TERRAIN MODELING USING RAPID PROTOTYPING

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Abstract

Models have a variety of purposes, including education, testing and sales. At present most models in civil engineering and architecture are made using clay, cardboard, foam, and wood. These models are usually cut by hand and then assembled piece by piece. This process can be very time consuming, and it can take weeks to get a model. Also, since terrains have complex geometries, they are difficult to reproduce using these methods and large inaccuracies result. This research sought to develop ways of creating a model from Geographic Information System (GIS) data on Rapid Prototyping (RP) machines. This research included looking at several computer programs and RP machines. The final model was created using four different programs, including a GIS data converter, Land Desktop, AutoCAD, and RP Magics. Final models were successfully built on the Z Corporation's Z406 system and a Laminated Object Manufacturing machine. The results of this research allowed extremely accurate terrain models to be built in a matter of hours, which could be used to test a structure's interaction with its environment, educate people about geological landforms, and to sell ideas such as a new building or environmental protection.
Keywords: Terrain Modeling, Rapid Prototyping, Educational Models, Watersheds

1. Introduction

Water quality is extremely important to everyone's health and ability to participate in water related activities, such as swimming or fishing. Many agencies such as sewage districts and environmental societies are taking an initiative to educate the public about watersheds and their effects on water quality. They have employed many means to do this such as the internet, leaflets, and posters. However, agencies like the Milwaukee Metropolitan Sewage District are looking for new ways to interest the public in watershed protection. One idea for exciting interest in people to protect their water resources is through a model of the watershed in which they live. The model would show the physical form of the watershed as well as demonstrate how it works, land usage, pollution levels, and how all of these affect water quality.

A rather large challenge for a model of this sort would be to create the terrain itself. In order to have the full impact to teach people about watersheds, the terrain should appear as it does in nature. There is geographic information available that describes all of the land in the United States. This data could be used to create a terrain model. Rapid Prototyping (RP) technology offers a unique approach to this problem. RP allows a model with the complex and unique geometries of a terrain to be built automatically from a CAD file with great accuracy. These models can be produced in a matter of hours. To create a terrain model using conventional methods would take weeks. According to Peter Sheerin, RP can create models at a lower cost in less time than models created using conventional methods. [9]

This research sought to develop a way to take Geographic Information System (GIS) data and create a model of the terrain from that data on a rapid prototyping machine. The biggest challenge was converting the GIS data into a form that the RP machines could read and build.

2. Background

2.1 models

The main goal of this research was to create a terrain model using GIS data and RP. Over the past 50 years models have been used for a variety of purposes and have become increasingly important. Ship builders, automotive engineers and aerospace engineers use models to test designs. Also, building models are created to test layouts in factories and large buildings. Lawyers use models to reenact crime scenes. Architects create models of proposed buildings to sell the idea to clients. Models are also one of the most powerful tools for education. In terms of cartography 3D models are very useful. There are a plethora of uses for models, and many applications for terrain models.

Models are powerful tools because they show 3D objects. Since models are in 3D, information in the third dimension is not lost, which is a common problem in cartography. On 2D maps the third dimension is represented by size, color, shading, texture, shape, and orientation. Some of the users of maps have difficulty interpreting the visual variables of the maps since they do not have the training. As Wolf-Dieter Rase points out, "Humans have a lifelong training to interpret 3D objects or pictures thereof and to construct a mental model in 3D." [8] A real 3D model would be better to show geographic information. Also he states that, "Physical models have the advantage over 2D drawings that slight movements of the head or body suffice to look at parts of the model covered by obstacles in the line of sight, for example high prisms or mountains in the foreground." [8] This makes 3D models easier for people to view and understand.

2.2 digital terrain data

The terrain data employed in this research was from the United States Geological Survey (USGS). The data can only be downloaded in one format, which can then be translated into forms that are compatible with CAD programs. The government requires that all of the digital spatial data be distributed in the Spatial Data Transfer Standard (SDTS). This data, once downloaded, was transformed into a more useful format of the Digital Elevation Model (DEM). There are many freeware SDTS to DEM converters available on the internet. Once the digital terrain data is in the DEM format, it can be imported into Geographic Information System (GIS) software such as Land Desktop, which is available through Autodesk®. A DEM formatted file is created by dividing the map area into an xy grid with known z elevations for each xy coordinate. This format makes a rolling terrain possible as triangular 3D faces can be formed from this information. This rolling terrain can be turned into a solid shell and format so that a model can be built on an RP machine.

2.3 rapid prototyping

Rapid Prototyping (RP) was employed in this research to build terrain models. RP technology built these models from a CAD file. The software employed by the RP machines sliced a solid file into layers and built 3D parts layer by layer. There were two RP machines used during this research, the Laminated Object Manufacturing (LOM) and the ZCorporation's Z406 System.

