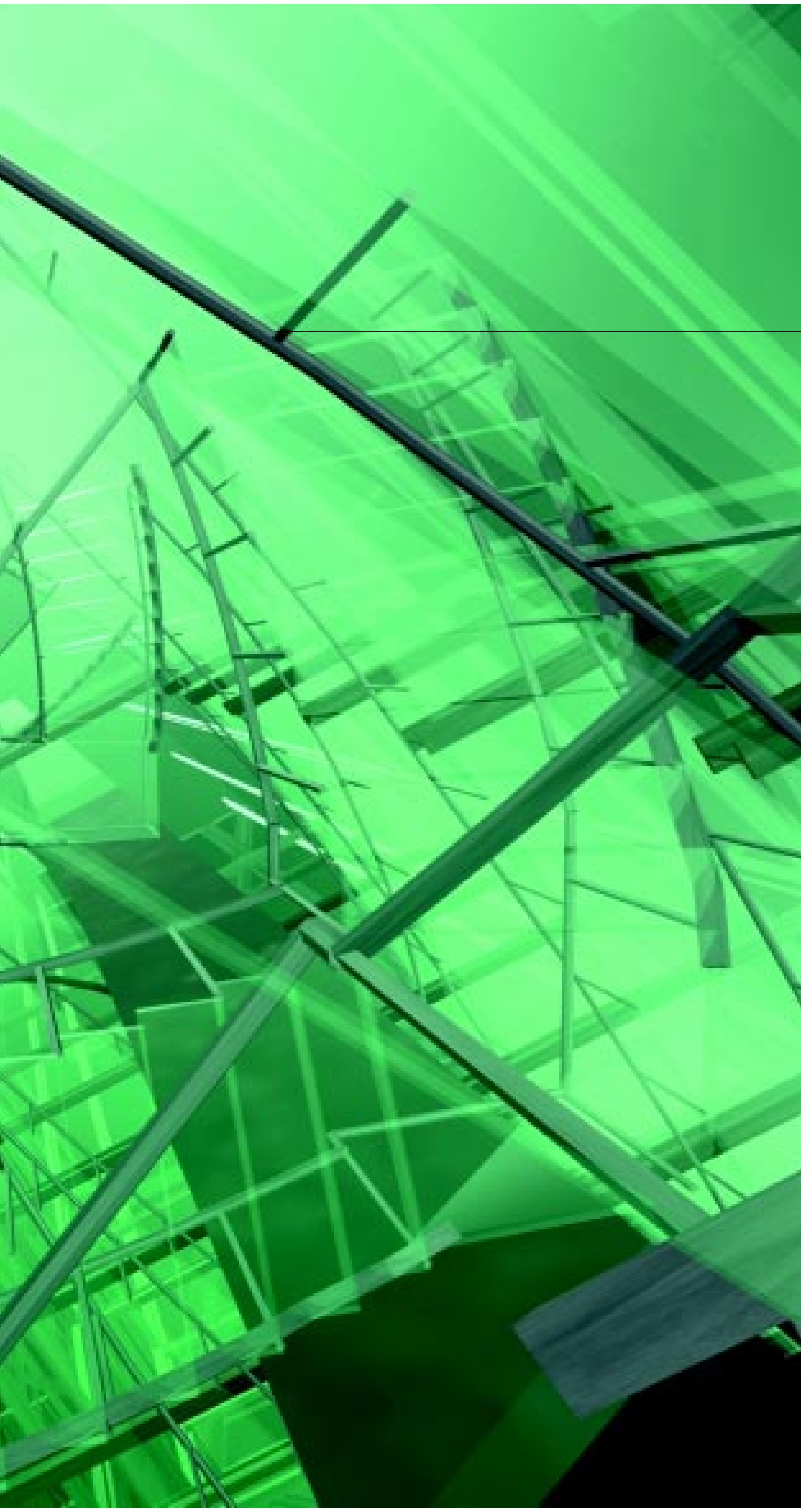

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Developments in 3D Scanning and Digitizing: New Strategies for an Evolving Design Process

The computer is now a widely accepted tool in architecture as a production and business tool. Acceptance of digital technology as a design aid has been much slower, but continuing developments in ease of use, capabilities, and lower costs are encouraging the use of three-dimensional design modeling. As the demand for 3D design computing grows, peripheral digital technologies are also developing and being integrated.

