The Maitreya Project

Large Scale Prototyping
A Case Study

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Introduction

Imagine a statue, made out of bronze, more than three times taller than the Statue of Liberty, designed to last 1000 years. That is what Javelin was asked to do when the Maitreya Project contacted them for prototyping assistance in the summer of 1998 .

The Maitreya Project, an international Buddhist organization plans to build the largest statue in the world. They plan to build a 500 foot representation of the Maitreya Buddha in Bodhgaya, India, a Buddhist holy place located in northeast India, just south of Nepal. The Maitreya statue will be significantly larger than Japan's 394 foot high Ushiku Buddha [1, 2].

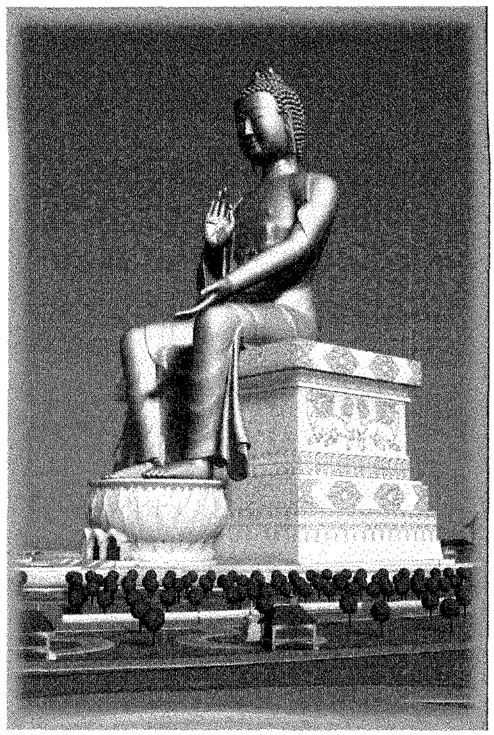
A hand-sculpted original model of the statue was created by commissioned artists. In order to evaluate architectural perspective, the hand-sculpted statue was sent to Javelin's facility in Salt Lake City, Utah so that the original artwork could be captured digitally and a 5:1 scale-up produced.

Accurately and rapidly reproducing the original statue while at the same time minimizing costs pushed the current limits of Solid Freeform Fabrication (SFF) technology. While the original intent of the work conducted in Salt Lake City was to create a computerized version of the hand-sculpted statue's geometry, produce a 5:1 scaled model and verify the CAD file, the project grew to encompass much more than that.

Approach

The Maitreya Buddha model, built by Javelin, made use of the several reverse engineering (RE) and SFF technologies that included:

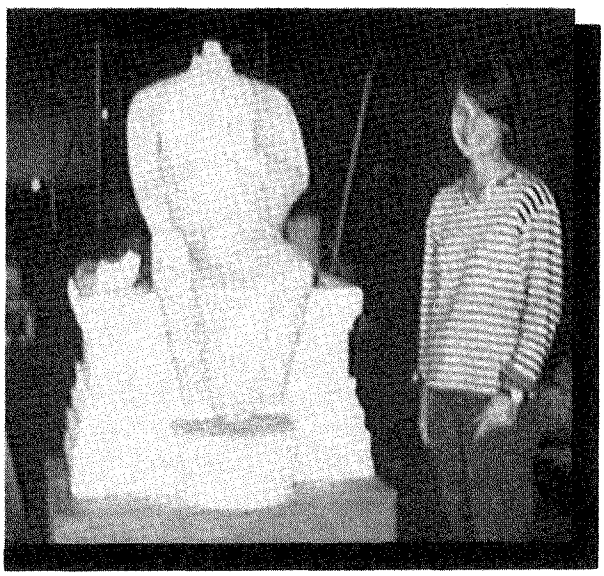
- Computer-aided design (CAD)
- Fused Deposition Modeling (FDM)
- 3D Printing
- U-of-U Shapemaker 2000™ System
- Digitizing
- CT scanning
- Soft Tooling



Maitreya Buddha [3]

It was recognized, from the start, that building a 20 foot statue entirely using one of the more common rapid prototyping systems, such as stereolithography or FDM, would be both too expensive and slow for the Maitreya Project budget and time-frame constraints. Computer Numerical Control (CNC) machining was initially considered but the approach was rejected because the costs required to produce CNC code were out-of-line for the budget. One group estimated that it would take at least a month to generate the multiple 5 axis machine code and they would not guarantee specific geometry features associated with undercuts and overhangs.

