REVERSE ENGINEERING ARCHITECTURAL HARDWARE

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ABSTRACT

There is a need to reverse engineer architectural hardware, with hinges and brackets being typical, for use in the restoration of buildings in which the original hardware is damaged. Another use for reverse engineering of architectural hardware is to take existing hardware and modify its design for use in future construction. The capture of the geometry to be used for the reverse engineering of the architectural hardware was developed with a hinge and an angle bracket being digitized. After digitization the hardware examples were transferred into parametric solid modeling software. In the solid modeling software a simple animation, the swing of a hinge, is shown. An illustration of modifying the texture of the hinge is shown by simulating its rusting using the solid modeling software. An angle bracket that was digitized and turned into a parametric solid model was converted into an STL file. This STL file of the captured geometry for the hardware was transferred to rapid prototyping machinery and a prototype was developed to illustrate the modeling of existing hardware. The parametric solid model of the angle bracket was transferred to a CAM package and a model of the hardware was turned into CNC code. The code was sent to and cut on a CNC machine tool creating a duplicate of the item.

1. INTRODUCTION

There are many reasons to reverse engineer products like architectural hardware (Waggoner, 2004). Antique items with high value may need to be reproduced due to their inability for function due to wear and age. These items may be used for reproductions to be generated for future building construction.

An existing design may need to be modified for future use. This is where a design with historical value or importance is used as a starting point for future development. Documentation of historical hardware may be of importance. In the case of functioning hardware, it may be stored digitally for replacement by future generations.

To illustrate the reverse engineering process for architectural hardware a hinge and an angle bracket were selected.

2. REVERSE ENGINEERING THE HINGE

Figure 1 shows a hinge that was chosen for the reverse engineering process. It was initially scanned as seen below:
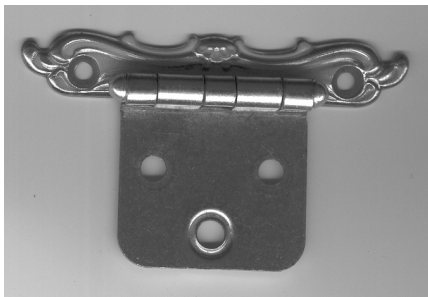

Figure 1. Scanned Cabinet Hinge

2.1 Scanning the Hinge as a Bitmap

The hinge in Figure 1 was scanned using a Hewlett Packard ScanJet 3400 C flatbed scanner and a bitmap file format was generated. The bitmap was transferred to software to turn it into a CAD drawing, but it was difficult to separate the hinge into pieces. The solution for this was to cut the hinge apart. Painting the hinge white and digitizing it against a black background helped in the gathering of the digitized outline form of the image.

Figure 2. Digitizing the Hinge in Pieces

Figure 2 is a bitmap of the hinge part from the flatbed scanner. The bitmap was transferred into ALGOLAB (a free downloadable trial software available on the Internet at http://www.algolab.com/). The software can also be purchased.
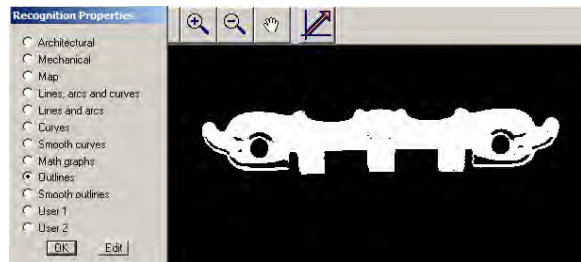

Figure 3. Hinge Part in ALGOLAB Software

2.2 Converting the Bitmap to a DXF File Format

Figure 4 shows a CAD drawing generated in the ALGOLAB software of the scrolled portion of the hinge.
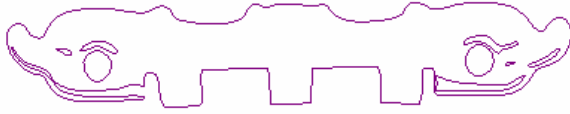

Figure 4. Outline in CAD Drawing Created in ALGOLAB

Some editing of the drawing was done. The DXF format drawing was opened in SolidWorks DWG editor and saved as a DWG file for transferal into SolidWorks 2006 (Sp 4.1). In Figure 5 the drawing has been opened in SolidWorks and the extrusion process has been started.

