaps'.



Tutorial

## *2. Setting Up a Primarily Automated Digital Workflow in Adobe Photoshop*

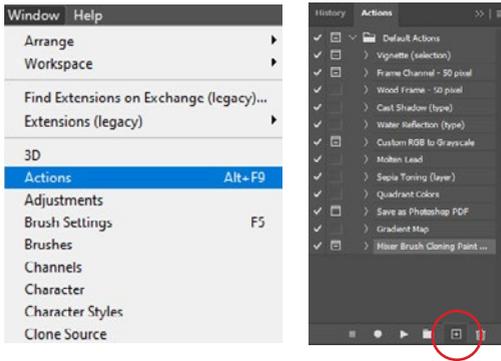
## a. ENTER PHOTOSHOP

Choose one image from your folder of images and open in Adobe Photoshop.

This image should be one of the images with the most data and/or colour within your data set.

Open the image in Photoshop and create an Action

(Window → Action → Create Action)



## b. SIZING

Crop your image to the desired selection using the cropping tool.

If your data set has been exported from 3DSlicer, the image size percent will need to be locked, then changed to 200 for the scale to be 1:1.

(Image → Image size)

The width and height of the image can be changed to achieve desired proportions, however resizing the print will not impact the height of the image stack and instead will disportion your image stack.

If you wish to resize your images, make sure the width and height are locked, change the unit to millimetres, then resize your image.

### **c. SETTING THE BACKGROUND**

To create a model that has a clear bounding box or clear pathways within the model, VeroClear material properties need to be assigned.

VeroClear is assigned through RGB values.

R: 227 G: 233, B: 253

*(Make a new layer → Move it to the back → Set VeroClear setting in Colour Picker → Use the paint bucket tool to fill the background with VeroClear → Merge the two layers)*

Once filled, the background will appear blue tinged, but will print clear.

To print with empty pathways, don't add any background, instead keep it transparent.

### **d. XY RESOLUTION**

The J750 has different resolutions in X and Y.

· X resolution = 600 DPI

· Y resolution = 300 DPI

To meet these parameters, the DPI must be changed.

This must be completed in 2 steps rather than all in 1.

*(Image → Image Size)*

- a. Unlink width and height  
Change unit to percentage  
Change width to 200%  
Change height to 100%  
Save
  
- b. Reopen Image Size  
300 DPI  
Save

**e. MATERIAL ASSIGNMENT (DIGITAL HALFTONING)**

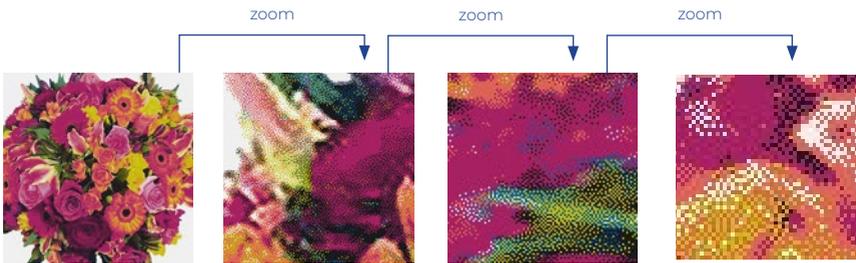
The 3D Printer has to create gradients in material (such as gradients in colour) out of the materials that are in the 3D Printer (these materials were the ones you decided on earlier (page 10). If you want to make the colour green, for example, you will need to mix VeroCyan-V™ and VeroYellowV™ pixels.

How does this work?

Just like the pixels on your TV screen or 2D printing on a normal printer!



Original Image



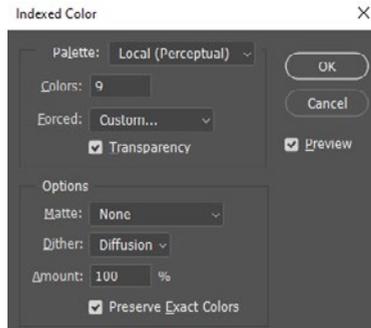
Index Coloured (Digitally Halftoned)

## f. MATERIAL ASSIGNMENT

The colour file must be changed to the colours that are on the J850 rather than all RGB colours. Load the 7 colours that will be loaded on the J850.

