

This invention is a process by which 3-dimensional objects can be produced from digital 3D models using a typical office laser printer (that is, one designed for printing text and graphics onto conventional 2D paper) rather than the elaborate and expensive 3D printing machines that are the current state of the art.

Nearly all laser printers print with “toner”, a colored substance of varying composition that is applied to paper with pressure and heat - this property of toner can also be exploited after the fact in order to bond the printed areas of the paper to other sheets. By selectively bonding paper together in a controlled pattern and then removing the excess paper, one can achieve a 3-dimensional object.

In general, the process consists of:

- a. Use software to calculate 2-dimensional cross sections of a digital 3D model, representing each cross section as an arbitrary shape of some color or pattern against a plain background.
- b. Print each cross section onto a piece of typical “office paper” (or other substrate) with a typical home/office laser document printer, such that laser printer toner (or other substance) is deposited on each page in the shape of a cross section of the object
- c. Stack the printed pages into a clamp that may include features designed to hold the pages in proper alignment while pressure is applied to the top and bottom of the entire stack

Illustration 2.

- d. Heat the entire clamped stack at a temperature sufficient to melt the toner (or other substance) applied by the printer, causing the sheets to bond to one another in the areas where the cross sections were printed
- e. Continued heating until the paper (or other substrate) undergoes a change in properties that assists the removal of the ambient material later; for example, heating conventional paper until it becomes brittle
- f. Removal of the ambient (unbonded) areas of the paper in order to reveal the 3D object formed by the bonded stack of printed cross sections

Specific aspects of each item are as follows:

A) Software

1. The software is capable of receiving a digital model describing a 3D geometry and

calculating the 2D cross section of the geometry in some arbitrary cutting plane

2. The software can display the 2D cross section as an image and either save it to a file or print it directly to the laser printer/printing hardware
3. The software can automatically produce a number of these cross sections by translating the cut plane in a proscribed direction with a proscribed spacing, generally corresponding to the thickness of the paper
4. The cross sections are calculated as boundary (i.e. the intersection of the 3D object's exterior and the cut plane) and the software offers a number of options for the representation of the boundary and interior. For example:
 - a. Solid fill - the boundary defines the perimeter of a region of solid black or solid color; this achieves the maximum application of toner (or other substance) in order to achieve maximum bonding of each sheet.

Illustration 3. Fig 1.

- b. Reduced fill - by printing a shade of gray, a lighter shade of some color, a pattern that is not completely filled, or some combination thereof the consumption of toner can be reduced at the expense of the strength of the inter-layer adhesion. When using a pattern-type fill the software can control the positioning and rotation of the pattern from one layer to the next in order to ensure that the pattern overlaps sufficiently.

Illustration 3. Fig 2,3.

- c. Solid boundary + reduce fill - the effect of the lost strength when conserving toner in the shape's interior can be minimized by retaining a solid boundary around the perimeter of the object.

Illustration 3. Fig 4.

- d. Colors - the software may be able to colorize sections of the perimeter or the filled interior in order to attain some coloration on the finished model; this requires printing with a color laser printer, of course.

Illustration 3. Fig 5.

5. The software may also be able to add features to the model (or the cross sections) such as to make removal of the ambient material easier. For example, when using plain paper embrittled by heat, the principal challenge in "freeing" the object from the stack of

paper is that the paper often tears some distance away from the edge of the object; this creates a model with poorly defined edges due to the small and difficult-to-remove extraneous pieces of paper around its perimeter. The paper can be encouraged to break away in the proper location by adding toner to form a “tab” a slight distance from the perimeter of the object; bending up on the tab will crack the paper in the gap between the tab and the object.

Illustration 4.

- a. Such tabs should bond only a small number of consecutive pages together - enough such that the tabs are tear resistant and encourage the paper to break in the gap between the model and the tab, but not so many as to make the paper difficult to break. Thus the tabs should only be included, for example, on every other cross section (in order to create tabs 2 pages thick). To create tabs three pages thick one out of every three cross sections would be printed without tabs:

Illustration 4. Fig 1.

- b. When printing tabs more than 2-sheets-thick, the curvature of the object may cause the tab’s layers to overlap improperly, in some cases even bonding the tab to the model itself (see circled areas below). The software can control the placement of the tabs so that the minimum spacing of all layers of the tab is maintained, even between multiple layers/cross sections.