2.3 Manipulating the Digitized Model in the Solid Modeling Software

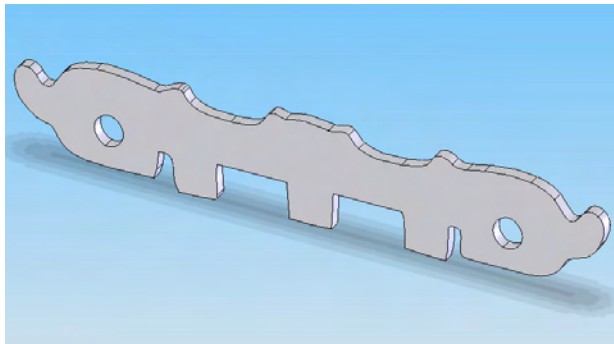Figure 5. Extruding Pieces of the Hinge

Figure 6. Extruded Hinge Piece

After the hinge had been extruded, some of the internal details needed to be created in the solid modeling program. The use of a 3D scanner and the generation of a point cloud instead of an outline could be used to eliminate the need for the constructions in the solid modeler. The goal of this research was to use inexpensive means to duplicate the hinge.
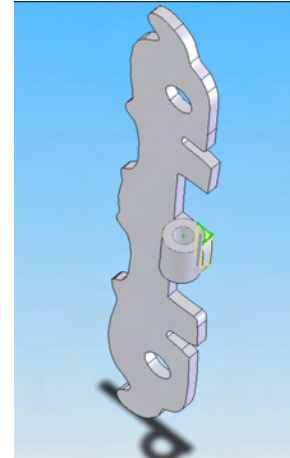

Figure 7. Creating the Center Cylindrical Section in the Solid Modeler

 In Figure 7 some of the extraneous geometry is being cut away. That geometry resulted from the transfer from 2D to 3D modeling.

Figure 8. A Linear Pattern Was Used to Duplicated the Center Part of the Hinge

Once the center section of the hinge was generated in Figure 7 it could be duplicated by using a linear pattern in the software as seen in Figure 8 (SolidWorks, 2006).

The flat part of the hinge needed to be duplicated. This was done using a similar procedure to those used with the other hinge part.
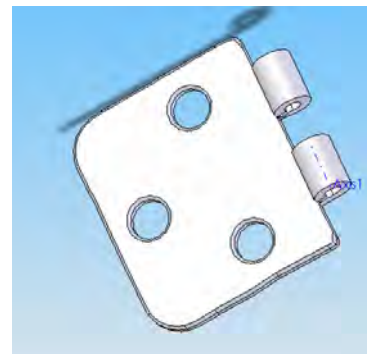

Figure 9. Reverse Engineered Flat Part of Hinge

Figure 10. Creating the Hinge Pin

The hinge pin was drawn in the solid modeling software due to its simplicity. With simple parts that may be the best and cheapest way to reverse engineer them.
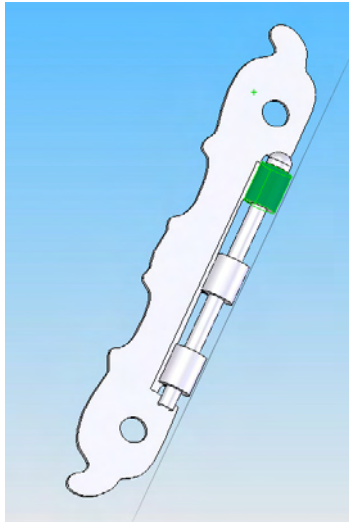

Figure 11. Creating an Assembly -- Hinge Part and Hinge Pin
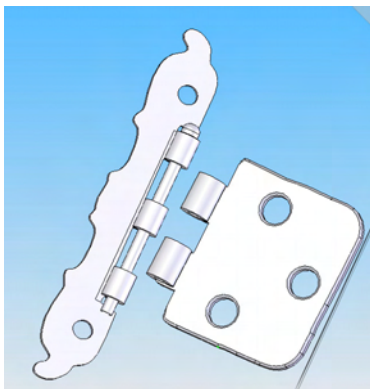

Figure 12. Adding the Flat Hinge Piece to the Assembly

Constraints such as coincidence, distance, and concentricity were used in making the assembly.
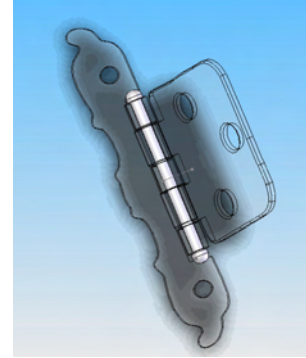

Figure13. Editing Parts Inside an Assembly

The riveted end was put on the hinge pin after it was in the assembly. The original hinge pin was too long and it was also shortened during that editing process. The parts are edited within the assembly which is a powerful aspect of the solid modeling process. Techniques used in the (SolidWorks, 2006) advanced part modeling were also used in this pin development.