This paper describes on-going research into how current and near-future developments in three-dimensional scanning and digitizing technology that have the potential to substantially change processes of architectural design. Scanners, or digitizers, assist in transforming physical objects and models into digital representations. The capabilities of 3D scanners in architectural design have only begun to be explored. Existing and emerging 3D scanning technologies are briefly described followed by a discussion of sample existing, new, and potential uses of these capabilities as a design tool. An experiment is conducted to contrast the differences between stylus-based and laser-based digitizers in an architectural design environment.

Developpements en scanning and numérisation 3D:
De nouvelles stratégies pour un processus de design en voie d'évolution

L'ordinateur est maintenant largement accepté en architecture comme outil pour la production et le commerce. L'acceptation de la technologie informatique en design a été beaucoup plus lente, mais des progrès continues au niveau de la facilité de l'utilisation, des capabilités, et des coûts moins élevés encouragent l'utilisation de la modélisation 3D en design. A mesure que la demande pour les méthodes électroniques en design 3D augmente, les technologies digitales périphériques sont de plus en plus développées et intégrées.

Ce papier décrit les recherches courantes concernant la façon dont les développements présents et futurs au niveau de la numérisation 3D et de la technologie numérisante ont le potentiel de changer considérablement le processus de conception en architecture. Les numérisateurs aident lors de la transformation d'objets et modèles physiques en représentations digitales. Les études sur les capabilités des numérisateurs 3D viennent juste de commençer. Les techniques de numérisation 3D existantes et en voie de développement sont brièvement décrites. Il s'ensuit une discussion d'exemples d'applications courantes, nouvelles et potentielles de ces capabilités comme outil de design. Une expérience est menée pour faire le contraste entre les numérisations basées sur le stylo et celles basées sur le laser, dans un environnement de design architectural.

introduction

Recent experiments are opening new methods for designers and architects to interact with manual and computer media. Our on-going research into how current and near-future developments in three dimensional scanning and digitizing technology could change existing processes of architectural design. 3D digitizers have the capability to transform physical objects and models into digital representations with moderate ease and considerable precision.

Traditional computer design techniques sometimes include the creation of computer models for communicating shape dimension and three dimensional space. One problem is the time-consuming process of gathering the information from a project because it takes time and energy. Digitizers can decrease the time needed for this process because it can capture adequate detail and resolution of a model. They can also record information of geometry that is mathematically difficult to duplicate with traditional CAD methods. A 3D capture device works in concept much like a photocopy machine and this technology is fairly well-established (Wohlers 1995). Unfortunately, existing capabilities and newer capabilities such as those that allow for 3-D mouse controls that view locations, set light-sources, and define animation trajectories in real time are not being fully explored (Gulick 1996). With capabilities expanding and prices dropping, 3D scanning strategies are likely to find their way into more design processes (The Computer Paper, October 1995).

types of digitizers

There are several types of 3D scanners. Some are capable of capturing full sized human figures and motion while others are limited to desktop-sized objects. New scanners are being developed that can scan building-sized objects. Different scanners are designed to capture different aspects of a model. Digitizers are commonly categorized by their primary capturing strategy. There are five essential types; the mechanical probe, photogrammetric, laser-aided, phase shifting, and tomogramatic scanners.

The mechanical probe captures a series of points in a three-dimensional space using a stylus. Accuracy is dependent both on the hardware and on the skill level of the operator manipulating the stylus. The maximum size of objects digitized with this method is limited by the range of the stylus arm, though it is possible to seam together multiple sessions to effectively scan larger objects. Digitizing interior spaces of objects is limited by the size of the stylus and its ability to be positioned inside the space. A typical technique for modeling an object with a stylus involves placing datum lines on the subject matter (Figure 1). This way, a gridded mesh can be easily created for manipulating a model. The models that get digitized with a stylus are often monolithic in structure but may have concavities that are difficult to reach. The stylus digitizer is often able to capture concavities. While Frank Gehry's architectural office is noted for their incorporation of a mechanical probe or stylus digitizer in their design process, they are not alone. Other firms, such as Hodgetts and Fung have also been using a MicroScribe3D brand digitizer for some time to create computer models based on their physical models for technical and presentation drawings (Sullivan 1997) (Figure 2-3). Polhemus uses a patented electromagnetic concept that records azimuth, elevation, and roll in places that would normally be hidden by a laser's view. It allowed the engineers from Industrial Light and Magic to record position movements in creating the Academy Award winning effects for the film Jurasic Park that would otherwise have been exceptionally difficult to create. (Costello 1996)

With laser-aided measurement, a laser is reflected off of a physical model. The laser scanner substantially reduces the labor that is necessary using the stylus method. Manufacturers make standard and custom designed scanners for industrial, animation, anthropology, and medical applications. The technology scans an object and creates a detailed texture map of the surface's color within a few seconds. It is frequently used in motion picture animation and special effects. The scanners can scan at an accuracy of up to 0.0001" (Cyberware 1997). Scanners have been developed and are currently being tested that will be capable of laser scanning very large objects (Figure 4).

