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Physical Models for Cartographic Applications

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Zusammenfassung

Perspektivische Darstellungen, Stereogramme und Animationen sind Standardwerkzeuge für die Visualisierung von georeferenzierten Informationen geworden. Für die schnelle und preisgünstige Fertigung von Werkstücken wurden in den vergangenen Jahren computergesteuerte Geräte entwickelt, mit denen auch vielfarbige 3D-Modelle von Geo-Objekten produziert werden können. Mit einem 3D-Drucker wurden farbige Modelle gebaut, die immaterielle Oberflächen aus demographischen und sozioökonomischen Informationen, die Ergebnisse von Erreichbarkeitsrechnungen und digitale Geländemodelle repräsentieren. Die Oberflächen wurden genutzt, um 3D-Bilder in Glasblöcken mit der Technik der Glasbinnengravur zu erzeugen.

Summary

Perspective drawings, stereograms and real-time animations are now standard tools for visualizing geographical data. Recent techniques developed for the fast and inexpensive production of mechanical parts can be used to build multicolored physical models of three-dimensional cartographic objects. To evaluate the technology available several models were built using a color 3D printer, visualizing conceptual surfaces derived from demographic and economic data, travel distances and terrain. Similar surfaces were used to produce 3D images inside glass blocks by Laser subsurface engraving.

1 From 2D to 3D

Recent advances in cartographic visualization have largely been driven by four developments:
- the tremendous cost reduction and performance improvement in computer hardware,
- the evolution of methods and algorithms for the display of 4D scenes (space + time),
- the transition from static to dynamic media,
- the availability of vast databases with geographical information, which is not restricted to terrain and landmarks.

The enhanced cost-effectiveness ratio of computers and graphic peripherals has encouraged the development of methods for the generation of photo-realistic scenes for virtual reality (VR) applications. Developers and users of geographical information systems have adopted VR technology to visualize spatial objects, and VR has also allowed a 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 and the CD-ROM.

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For the display of maps on 2D media a certain amount of simplification or generalization is necessary to transmit the message, especially the coding of the third dimension into the two dimensions of the display media. On planar maps the third dimension is encoded by visual or graphic variables (size, lightness, color, texture, shape, orientation). The reader of the map must be able to decode the variables and mentally reconstruct the third dimension, perhaps assisted by a legend, but this process is not intuitive. Some people have problems in decoding the visual variables of maps because they do not have the necessary training or experience, and then the message in the map is never received.

Humans have had a long training in interpreting 3D objects or pictures of objects and constructing them as 3D mental models. This experience is both evolutionary, from primates to homo sapiens, and individual from infant to adult. A mental model may be induced by using

- perspective drawings,
- stereoscopic displays,
- physical models.

Perspective drawings on 2D media take advantage of the viewer's lifelong experience in recognizing and interpreting depth cues in pictures. Even so intuitive interpretation can fail in certain cases, called optical illusions. The main shortcoming of using perspective in 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 (Buchroithner & Schenkel 2000, Rase 2003).

2 3D Physical Models of Buildings and Cartographic Objects

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 certainly 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. 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 who have limited experience in map reading. A real 3D model may be able to transmit the cartographic message much better and faster than a two-dimensional map.

3 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 peripherals which are able to build physical models at reasonable cost within short time frames (*rapid prototyping*, RP). Color is an essential graphic variable in cartography. New RP devices which can apply color in high resolution and in many program-controlled shades, which makes it feasible to use rapid prototyping technology to build physical models of 3D cartographic objects. The rich color spectrum and the use of standard inkjet printer parts may be why the manufacturers call their devices 3D printers.

The different technical approaches to rapid prototyping can be subsumed under three 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).

One example of the *Michelangelo* method is numerically controlled milling. Although low-cost NC machines have been available for several years, NC machining is typically slow and expensive. Methods of the *Chillida* type can be used to create multiple copies of objects at moderate cost. In France many bookstores offer terrain models of most *départements,* including color-coded height bands, rivers, streets,