(Image → Mode → Indexed Colour)

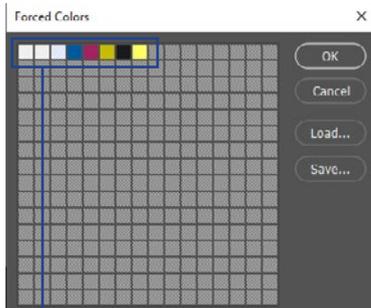
- a. Change the Palette option to Local (Perceptual), and Colours to 9 (or the minimum that you are able to input).  
Change Forced to Custom and load in the J850 colour table.



- b. Make sure that Transparency is also checked.  
Under Options tick Preserve Exact Colours.  
Press Ok, and Ok to save.

Swap back into RGB colour mode.

(Image → Mode → RGB)



These are your machine materials. You can find the specific RGB values on the GrabCAD Voxel Print website but below are what they currently are. Input these values to assign your colours/materials.

-  VeroCyan-V™
-  VeroMagenta-V™
-  VeroYellow-V™
-  VeroBlackPlus™
-  VeroPureWhite™
-  VeroClear™
-  Agilus30™

## g. SAVING

Save your file as PNG in a new folder

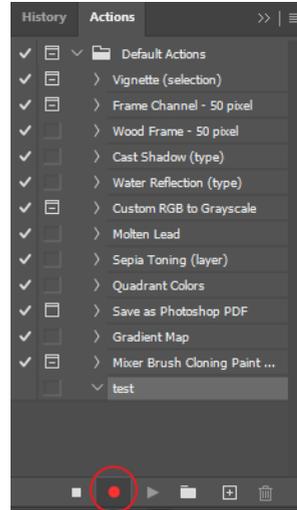
*(File → Save As → PNG → New Folder)*

Choose a new folder where all your index coloured files will save to.  
Close the file and choose don't save to the original file.

## h. ENDING ACTION

As all steps have been completed, the recording of actions needs to be stopped.

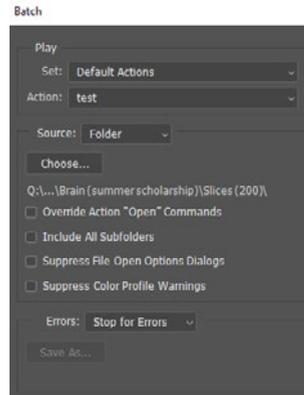
*(Window → Actions → Stop)*



## i. AUTOMATING THE BATCH PROCESS

To apply your actions to your stack of images, it must be batch processed.

*(File → Automate → Batch → Select recorded action → Select folder where the original images are → Let it run)*



Tutorial

## *3. Renaming in Adobe Bridge*

Once your image stack has been processed and digitally halftoned, you need to rename your files correctly.

You can do this on Adobe Bridge (batch rename) or manually.

Files must be renamed to ensure compatibility with GrabCAD Voxel Print Utility, a software add-on for GrabCAD Print

## a. RENAME YOUR FILES

Open the folder where all your index coloured images have been saved to.

(Select all images → Tools → Batch Rename)

Remove: date and time

Remove: text - \_

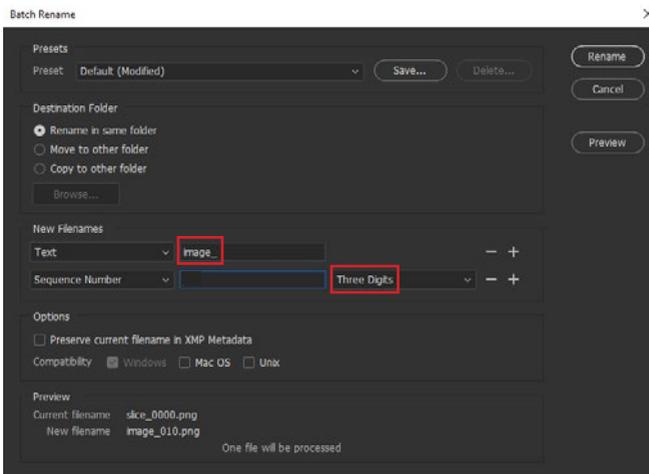
Remove: Text - Type Text

This should leave you with only *Text* and *Sequence Number*.

