Visualization of Cartographic Surfaces Using 3D Printing and Subsurface Engraving

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Abstract

To build multicolored physical models of three-dimensional cartographic surfaces new computer-controlled devices can be used which were developed for the fast and inexpensive production of mechanical parts. To evaluate rapid prototyping technology several physical models were built, visualizing conceptual surfaces interpolated from demographic and economic data, and travel distances in traffic networks. Similar surfaces were used to produce 3D images inside glass blocks by using laser subsurface engraving.

1. Virtual reality vs. physical reality

The enhanced cost-effectiveness ratio of computers and graphic peripherals has provided new methods to generate photo-realistic scenes, which are known as virtual reality (VR). Developers and users of geographical information systems have adopted VR to visualize spatial objects. Computer graphics and VR have also facilitated the transition from static planar maps on paper or flat displays to perspective and stereographic representations, which can also include the time dimension. Such dynamic visualization has been made possible by high-performance desktop computers and new high-capacity distribution media, such as the World Wide Web, the CD-ROM and DVD.

Perspective drawings on 2D media take advantage of the viewer's lifelong experience in recognizing and interpreting depth cues in pictures. The main shortcoming of using perspective drawings for cartographic applications is the inability to obtain distances and directions from measurements in the picture, although interactive software provides solutions to that problem.

Stereoscopic displays make use of the ability of the human brain to construct a 3D mental model from two slightly different images, one corresponding to each eye. Stereo images may be provided by binocular viewers, shutter glasses, lenticular and barricade displays. Stereoscopic viewing can also be induced by non-binocular optical effects, such as SIRDS (single image random-dot stereograms), chromostereoscopy, or holography [1].

Despite the availability of virtual reality technology, physical models of buildings are still requested in architectural competitions, even though VR techniques provide more visual information than a model. For example VR allows interiors to be visualized from different viewpoints and under varying light conditions during a walk-through, or the view through a window, in both directions, can be generated. Why are physical models still requested? One reason may be that the cost of the model is a marginal quantity compared to the cost of the competition, let alone the real building. Probably architects have also a fondness for the haptic experience, the opportunity to feel an object with their own hands.

Physical models have the advantage over 2D drawings that slight movements of the head or body suffice to compare heights, to solve optical ambiguities or to reveal parts of the model that might be obscured in fixed view. In case of non-dynamic media multiple drawings may be necessary to present all parts of a scene. The quest for haptic experience may be valid not only for architects but also for decision-makers in regional planning with a limited experience in map reading. Under certain circumstances a real 3D model is able to transmit the cartographic message much better and faster than a two-dimensional map.

2. Rapid prototyping technology

Numerically controlled machines capable of the production of mechanical parts have been in use for more than four decades. Advances in microelectronics have led to computer-controlled devices which are able to build physical models at reasonable cost within short time frames (*rapid prototyping, RP*). The prototypes serve mainly to judge on the form and appearance, in certain cases to evaluate the mechanical function [2]. Usually the prototypes are not exposed to the mechanical stress that their real counterparts have to withstand, for example the prototype of a steering wheel for a car. Thus it is not necessary in most cases to use the same material of which the final part will be made.

The different technical approaches for the computer-assisted production of parts can be subsumed under four headings with equivalents in the fine arts:

- Aggregation: A model is built up from small amounts of material, in the same way a sculpture or a scale model is formed in plaster or some other plastic material (the *Rodin* method).
- Removal: A block of material is cut with a tool that removes successive small quantities of material until the final form is reached, as a block of marble is transformed into a sculpture (the *Michelangelo* method).
- Transform*:* The material is formed by pressure and heat, as a blacksmith forms a red-hot bar of iron (the *Chillida* method).
- 3D drawing: tiny points inside a glass block are melted by a laser beam and become opaque (the *Dürer* method).

An example of the *Michelangelo* method is numerically controlled milling. NC milling is typically slow and expensive compared to the newer techniques available nowadays.

Methods of the *Chillida* type can be used to create multiple copies of objects at moderate cost (the artist Chillida created huge metal sculptures by industrial forging of iron rods and bars). The equivalence in 2D is the printing process. In France many bookstores offer terrain models of regions and *départements*, depicting color-coded height bands, rivers, streets and settlements (www.mediaplus.fr). These models are made from a thin foil of thermoplastic material which is transformed by heat and pressure using a mould, most probably produced by NC milling from a numerical representation of the relief.

The *Rodin* methods, the aggregation of material, have the greatest potential for rapid prototyping in general and for the creation of cartographic surface models in particular.

