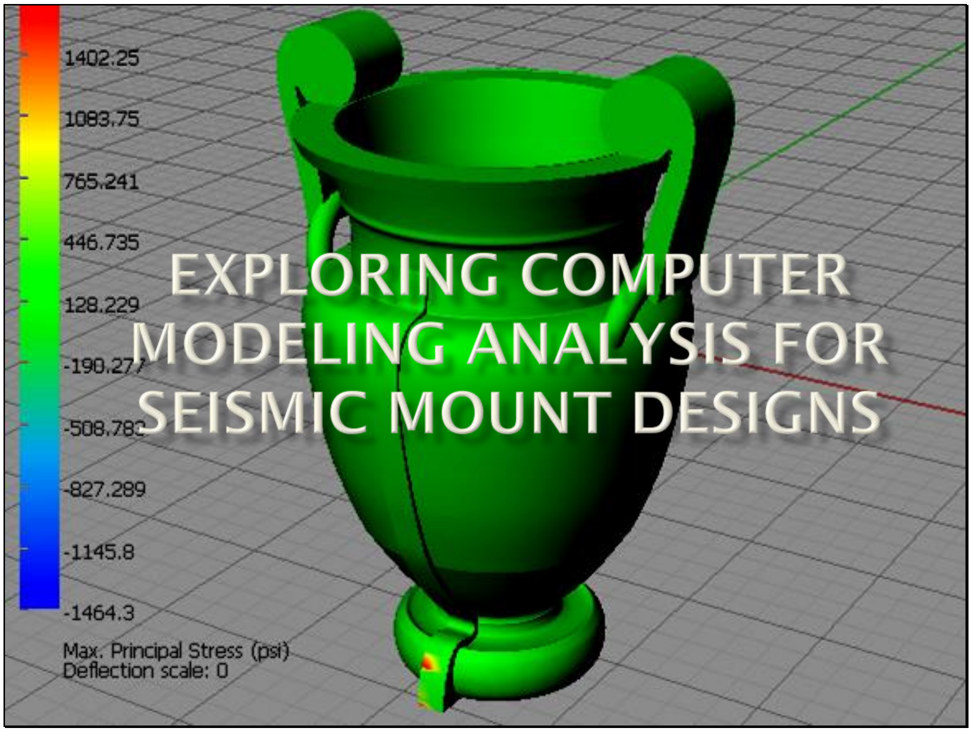
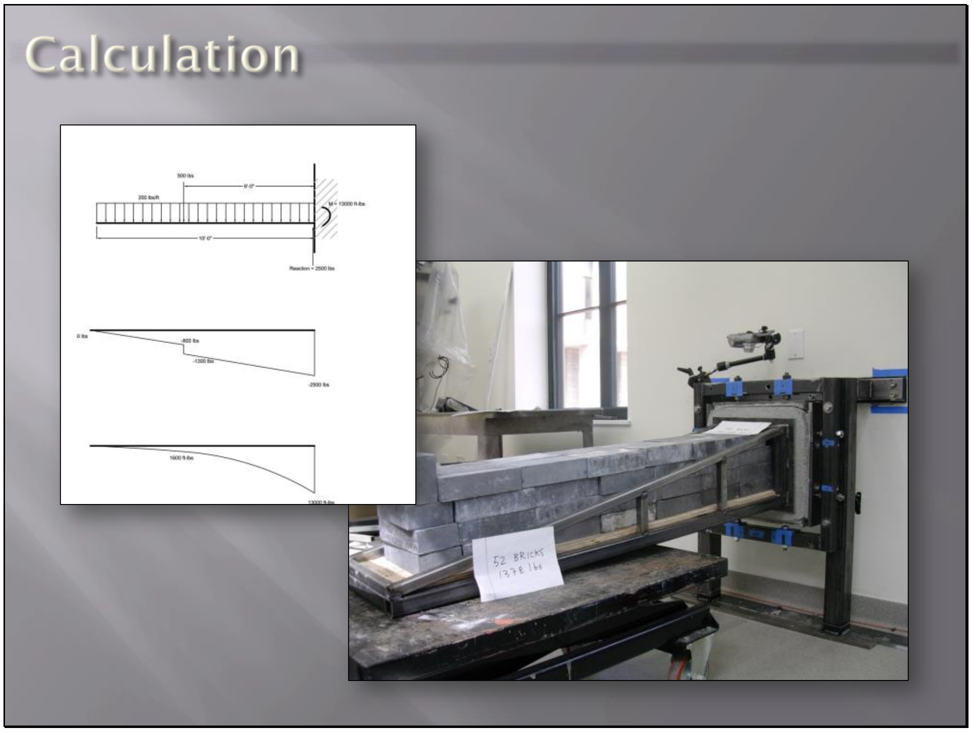


Designing mounting systems for large or fragile objects are always a challenge, especially when addressing displays in seismic zones.

While common sense will usually direct a mount design, understanding how the mounting system will react to the forces of an earthquake can be difficult to predict without careful analysis. Even more challenging is predicting what stresses may be imparted to the artwork.



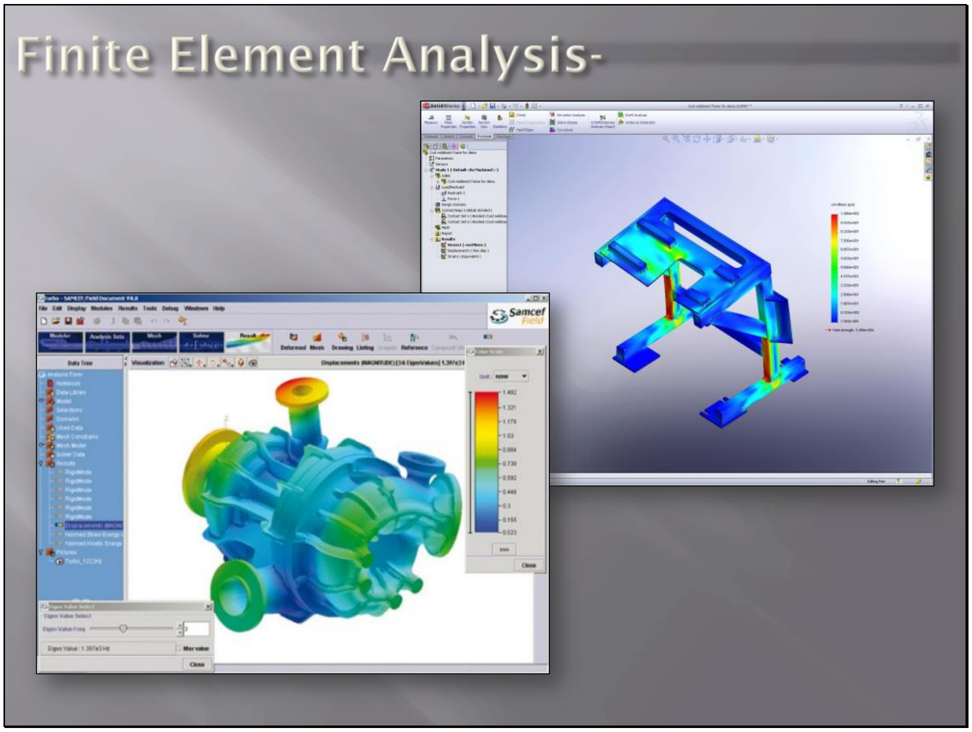
There are simple engineering calculations that can be used to better understand how a specific material and shape will behave under a specific load, but there are limitations when applying these formulas to shapes and mounting systems that are more complex.

In some situations, an object, and or their mounting system can be replicated and physically tested under various loads to better understand their performance-

Of course this if time and resources allow, which is usually not the situation.

Looking for other alternatives, the mountmakers in the Antiquities Conservation department at the Getty Museum began to explore other techniques that would assist in analyzing future mount designs.

Slide 3



One method that seamed promising was computer-aided simulation and analysis.

We began to investigate the feasibility of creating 3-D representations of an artwork, as well as its mounting system and subjecting them- virtually, to forces predicted as peak ground accelerations defined by a seismic study of the Getty Villa site.

Virtual testing and analysis is a growing technology that is commonly used in industry to design everything from small parts to large buildings.

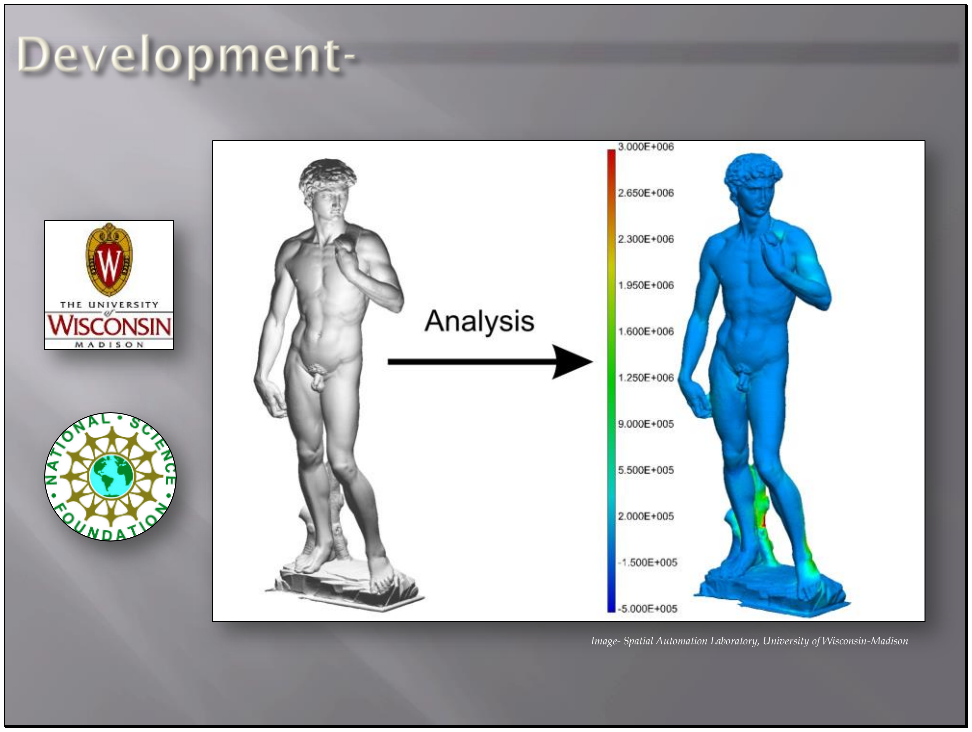
As computers have become more and more powerful, analytical software has become more sophisticated and accessible.

