Determining Suitable Orientations to Overcome Embedded Security Features in STL Files.

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ABSTRACT: Embedding specific design features at the CAD stage can be used as security measure to protect intellectual property. Thus specific 3D printing environments and settings need to be known to 3D print a flawless copy. Two secured STL files were provided and the imported into the CatalystEX slicing software. Several printing orientations were tested to find the optimal setting to print the ideal copies.

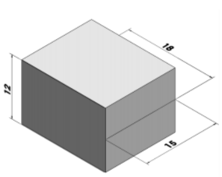
INTRODUCTION

Computer Aided Design (CAD) files can be designed with embedded security features, which can be exploited in the 3D printing process. Certain printing environments and settings can mitigate or exacerbate defects embedded in design files while in the STL processing phase. STL processing involves the slicing of the tessellated file to provide the printer with a set of instructions for nozzle movement.

MATERIALS AND METHODS

The researchers were provided with a set of instructions, specified printer settings, design file measurements, two finalized STL files (see Appendix Figure A and B), the CatalystEX slicing software, and an Elite 3D Printer. The STL files were imported into the CatalystEX software and different printer settings were tested. Settings were predominantly changed using the Orientation tab, the print was processed using the Process STL command, and the sliced layers were viewed with the Layer View menu. The processed STLs were added to pack and a CMB file was generated for the Elite Printers.

PRINTING DESIGN B



Design B

Figure 0

Design file B was characterized as a solid box with defined dimensions (see Figure 1). After inputting the defined settings, the design was processed and it was determined that the solid rectangular prism was embedded with spade shaped flaws on the surface of the prism, giving the surface several nicks. It was predicted that the nicks would have the effect of decreasing the overall integrity of the file. To ensure a correct print, the front view was selected, the measuring tool was deployed, and the values were compared with the given values in Figure 1.

To overcome the surface faults in the design file, a matrix of printing orientations was created and tested. Table 1 is a summary of the initial test conditions followed by the best conditions found in the remaining angle and rotation combinations.

Plane Orientation	Angle Orientation (°)	Rotations Carried	Used?	Reason
Front	90	X	No	9 surface nicks
Top	90	X	No	9 surface nicks
Bottom	90	X	No	9 surface nicks
Bottom	45	Y	Considered	12 surface nicks
Bottom	-30	Y, Z, X	Strongly Considered	1 surface nick
Bottom	-45	X	Considered	5 surface nicks
Bottom	**-45**	**Y, X, Z**	**Yes**	**No Defects**

Table 1: Selected features on the orientation tab of the CatalystEX software for shape B

Initially, the three plane orientations (front, top, bottom) were all processed in the given angle orientation (90°) and rotation (X) (see Figure 2 for Iso view; 90°, X). It was determined that, for file B, regardless of plane orientation, the defects did not change. Thus, in order to save time, the bottom orientation was selected for the remainder of the trials.

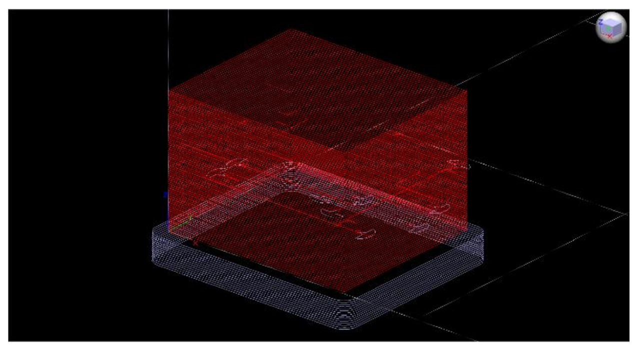


Figure 1a: Isometric view of the 90°, X orientation depicting several integrity flaws and surface nicks

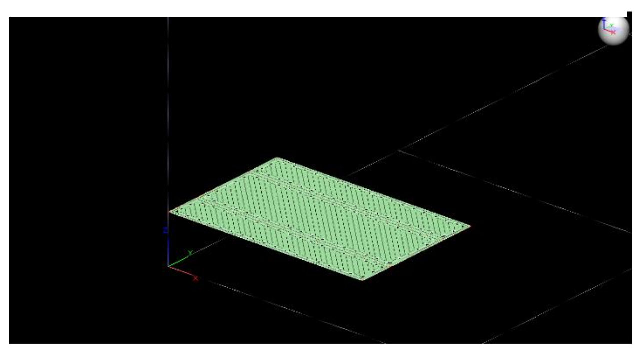


Figure 1b: Isometric view of the 90°, X specifically depicting a weakness in the structural integrity of the model

