Innovative solution for relief printing without limiting heights

François Lecordix

National Institute of Geographic and Forest Information - francois.lecordix@ign.fr

Abstract: By following technological developments in 3D printing, IGN experimented in 2015 with an ink jet-based relief printing solution, proposed by the Océ company. The first result was presented at the International Cartographic Conference in Rio de Janeiro in 2015, for the Belle-Ile map. The proposed technology solved several essential needs for relief mapping: high printing resolution, large size, colorimetric respect, ... But it still faced two problems: still high printing costs for the general public (compared to the prices of thermoformed maps produced in multiple copies) and still limited printing heights (less than 2 - 3 cm). In 2022, IGN proposed an innovative solution to overcome the problem of limiting printing heights, without increasing production costs. The new solution combines the previous ink jet relief printing technology with the Stratoconception® technology existing in the 3D printing domain. The solution is presented in detail in this paper with an example result.

Keywords: relief map, 3D printing, cartographic stratoconception

1. Introduction

During the Second World War, the need for relief maps increased on both sides of the fighters, and new processes were invented to speed up production, such as the American ribbon method (Sutter et al., 2006), which allowed the initial moulds to be built more quickly, or the German Wenschow method (Reed, 1946). After the Second World War, inspired by Wenschow's solution, the Americans used thermoplastic sheeting to design the thermoforming process which is still the solution used today to produce relief maps all over the world.

In France, for example, the National Institute of Geographic and Forest Information (IGN France) is still producing relief maps using this process by printing on vinyle sheets and using specially created moulds, if the area to be mapped can generate sufficient purchasing demand to balance the costs of producing the various intermediate models. The minimum threshold for the production of a first edition of relief maps is around one thousand copies.

However, there is a need for on-demand relief mapping anywhere in the country. This need is also confirmed at a global level by the solution for providing print-ready digital terrain models offered by the TouchTerrain web service, which recorded 38 requests per day between July 2019 and January 2021, for 3D prints, according to Harding (2021). However, according to the illustrations proposed in the article, the 3D prints produced are only in monochrome and the user must either hand-colour their 3D print or accompany it with 2D colour mapping to visually combine the relief and paper mapping.

If the need for on-demand 3D printing exists, the solutions to meet this need are either still impossible for large formats, or, for small formats, of mediocre quality or far too costly to provide the expected response.

Since 2014, the IGN has been conducting a technical watch on existing solutions to consider a colour relief printing service for on-demand mapping, without going through an overly expensive thermoforming process. A first French technological innovation was presented at the ICC 2015 in Rio de Janeiro to obtain colour relief maps, albeit with a height limitation. Still using this colour relief printing technology, IGN proposes in this paper an innovative solution to get around this height limitation and provides the first experimental results.

2. Existing Solutions for Relief Mapping

2.1 Thermoforming

Developed in 1947 by the Army Cartographic Service in Washington (Stanley, 1947), thermoforming relief mapping involves the production of three intermediate models:

- A master model in plaster (originally in aluminium) of the relief obtained from the geographical data. This model can be reworked to smooth some parts. It cannot be used directly for thermoforming because it is made of a material that is not strong enough. These models are now produced by 3D printers from DTMs.
- A negative of this previous master model which will provide the relief in hollow.
- The final mould obtained from the previous negative by casting a resistant resin (epoxy) which reproduces the initial model. This mould will then be perforated at multiple points to make air suction wells which will then allow the printed maps to be plated onto the matrix thanks to the suction.

Proceedings of the International Cartographic Association, 5, 11, 2023.
31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent single-blind peer review based on submitted abstracts. https://doi.org/10.5194/ica-proc-5-11-2023 |

Once this mould has been produced, it is then possible to start production of the relief maps by thermoforming. For this purpose, the map is printed on vinyle support either in large numbers using offset printing or in a few copies using a digital press. After the ink has dried, the vinyle sheet is precisely aligned with the mould. The air is withdrawn from the vacuum chamber through the use of a vacuum pump. By creating the vacuum the sheet of vinyle containing the map image is pulled tightly against the mould. The heating unit is applied to the vinyle. As the heat increases, the vinyle becomes soft and is drawn down into the mould with considerable force. The embossed vinyle map is the allowed to cool in the mould with the vacuum pull maintained.