Most of these programs use a method referred to as Finite Element Analysis, which, in a very simple description, utilizes a process designed to break-up a 3-D object into very small pieces and calculate array of complex simulations and analysis-

Predictions such as; stresses, deflections, deformation and material failure can be assessed with relative ease.

Unfortunately, most of these programs are designed for industry and are relatively expensive, making their use cost prohibitive.

Slide 4



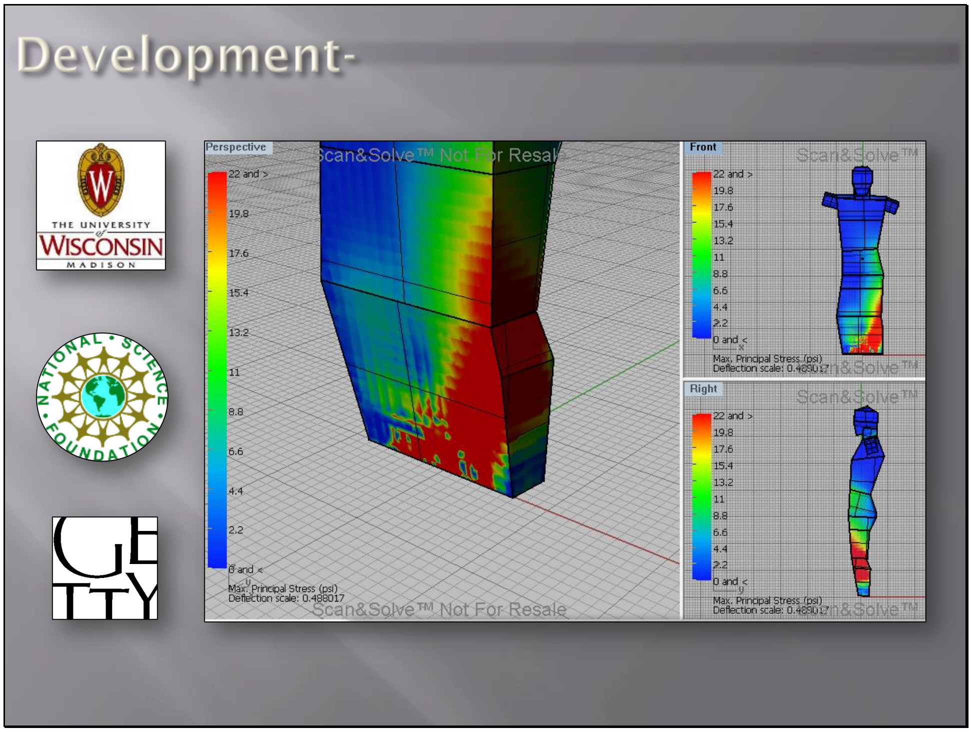
Realizing this situation, researchers at the University of Wisconsin-Madison and Florida International University, begun to develop a simplified, low-cost alternative to finite element analysis technology, with support from the National Science Foundation-

The result of their research is a program called Scan and Solve.

Unlike traditional finite element analysis programs, which involves breaking the object up into tiny pieces, Scan and Solve program simplifies the process by analyzing the data of a 3-D shape directly.

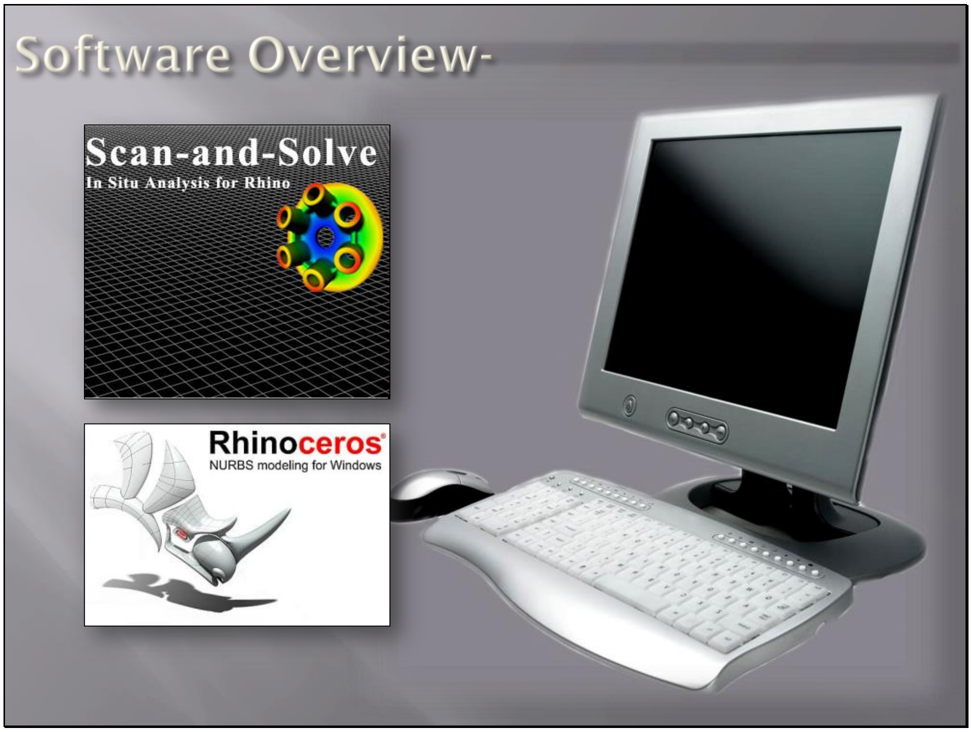
The program was used to analyze Michelangelo's David to identify areas of vulnerability due to the stresses of gravity, using existing 3-D scan data- the scan is shown at left, as well as the predicted stresses on the right.

Slide 5



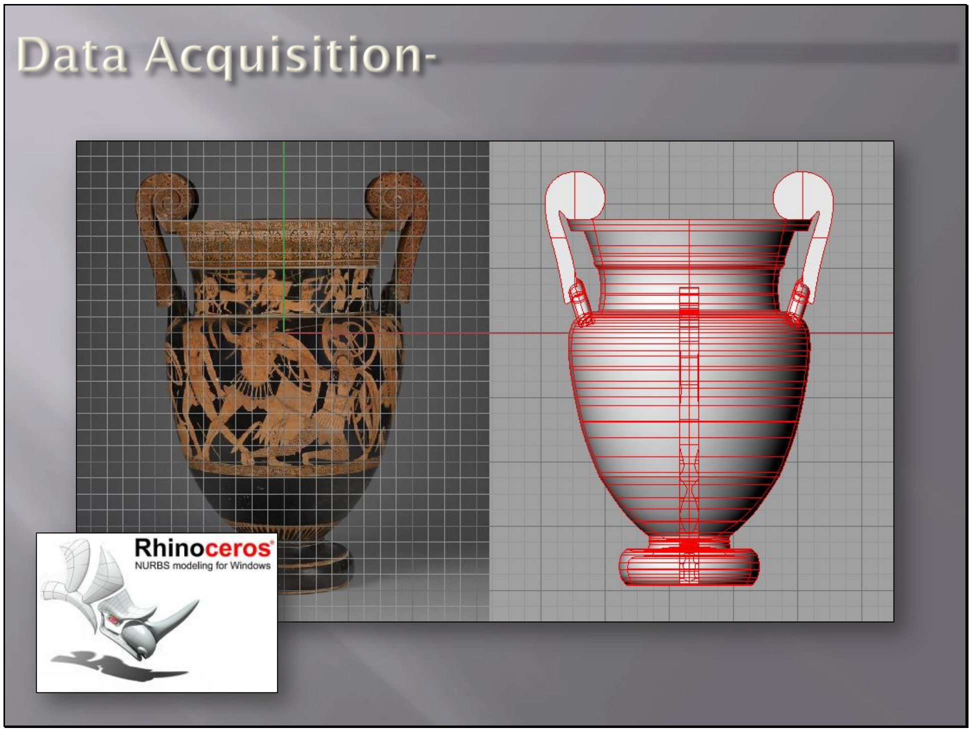
Subsequently, the Getty Museum and the University of Wisconsin-Madison begun to collaborate, and in 2010 was awarded a NSF research grant. The goal of the project was to investigate feasibility of making technological advances in the conservation of cultural heritage, using methods and techniques of computer-aided design and simulation-based engineering.

Each group brought their own expertise to the project, the University of Wisconsin-Madison with software development and the Getty Museum with its knowledge of cultural heritage and preventative conservation.



The project required the museum to start using a 3-D modeling program called Rhino, which is the environment Scan and Solve works in as a plug-in program.

As with any new software, there was a learning curve, but fortunately Rhino turned out to be an intuitive program that was easy to use and after a short while, we were easily creating 3-D models that we could start analyzing in Scan and Solve.



One of the biggest challenges of the project turned out to be the acquisition of data.

We quickly realized that some objects, such as the vase pictured here, could be replicated with some accuracy by being modeled directly in Rhino.

As in this example- By using a good frontal view of an object and scaling it to the appropriate size, a profile can be traced and then extruded into the vase form using the Rhino program.