After a review of model-making options, a water-jet system under development at the University of Utah, appeared to have the best potential for building the majority of the statue's geometry. The decision was made to proceed with the 5:1 scale-up using their water-jet based rapid prototyping system. 3D Printing and FDM systems were selected as backup for features that were too small to build in foam, based on cost and strength, respectively. Because no computer model existed for the hand-crafted Maitreya Buddha, significant effort was required to create polygon and NURBS-based solid models.

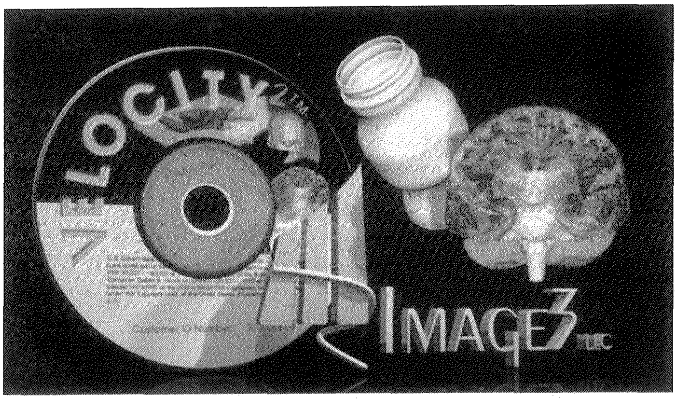


Original Artwork and Denise Griffin, Maitreya Artist

Reverse Engineering

Reverse engineering (RE) involves taking an existing part for which there is no accurate CAD data (perhaps because the part is old or was modified after the mold was made) and essentially recreating the part. Most RE approaches involve imaging or digitizing the RE object and then cre-

TM University of Utah's Ruled Edge Layer Prototyping System ating a computerized reconstruction that can be integrated, in 3D, into the particular design environment. The process of capturing the geometry, extracting contours and surfaces from reconstructed images, and creating a CAD-compatible representation is the most common example of reverse engineering. Related activities, such as extracting defect and dimensional data from the image and comparing the results with an already existing CAD model is commonly referred to as part characterization.

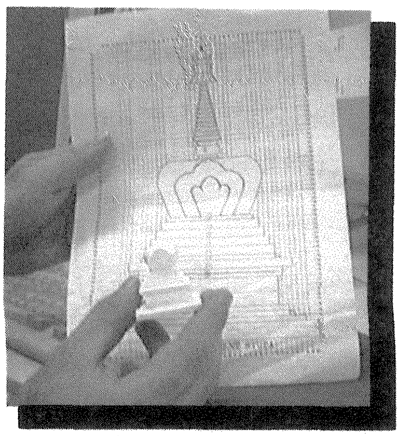


CT Scans Were Reconstructed Using Velocity^2 Software [4]

The Maitreya statue sent to Javelin was a work-in-progress. This created significant RE challenges. When received at Javelin's studio, the statue's head was not attached to the body. Neither were the ears, hair curls, hair knot, stupa or the third eye. Only one foot had been sculpted, and that too, was not attached to the body. The original artwork arrived in Salt Lake City at the end of September. The goal was to finish the 5:1 foam scale-up by the end of November. Because laser scanning typically creates very large data sets, digitizing was selected to capture the majority of the geometry. Even with an approach that concentrated on file size minimization, the medium resolution polygon model contained over 800,000 polygons.

Digitizing was supplemented by CT scanning and/or CAD for geometry features that were either missing or too small for digitizing. In this case, digitizing also produced a "cleaner" model - one where imperfections pointed out by the artist could be avoided versus laser scanning that will faithfully reproduce the item - including flaws.

Some pieces of the art were not suitable for digitizing as the hand-crafted pieces were either very small, on the order of a few inches, or missing. Some pieces, such as the decorative patterns that will be found on the statue's throne, underwent CT scanning and the images were reconstructed using Velocity^2 software to produce the STL file needed for SFF.