Due to the mechanical constraints, not every form of relief is possible with thermoforming. For example, large slope breaks are not possible as this would break the vinyle sheet. These technical constraints mean that the relief shapes must be smoothed out on the initial mould beforehand and certain shapes cannot be considered.

It should be noted that this process is associated with the 2D printing world and that we start from a 2D print that will be deformed into a representation that will be qualified as 2.5 D (2D surface deformed into 3D) rather than 3D.

2.2 Additive manufacturing from the world of industry

Additive manufacturing has grown rapidly in recent decades, with several technologies developed, some of which are now available to individuals, to meet a variety of needs. After the creation of a 3D digital model adapted to the chosen printing solution, there are different production technologies presented by Barlier (2020):

- Polymerisation of a resin under the action of a laser: a resin bath is solidified layer by layer under the effect of a catalysing agent (UV laser, red inactinic bulb, etc.).
- Spraying of drops of material (light-curing resin, molten wax, etc.)
- Projection of a binder onto a powder-like substrate. This family includes all processes that apply the basic process known as 3D printing. They allow printing with different colours.
- Solidification of powder under the action of a medium to high power energy source (laser or electron beam).
- Projection of powder (or wire fusion) in an energy flow (laser or plasma). Here, all the processes that produce 3D objects by depositing molten material are grouped together. They allow the fusion of many metallic materials such as stainless steels, titanium alloys, from several variants of the deposition nozzle, the main component.
- Melting of wire through a heated nozzle. This process, the most widespread for the general public, consists of depositing molten wire through a nozzle to print in successive transverse 3D layers. This technology allows the use of thermoplastic materials, wax, but also more original materials such as chocolate.
- The assembly of layers from cut sheets or plates. This category covers processes based on materials available in sheets. These sheets can be continuous, e.g. in the form of rolls, but also discontinuous, e.g. in the form of plates of different materials, from wood to steel (Stratoconception). These additive techniques involve cutting and joining or joining and cutting of these sheets.

Hybrid additive manufacturing consists of combining at least two of its processes. The objective of these combinations is to take advantage of the different performances of the processes as well as their complementarity.

2.3 Limitations of existing additive manufacturing for relief mapping

The various additive manufacturing solutions listed above are too limited to meet the needs of relief cartography: insufficient size (a minimum size of 1 m^2 is desirable to ensure the production of maps for the IGN catalogue), printing resolution too low in powder-based solutions to consider printing writing (400 dpi minimum), low colour diversity, insufficient robustness and quality for solutions using coloured sheet assembly, etc.

To date, there is no solution in the field of additive manufacturing to meet the needs of the production of relief maps, although there is a demand from the general public.

2.4 The first significant step towards printing relief maps

In 2015, at the ICC in Rio de Janeiro, IGN presented the first large size relief map obtained by 3D printing with the ACI award-winning map of Belle Ile. Proposed by the company Océ, a subsidiary of the Canon group, the relief or 2.5D printing was basedon an inkjet printing solution with the possibility of adding thickness to the ink in order to achieve the relief. This printing solution proposed by the Océ company was abandoned in 2016, but taken up again in 2020 by the startup Mihaly, created by the French designers of the technology then working for Océ.

This technical solution was detailed during the Time, Art & Cartography conference held on 16-18 March 2016 at the University of Strasbourg (France), when the large-format (105 cm by 135 cm) relief map of the Battle of Verdun was presented by Lecordix (2016). A graphic semiology adapted to the relief representation could then be experimented following a manufacturing process presented in Figure 1.