A new technology is *laser subsurface engraving* which, strictly speaking, does not belong to the rapid prototyping family, but uses the same data and file structure to define the model.

3. Printing in three dimensions

The most frequently used technologies for rapid prototyping belong to the *Aggregation* group, with the power-based devices as the most recent developments. A thin layer of a powder, such as starch, plaster, photopolymer or metal, is deposited onto a building platform. The regions of the layer that are to become part of the model are fixed by selective spraying of an adhesive, by polymerization with an UV light beam, or by local heating with a laser beam (selective laser sintering). When the first layer has been fixed the second layer is deposited, and so on, until the final layer is accomplished. After completion of the model the loose powder is removed by shaking or with the help of an air jet.

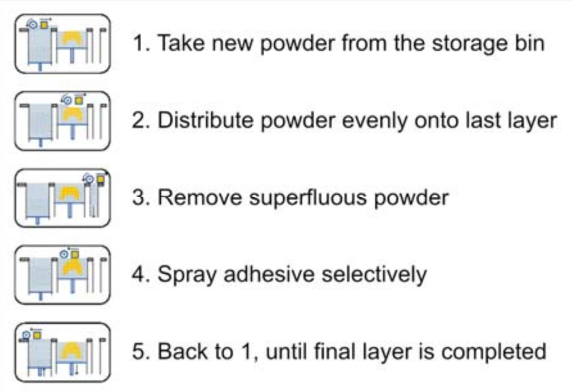

Figure 1. Building steps for 3D printer Z510

Until a few years ago the direct application of color during the buildup stage was not available, and the raw models had to be colored manually, for example with an airbrush. Color, however, is an essential graphic variable in cartography. For economical reasons the application of color must be integrated into the building process of the model.

In recent years new RP devices were developed which can apply color in high resolution and in many program-controlled shades, which makes it feasible to use the technology to build physical models of three-dimensional cartographic surfaces. The rich color spectrum and the use of standard inkjet printer parts may be why the manufacturers call their devices 3D printers.

The first 3D printer with integrated high resolution color capability was introduced in 2001 by the company ZCorporation (www.zcorp.com). As well as using transparent adhesive, the device can apply three colored adhesives containing pigments of the subtractive base colors cyan, magenta and yellow. The result is a multicolored part. The finished model can be infiltrated with a special liquid, such as epoxy or cyanoacrylate, to improve the mechanical strength and to protect against high humidity.

The 3D printers Z510 and Z810 (the latter with larger build dimensions) are currently the only devices on the market that provide multicolored parts. The capability to integrate color into the build process opens many new applications for RP in addition to cartography and GIS. For instance multicolored models of molecules, buildings or plants can be produced, and there are many potential uses in medical visualization improving clinicians' understanding of data from x-ray or magnetic resonance scanners.

The software for the 3D printer Z510 slices the numerical representation of the model into layers of a selected thickness, in the range 0.089 to 0.203 mm. The thickness of the layer determines the resolution in the *z*-direction, and hence the production time. A compromise value of 0.1 mm was used for the models referenced here. Approximately two colored layers can be built per minute. The Z510 printer can handle models up to 254 x 356 x 203 mm.

The surface of the part is represented by a triangular mesh which can be stored in different file formats for 3D models. In our case the VRLM97 format was used. Many CAD programs and viewers are available which allow the display of VRML files for visual inspection of the models, including syntactical checks of the triangular mesh.

The boundaries and other lines are represented by thin tubes. The tubes, the situation and the legends all