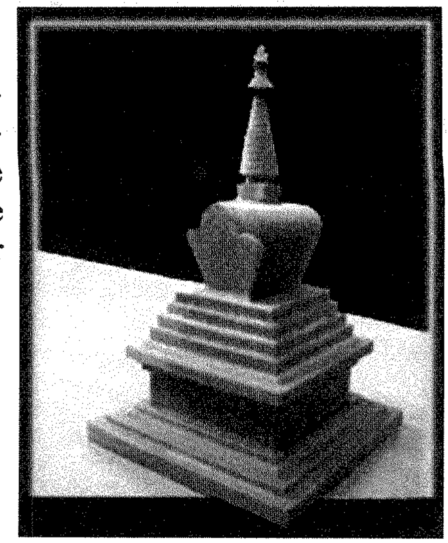


Artist's Stupa Drawing and Small Sculpture Representation

Computer Aided Design

Wherever possible, features were identified that could be modeled using high-end CAD packages such as SDRC's I-DEAS, Pro-Engineer, Maya, and Alias Wavefront. In some cases, artistic sketches were available. Other features were created from information provided by the artists. The Stupa, Hair Curls, Hair Knot, and the Third Eye of the Maitreya Statue were computer designed by engineers using advanced CAD programs.

Mirroring



3D Printed Stupa Formed From
CAD File Modeled By Javelin
5:1 Scale

The Project also wanted to mirror sections of the statue. The artists felt that features on the right side of the statue were better defined and more artistically pleasing than the left side. Wherever possible, they wanted to mirror right-side features. With digitizing it is fairly easy to define mirror regions. Items the were mirrored during digitizing include:

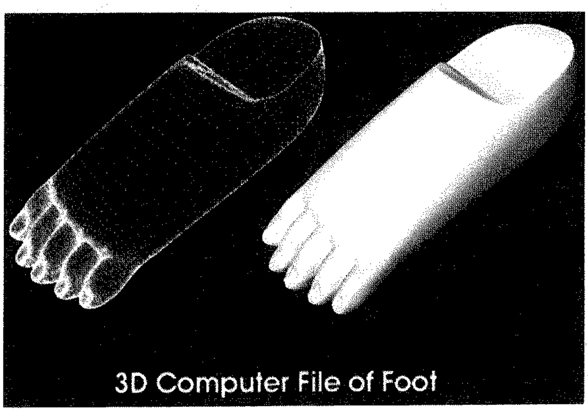
- Left side of the face was mirrored from the digitized data from the right side,
- Right half of the neck was mirrored from the digitized data from the left side,
- Left half of the torso's lap and lower legs were mirrored from the digitized data from the right side, and
- Left foot was mirrored from the right foot.

While mirroring assures that left and right halves are identical, it created unique computer file and actual statue alignment "fit" problems. Specific problem areas included:

1. Making the Hair Curls fit on the curvature of the head. Imagine a bathing cap that fit snugly on a head. Then a different version of the head was created by mirroring the right side of the head. The new, mirrored head will have a slightly different size and curvature. Fitting the same bathing cap, snugly, to the new head could be difficult, if not impossible without changing the size of the bathing cap.

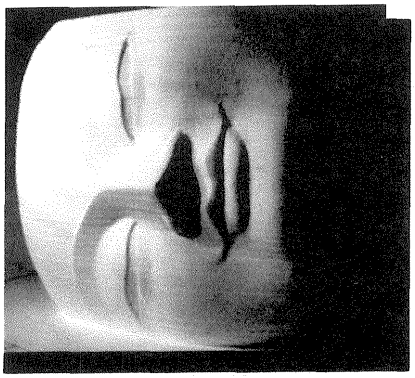
2. Making the "mirrored" lap torso fit identically to the upper body torso that was not mirrored.

3. Extended hand placement. The statue's extended left arm rests on top of the left knee. On the original statue, the thigh of the left knee is actually longer than the thigh of the right knee. For the computer file, the mirrored right knee was used. However, in the mirrored version the back of the hand touches in a slightly different location because of the "shorter" knee. With a 5 times scale-up, this different hand placement created visual concerns.



Computer File Created From Digitized Right Foot. The Left Foot Was Created From the Mirror Image of the Right Foot.

4. The face presented the most significant "mirroring" problems. This was done to allow the artists to choose between faces. The left mirrored face was rejected outright by the artists, they absolutely did not like the left mirrored face.



Polystyrene Head
Built on the U of U system.
Right Side of the Face was Mirrored

While mirroring allows a computer file to be created that is more "exact" in its geometry features than an original piece of art, it can also result in visually different geometry. Care should be taken to understand the impact of mirroring and not assume that visual differences are due to problems in construction or computer modeling.