A digital surface model is calculated by combining, on the one hand, the relief provided by the DTM and, on the other hand, the possible heights of elevation that are set for different objects on the map (paths, houses, tourist points, ...) according to choices of relief legend. Combined with the coloured raster map of the same territory, the printer

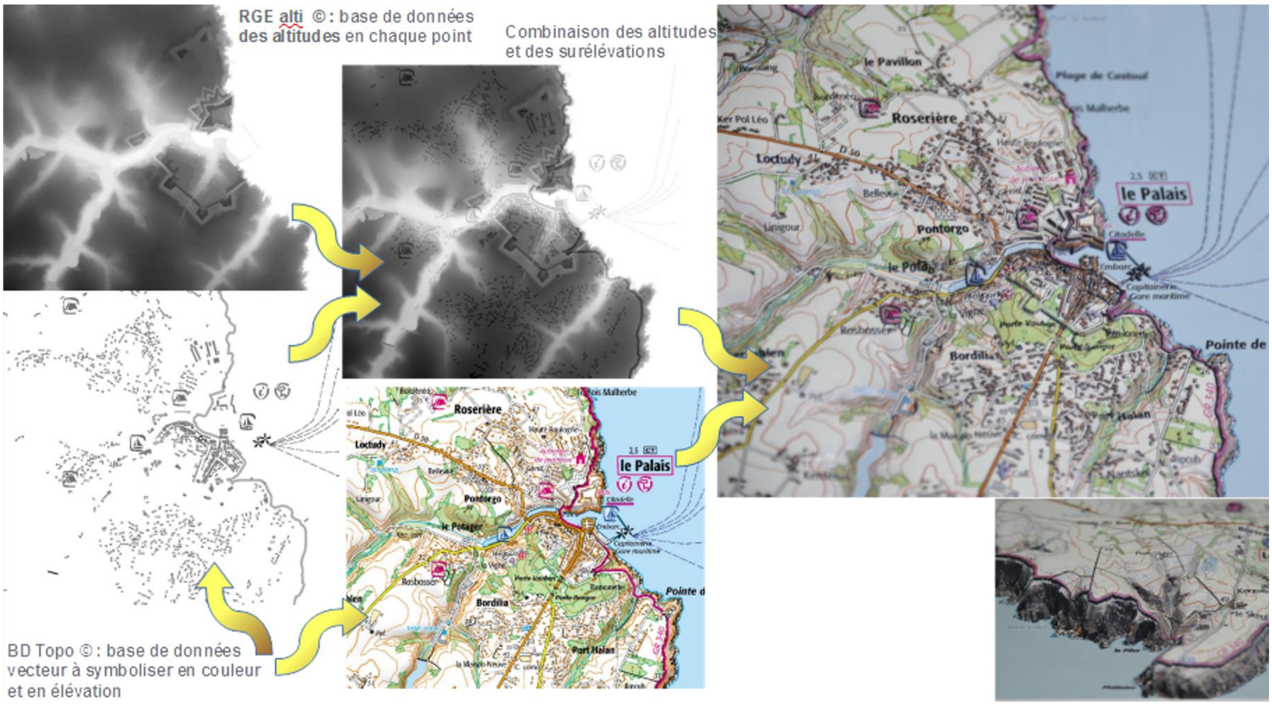


Figure 1. Process to prepare the two raster files for relief printing of Belle Île

will exploit both files and deposit, by scanning the whole surface, a grey ink which will pile up to create the relief of the place very precisely, and, at the end, the top of the relief with the CMYK inks of the plotter to obtain the relief map in colour.

The proposed technology solves several essential needs for relief mapping: high printing resolution (600 dpi), large dimensions, respect of colorimetric tones, ... On the other hand, it comes up against two problems: the still high printing costs for the general public (compared to the prices of thermoformed maps produced in multiple copies) and above all the still limited printing heights (less than 2 to 3 cm).

3. Cartographic stratoconception

3.1 Thermoforming

In 2022, the IGN proposed an innovative solution to overcome the problem of limited printing heights without increasing production costs.

This solution was inspired by the cardboard dog head exhibited by CIRTES company at trade fairs (Figure 2) and realised by the patented Pack&Strat® application. This application is dedicated to 3D digital rapid packaging and uses the patented Stratoconception® rapid micro-milling process for wood, carboard, foams ... Cardboard and foams are cut using a computer-guided cutter. This dog's head, which could remind one of the notion of contour lines, proves that it is possible to make shapes without height limitations, inspiring the innovation described below.