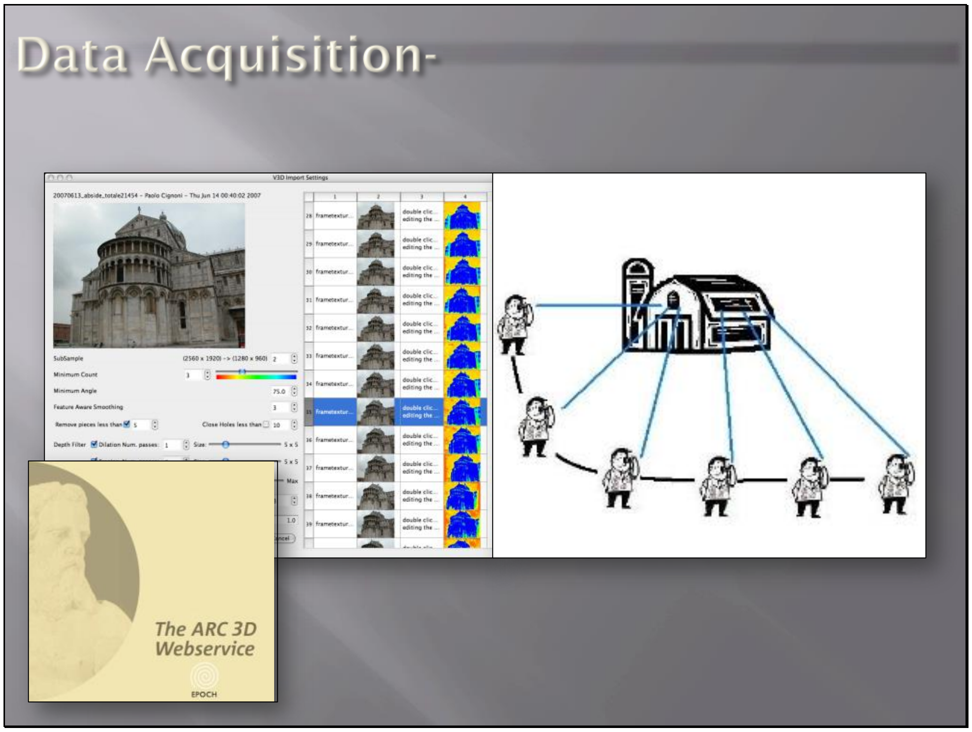
Slide 8

Complex, non-symmetrical shapes proved to be more difficult to create in Rhino, which lead us on another search for alternative methods to acquire data.

Laser scanning is a common method of acquiring 3-D data. There are many options available since the equipment commonly used in industry. But again, can be expensive and cost prohibitive to use.

Following the basic premise of the project- exploring low-cost and accessible methodologies, we found some alternatives such as this one from David Scanner, which is easy to use and is designed to work with inexpensive equipment. A basic version is available free and licensed version is quite affordable.

Slide 9



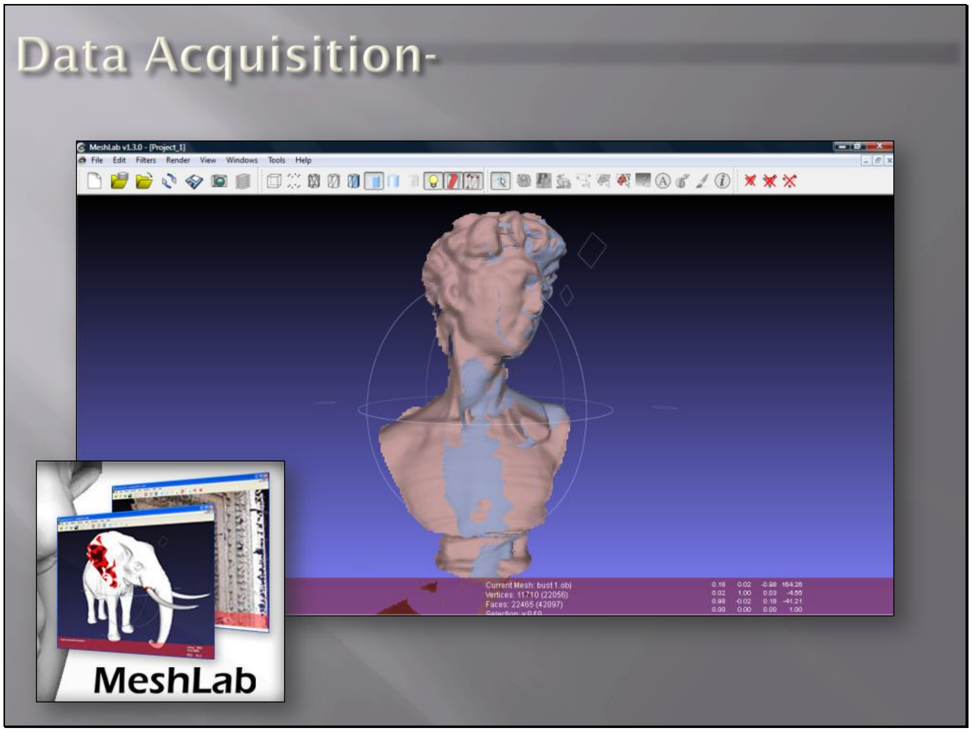
Another intriguing low-cost method of data acquisition is a free service from the University of Leuven, Belgium.

The ARC 3-D Web service uses a photo reconstruction process, which converts normal images into 3-D data.

By submitting multiple images of an object to the University's server using a simple interface program, the server then computes the image data, usually within an hour and the results can then be downloaded.

The processed information then needs to be reconstructed and converted into a usable form.

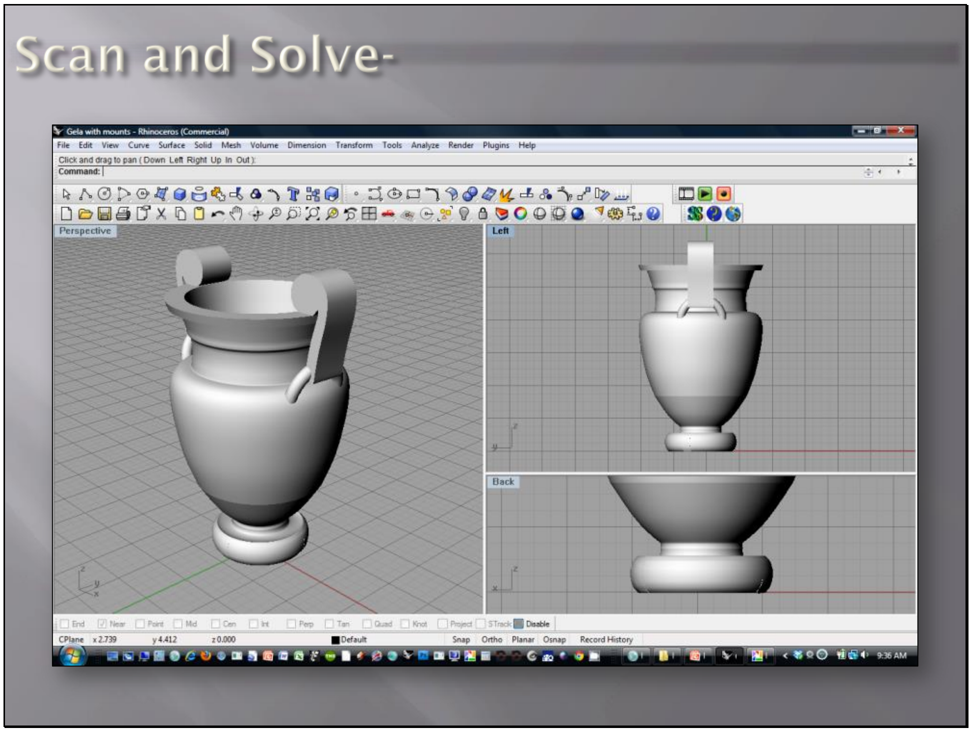
Slide 10



Raw data from the free version of David Scanner and ARC 3-D need to be reconstructed before the analyzing process.

This can accomplished is a mesh editing program such as this one called Meshlab, a free program developed by the Institute of Information Science and Technologies in Italy.

Of course all of these steps of data acquisition and making your model can take a bit of time and patience- but it’s worth the effort since most of the programs are free.



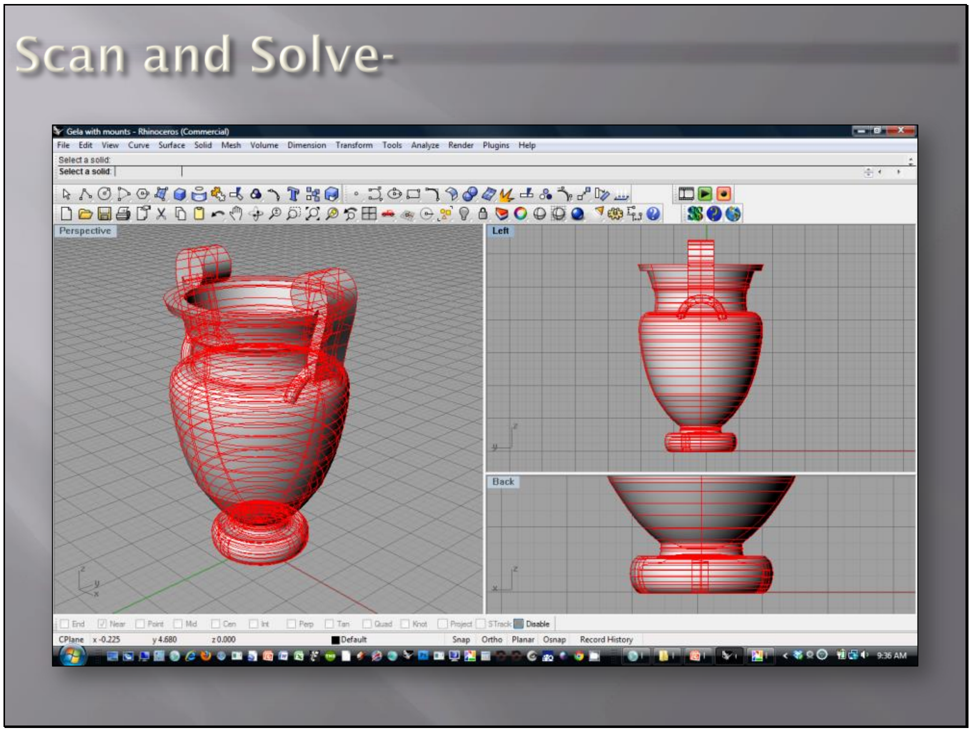
Once the model has been made, simulations can be run in Scan and Solve to analyze the effects of force on the model.

I'm going to give a quick walkthrough of the Scan and Solve analyzing process.