Photogrammetry captures a model photographically and most often uses multiple views which are seamed together with varying levels of automated assistance. Photogrametry can capture whatever is visible by the camera. These scanners are used in a similar way as the stylus digitizer but avoid the manual labor involved in plotting each point on the model.

With phase shifting methods a well-defined and high-contrast moire pattern is projected on the model and recorded by a video camera. Uneven points on the object produce characteristic changes in the moiré thus permitting determination of surface points. This method is capable of capturing both exterior and interior geometries. The method is capable of passing through an object to find the void spaces. This is where it is crucial for an architectural model. It is important the scanner is capable of moving around the object, but the moiré will theoretically take all the surrounding pieces of a model. The ultra sound technique similar to this, allows real time capturing for the medical profession (Prager 1996).

Computer tomograms (CT) produce a voxel structure of an object. Due to the energetic performance of the scanning beam, it is possible to penetrate solid material, the inner structure, connections, and even differentiate between materials. A CT scanner can capture exterior and interior structure, materials, and connection. However, file size can be substantial. There are limited accuracy levels and the image must be transformed from a bitmap imaging system to a CAAD accurate model for architectural purposes (Streich 1996).

Resolution accuracy, object size, and scanning distance are also important differences for the types of scanners. For example, a laser scanner is capable of capturing objects at resolutions as high as high as 300µm. Lower cost digitizers may use a normal supermarket cash-register laser scanner that can capture objects that are approximately thee inches square. However, much more powerful scanners are being developed that can capture building sized objects. Most desktop scanners can only capture objects within a certain reaching distance. Even some laser scanners are designed to only reach objects no closer than one foot and no further than three feet.

Figure 1. Taping datum lines on a car. Photo Courtesy of 3Name3D.

Figure 2. The Microscribe digitizer at Hodgetts and Fung.

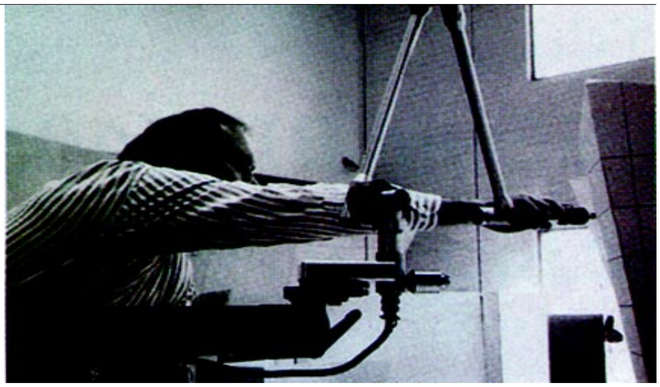

Figure 3. The stylus digitizer at Frank O. Gehry Associates.

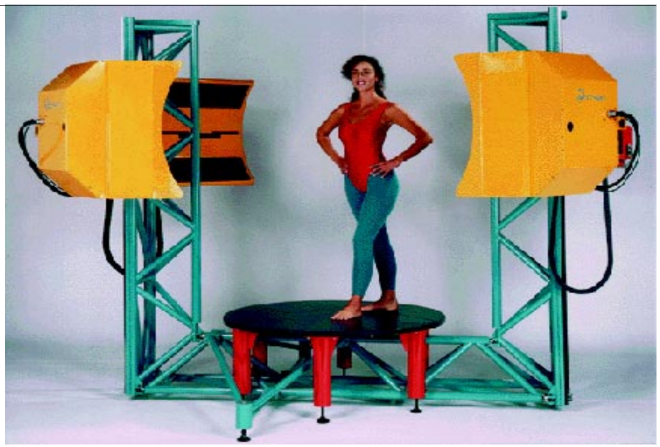

Figure 4. A Cyberware laser scanner.

Figure 5. A geometrically complex physical model by Frank Gehry.