The following combinations were determined to be the best candidates for printing because of the low number of defects that were found. When 3D printing, while the façade is an integral feature to consider, as it determines the presentation and sometimes the functionality of the product, it is also of utmost importance to consider the internal flaws. A greater number of internal flaws, although not immediately visible, will eventually lead to a shorter life span of the product (more prone to damage) or decreased functionality (unable to perform under stress).

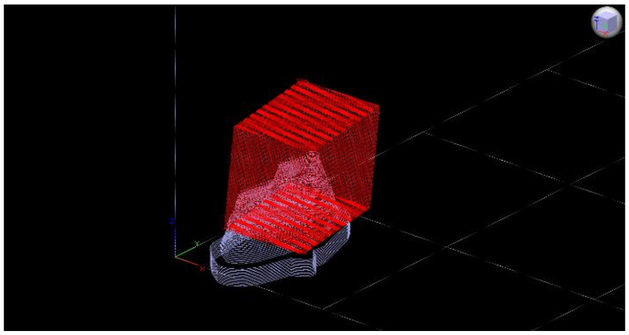


Figure 2a: Isometric view of the -30° and bottom YZX oriented piece depicting a fewer number of defects in post-processing.

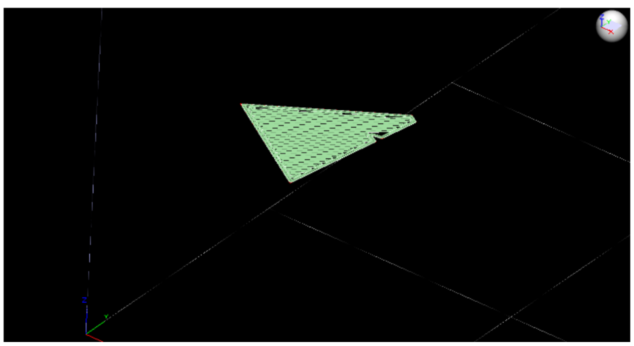


Figure 2b: Isometric view of the -30° and bottom YZX oriented piece depicting a surface nick that would compromise the surface of the piece.

In comparing Figure 2 with Figure 1, changing the orientation of the piece clearly results in a fewer number surface and internal defects. Furthermore, it was initially hypothesized that the segmentation (see Figure 1b) may be excusable since it would be sandwiched within the layers. However, the segmentations show up as gaps on the surface of the print. Thus, the final orientation was selected to be as shown in Figure 3. The file was exported to pack to obtain a CMB file (see Appendix Figure A).

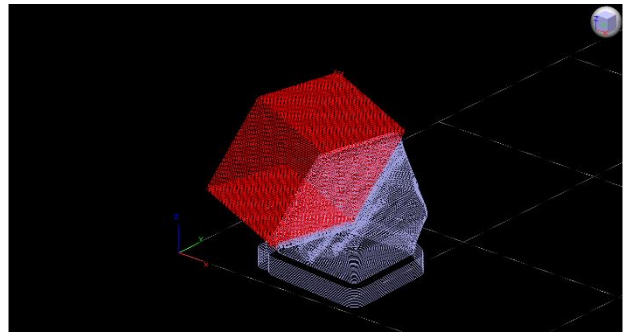


Figure 3a: Isometric view of the -45° and bottom YXZ oriented piece depicting a zero number of defects.

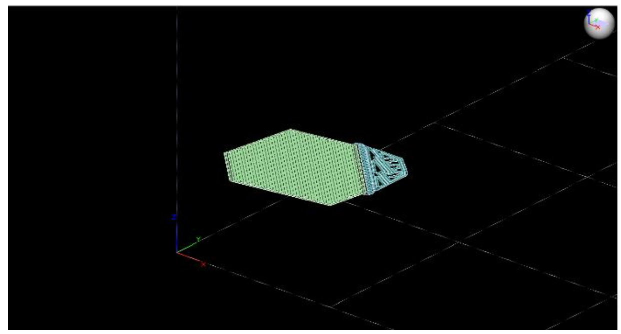


Figure 3b: Isometric view of the -45° and bottom YXZ oriented piece depicting a specified layer that will print in a continuous tool path with no defects.