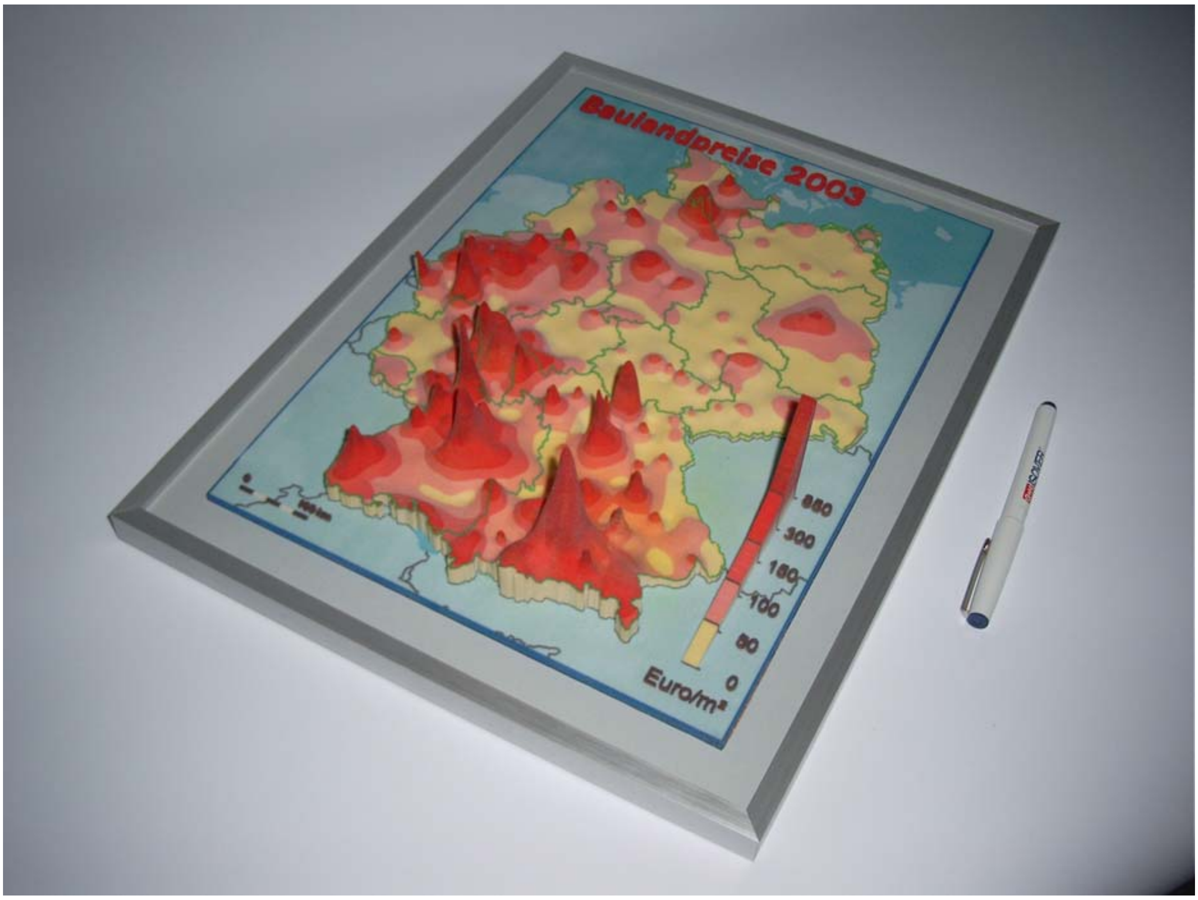

Figure 1. Physical model: surface of average land prices in Germany (framed)

consist of 3D triangular meshes. The text strings are 3D parts extruded from the TrueType character definitions (glyphs). The form of the extrusion and the bevels can be controlled with several options. The graphic resolution of the glyph is selectable, depending on the character height. Any TrueType font can be used, provided that the syntax of the glyphs is correct (which is not the case for all TrueType files available, as we found out).

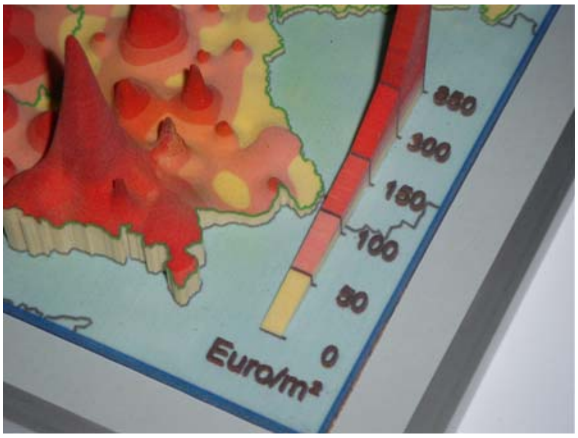

Figure 2. Enlarged legend and text

The continuous surfaces depicted in the models were interpolated from point or polygon data, with the geometric base data prepared using the ESRI ArcGIS package (shapefile format). Interpolation of polygon-based data was performed using the pycnophylactic interpolation method [3, 4]. The interpolation and the triangle generation including the meshes representing the tubes, areas, legends and 3D text, are done with our own software. Standard VRML viewers are used for visual checks of the models before the files are transmitted to the 3D printer.

Some of the models built show the results of accessibility computations for the railway and road network in Germany [5]. The heights of the surface represent the average time distance to the next central places, to railway stations for long-distance travel, to airports, or to other public services.

Jacobs [6] and Mueller [7] have built physical terrain models using the 3D printer.