Unfortunately, there are currently only a handful of architects that use 3-D scanning technology, primarily because of the cost. As 3D capturing continues to become cheaper, it is likely to come into wider use. 3D Scanners are now capable of running on desktop PC's requiring no more than standard architectural workstation configurations. For example, the scanner used for the experiments described later in this paper runs on a Pentium 166Mhz machine with 64MB of RAM and used Raydream Studio 3.0 for capturing the digital information. The file formats follow the typical guidelines of most software packages. (IGES, OBJ, VRML, DXF, 3DS) (Bouinatchov 1998).

Frank Gehry and Associates uses the digitizer during most of the design process. Their work is known for its irregular geomentries, which are often even difficult to visualize, much less prepare construction documents for. The office uses a Faro© arm digitizer to capture his study models and converts the information into a software program called CATIA. The software creates a surface model. A model is often milled to verify accuracy design specifications. Then the computer model is studied for structural curvature (Figure 5-6) (Stein 1997).

some possibilities for 3D capture

In our study, we explored five strategies for using 3D capturing as a design aid: calculating areas and surfaces, light and shadow studies, visualization , morphing, and documentation of existing site and building conditions.

One potential advantage of using a digitizer to capture a physical model so that a computer can help with complex area and volume calculations, for example, to calculate the floor area of an arena with its unusual geometries. Calculating surface to area ratios is another possibility. This is valuable because it can determine stresses within a given material. For example, Frank Gehry's office studies his architectural forms with various skin materials until one match Gehry's aesthetic and the engineer's approval. For the Guggenheim Museum in Bilbao, Gehry used a titanium skin in part because it was capable of being formed to his architectural shapes and at the same time act as sheer plates between the steel framing behind it. Without using the 3D digitizer and other technologies, this process would be very different (Stein 1997).

Environmental concerns dealing with daylight demonstrate another possible advantage to 3D scanning. Shadow casting is important especially when a courtyard or room needs to be well lit or protected at a certain time of day. Determining shadow casting is difficult when the geometry of a building is complex. By manipulating a computer model, one can determine what surfaces need to be reshaped in order to satisfy both the design and construction of the piece.

Photo montage of a computer model onto a site photograph is a fairly common method that has become increasing digitally supported. With a large scale scanner, it would be possible to capture the site data in 3D and then incorporate a 3D model. These 3D "sited" models might also be used as part of a web-based communications to clients.

In another strategy, designers could use the 3D scanner to capture an element to be used as a metapgorical geometry base. For example, if an architect wanted to reflect the idea of a flower in a project, they could create a similar geometry by 3D capturing a flower. A related strategy is to combine a series of elements into one product using morphing techniques, such as taking two or more study models and morphing the ideas together. This idea could reflect the design schemes in a way that was never though possible. Benjamin Wood of Wood and Zapata currently uses this technique with two-dimensional images. He shows clients the transformation of a old and final design of a project. He uses a very low cost software program called Morph which converts two or more images and animates the transformation (Sullivan 1997)

For site and context analysis, particularly where existing buildings are involved, laser scanning offers the promise. CYRA technologies, developed in Berkeley, California, has developed a laser radar scanner. This device is capable of scanning anything in its field up to 80 meters away. It creates a vector-triangulated base computer model within its own software program and can export in any of the very common file formats. The potential uses of this type of scanning are tremendous. For

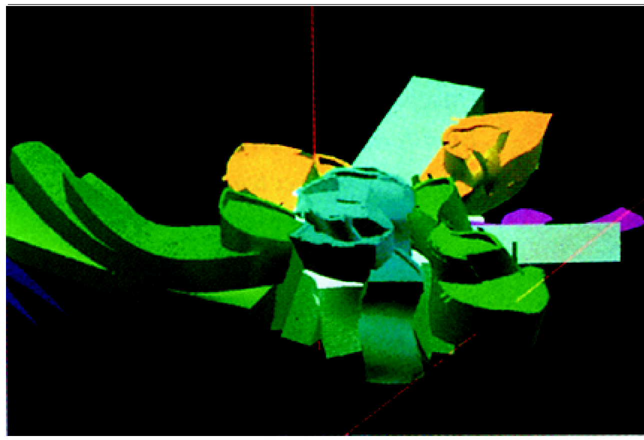

Figure 6. DA computer model from the digitized physical model (Frank O. Gehry).