2.4 Animating the Hinge

Figures 14 through 16 are screen clips of an animation of the hinge. Saved as AVI files they give a realistic view of the mechanism in motion.

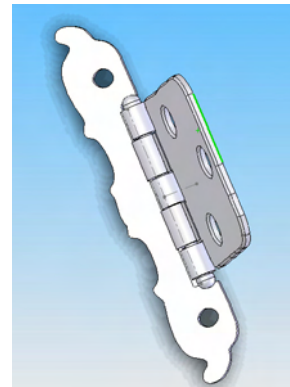Figure 14. Screen Clip of the Animation of the Hinge

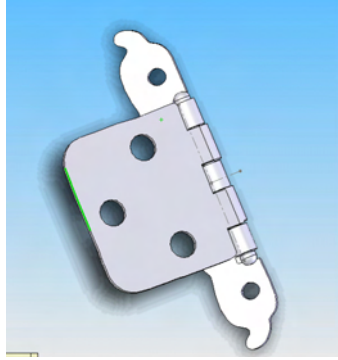Figure 15. Another Screen Clip of the Animation of the Hinge

Figure 16. Final Screen Clip of the Animation of the Hinge

2.5 Adding Detail to the Hinge

The scanned CAD drawing was added on to the hinge part in Figure 17. The some of the detail was extruded in Figure 18 and the part was updated in Figure 19.
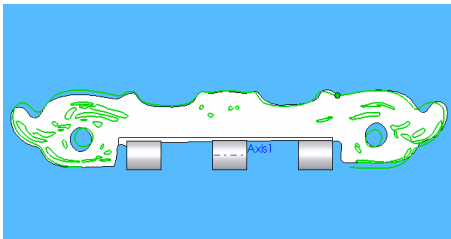

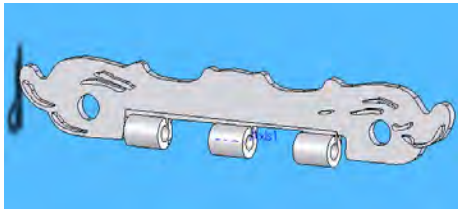Figure 17. Adding Details to the Hinge
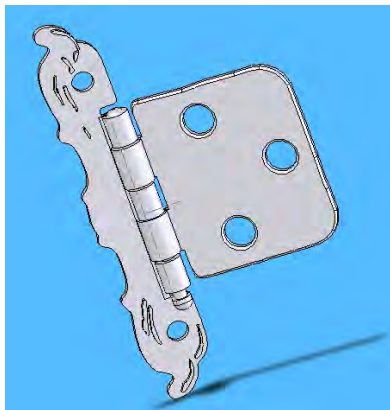

Figure 18. Extruding Detail on Hinge

Figure 19. Updating Hinge Assembly

This detail is better generated with a 3D scanner. For that type of work a laser scanner with point cloud generating capabilities would be a better way to go (Grimm, 2005).

2.6 Applying Surface Textures to the Model

It is possible to put different finishes on parts in SolidWorks and other parametric solid modelers. Figure 20 is a rust-like finish that can be added to the part in the solid modeler. The rusty finish was applied to a model of the hinge without the surface details, but certainly could be applied to that model also.

Figure 20. Applying a Rust Finish to the Reverse Engineered Bracket

3. REVERSE ENGINEERING THE ANGLE BRACKET

The angle bracket was reverse engineered in a similar fashion to the hinge. It was scanned using the same flatbed scanner that was used on the hinge and turned into a 2D CAD drawing using ALGOLAB software.