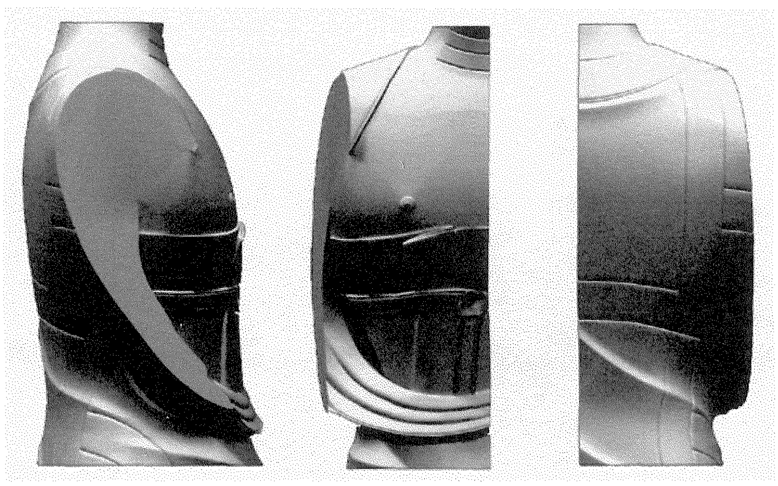
File Sectioning and Manipulation

The University's system employs a 4' by 5'build envelope. The 3D file had to undergo electronic sectioning to fit within the build envelope. Several CAD packages were used to achieve this. Sectioning of the computer file was further complicated by eventual statue shipping requirements. Each portion of the 20 foot statue could not exceed, including packaging materials, the maximum allowable crate size for air cargo.

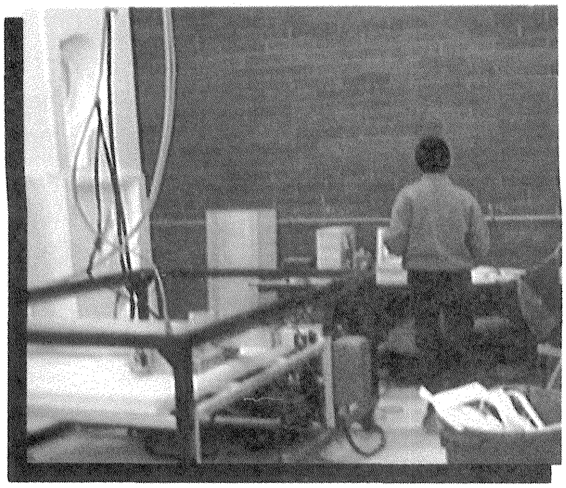
Solid Freeform Fabrication

Once the STL file was approved by the artists, the University's system was used to cut over 90 % of the statue's geometry, layer-by-layer, out of 1 lb density polystyrene foam sheets. Cutting occurred over 25 days and 256 hours were logged. The statue contains over 2000 layers. Most of the layers were 1/2" thick , although quarter inch sheets were used to build the head and the hands.

The Ruled Edge Layer Prototyping System (Shapemaker 2000™) under development at the University of Utah allows the production of prototypes directly from STL files. The Shapemaker software first slices the STL file into thick layers (1/4" to 2") where the layer edge is approximated by a sloped surface to better approximate the CAD geometry. A high pressure water jet is then used to cut these ruled edged layers from plastic foam. The dramatic advantage provided by the water jet cutter is that the cutting tool has a diameter of less than 0.01". The com-



Upper Statue Torso After Computer File Sectioning bination of layered decomposition and a small diameter cutting tool allows the Shapemaker to produce a complex geometry quite easily.



University's System Running in Javelin's Studio

For example, the hand shown below contains geometry that would be difficult to machine. Machining would require a skilled machinist to develop a manufacturing plan including multiple setups and probably sectioning of the hand into smaller machinable parts (in order to machine between the fingers). The Shapemaker was used to build the part in a single standard procedure. Each slice, often containing multiple pieces, was contained in a registration box that allowed the entire slice to be handled as a single piece during registration and bonding. This piece was cut, registered, and bonded in roughly 4 hours.

Some of the statue's features were too small to be built on the Shapemaker. The Third eye, Stupa, and Hair Knot were built in ABS using FDM. Also, a mirrored ABS foot was built for the original statue, as the artists never created a left foot for their original artwork. The artists covered the ABS foot with the same resin that they sculpt with and then attached the coated ABS foot to the original statue.