By using this model of a vase, I will run a simulation of the object being rigidly clipped in three places around the foot and subjecting it to a horizontal force of .5g, in the x-axis.

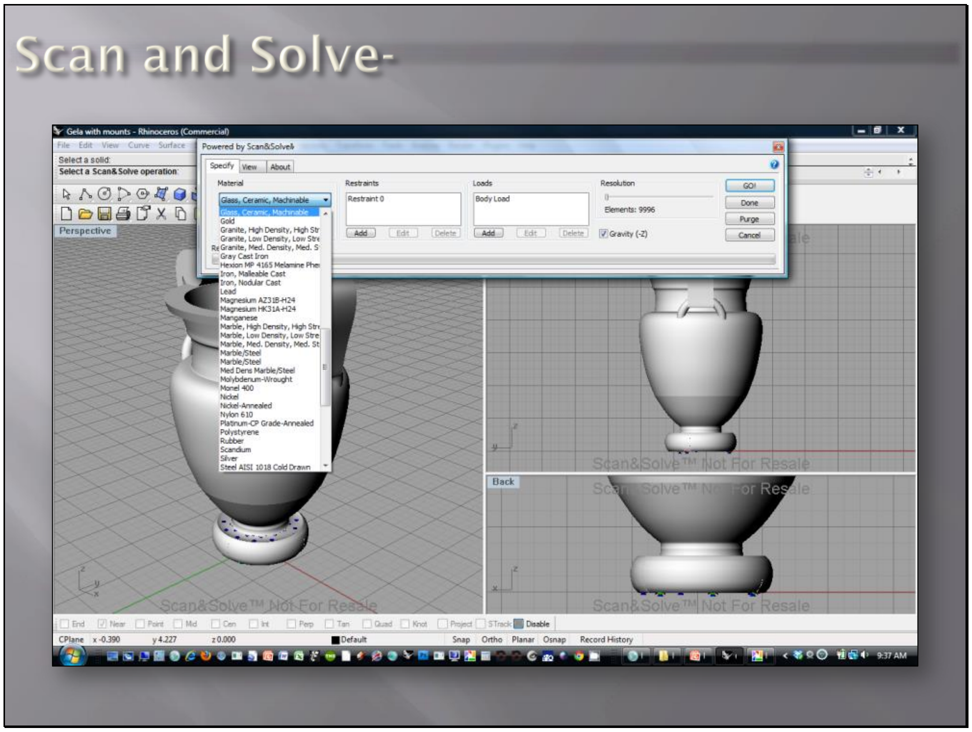
First the 3-D model file is opened in Rhino-

Slide 12

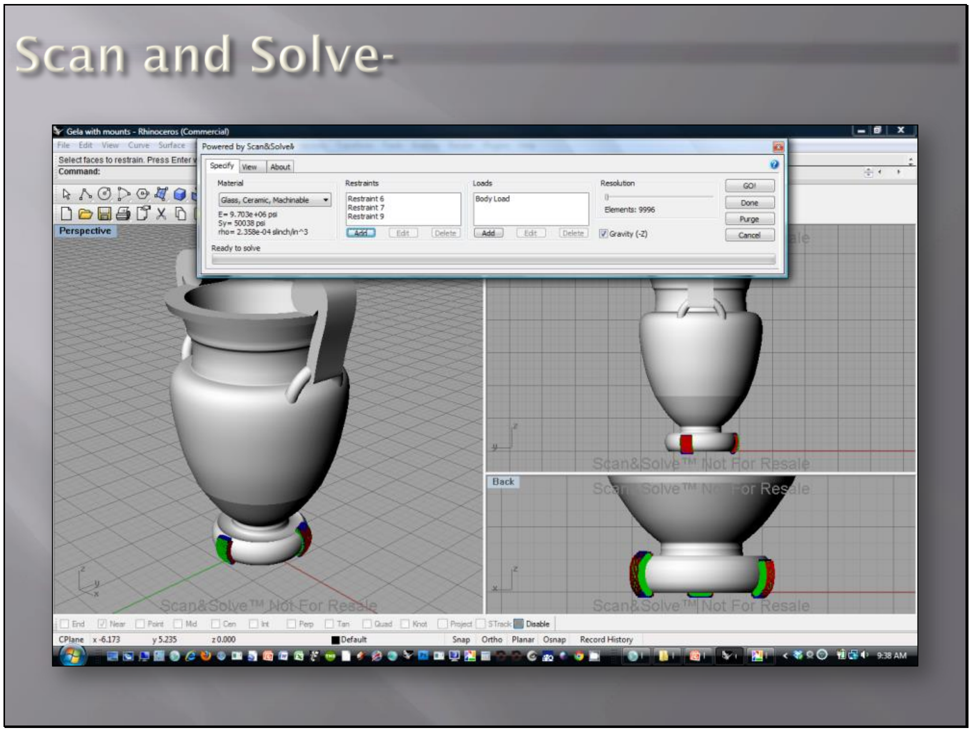


Scan and Solve is activated and the object is selected-

Slide 13

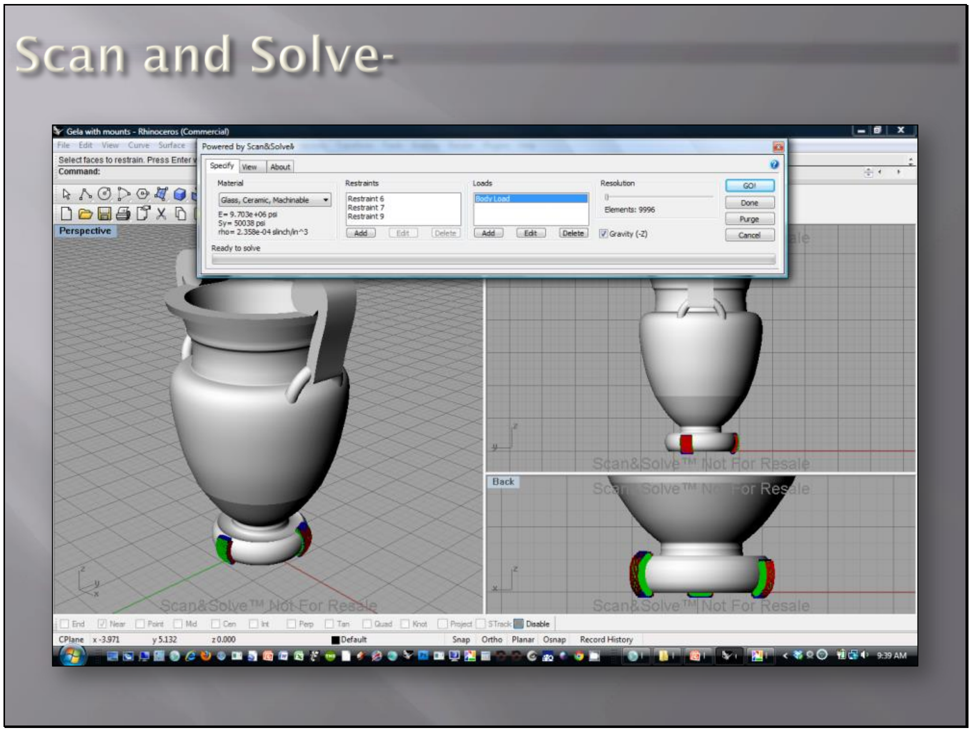


The object's material is selected from the material library. Custom materials can be created if necessary-



Restraints are selected- in this example, the surface area of three clips were drawn on the vase before starting the analyzing process, so they could be selected as restraints later-

Slide 15

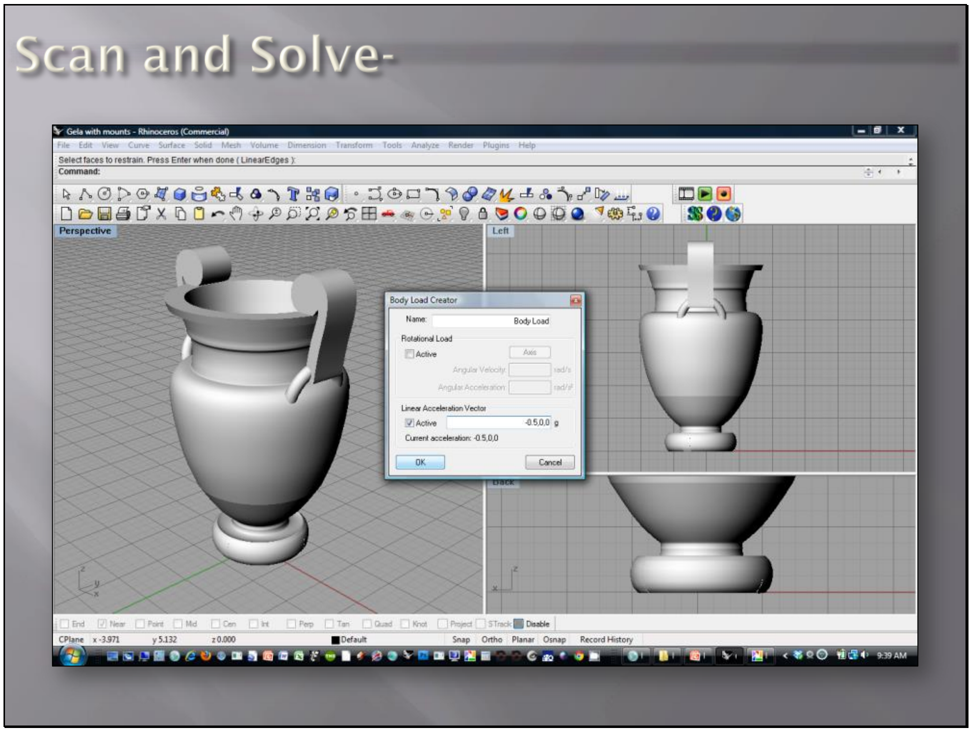


Next the force input is defined.