3.1 Digitizing the Angle Bracket

There were issues with shadows and the thresholding of the exterior lines in the drawings so some CAD editing was performed. These shadows can be seen in Figure 21.
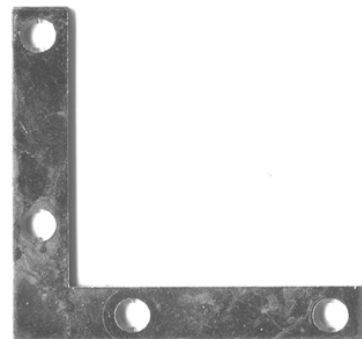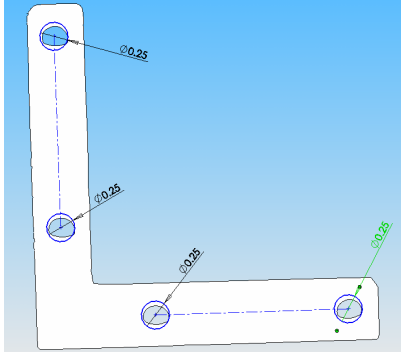

Figure 21. Angle Bracket

Figure 22. Correcting Shadows in Holes

3.2 Preparing to take the Solid Model for STL File Creation and Transfer to CAM

Due to CAM implications, the holes had to be turned into circular hoes. A more powerful bitmap converter with a stronger algorithm would be more capable at defining geometric shapes like circles. In CAM, the holes could be cut as pockets, but to use a drilling cycle round holes were needed.
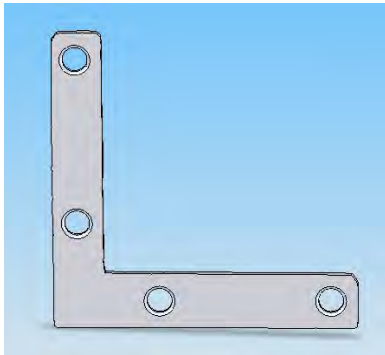

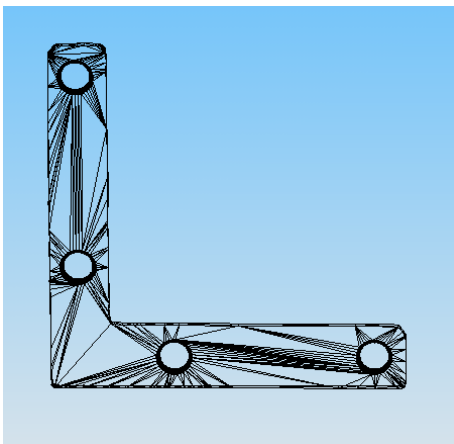Figure 23. Chamfering Hole in SolidWorks

3.3 Creating an STL File

Figure 24. Creating an STL File

In Figure 20 the holes were chamfered in SolidWorks. The file was turned into an STL file in Figure 24. his was sent out and a rapid prototype was created using a Z-Corp machine.

3.4 Transferring the File to Mastercam

The geometry of Figure 23 as sent into Mastercam XMR2 for creating a CAM file.
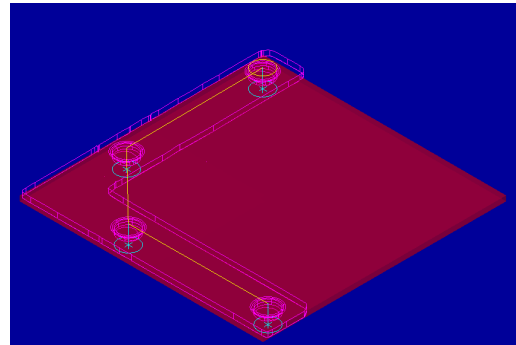

Figure 25. Hole Drilling Being Simulated in Angle Bracket Using Mastercam XMR2

The solid model comes into Mastercam as a 3D entity. A work boundary can be seen in Figure 25. This is called stock setup (Mastercam, 2005) and defines the limits of the workpiece.

In the Mastercam software tools are chosen. In this case an end mill and a drill were required. The software develops a reasonable feed and speed rated to run these tools at. These speeds and feeds can be changed or overridden by the computer operator if that is desired.