The process is based on a hybridisation of the previous inkjet relief printing technology existing in the world of digital plotters with the Stratoconception® technology existing in the world of 3D printing, which we will be detailed below.

Figure 2. Stratoconception® from CIRTES to make a 3D dog head with layers of cardboard.

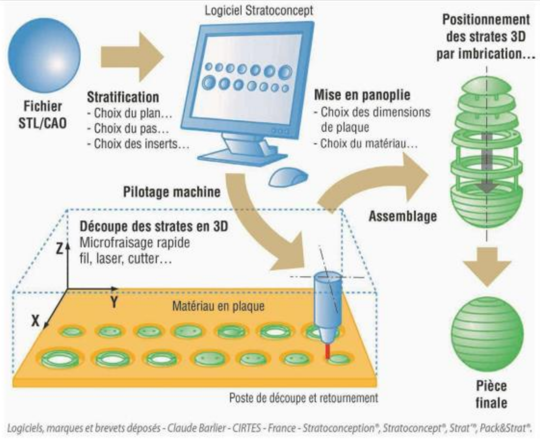
3.2 Stratoconception® developed by CIRTES

The description of the Stratoconception® technology is described by its designer Pr. Barlier (2020) (Figure 3):

> *The Stratoconception® process was initiated and patented by Claude Barlier in the mid-1980s and was commercialised in 1991. This is a solid layer additive manufacturing process which consists of breaking down the CAD model of the part by calculation into a set of elementary 3D layers, called "strata", into which reinforcements and inserts are introduced. The elementary layers are put in a panoply (front/back) and manufactured in a plate material by means of rapid*

micro-milling, laser, water jet or cutter cutting. These thick 3D layers represent a slice very close to the original CAD model - unlike other processes which reconstruct the part from single 2D layers - they are produced directly in three dimensions by 5-axis cutting, which makes it possible to obtain ruled surfaces, or better still by 2.5-axis rapid micro-milling. In the latter case, the profile is representative of the initial 3D CAD, in terms of size, geometry and surface finish.

The layers are then positioned with inserts, or interlocked or joined with bridges to form thin-walled parts to create the final object. The final assembly can be achieved by mechanical joining, structural bonding, brazing, diffusion welding or hot isostatic pressing (HIP) depending on the material and the intended end applications. In some cases, it is possible to finish the layers after assembly by stacking (integrated into the process). The means of positioning and the type of assembly are taken into account from the moment the object is broken down, and contribute to the mechanical strength of the parts.



Logiciels, marques et brevets déposés - Claude Barlier - CIRTES - France - Stratoconception®, Stratoconcept®, Strat™, Pack&Strat®.

Figure 5.39 Schéma de principe de Stratoconception® (Source : CIRTES)

Figure 3. Diagram of the Stratoconception® for 3D objects.

This solution provides a basis for creating a relief without height limitation with a strata support, to which the colour and final shape of the relief must be added.

3.3 Cartographic Stratoconception

As previously mentioned, the inkjet technology proposed by Mihaly consists of sending specific ink onto a layer of support. By accumulating progressively with each scan of the surface, this ink will rise progressively to obtain the desired relief and the final layer will be carried out by inkjet in CMYK on this relief. The proposed elevation is limited to a height of 2 to 3 cm. A schematic cross-section of the printing process is provided in Figure 4.

In the proposed innovation for relief printing, the elevation file is duplicated in two files, called even and odd layers, which will undergo similar but offset processing to bring the height of the raised print to between 0 and the thickness of the layer of the support on which the relief printing will be carried out, as shown in Figure 5. Thus, if the support used is 5 mm, the printing of any portion of the map will be between 0 and 5 mm, modulo 5 mm, to obtain the expected height of the relief map.

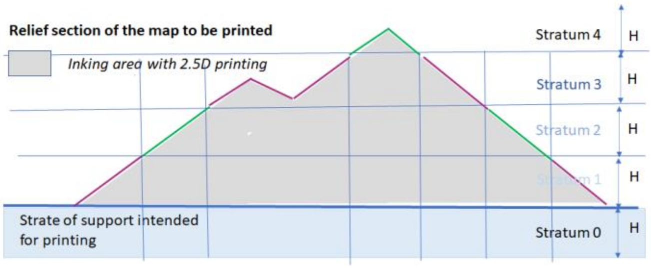


Figure 4. Schematic cross-section of the relief printing.