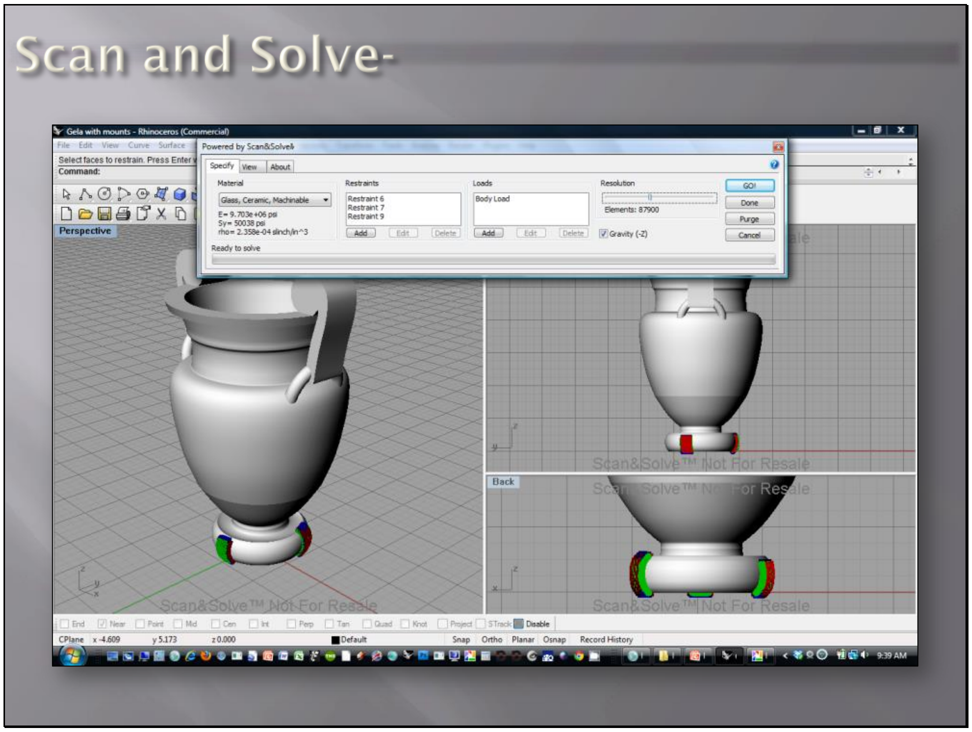
The degree and direction of force can be defined, as well as the location of the force on the object.

In this example the force will be directed at the center of gravity of the object.

Slide 16



Now the degree and direction of the force is defined- .5g on the x-axis-

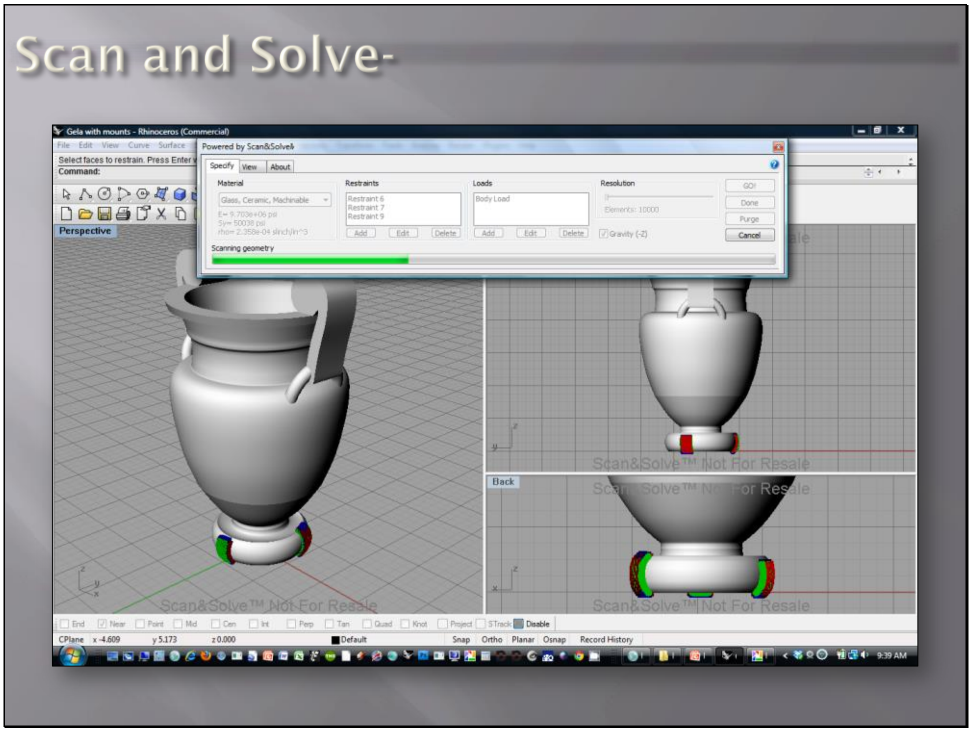


The resolution of the analysis can be defined-

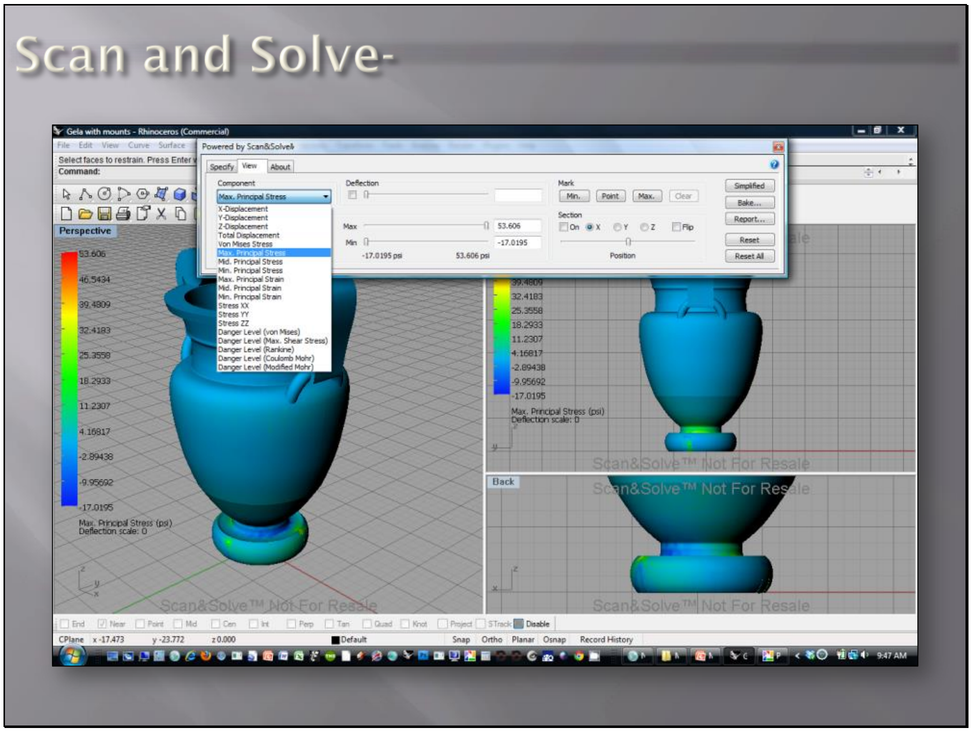
The higher the number, the more precise the analysis, but it also takes longer to compute.

Ideally a few analysis are run starting low and working higher looking for consistent data.