Even though 3D printers now cost less than half as much as a high-quality mechanical 2D plotter did about 20 years ago, it is not economical to buy a 3D printer for only occasional use. It is less expensive to use the services of a contractor to build the models. The VRML files with the model representations were sent to 4Dconcepts (www.4dconcepts.de) as attachments to e-mails. Assuming that no errors are detected during an extra check at the contractor's premises, the model is built on the printer, infiltrated with the stabilizing liquid, and then returned to the customer by a parcel service.

4. Laser subsurface engraving

Laser subsurface engraving (also known as laser etching) is performed by a computer-controlled device where a focused laser beam melts a tiny spot in a glass block, destroying locally the transparency of the glass. The melting of many spots results in a visible 3D model, which might be a building, a human portrait, or a cartographic surface. The laser beam and its focus are moved in relation to the glass block using data derived from a numerical representation of the object. It is obvious that the melting process has to start with the lowest layer, otherwise the laser beam would be occluded.

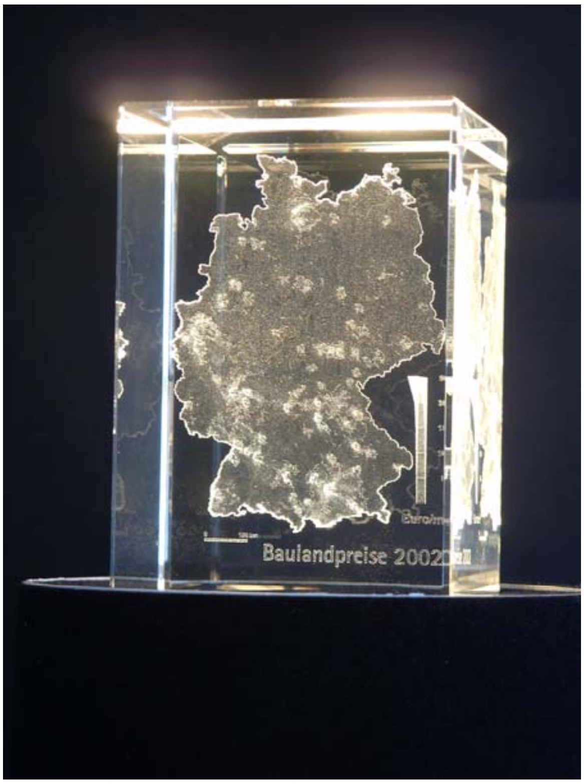

Figure 3. Glass block with 3D surface

The equivalent 2D representation is a pen drawing or an etching which is why I like to call this the *Dürer* method. The object inside the glass block is monochrome. Putting it on a pedestal providing adequate illumination is advisable to insure good visibility.

Nearly identical VRML files as with the 3D printer were used to generate the surfaces inside the glass block. The files were sent by e-mail to the company which builds the computer-controlled laser engraving devices (www.vitro.de). The manufacturer of the device offers now additional software to its customers, intended to improve the visual appearance of the models in the glass block.

For some time now a franchise organization operates many shops in several countries, providing etching devices and 3D cameras necessary to do 3D portraits on the spot (www.looxis.com). Most of these shops are able to accept 3D files and produce the laser etching for customers.

5. Benefits of physical 3D models

Physical models of GIS objects are unlikely to replace paper maps or virtual reality techniques. However, a model has all the advantages of a perspective drawing or a stereogram. In addition, viewing ambiguities, such as the inversion of the depth impression, a recurrent problem with 2D drawings and sometimes also with stereograms, can be resolved by a minor movement of the head or body.

The estimation of distance and height within the model is easier with a physical model due to the lifelong experience with 3D views. When a group of people are trying to grasp a spatial situation or process a physical model can have advantages over VR methods. VR equipment is still expensive, less transportable than a physical model, and is not usually able to support multiple users. The production of a physical model, to be fair, is not cheap either.

A physical model can be used for representative and promotional purposes, for example on display in the entrance hall or an office, or exhibited at a fair. In this context models have an important job as *conversation pieces*. The technical explanation how the model was built can lead to a discussion of the problem that the model is trying to clarify. This is very important in environments where decision makers have no immediate relationship with spatial science, GIS or cartography. The model is the medium to introduce the message in a roundabout way, a kind of subversive cartography.

An illuminated glass block with the etched object inside falls into the same category, as an eye-catcher or conversation piece. It can also serve as an inexpensive theme-related trophy or a personalized present.

Something unexpected happened when I showed these models to my colleagues for the first time: nearly everyone spontaneously tried to touch the surface of the model. To touch the material and the surface forms, to use the haptic sense, is obviously a basic desire, equivalent to the desire to use the other senses. Touching is not reserved for people with a visual handicap, although they would certainly benefit from the economic advantage of producing special maps by rapid prototyping techniques.

10. References

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