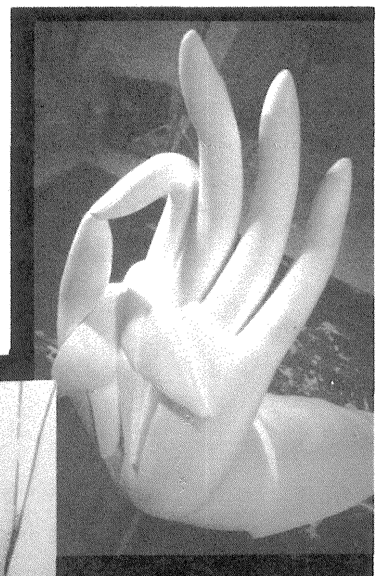
3D Printing was the SFF process used to create sign-off models for the artists as different sections of the large model were being produced. 3D Printing was also used as patterns for soft tooling of the Hair Curls and Ears.

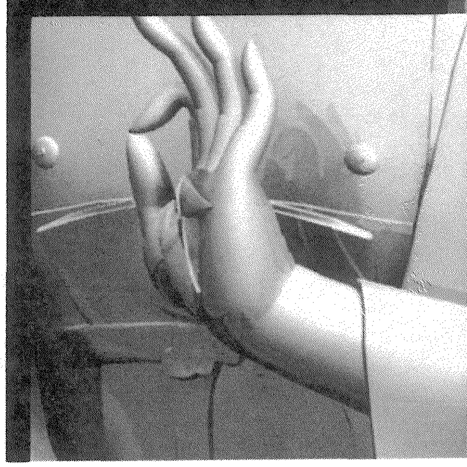
Rapid Tooling

About 300 hair curls were needed for the statue's head. Hair Curl patterns were built on Javelin's 3DP machine. These patterns were used during the creation of soft tools. Polyurethane foam was shot into the tools to produce each hair curl. The statue's ears were also produced in this manner.

Measurements

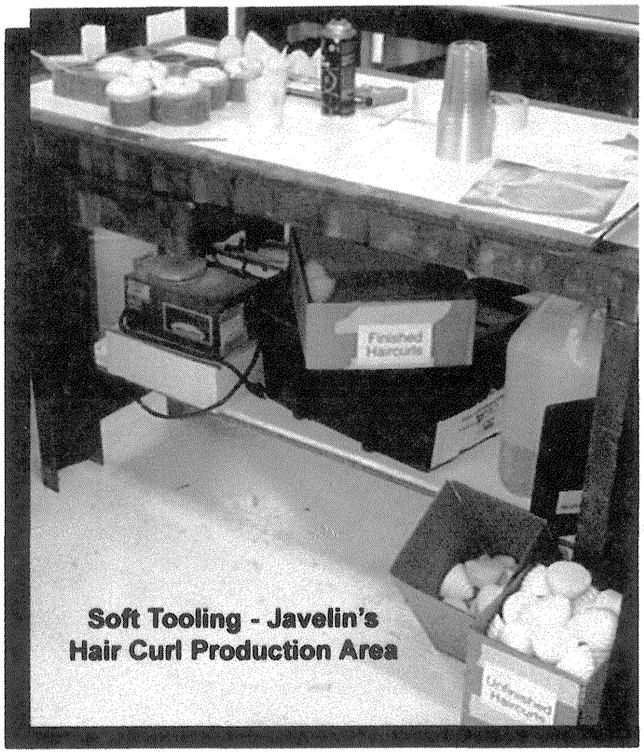
Over 80 measurement points were used to document build accuracy. A Design Factor (DF) was calculated for each measurement and the difference between the actual and calculated





Computer Model of the Raised Hand (left) and the Actual 5:1 Hand Built in Foam (above)