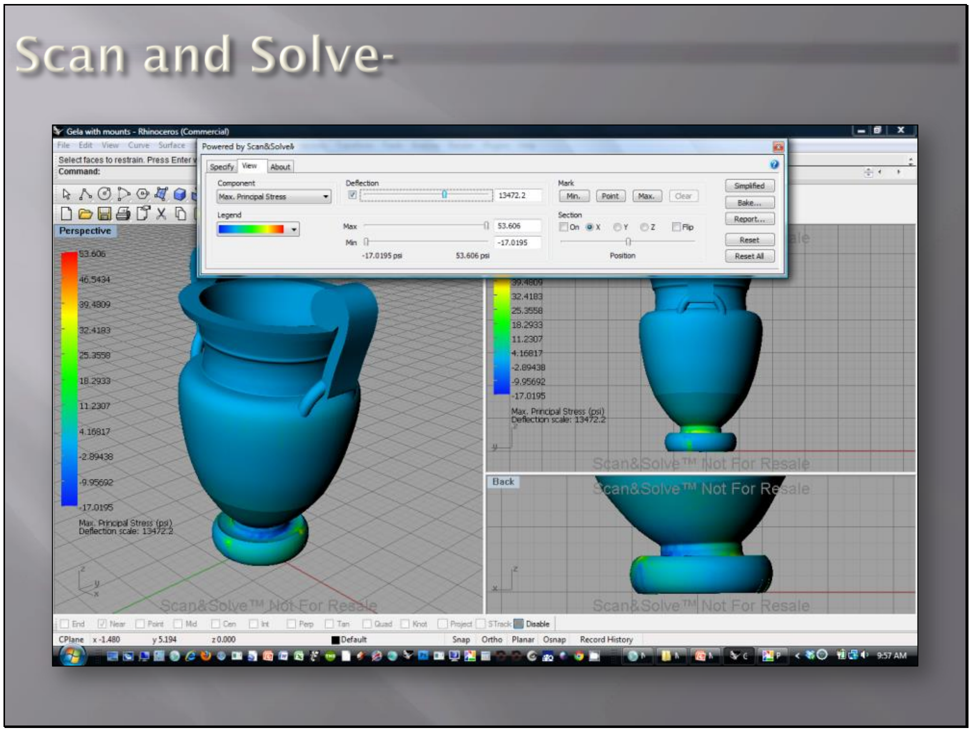
Slide 18



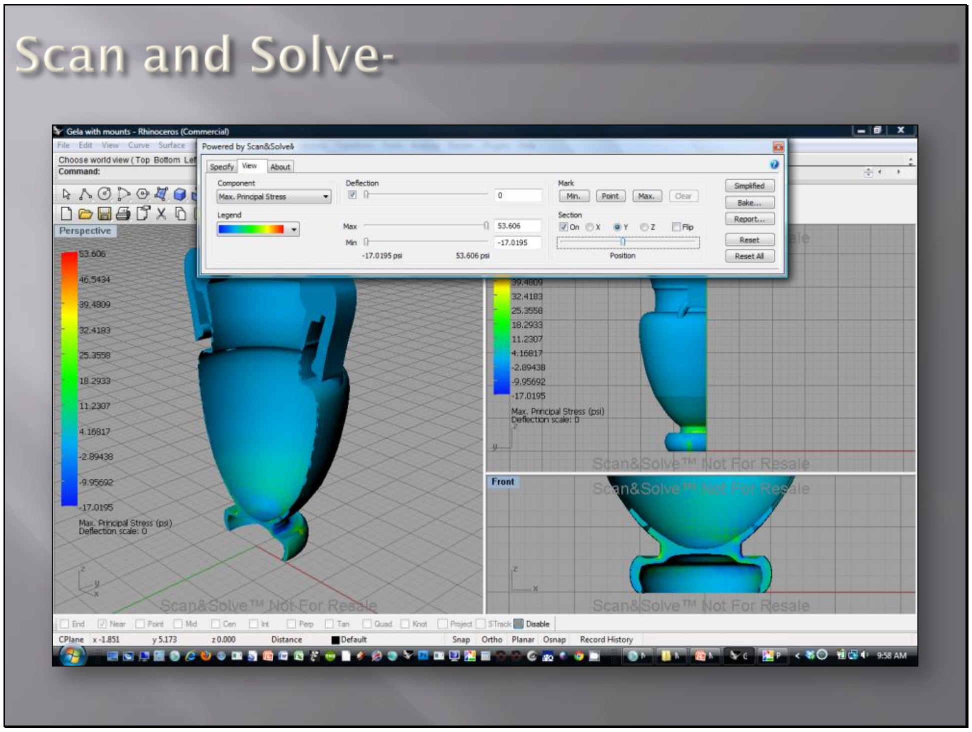
The program runs the analysis-



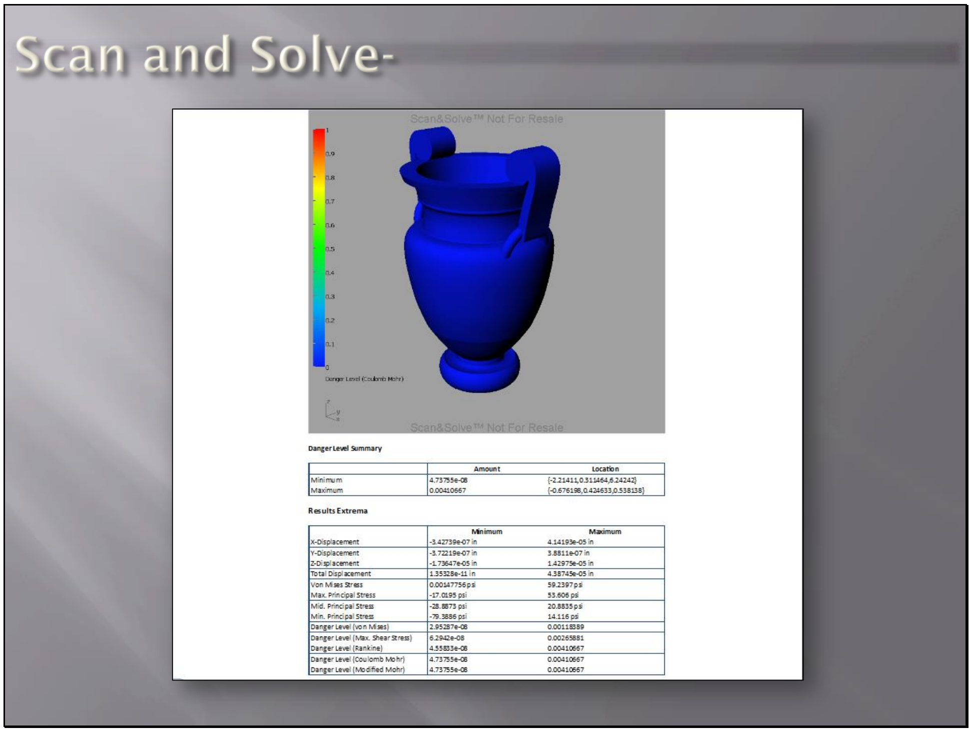
Once the analysis is complete- a series of choices are available to view the predicted stresses, strains, displacement and material failure.



The displacement function not only gives a predicted amount, but an option to increase the displacement value to better understand how the object is reacting to the force.



The model can also be sliced to see how the structure of the model is behaving.



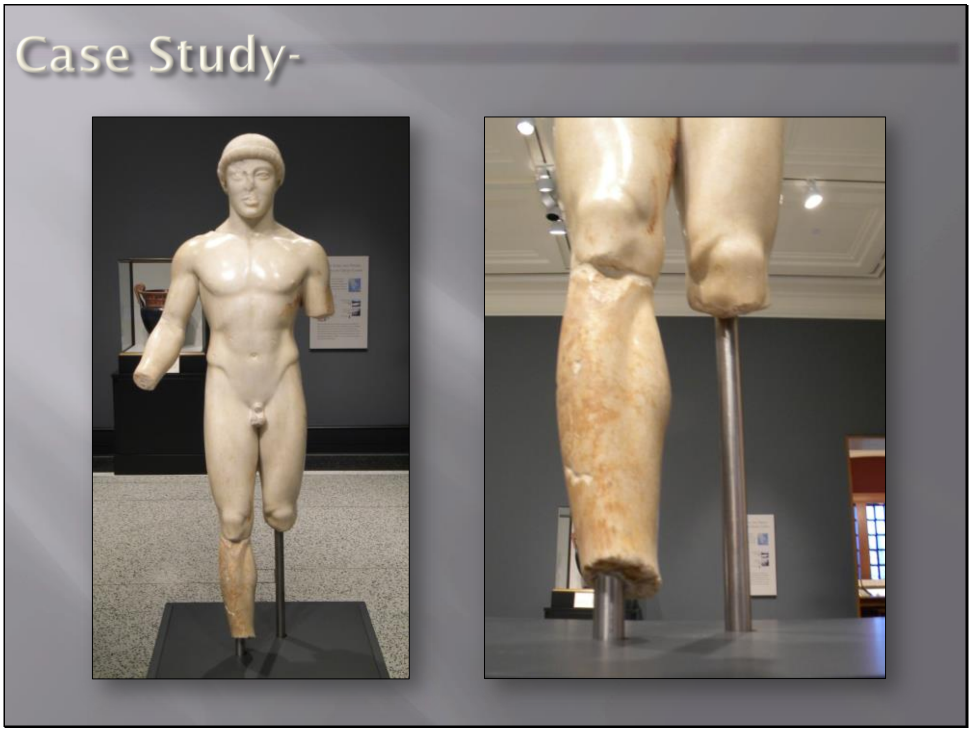
Danger Level Summary

	Amount	Location
Minimum	4.73755e-08	{-2.21411,0.311464,6.24242}
Maximum	0.00410667	{-0.676198,0.424633,0.538138}

Results Extrema

	Minimum	Maximum
X-Displacement	-3.42739e-07 in	4.14193e-05 in
Y-Displacement	-3.72219e-07 in	3.8811e-07 in
Z-Displacement	-1.73647e-05 in	1.42975e-05 in
Total Displacement	1.35328e-11 in	4.38745e-05 in
Von Mises Stress	0.00147756 psi	59.2397 psi
Max. Principal Stress	-17.0195 psi	53.606 psi
Mid. Principal Stress	-28.8873 psi	20.8835 psi
Min. Principal Stress	-79.3886 psi	14.116 psi
Danger Level (von Mises)	2.95287e-08	0.00118389
Danger Level (Max. Shear Stress)	6.2942e-08	0.00265881
Danger Level (Rankine)	4.55833e-08	0.00410667
Danger Level (Coulomb Mohr)	4.73755e-08	0.00410667
Danger Level (Modified Mohr)	4.73755e-08	0.00410667

A report can be saved that outlines all of the calculated information for evaluation and comparison.



During our work with the University of Wisconsin, we had the opportunity to use the Scan and Solve program in conjunction with several other projects- such as this magnificent ancient Greek marble statute that was lent to the Getty Museum by the Museo Archeologico Regionale in Agrigento, Sicily.

Before exhibiting the object, the Museum's conservation team collaborated with conservators from Agrigento analyze the object for a seismic mounting system, which included a base isolation system that would be used at the Getty and returned with the object to Agrigento at the end of the loan.

There were some concerns about the pins supporting the object and we use this opportunity to employ Scan and Solve to help with our study of the existing supports.