The main result of the CAM process is the generation of a CNC file that can be run on a machine tool. Figure 26 s an example of such a file. It is a machine ready file that is specific to the requirements of a machine tool. These can be saved for future modification or use.

```
:ANGLE_BRACKET
N100M0M96/6
N110M96/0
N120G70
N130G90
N140M05
:TOOL DIA. – .2500
N150S1069T104/0/.25M06
N160M3
N170G00X.2375Y2.7596Z.1
N180G83X.2375Y2.7596Z.225Z.1Z.1F42.78
N190X.2535Y1.0647
N200X1.0724Y.2689
N210X2.7822Y.2794
N220G80
N230M05
N240M25
N250M2M96/9G4/1
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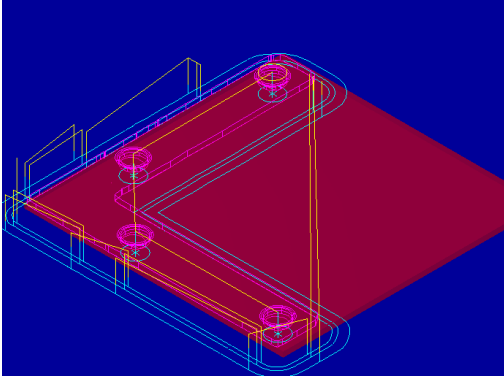Figure 26. CNC Code for Drilling Only – As Created in Mastercam XMR2

Figure 27. The Contour of the Periphery of the Angle Bracket
Being Simulated in Mastercam XMR2

The algorithm that ALGOLAB uses creates a disjointed CAD file. It is broken into pieces and these cause the tool to retract and then need to return to the cutting process. Figure 27 illustrates this. Considering the price of the software this is not bad compared to other previous inexpensive software processing.

Earlier versions of a variety of software yielded points that were disconnected. This version of ALGOLAB gives line and arc segments which are much better, but still has this limitation in Mastercam XMR2.

This parallels the problem that was experienced with the holes generated with the ALGOLAB software. As mentioned earlier, the holes could be cut as contours with an end mill, but there is not enough definitive math/CAD data to drive the center of the circle. This requires the exact X, Y, and Z coordinates. Best fit circles were *sketched* in using 2D CAD functions in the SolidWorks software. Circle-fitting is a tough algorithm to find in this price range of software.
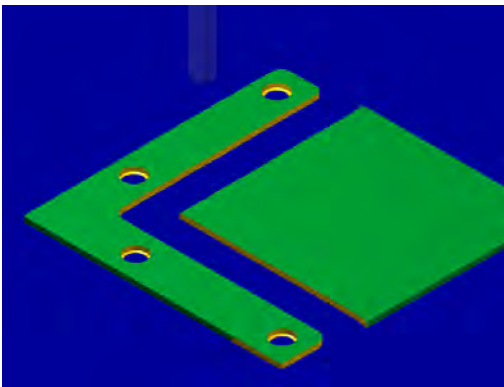

Figure 28. Simulation of Hole Drilling and Periphery Being
Cut in Mastercam XMR2

A part was cut on a Centroid-controlled Xcello CNC milling machine. The endpoints in the geometry caused the machine to retract quite a bit in the cutting process.

4. CONCLUSIONS

The project worked quite well considering the low dollar cost of the digitizing equipment and software. The author has been exposed to Geomagics Raindrop software which does a nice job of handling complicated surfaces. Geomagics software is quite expensive and would be hard to justify without direct cash generating projects.

With some CAD and solid modeling manipulation in addition to the digitizing of the architectural hardware it was possible to generate solid models, rapid prototypes, and CAM-derived prototypes of the hardware. Reverse engineering was achieved to some degree of success. The processes could be described here as *2 ½ dimensional* where X and Y are described, followed by a finite Z depth in which the design is *extruded*.

It was surprising how well size was represented as parts were modeled. The hinge was assembled with very few changes to the parts meaning that the relative sizes of the parts were being held quite consistently. The back of the hinge, Figure 6, was used for the initial extrusion followed by the front, Figure 17, for the extrusion of details and with some scaling they matched fairly close. That gives further support to the ability of the software to maintain size. Further studies need to be done to determine how much variation there is in the transfer of size in the digitizing portion of the study.

Ultimately, if more quality is needed, there is no question as to what more sophisticated hardware and software could do. Researchers can get a feel for the technologies at a very low cost level using the methods outlined in this paper.

REFERENCES

References from other literature

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Reference from website

Grimm, T. 2005. " Reverse Engineering: Magic, Mystique, and Myth," Edgewood, KY, http://www.deskeng.com/Articles/Feature/Reverse-Engineering:-Magic,-Mystique,-and-Myth-20050714551.html (accessed 5/26/2007)