PRINTING DESIGN A

Design file A was characterized as a complex, open prism with several hole and shell operations carried out on it (see Figure 4). Similar to file B, the design was processed and it was determined that the main flaws involved were the presence of segmentations, which decrease structural integrity. We also hypothesized that part of the embedded security involved merging multiple parts, because as Figure 5 shows, there is some inconsistency in the printing texture.

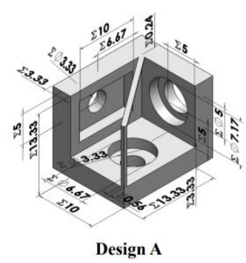


Figure 4

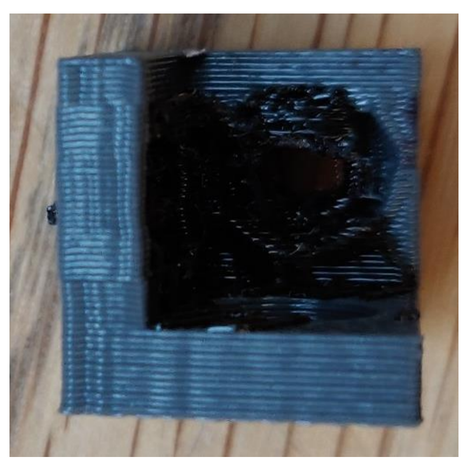


Figure 5: A top view of Design A printed, depicting a textural inconsistency on the left column

Similar to the process used for Design File B, another matrix was created to test several print orientations. Table 2 is a summary of the initial test conditions followed by the best conditions found in the remaining angle and rotation combinations.

Plane Orientation	**Angle Orientation (°)**	**Rotations Carried**	**Used?**	**Reason**
Bottom	90	X	No	10 Segmentations
Bottom	90	XYZ	Considered	1 Segmentation
Bottom	90	XY	Considered	2 Segmentations
Bottom	45	XZ	No	11 Segmentations
Bottom	-40	Y	No	5 Segmentations
Bottom	35	ZY	No	6 Segmentations
Bottom	**-30**	**Y**	**Yes**	**No Defects**

The main goal for Design File B was to find an orientation that would eradicate any segmentations, as this was hypothesized to be the main cause for weakness. Figure 6a shows layer 0.434 from a piece oriented at 90° in the X and Y direction: there were two large segmentations in the layering which led to defects. On the other hand, layer 0.434 in the final orientation, 30° in the Y direction, did not have these segmentations.

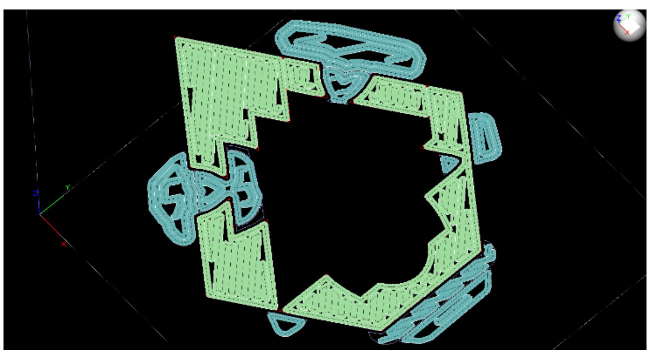


Figure 6a: Layer 0.434 at a 90° bottom oriented in the X and Y direction with segmentation, implying structural weakness and surface blemishes

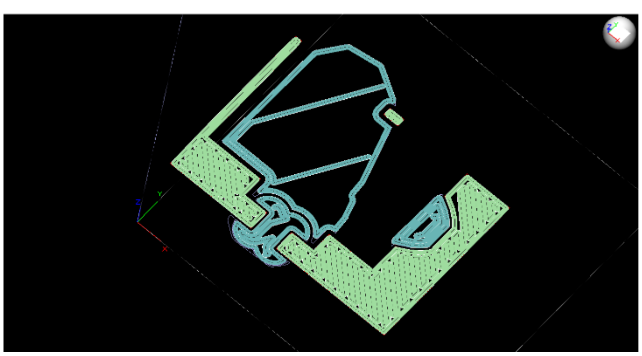


Figure 6b: Layer 0.434 at a 30°and bottom oriented in the Y direction lacking segmentation, implying a continuous toolpath.