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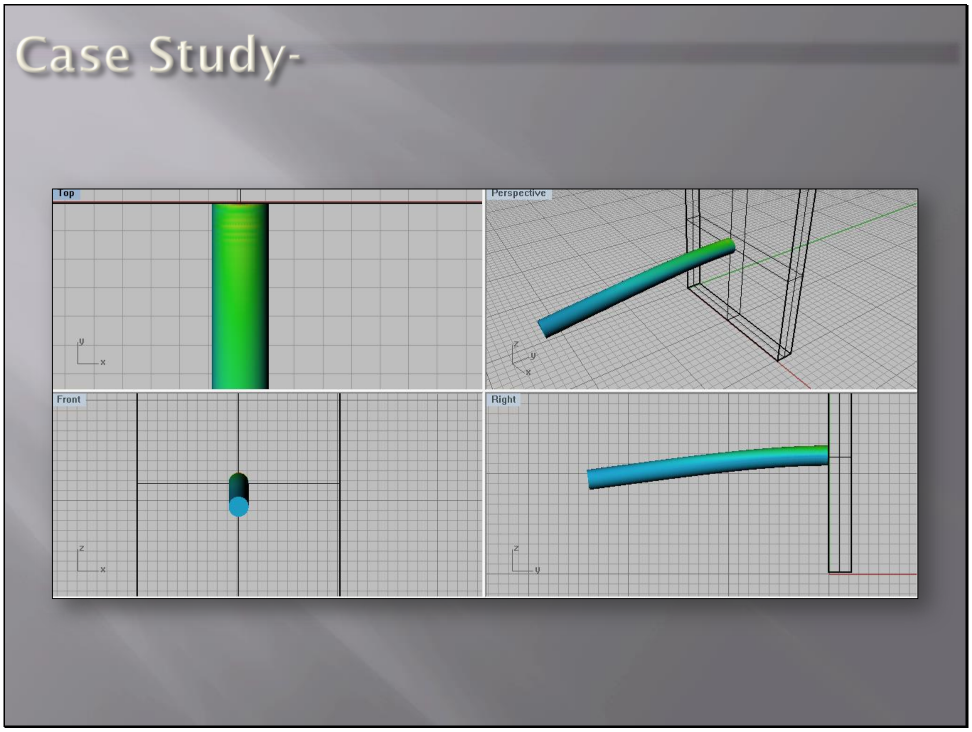
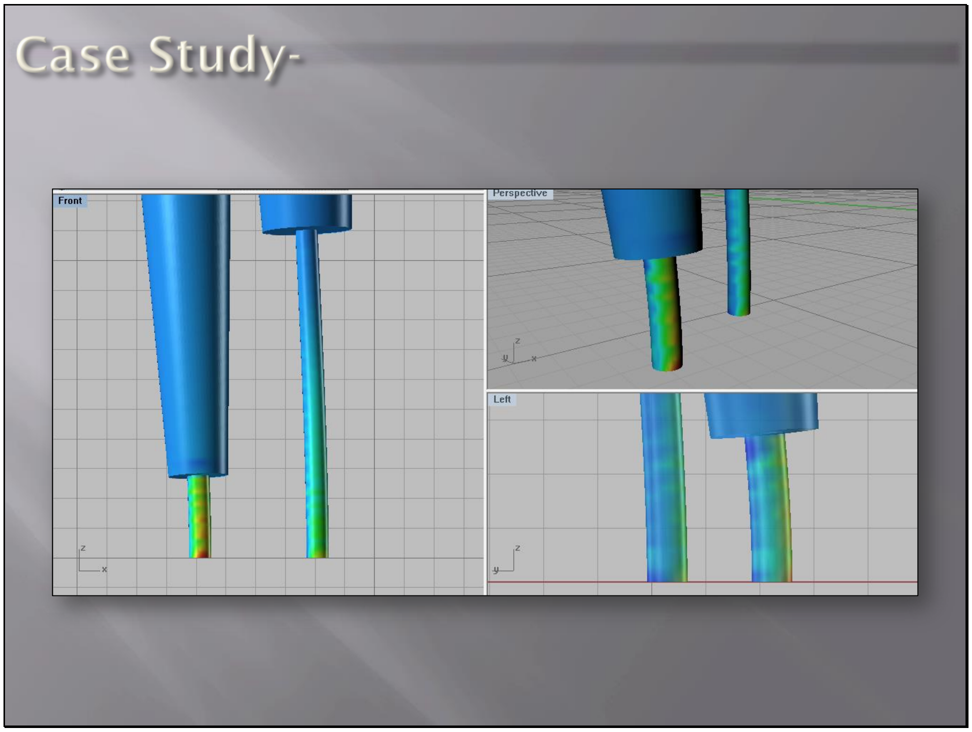


We started off simply by looking at the pins, separate from the statue to better understand their behavior under load.



Next, we looked at the pins together. Since one pin is considerably shorter than the other, the program was predicting an uneven stress distribution and torquing motion of the model.

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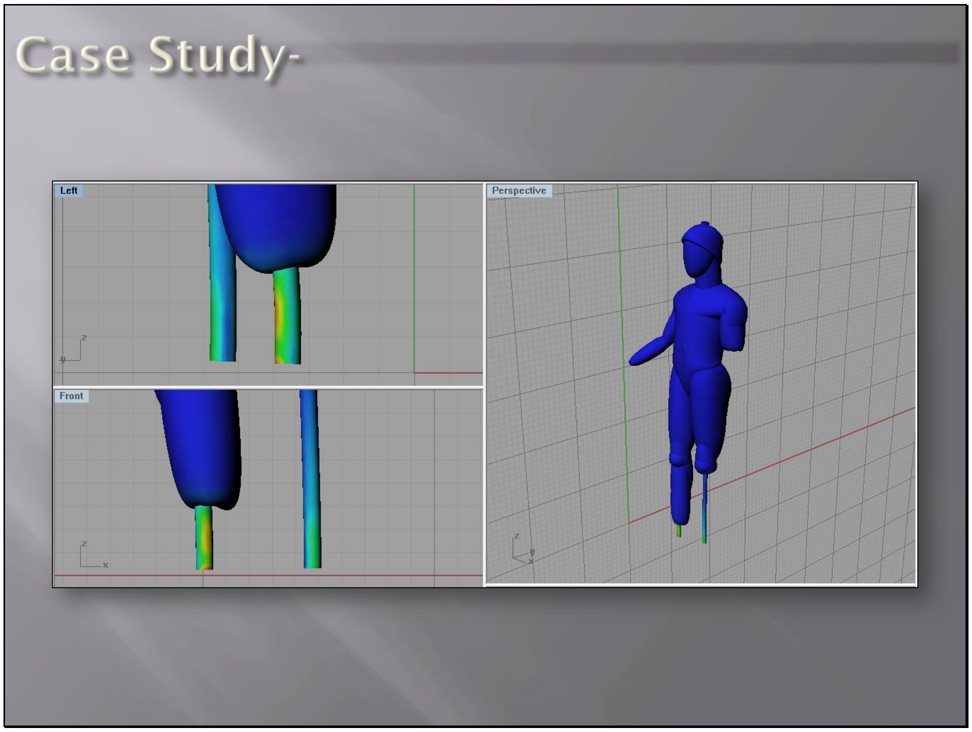
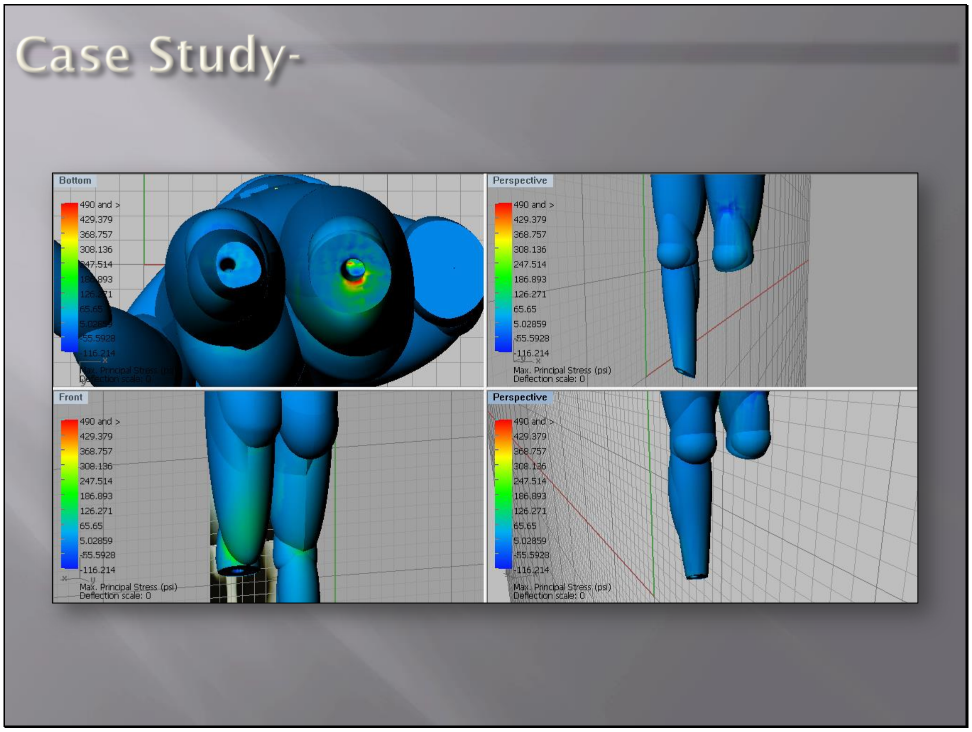


With help from our partners at the University of Wisconsin, we quickly became more proficient with Rhino and Scan and Solve and were able to create a modest replication of the statue. This model gave us a much better understanding how the pins with the statue might react to various horizontal forces. Again the program was predicting an uneven distribution of displacement causing a torsional rotation of the statue and concentrated stresses on the short pin.

One limitation in the Scan and Solve program became apparent once we had a more complex model-

The program can only analyze one material at a time. We were able to work around this by creating a custom hybrid material that had the characteristics of steel, but the density of marble, so the program would be using the correct mass of the statute in its calculations.



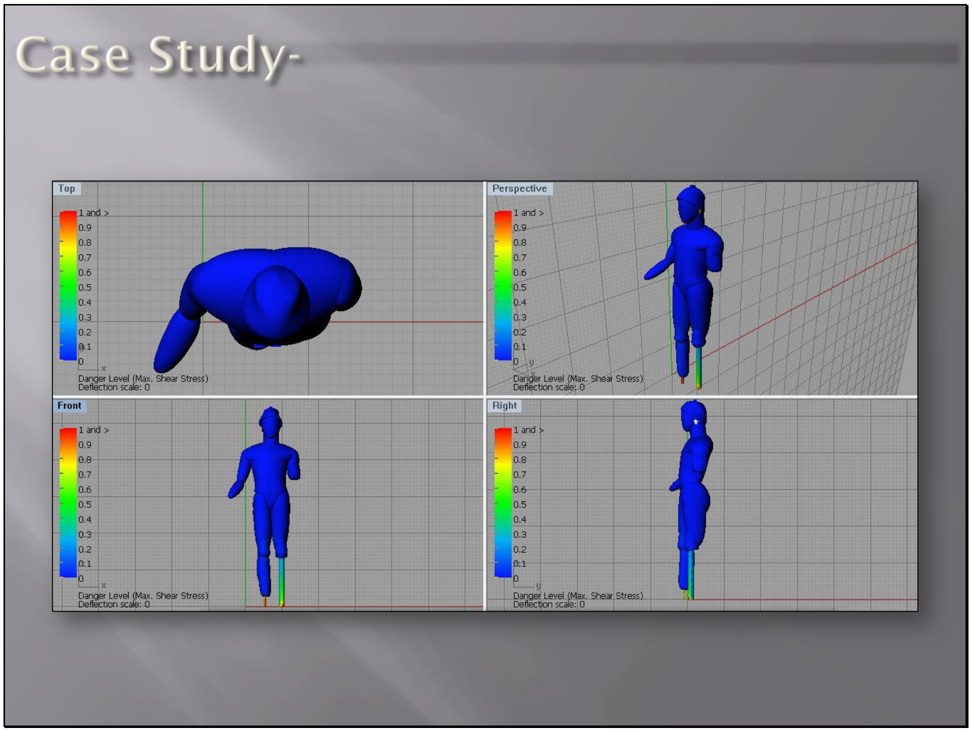
This method worked well for analyzing the pins, but did not allow us to see what stress might be imparted to the statue from pins.