The first machine used to create a model was the Z406 system (Figure 1), which is a 3D printer with the ability of printing in full color. This was important in this research there was an idea to overlay a map over the 3D terrain to enhance the information included, and this machine had the ability to print the map directly onto the model. The model was created by layers being printed onto a fine powder which was put onto a platform with a roller. A printer head which contains an adhesive and pigments which bound and colored the model traced the shape of each layer. [5] The Z406 system was capable of printing two layers a minute in the color mode, which means that a simple terrain model could be built in just a few hours. [5] If the same model were to be created using conventional methods of building the model by hand, it would take weeks.

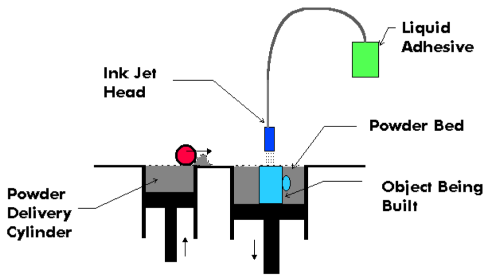

Figure 1: Z406 System [5]

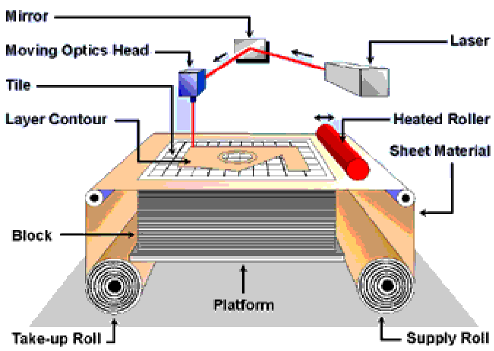

Figure 2: LOM [6]

The second machine employed for building a model as part of this research was the LOM. The LOM used a carbon dioxide laser to burn each layer from a CAD file on a sheet of paper with a polyethylene coating on the backside. A sheet of paper is added for each successive layer and steam is used to heat the coating so that the new layers fuse to the previous layer. [6] Once the model is completed, a border and small cubes had to be removed from the surface and then it had to be sanded and coated to protect the materials. The part is then like a block of wood. This model could incorporate landmarks and other data on them in one of two ways. Since it has a smooth surface, a projection unit could project images directly onto the model. Or, the laser engraver could burn streets and landmarks directly onto the model. This model was completed in a few days. Since the RP machines build everything layer by layer, the complex geometries of a rolling landscape were easily created with great accuracy.

2.4 watersheds

A watershed is all of the land that drains into a certain body of water, such as a river or a lake. [3] It is defined by the landforms. Figure 2 shows a hypothetical watershed with the boarder shown in white. In a watershed water rains down and flows from the area of high elevation to low lying areas where there are lakes and rivers. The water flows down the land according to the contours; on the diagram the arrows show these flow paths. The terrain affects the levels, flow and the cleanliness of the bodies of water with in them.

The quality of a body of water depends on many factors, one of the largest being the way that the land in its watershed is used. The water that runs over roads carries different contaminants than water that runs over a farm, and both of these carry more contaminants than water that runs over a wetland area, which will filter out many of the contaminants. Every piece of land is part of a watershed. Milwaukee is part of the Milwaukee River Watershed (See Figure 3), which is part of 7 counties and covers 685 square miles. [10] This project had to be completed in 10 weeks, so in the interest of time a small portion of terrain located in the southern portion of the Milwaukee River Watershed was taken into consideration.

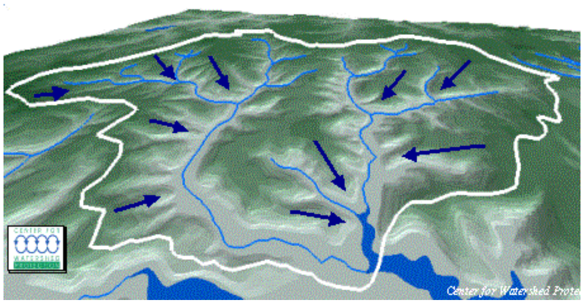

Figure 3: Arbitrary Watershed [4]

Figure 4: Milwaukee River Watershed [2]

3. Objective

This research project sought to employ rapid prototyping to create unique 3D terrain models from GIS data. These models could be used to test a structure's interaction with its environment, educate people about geological landforms, and to sell ideas such as a new building or environmental protection. This research included finding a way to translate GIS data into an RP compatible format and finding the best RP machine on which to create a model.