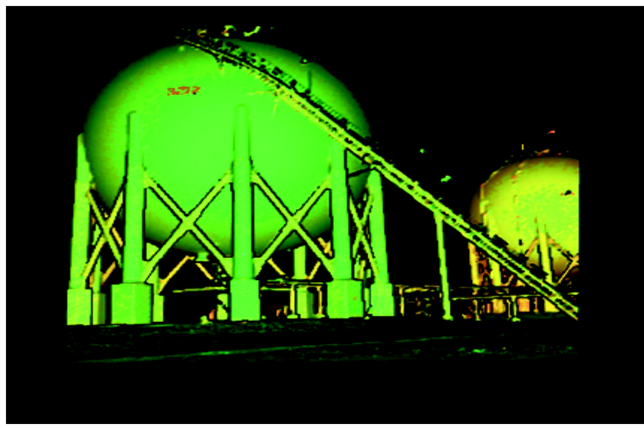

Figure 7. Cyra Technologies example laser scan of a full size refining facility.

Figure 9. Digitizing the physical model with the stylus.

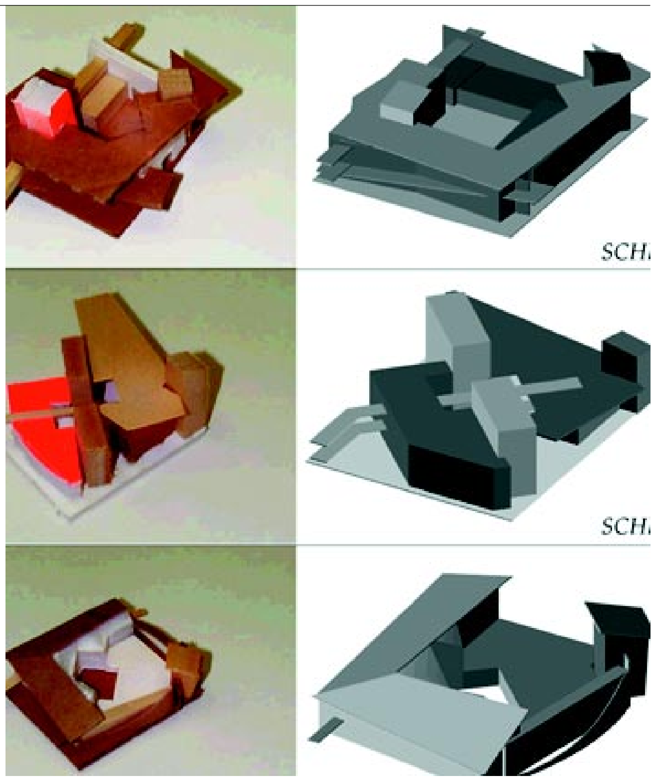

Figure 10. The three alternative schemes digitized.

example, for historical preservation or adaptive reuse, the existing conditions could be accuratelycaptured in 3D with only a set of scans. (L. Addison 1998) (Figure 7).

experiments

Within the structure of a design studio format, we conducted a few small experiments using the stylus and laser scanning techniques. The experiments attempt a stylus-based technique and a laser-aided technique in a search to make each suitable for supporting design strategies.

The design project involved three design schemes with a mixed-use program including retail, industrial, and residential spaces. The idea was to bring all of the programmatic elements together facing a courtyard as a social gathering space. The objective of the experiment was to see how these study models would react in the environment located in the Arts District in downtown Los Angeles. We attempted to demonstrate that creating a digital model would be faster using a digitizer rather than recreating the entire project from scratch.

The models were constructed of foam core, cardboard, museum board, and basswood. Each material demonstrated different programmatic systems along with an idea of some material reference, As soon as the physical models were constructed, they were digitized using a stylus-based Personal Digitizer by Immersion Corporation. It uses a software program called Hyperspace 3D. The software allowed to transfer the three dimensional points into the computer directly into a DXF format. The DXF file was then imported into FormZ RenderZone 2.9.5. The experiment used a PowerMacintosh 7100/80 and a Pentium 100 PC. Both platforms were used to demonstrate that the technology is platform independent (Figure 8-9).

In these three examples the vertices were digitized to capture the massing of the model. Because of their geometry, the roof angles were the most important pieces to capture. As soon as the geometry was plotted, the models were exported into FormZ to add further detail. The details were adjusted in FormZ because of its capabilities in creating objects with scaleable dimensions and because the experimentors' substantial experience with the program. After the details were added in FormZ, the models were exported into 3D Studio Max II. All of the renderings were created in 3D Studio Max II because of its speed and its animation capabilities.

The next step was to take advantage of the digitizer for creating a motion path animation. To create the path, one must place three dimensional points in the areas which best described each scheme. From this, the points were merged together to create the motion path. The path was then exported to 3D Studio, and attached to a camera object to generate the animation. The animation helped explore different ways of design the slope of the roof to ensure that certain views would not be blocked that overlooked the downtown skyline.