For this, we removed the pins from the model and created approximate pin holes in the statue.

We then reverted to a medium density marble material for the calculations and restrained the model using the interior surface of the pin holes- making an assumption the pins were rigidly connect to the statue.

This gave us stress predictions for the areas around the pins as well as the leg areas. The information was also compared to the existing repairs on the statue to see if there might be any areas of concern.

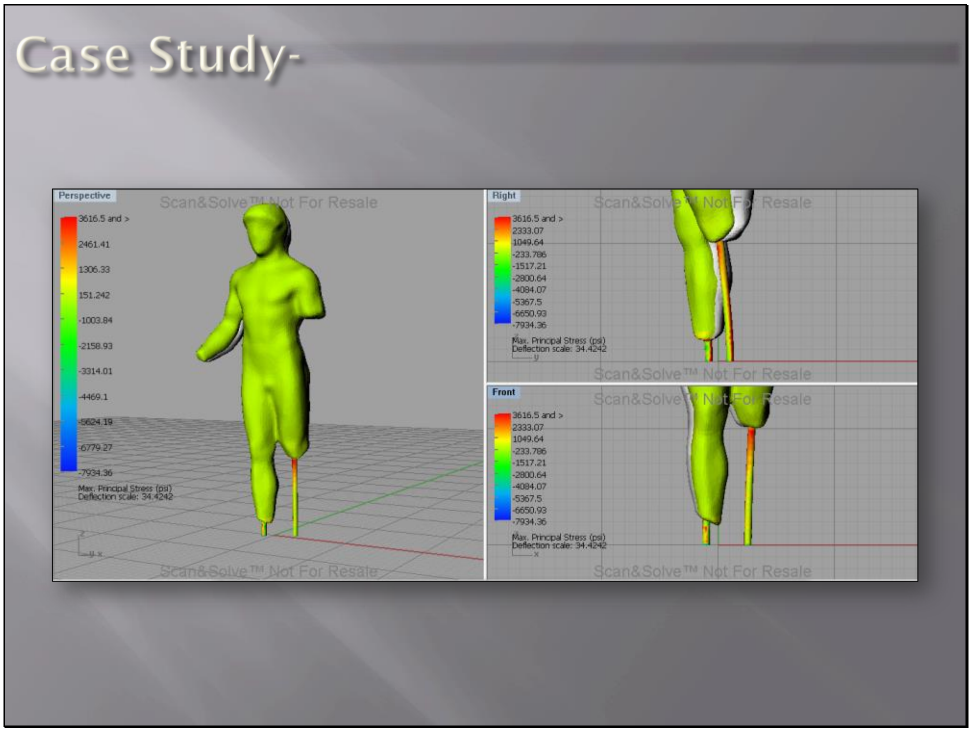
The program was calculating that the pin were absorbing a considerable amount of the applied force and deflecting. What was harder to evaluate was the amount of stress transferred to the statue from the pins and whether their deflection was good or potentially harmful to the statue.



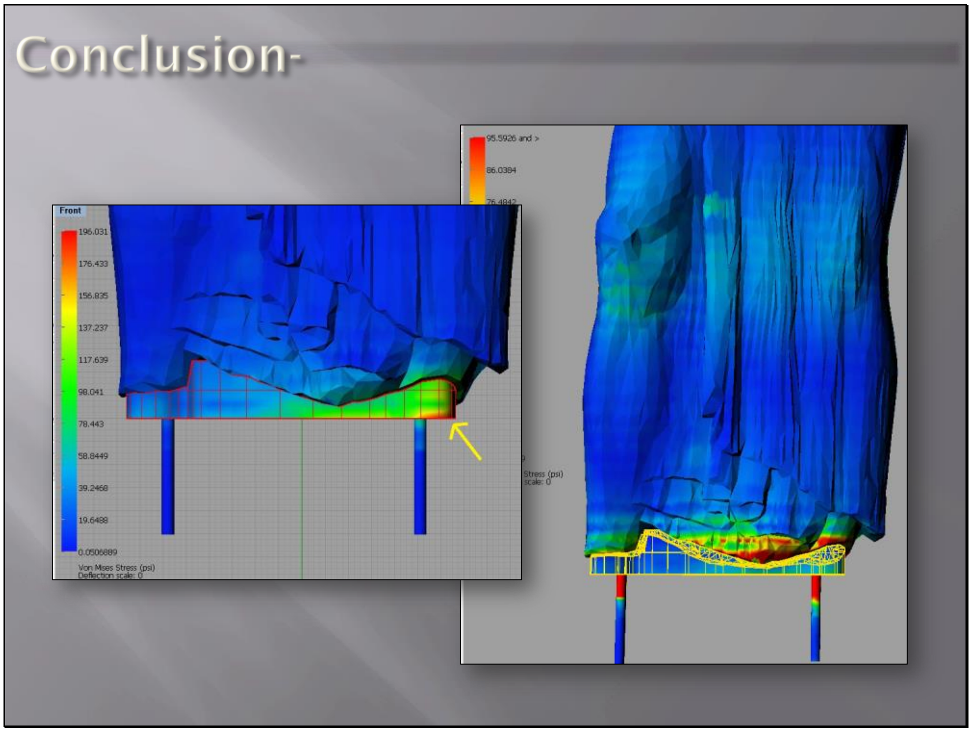
To see if the predicted displacement and stresses could be reduced, larger pins were substituted and the test were run again-

The larger pins behaved better than the existing pins under simulated forces- but it was later decided, not to pursue changing the existing pins.

One significant result of the earlier analysis was the predicted reduction of stress and deflection of the pins by using a base isolation system*. This was simulated in the program by running the same tests as before, but at a 60% reduction of a full .7g horizontal force (earthquake force predicted at the Getty Villa site). *The use of the Getty designed isolation system is expected to reduce at least 60% of horizontal ground motion during an earthquake.



Later in our analysis, we used the David scanner program to produce a scan the statue, which we ran a number of the same tests as the drawn model- no major deviations were seen between the earlier tests and the scanned model.



There have been many benefits to our on-going collaboration with the University of Wisconsin-Madison.

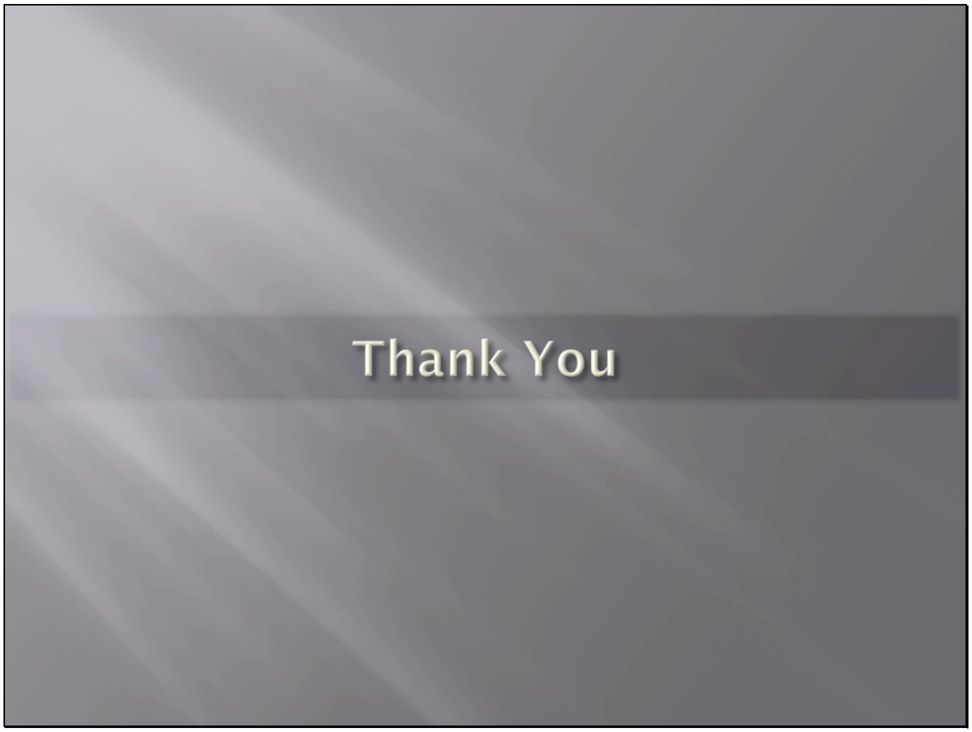
By working closely with Professor Vadim Shapiro and his colleagues at the University, we have been able to identify areas of the Scan and Solve program that can be enhanced to better benefit its use in museums, for the preservation of cultural heritage.

One of these improvements is potential for Scan and Solve to be able to analyze multiple materials. Though still in the testing phase, this option will be a great benefit in calculating how a mounting system performs and its effect on the object being supported.

With this feature, the dynamics of the whole assembly can be assessed vs. analyzing each element separately and having to making assumptions on their interaction.

As a final note- as promising this technology is, it is our belief that the use of virtual testing should never be solely relied on to make a final conclusion.

Our experiments with this technology are designed to be able to use it as a tool to help us make better, informed decisions.


Thank You

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Acknowledgements-

Antiquities Conservation , Getty Museum
- Jerry Podany
- McKenzie Lowry
- David Armendariz

University of Wisconsin-Madison
- Vadim Shapiro

Intact-Solutions
- Michael Freytag

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