A further consideration in 3D printing this piece was the surface area of the bottom layer. A greater surface area and greater mass towards the bottom of the printing toolpath allowed for a higher quality print because it provided a much greater adhesion to the support or the plate. Thus, the final print settings used also oriented the thicker components so to have them printed in the bottom

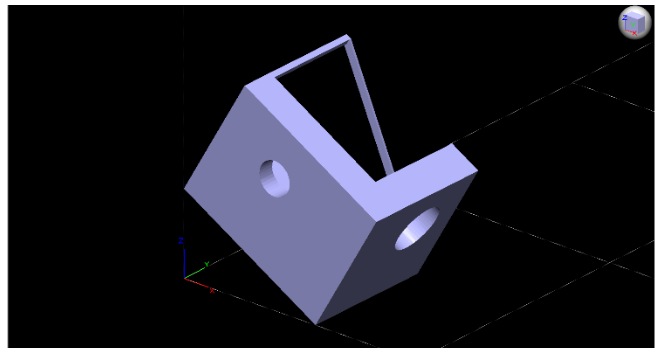


Figure 7a: An iso view of the final orientation with the thicker components oriented towards the bottom of the toolpath

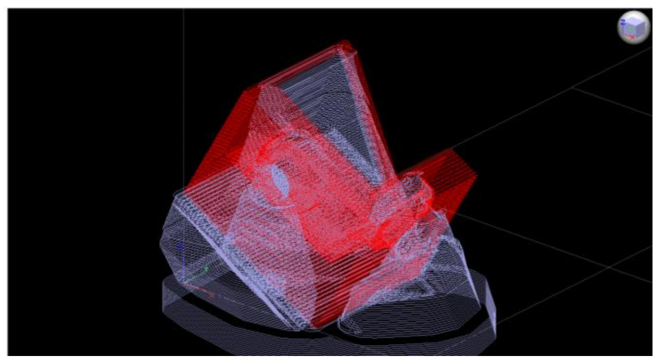


Figure 7b: An iso, sliced view of the final orientation, depicting no surface or internal flaws on the piece.

layers (see Figure 7a). Again, the file was exported to pack to obtain a CMB file (see Appendix Figure B). The two CMB files were also merged to create a single toolpath for the final print (see Appendix Figure C)

CONCLUSIONS

Embedding security features in the design stage enables the designer to introduce structural flaws into the exported STL file. While this style of security can seriously render an incorrectly printed piece useless, it also introduces a level of uncertainty for the designer. For example, the designer may also have imperfect knowledge regarding which printing environment works best. Essentially, embedded security features in the CAD file can be overcome by spending enough time to brute force different orientations. Furthermore, it is hypothesized that different CAD software may export different STL files, along with the fact that different slicers may slice the STL files in a different or make Boolean assumptions to merge a part that is embedded into another.

Thus, a future suggestion for security features in proprietary design files may involve an encoding-decoding algorithm that is utilized before processing the STL file and would mask certain features of the STL file for unknown third parties. The advantage of such a workflow would be that, instead of having to manually embed security features in the core CAD stage, one could have an automated and adaptive security algorithm that would be effortlessly scalable for and applicable to complex, real-life 3D printing scenarios. Moreover, multi-factor authentication (MFA) methods can be incorporated into such an algorithm in order to increase the reliability of the workflow.