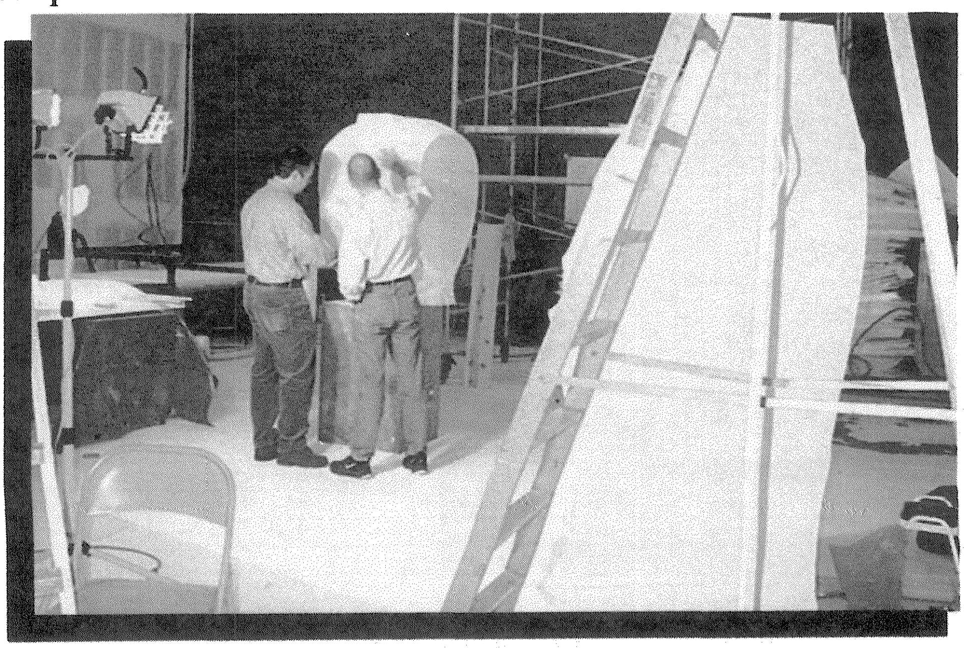
5 times scale-up was determined. An overall DF of 5.05 was achieved. That Design Factor, for a scale-up of this magnitude, is very good. An overall build variance of 1.06% was obtained.


Soft Tooling - Javelin's Hair Curl Production Area

Realistically, variations should be expected from the original statue. Because the artists felt that the left side of the hand-sculpted statue was not as "finished" as the right side, portions of the statue were not digitized but were improvised by mirroring the opposite digitized sections designated by the artists.

Additionally, many portions of the hand-sculpted statue simply were not completely finished. The artists gave directions to compensate for the missing geometry and feature placement so that the CAD files could be created. As a result, some of the geometry does not exist on the hand-sculpted statue. For example, the ears were never attached to the original statue, therefore measurements cannot be taken for comparative purposes with respect to the ears.

Similarly, final placement of the Stupa, Hair Knot and Hair Curls were not completed by the artists on the original statue. These minor issues with the original statue complicated measurement comparisons.



Peter Griffin, Maitreya Project Artist and Scott McMillin, Javelin Engineer, Discuss Foam Head Build Progress in Javelin's Studio

Finishing

Hand Sculpted Statue Shown with the 5:1 Scale-up in the Background

The decision to have Javelin finish the statue rather than artists employed by the Project occurred during the actual build period. Finishing consisted of:

1. Hand sanding,
2. Coating / patching with a latex-based filler,
3. Sealing with a latex paint,
4. Polyurethane protective hard coat, and
5. Metallic gold paint.

More hand work was done on the foam model than had been anticipated due to a combination of factors. The thickness (z height) of 1 lb density foam sheets was found to vary considerably. Since the statue was built in several "blocks", problems were encountered with aligning different glued sections. Additionally, it was found that the artists had a tendency to re-work the polystyrene foam statue as if it had become the art-piece rather than a copy of the original art. This created quality control problems and greatly contributed to the amount of hand finishing required.

20 Foot Statue Assembled in Javelin's Parking Lot Prior to Painting. Small, Hand-sculpted Statue is in Front of the Large Statue.

Summary

The completed statue was shipped to the Land of Medicine Buddhist Center in California where it is currently on display. A second 20 foot statue is planned for the Fall of 1999.

References

1. "Big Buddha Takes Shape in South Salt Lake" in the *Salt Lake Tribune, 12/5/98.*
2. "Rapid Prototyping Builds Karma for the Next Millennium", March, 1999, in *Rapid Prototyping Report,* Vol 9, No. 3, CAD/CAM Publishing.
3. Rendering produced by CounterPoint Studios, Salt Lake City, UT. CAD file created by Javelin, Salt Lake City. UT and and Viewpoint DataLabs, Provo, UT.
4. Velocity^2 software is an Image3, Salt Lake City, UT product.