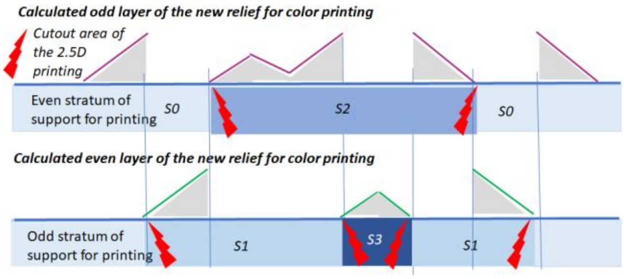


Figure 5. Schematic cross-section of the odd and even layers relief printing, with position of cutout area.

The process of cutting the even and odd numbered layers prepared as described above is applied flush with the lowest print heights (Figure 5) so that the part of the support layer N will serve as a support for the support of layer N+1 (Figure 6).

It should be noted that the height of the support layer should not be too high for 2.5D printing to be possible with Mihaly's printer (less than 2 to 3 cm) and not too low so as not to multiply the support layers with very thin layers.

The reconstitution of the total relief consists then in piling up alternatively the even and odd layers which were cut at the limits of zones indicated in the Figure 5, following a method identical to that of a puzzle.

It should also be noted that this puzzle aspect also provides a playful interest in the product obtained, as was shown by the first result produced.

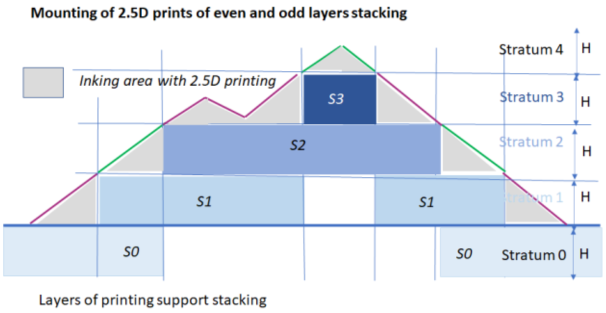


Figure 6. Schematic cross-section of odd and even layers stacking to create the relief map without height limitation.

3.4 Technical choices of realization

In order to apply the principles described above, a first experiment was carried out. It was necessary to make technical choices on various points which is mentioned here.

3.4.1 *The support*

The support must meet different technical requirements due to the manufacturing and operating process. For the global manufacturing process, the support must be compatible with Mihaly's 2.5D inkjet printing process and with the selected cutting process of the even and odd printing layers. In addition, the support has to meet the stability requirements for the assembly to take place and to withstand the test of time. For the first test, the KAPA® Fix foan panel in 5 mm was chosen.

3.4.2 *The order of operations*

Once the support has been chosen, a new technical difficulty arises with the order of operations to be carried out between printing and cutting. If it seems logical to carry out first the printing and then the cutting, this solution will run up against risks of degradation of the printing by the cutting solution or even impossibility of cutting related to the presence of the relief on the support which will prevent the passage of the cutting head or the deposit of the plate in reverse.

To simplify the first experimentation, the choice was made to carry out first a partial cutting, then the printing on the even and odd pre-cut layers. It should be noted that the geometrical setting was done visually for the printing which led to some position defects.

The reverse order of operations (printing with registration marks and then cutting) is currently being tested.

3.4.3 *Printing*

For the printing, the only solution allowing to print with heights exceeding 1 mm is the one proposed by the company Mihaly. This solution makes it possible to carry out the printing of the even and odd layers prepared upstream according to the specifications given in 2.4 (to prepare the complete relief and the colour map) and in 3.3 (to prepare the lowered relief of the even and odd layers).

3.4.4 *Cutting*

Many digital cutting solutions exist, adapted to the thickness and type of material of the cut plate: cutter, saw, laser, hot wire, water jet, ... However, the presence of the ink in relief on the support to be cut makes the operation more delicate. The choice having been made for the first experimentation to cut before printing, a solution of pre-cutting by cutter was retained (Figure7).