APPENDIX

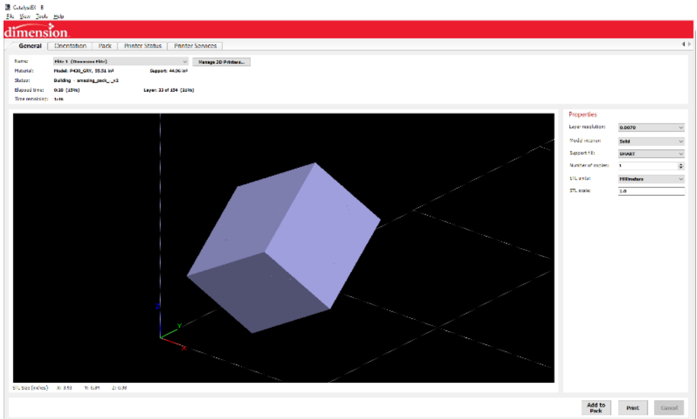


Figure A

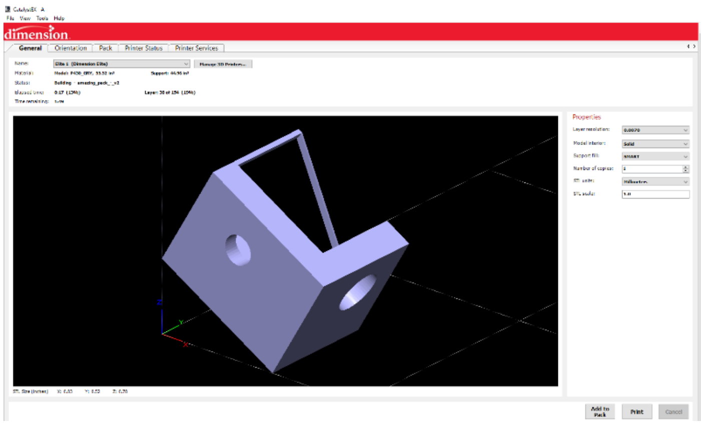


Figure B

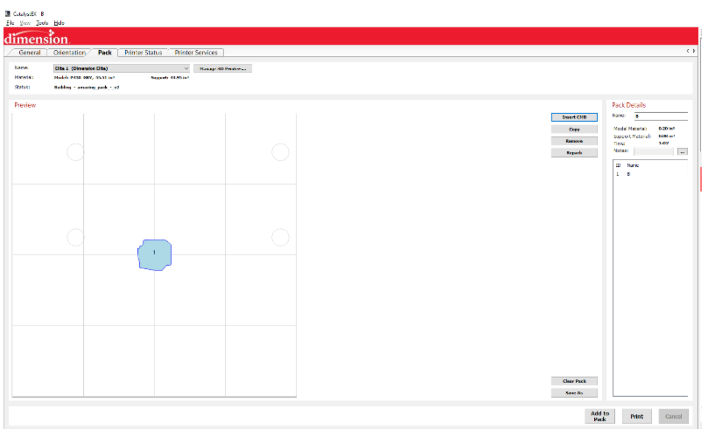


Figure C

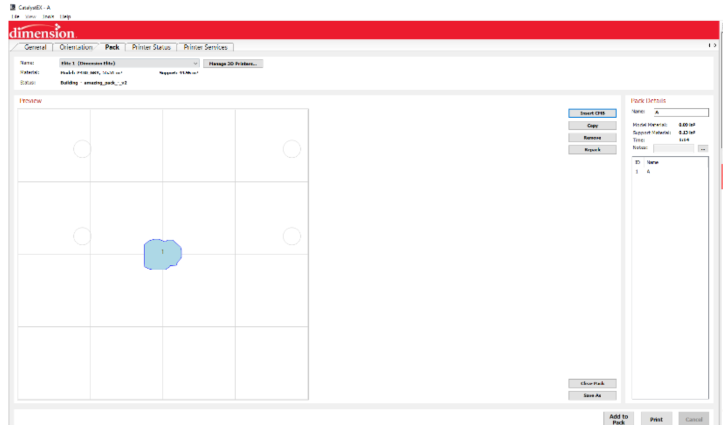


Figure D

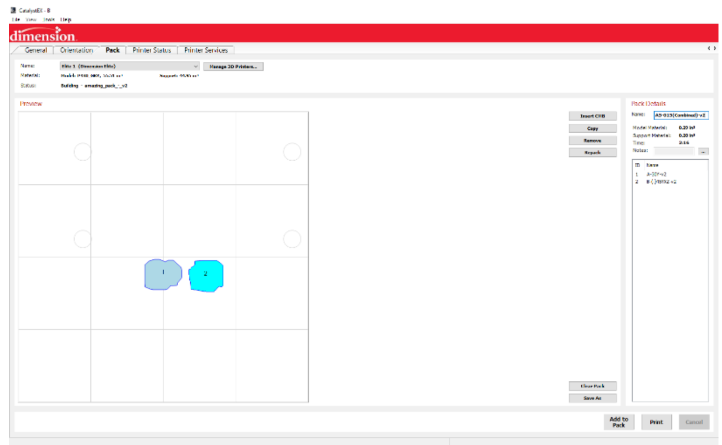


Figure E