Illustration 5. Fig 2, 3.

- c. In the simplest embodiment the tab may be a simple perimeter around the object. This has the advantage of able to be torn away in a single “pull”, however it places high loads on the object that may cause delamination:

Illustration 4. Fig 2.

- d. Adding one or more “breaks” in the perimeter allows the tab to break into pieces as it is lifted. This reduces the force applied to the model and lowers the chance of delamination:

Illustration 4. Fig 1.

- e. The “breaks” may also be shaped in order to facilitate easy separation from each other:

Illustration 4. Fig 3.

6. The software can arrange one or more 3D models into one stack of paper. The software will collect information from the user on the size of the paper, the margins, the desired scaling of each model, the desired position of each model, and the properties of the desired tabs (if any) for each model in the paper stack.

Illustration 6.

7. As the finished cross sections are computed, the software may print them directly or save them in a format which allows the computed sections to be printed elsewhere without any special software (e.g. a commercial printer or office). Output options:
 - a. Output each section directly to a printing device
 - b. Save each cross section as an image file
 - c. Combine all cross sections into a paged file such as a document (Word, PDF, etc) or paged image (TIFF, etc)

B) Clamp

1. At its most basic the clamp is two plates, large enough to cover the surface of the paper stack (which is 8.5" x 11", typically). The plates must be rigid enough to apply even pressure on the stack and tolerant of high temperatures; $\frac{3}{8}$ " thick aluminum suffices. Higher pressure leads to better overall adhesion; more than 50 pounds per square inch being ideal.

Illustration 7.

2. The usability of the clamp is greatly improved if one side of the clamp is equipped with pins or other features that can support and align the sheets paper. The other side of the clamp is equipped with holes for the pins to pass through while pressure is applied. At least three pins are required to align the paper in both dimensions.

Illustration 8. Fig 1.

3. Careful positioning of the pins (and or additional pins) can support multiple paper sizes. Shown below is one such arrangement to support both 5"x7" and 8.5"x11" paper:

Illustration 8. Fig 2.

4. Pressure is applied with some system of clamps or screws around the perimeter of the plates. Simple C clamps are effective, however nuts on threaded studs permanently pressed into the lower plate are easier to use.

Illustration 9. Fig 1, 2.

5. When using plain paper and embrittlement with heat, the stack will settle slightly during heating. This makes it necessary to include springs under the clamping devices so that adequate pressure will be maintained. Examples are coil or disc springs.

C) Paper

1. Plain paper is cheap and readily available, making it an attractive choice for use with this invention. Embrittlement occurs after 2.5 to 3 hours at 425F - more time may be required for large stacks which heat slowly. Removal of the ambient paper is a manual process; the user attempts to crack the paper away from the object at its periphery. This can be time consuming and messy, but it is effective. Final "clean up" of the object is accomplished with a brush, wire brush, abrasive pad, sand/media blaster, air stream, etc. Low density papers are preferable as they are easier to remove from the object; the paper choice is usually limited by that which the printer is capable of feeding. 16lb paper is acceptable in both regards.
2. An alternative paper might be water soluble paper. When using soluble paper the object would be bonded with heat at a lower temperature - 150F - for only as long as required to heat the stack to a uniform temperature. Prolonged heating, or higher temperatures, damages the solubility properties of the paper and should be avoided. The stack would then be placed in a bath of water so that the ambient papers would dissolve, leaving the object. An acceptable paper would exhibit extremely low edge wicking, such that the paper did not dissolve from inbetween the layers of toner. Additives like xantham gum might be used to lower the incidence of edge wicking by thickening the water bath.
3. Still another alternative might thin sheets of a composite material comprised of an insoluble component with a soluble binder, or a component with a high melting point with low-melting-point binder. For example, thin sheets of milled glass fiber with a dextrin binder may be fed through a printer where the toner will bind the milled fibers. Then, as with soluble paper, the stack is heated to bond the sheets together, followed by a water bath to dissolve the dextrin, causing the ambient fibers to be released and reveal the object. Another example would be a sheet of milled glass fibers in a wax binder - in this case high heat would be used to melt away the binder and the ambient material while simultaneously charring the toner into a heat resistant state.