4. Approach

4.1 available information

There is a lot of geographic data available on the internet. This research sought to take that data and turn it into a 3D model. In order to do this, all of the data had to be found and collected. The data used as part of this research is public domain data which came from the free download website through the United States Geological Survey (USGS).

The data available from USGS was in 7.5 arc-minute maps, in the Milwaukee area this corresponds to a map of dimensions of 9 miles north to south and 6 miles east to west. It is available in a Spatial Data Transfer Standard (SDTS) format. SDTS is designed to transfer data from one computer to another, even if they are different platforms, without losing or corrupting data. [1] The data in an SDTS file can be any one of the many formats used to display topographic data. The data within the file used in this project was of a Digital Elevation Model (DEM) format. A DEM is useful as it is in a format which can be used to create a realistic view of a terrain. However, most CAD programs cannot work with the DEM data in an SDTS format, so a conversion was necessary. To convert the file from a SDTS format to the DEM format that CAD programs can use, there are several freeware converters available from USGS.

4.2 obstacles

There were many obstacles during the course of this project. They included how to create the terrain and how to incorporate landmarks so people can find where they live and work.

The first obstacle was actually creating the terrain, and finding the best method to do it. After researching many software programs that would use the DEM data from USGS, Autodesk®'s Land Desktop was chosen. This program allowed a DEM file to be imported and a terrain to be built and manipulated. Once the software was chosen, the next challenge was to decide which RP machine would be used to build the model. There were many options, and each had its strengths and weaknesses. With most of the RP machines the biggest weakness was the inability to include landmarks, such as streets. There were however, three machines that could be used which could incorporate the streets directly onto the model, the laser engraver, the LOM and the Z406 system. The laser engraver could etch the streets directly onto the terrain on a laser engraved model and a LOM model, and the Z406 system could print a map directly onto the terrain. The Z406 also had the added bonus that other information could be directly printed onto the terrain as well, such as land usage or types of surfaces. Both the Z406 system and LOM were employed to create a model as part of this project.

5. Building a Terrain Model

Creating a terrain model took 4 different computer programs once the terrain data was downloaded from the internet. These programs included a SDTS to DEM converter, Land Desktop, AutoCAD, and RP Magics. First the terrain data was downloaded from USGS and converted into the regular DEM file format from the SDTS format using a converter that was available on the USGS website. It was important to convert the data into the DEM format since the program that models the terrain, Land Desktop, can only interpret the data if it is in a DEM format. Then the data was then loaded into Land Desktop, which is produced by Autodesk®. The DEM data makes a realistic looking terrain of 3D faces of the entire 7.5 arc-minute area covered by the DEM file (Figure 5). Figure 6 shows a close up of a portion of the Milwaukee River so that it is easier to see the 3D faces and how they form the terrain. Once it is loaded into the drawing, the vertical and horizontal scales can be adjusted to exaggerate the vertical scale, so that the changes in elevation are visible. In the scope of this research, the vertical scale was set to 1” = 100’ and the horizontal scale was set to 1” = 1500’. With this scale, a small area of 2 miles by 2 miles can be built on the Z406 machine and an entire 7.5 arc-minute map can be built on a single build on the LOM.

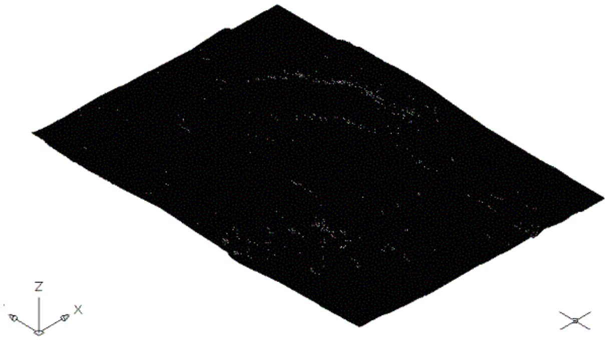

Figure 5: 7.5 Minute Map in Land Desktop

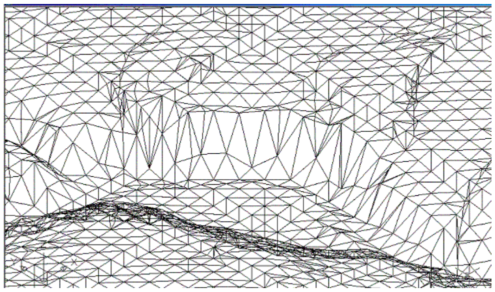

Figure 6: Close Up of 3D Faces

The terrain was loaded into AutoCAD so that it was possible to edit it. This included taking off the rough edges, making it rectangular, and breaking the terrain into smaller pieces so that the files were of a manageable size. Once all of the editing was completed the next step was to save the terrain pieces in a DXF format.