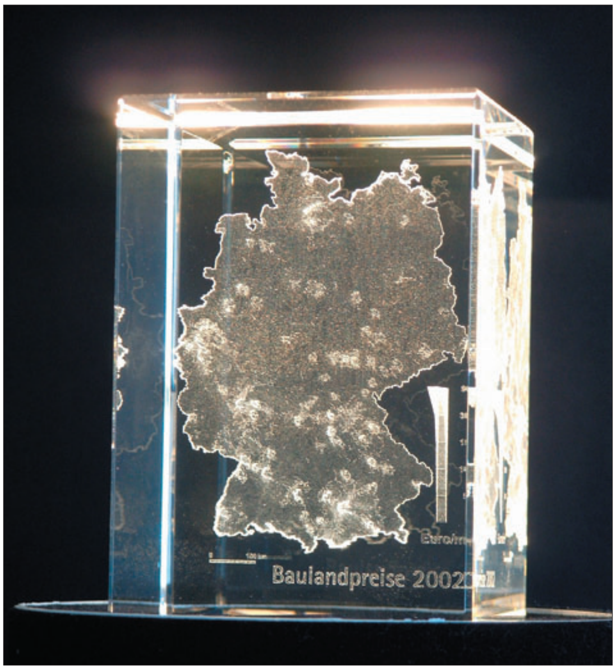

Fig. 1: Glass block with cartographic surface produced by subsurface engraving

and settlements. These models are made from a thin foil of thermoplastic material which is transformed by heat and pressure using a mould produced by computer-controlled milling from a numerical representation. 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* (*Glasbinnengravur* in German) which, strictly speaking, does not belong to the rapid prototyping family. A laser beam is focused on a point inside a block of glass for a short time. The energy of the laser beam melts a small volume of glass at that point, destroying the transparency. The melting of many points creates in a visible 3D structure, which might be a building, a human portrait or a cartographic surface. The laser beam and the glass block are moved with respect to each other under computer control, using movements derived from a numerical representation of the object (Vitro Laser 2006). The equivalent in 2D would be a pen drawing or an etching (which is why I like to call this the *Dürer* method). The object inside the glass block is of course monochrome. Putting it on a pedestal and illuminating it well is advisable to insure good visibility.

4 Building a Model by Stacking Layers of Material

The most frequently used technologies for rapid prototyping belong to the Aggregation group, but computer-controlled milling and color application can also create multicolored terrain models, for example by Solid Terrain Modeling (STM 2006). The machinery used by STM is proprietary, and data has to be transmitted to Fillmore, California. The finished model is subsequently transported back to the customer. Except for large models, the technology is not competitive with other possibilities now available.

Stereolithography was the first technique for rapid prototyping. A computer-controlled laser beam induces a phase change in a thin layer of photosensitive liquid. The liquid changes phase – becomes solid by polymerization – where the beam hits the surface. A new layer is then built on top of the solidified layer, and the procedure is repeated until the object is finished. Other devices aggregate drops or streams of thermoplastic material to build the model. There were also devices that use laser-cut paper sheets laminated to a block (LOM), but they have been superseded by less expensive techniques.

Powder-based devices deposit a thin layer of a powder, such as starch, plaster, photopolymer or metal. The regions of the layer that are to become part of the model are fixed by selective spraying of an adhesive, by polymerization with UV light, 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. After completion of the model the loose powder is removed by shaking or with the help of an air jet. Most devices allow recycling of the unused material.

Which process or device should be used depends on the purpose for which the prototype is intended. For instance, stereolithography achieves very smooth surfaces, but is expensive. Laser sintering, also called direct metal printing, produces metal parts which are stronger than polymer. The artist Bathsheba Grossman uses direct metal printing to create multiple copies of sculptures based on mathematical concepts (Grossman 2006). A combination of starch powder and wax can be used to build a pattern for investment casting. The pattern is covered with refractory slurry and then the wax is vaporized and replaced by the molten metal. Some powder materials can be finished with tools used for wood and electroplated subsequently to give the appearance of metal.

Until a few years ago color was not available in any RP process, and the raw models had to be colored manually, for example with an airbrush. In 2001, the ZCorporation, a spin-off of the Massachusetts Institute of Technology, introduced the first 3D printer with integrated high-resolution color (ZCorp 2006). 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 an epoxy or cyanoacrylate, to improve its 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.

5 Production of some Physical Models

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 described 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. In our case the VRLM97 format was used. The boundaries and other lines are represented by thin tubes. The tubes, the situation and the legends all consist of 3D triangles. The text strings are extruded from the TrueType 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.

The continuous surfaces in the models were interpolated from point- or polygon data, with the geometric base data prepared using the ESRI ArcGIS package (ESRI shapefiles). Interpolation of polygon-based data was performed using the pycnophylactic interpolation method (Tobler 1979, Rase 2001). The interpolation and the triangle generation including the triangles representing the tubes, areas, legends and 3D text, are all done with our own software.

Some of the other models show the results of accessibility computations for the railway and road network in Germany. A surface can be used to represent the average time distance to the next central places, to railway stations for long-distance travel, to airports, or to other public services. We intend to build a model that depicts terrain overlaid by land use patterns. Jacobs (2004) and Mueller (2004) have also built physical models of terrain 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 occasional use. It can be less expensive to use the services of a specialized firm to build models. We sent our VRML files by e-mail to the firm 4Dconcepts (4DConcepts 2006). Assuming that no errors are detected by a syntactic check, the model is built on