In addition to adding the motion path, the model was also used to calculate the floor area and volume of the model. This information could be very relevant in the early phases of design, especially when particular building materials are bid based on their square footage. The animation also revealed design flaws with the shadow casting under the courtyard. It was necessary to reconfigure the roof to add light into the exhibition area during particular times of day, especially between heavy business hours. After redesign, the models were re-exported to FormZ so that diagrammatic plans, sections, and elevations could be created from the computer model.

From all of these simple strategies one can make decisions about a project that may prevent errors in the design phase. This process benefits not only the design phases but also documentation and materials selection.

The laser-aided experiments involved a different physical model. This was done primarily because of the limitations due to the object-size requirements of the scanner. Again the design project involved a multi-planed roof structure with complex geometries. The objective was to see if the laser scanner could adequately digitize the model. The model was constructed of gray museum board along with drafting vellum to represent windows

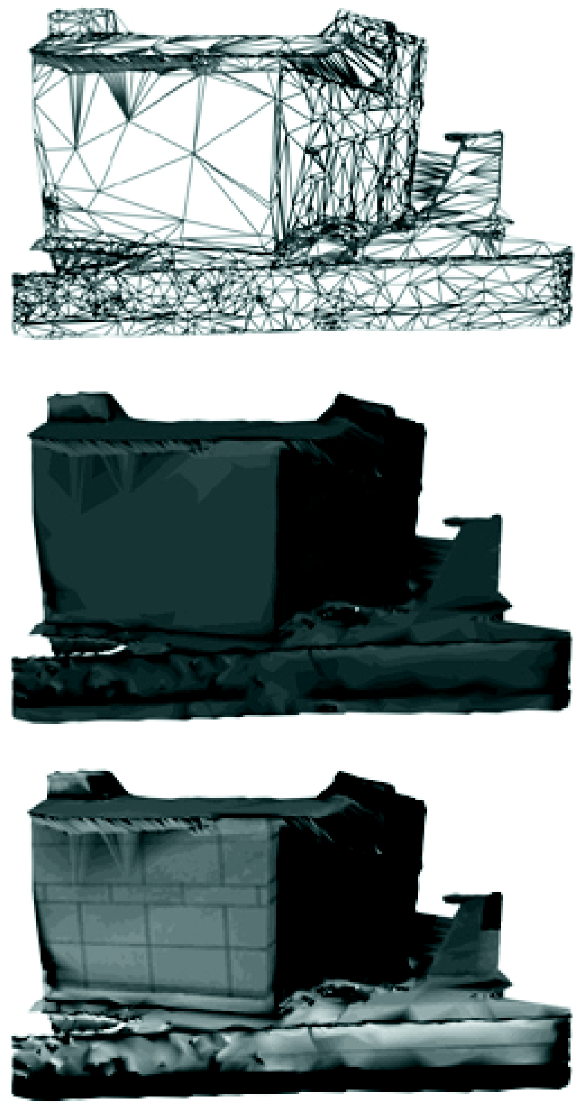

Figure 10. The first results from the laser scan experiment.

and openings. The model was placed into a foamcore base (Figure 10).

The scanner used in this part of the experiment ran on a Pentium 166Mhz PC with 64MB of RAM. The scanner has a tripartite capturing process: a standard grade A laser (similar to a shopping cashier scanner), a black and white camera, and a video camera. The laser sends light to the surfaces of the object and then reflects them back into the computer as 3D coordinates. The black and white camera determines the depth of the image map to be placed on the computer model. The video camera takes a picture of the object and maps it according to the black and white image. The computer models were captured in RayDream Studio Professional because the particular hardware choice required it to. Although this model scanner only worked with RayDream, there are others that work with other software.

To capture all of the geometry it was necessary to set up the model so that each side can be captured by the laser. This process took several attempts but after it was set properly it only took a few seconds to get both the overall geometry and image maps created. Once the scans were captured there seemed to be a problem with the way the laser read the tilted planes of the model. The model was incoherent. We learned through experimentation that our test scanner still had tremendous difficulty capturing purely planar elements.

future work

We are working with Professor Medioni of USC on finding applications for his new stereoscopic-based photogrammetric technique. We would also like to explore using CYRA's laser radar scanner for an existing physical model to demonstrate how the technology can be used in the documentation phases of a project. Contextual analysis and many other concerns could easily benefit from this process.

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