Change *Text* to your chosen file name, followed by \_ (eg. Image\_).

If you have more than 100 images, change sequence number to *001* and *Three Digits*, if between 10 and 99, start with the sequence number as *01* and *Two Digits*, rename with declining digits until your data sets starts from 1.

Once the images are selected and the first sequence is renamed, select the next set of images (1 - 99, or 1 - 9) and redo the steps, this time making the extension 01 and 2 digits, then 1 and one digit.



Tutorial

## 4. *GrabCAD*

**a. LOADING YOUR FILES**

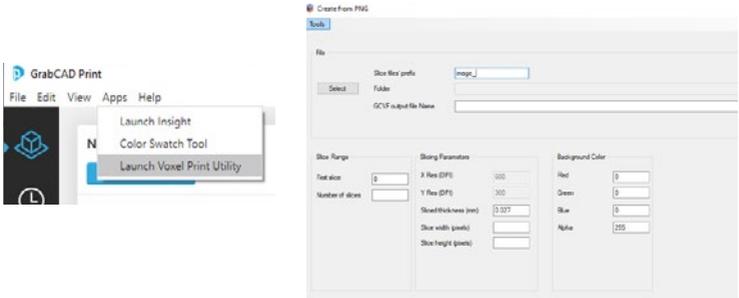
Voxel Utility Print must be used to stack PNG's to print as a 3-dimensional model.

(Apps → Launch Voxel Print Utility)

Add the name you called your images during the bridge steps (eg. Image\_), then choose the folder where they are located.

If the background was made to be VeroClear, leave Red, Green, and Blue as 0, and Alpha as 255.

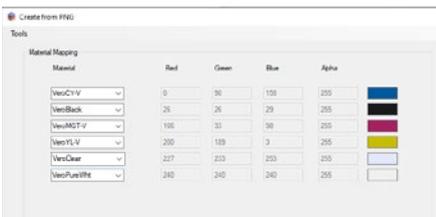
If the background was left transparent for empty pathways, change the Red, Green, and Blue to 255, and Alpha to 0.



**b. SELECTING COLOURS**

When selecting the colours that will be included in your model, the program will automatically detect which colours it needs to use to print your model. Change the names of the chosen colours to ensure they are the correct ones that correspond with the printer.

- Cyan - VeroCY-V
- Black - VeroBlack
- Magenta - VeroMGT-V
- Clear - VeroClear
- Yellow - VeroYL-V
- White - VeroPureWht
- Agilus - Agilus30White





STEP BY STEP

# Guide to Bitmaps

Tutorial

## *5. 3D Slicer*

**a. IMPORTING DATA**

Open 3DSlicer and either import your own data, or use the sample data under 'Download Sample Data' on the home page. Pick the set of data you wish to use, choosing between CT or MRI data.

*(Drop down menu → Sample Data → Volume Rendering)*



**b. VIEWING YOUR DATA**

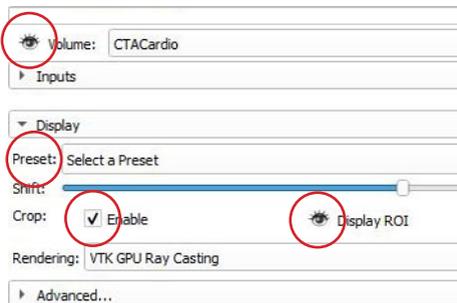
Enable the 3D view by clicking the eye next to Volume. Select a preset that you wish to use. Each present displays different components within your data.

*(Display → Select a preset)*

Display your data on screen for editing.

*(Crop: Enable → Display ROI)*

Before cropping your data, VTK GPU may need to reorient it to ensure it is cost effective for printing.



### c. ORIENTATION

If you're wanting a vertical slice from your model, the model needs to be changed to be lying horizontal. This is so that when inserted into GrabCAD it is the right orientation, and is the most cost effective.