Once the terrain was saved in a DXF format, it could be imported into RP Magics (Figure 7). In RP Magics, the terrain had to be rescaled to be in the right dimensions as AutoCAD exported the dimensions in feet, and RP Magics reads the dimensions in either inches or millimeters. Figure 8 shows the terrain once it had been rescaled. The landforms on the scaled terrain are far more noticeable, which is why the vertical scale had to be different than the horizontal.

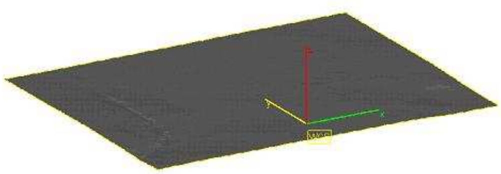

Figure 7: Terrain in RP Magics

Figure 8: Scaled Terrain

In order to build a model the part must have a thickness. The pieces of terrain that are in the preceding pictures have no thickness; they are just sheets of triangles. To create a thickness, the surface of the terrain was offset from itself by 1/8 of an inch. This created a thin shell of a terrain (Figure 9). The bottom of this terrain is uneven and so will not lay flat, so it is impractical for a display. To solve this problem a base was created. For the first model, the surface of the terrain was extruded downwards two and a half inches. Then, a plane was created 2 inches from the lowest point was created and a cut was made along that plane (Figure 10). This gave the terrain a flat bottom so that it could rest on a surface.

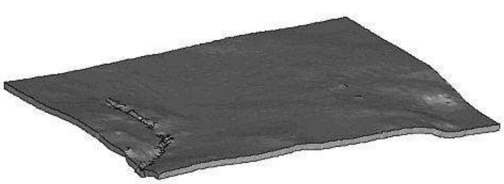

Figure 9: Terrain with Thickness

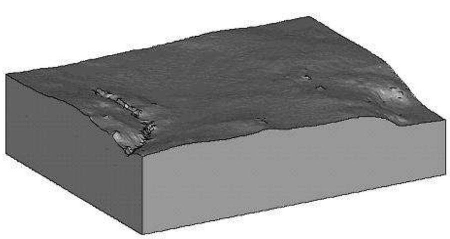

Figure 10: Terrain with Display Base

For the second model the same steps were followed through the creating a thickness. However, when it came time to create a base, a slightly different method was employed. Since several pieces of terrain were being combined to make a larger model, these pieces had to be combined first so that the base would all be one height so that the pieces would fit together. Each piece of the terrain was loaded into a single file, and they were manipulated so that they all lined up. There were some problems creating a flat base in the same manner as the previous model as the file was substantially larger. So, alternate methods were explored. The final method was to create a series of little posts around the edge of the model one inch high, and the gridding of the LOM would be turned off for that one inch, thus creating a flat base of one inch.

Two terrain models were successfully created; one using the Z406 system (Figure 11) and one using the LOM. These were the first models of their kind created at the Rapid Prototyping Center at the Milwaukee School of Engineering.

Figure 11: Terrain Model Made on Z406

6. Recommendations

The terrain models created as part of this research project are a great first step to creating practical terrain models which could be used for a variety of purposes. However, in order to make these models more useful, it is important to incorporate streets and landmarks directly onto the model so that the observers can have a sense of what they are looking at.

There are two possible ways to do this using the rapid prototyping machines. One would be to use the unique capabilities of the Z406 System. Since this machine has the ability to print color directly onto the model, landmarks, streets, and other information such as land usage can be printed directly onto the model itself. The second method would be to use the laser engraver to burn the streets directly onto a LOM part. Since the LOM parts are essentially wood, they lend themselves nicely to this method.

There is another way of incorporating streets, landmarks, and even other data, which would not use RP. That is through a projection system that would display images directly onto the model. This has the distinct advantage that the images projected onto the model could vary. This method would be ideal for watershed education as images of how the water flows, land usage, and water quality could be projected onto the model. This would make the terrain models very powerful teaching tools.

Although the display of information on the terrain models was not part of the scope of this research project, hopefully another research project will look into these ideas. There are many ways of incorporating information into the models, and it would make them more complete and more powerful than plain terrain models.

7. Conclusions

It is possible to create a terrain model from GIS data on an RP machine. The intricate geometries of the landforms were created with ease and great accuracy. Creating terrain models on RP machines allows for extremely accurate representations of the land. Terrain models of this sort have a variety of uses including architectural models, engineering design testing, city planning, and geological and watershed education. However, for these models to be fully effective, it is necessary to add information to the model such as streets and landmarks so that people can orient themselves to the terrain itself. Hopefully another research project will explore the options for the display of this data. These terrain models are valuable tools for cartographers, civil engineers, architects, city planners, and teachers.

8. Acknowledgements

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