It should also be noted that according to the chosen solution of cutting, technical constraints of curvature on the curve delimiting the zones to be cut out can appear.

4. First result

Following the technical choices described above, the cartographic stratoconception was implemented on a map extract of the Reunion Island. Figures 7 to 13 show the different steps to obtain the relief map without height limitation, after assembling the different cut and printed pieces in the manner of a puzzle, which fit perfectly together.

As mentioned previously, the manual setting of the printing on the pre-cut support introduced a slight shift of the printing compared to the cutting which increases locally the visualization of the connection zones.

Figure 7. Pre-cutting by cutter of the even layer.

Figure 8. Printing in relief of the even layer.

Figure 9. Printing in relief of the odd layer.

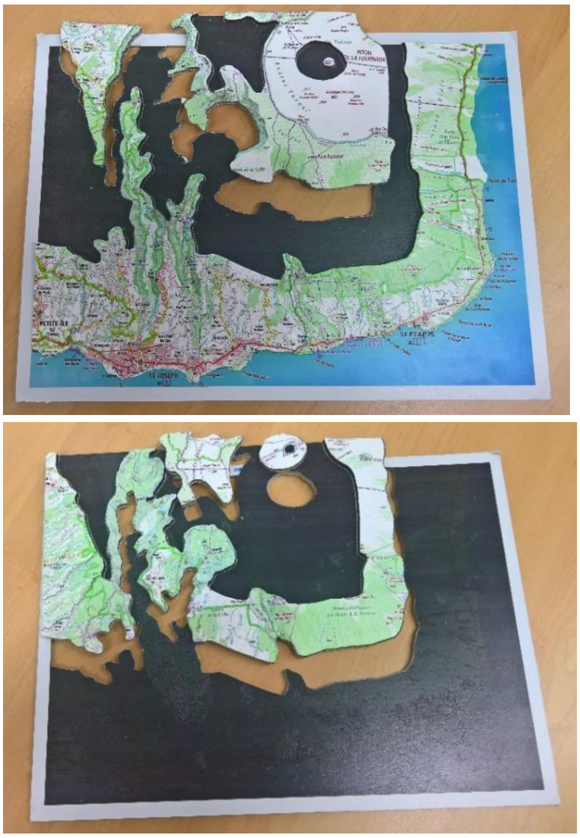


Figure 10. Separation of odd and even layers.

Figure 11. Mounting of odd and even layers stacking to create the relief map without height limitation.

Figure 12. Relief map after the mounting, with the layers of support stacking up.

5. Conclusion

An innovative solution for relief printing without height limitation has been designed and tested by IGN, hybridizing two French technologies: stratoconception implemented by the company CIRTES and colour relief printing by the company Mihaly. Convincing results have already been obtained, which allow us to consider setting up an on-demand relief printing solution, after a few more tests. This solution could make it possible to answer an existing significant demand of the general public.

6. References

Barlier, C. and Bernard, A., 2020. Fabrication additive – Du prototypage rapide à l’Impression 3D, 2ème édition, Ed. Dunod

Harding C., Hasiuk F., Wood A., 2021. TouchTerrain—3D Printable Terrain Models. In: *ISPRS International*

*Journal of Geo-Informatio*n, vol. 10 (3) :108. https://doi.org/ 10.3390/ijgi10030108

Lecordix, F. 2016. Nouvelle dimension pour la sémiologie graphique. In: *Cartes & Géomatique*, Saint-Mandé, France, vol. 229-230, pp. 105-115.

Reed, H. P., 1946. The development of terrain model in the war. In: *Geographical review*, New York, vol. 36, No.4, pp.632-652

Stanley, A. A., 1947. Plastic Relief Models. In: *The Military Engineer*, Society of American Military Engineers vol. 39, n°261, pp 287–290. http://www.jstor.org/stable/44567205

Sutter, F., Räber, S., Jenny, B., 2006-2017, Institute of Cartography and Geoinformation, ETH Zurich, http://www.terrainmodels.com/contact.html