The orientation cannot be altered once the model is created.

(Drop down menu → Sample Data → Volume Rendering)

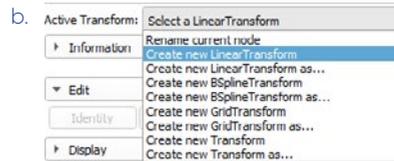
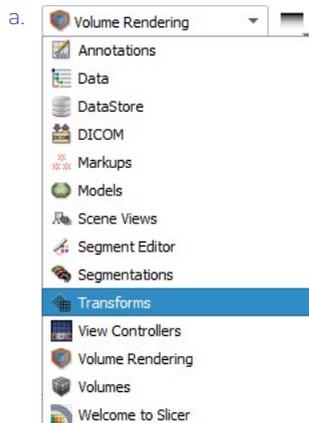
a. (Drop down menu → Transforms)

b. (Active Transform → Create new LinearTransform)

c. (Apply Transform → select your data set → press the green arrow to move it from Transformable to Transformed.)

d. (Rotation → LR → 90 degrees)

If this is done correctly, you will notice your slice will change to be horizontal.



## d. COLOUR EDITING

Return to the Volume Rendering tab. Move the cropping sliders in the 3D view to discover different elements within your data. Once your desired data has been chosen, you can begin editing the colours. The colours need to be altered to ensure they are bold when printed.

*(Drop down menu → Sample Data → Volume Rendering)*

*(Advanced → Bring up all Scalar Opacity Mapping points)*



The first (and possibly second) points may need to be left as they are, depending on the colour you're trying to achieve. You will be able to see how the colours change as you do this.

If you wish to change the colours in your model, change them under the Scalar Colour Mapping section.

## **e. MEASUREMENTS**

The measurements of your model can be seen and altered, ensuring your model is to the size you want.

*(Advanced → ROI)*

Drag the toggles to see which side of the ROI (cropping tool) changes. These also correspond to the colour sliders in the top right visualization.

The I-S is the thickness of the slice. Minus the smaller number from the larger number for the thickness of your slice (in mm), and divide by 0.027 for the number of slices that will be generated.

The P - A range must not have a difference of more than 40 as this is the width of the J850 printing bed, it is above 40 the print will be across two print lines and the cost will be heightened.

The L - R range may be whatever you wish as this is the length from left to right.

If you want your model to include more vertical data than horizontal, go back to step 3 and turn your data 90 degrees right.

## **f. EDITING YOUR DATA SET (CONTINUED)**

Continue editing your data set until the section displayed is what you want to capture. You may need to go between different steps until you are satisfied.

Any areas without colour can be printed with a clear material or without any material, these steps are covered in the *Guide To Voxel* section of this book.

## **g. BITMAP GENERATION**

Once you are happy with your section, you can generate you Bitmaps.

*(Drop down menu → SlicerFab)*

If SlicerFab is not an option, you will need to install it from the extensions manager.

Once in the Bitmap Generator, both the X and Y resolutions need to be changed to 150 DPI and the layer thickness needs to be set to 0.027mm. The scale should be set to 1.000x.

Create a new folder where the generated images will be saved to, make sure it is clearly named and you know the location of it.

## **h. THICKNESS OF MODEL**

After all layers have been generated using SlicerFab, decide upon how thick you want your print to be as this determines how many images you need in your print.

This was mentioned in step E. when scaling under ROI, but needs to be checked before submitting for printing.

When choosing the amount of bitmaps, think about how many are needed for the height you are wanting. Layers are printed at 0.027 mm high, so a height of 5 mm (approx.) is 186 images, and 10 mm high (approx.) is 370 images.

$(\text{number of bitmaps} \times 0.027 = \text{height of print})$

Once you know how many images you require, select that many from your total amount of image and put them into a new folder.

### *3. Tips and Tricks*

- White will make your colours more opaque but less transparent
- To make a transparent/translucent 3D print, it is better to use vivid colours
- It is worthwhile testing this with your own prints before printing the final model.