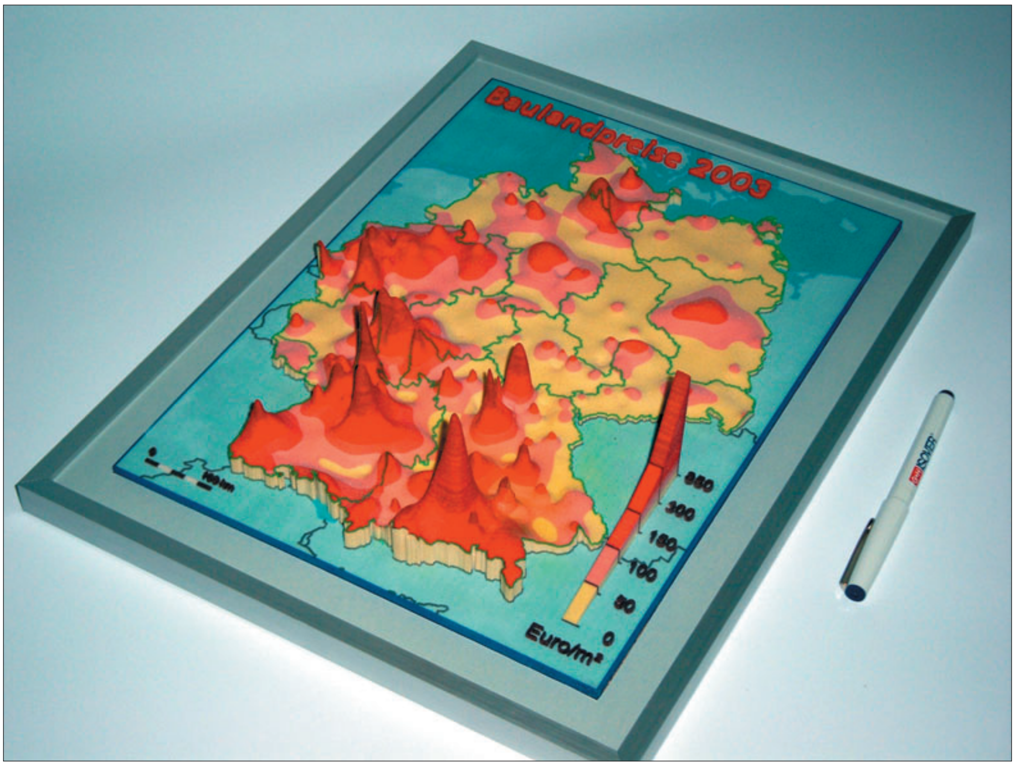

Fig. 2: Physical model of a surface interpolated from polygon-based data (average prices of building lots in 2003)

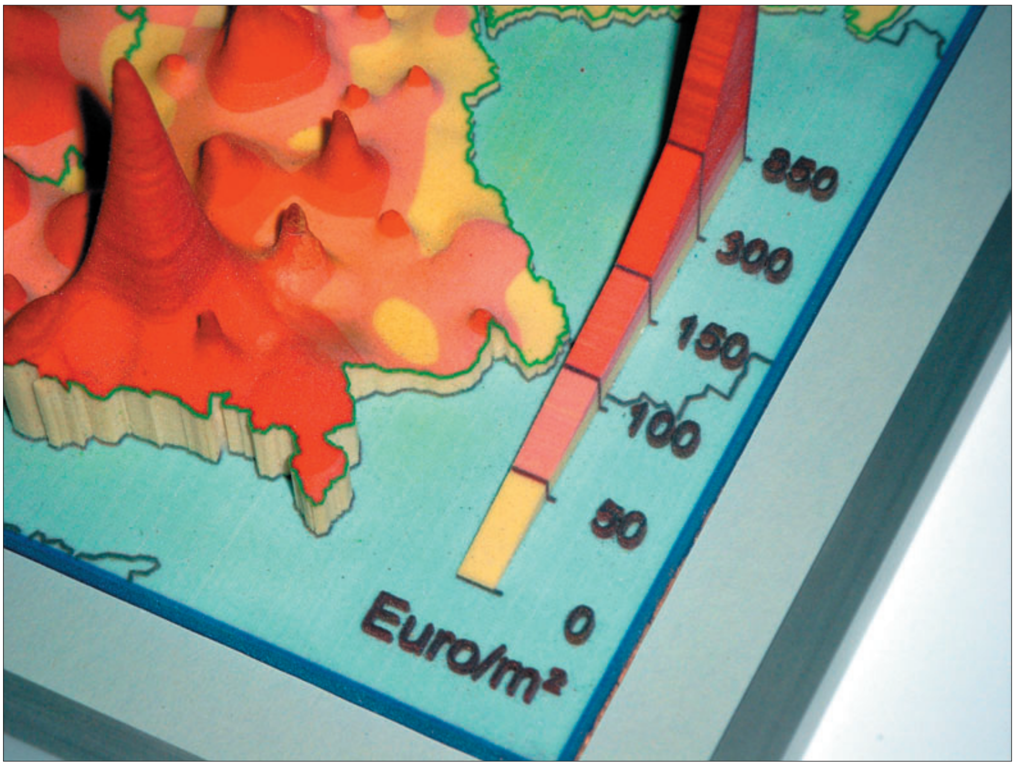

Fig. 3: Enlarged view of the model showing boundaries, 3D legends and text strings in detail

the printer, if necessary overnight, infiltrated with the stabilizing liquid, and then returned to the customer by a parcel service.

6 Main Applications of Physical Models of Cartographic Objects

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. As mentioned earlier, the estimation of distance and height is easier in 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.

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*. Sheer curiosity about the technical process can lead to requests for an explanation how the model was built. Such an explanation 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. 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.

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All hyperlinks were checked at 10 March 2006.

8 List of Figures

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Fig. 2: Physical model of a surface interpolated from polygon-based data (average prices of building lots in 2003)

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