DIY PLANETARIUM

A COMPLETE DOME CONSTRUCTION GUIDE

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For more detailed terms and explanations, see the Glossary in the back of this text. The Glossary defines terms and lists the pages they appear on.

Introduction

This manual is a completely new manual designed from scratch. I am qualified to write this manual as I have been building planetariums for over four years, almost have a degree in Computer Science at CSU and have studied math through Calculus II and Combinatorial Theory. This manual requires that the user knows basic trigonometry and how to manipulate trigonometric functions on a calculator. Construction methods are simple and require only that the user is very accurate when measuring dimensions and cutting out pieces.

A planetarium is a hemispherical dome constructed in a variety of geometries used to view content on a spherical surface as opposed to a flat screen. This surface adds an additional level of immersion making fulldome planetarium theaters ideal for entertainment, education and simulation. This technical manual will detail the full construction of a planetarium and its components from designing a pattern to installing digital hardware for a true fulldome projection. Great technologies tend to be *very* expensive as well. A professionally made planetarium, for example, will cost around twenty-five thousand U.S. dollars. This manual will detail all the necessary steps to produce a dome of professional quality for a budge less than twenty-five *hundred* dollars, or ten percent of that of the same manufactured product.

Materials

To construct a planetarium dome, two fields of materials will be needed. The first section is dome materials, the second, dome technology. Domes can be built out of many materials such as plastic, aluminum, cardboard and even fabric. This manual documents plastic dome construction, however, a skilled craftsman could build a dome out of any pliable material using the dimensions in this manual. Materials needed are as follows:

Dome Materials

Scissors	Masking Tape	Marker (Sharpie)	Tape Measure	Plastic Rolls	Calculator	Pencil	Paper	Box Fan

Additional notes: Masking tape 1.5” wide works the best for taping together gore sections. Any type of plastic may be used that has a width less than two meters and can be unrolled. Dual sided plastic that is black on one side, white on the other, is the optimal choice of plastic as it has decent contrast for projection inside but primarily, great protection from light on the outside. This is beneficial for showing films in rooms that can't be made completely dark such as a gym as the intimate theater atmosphere is ruined with any light. White plastic will also work if double sided plastic is too expensive or unavailable. The length of plastic required for a dome of any size can be calculated using the length calculation in the *Math* section of this manual.

Dome Technology

- Safety Mirror (18")
- Computer (1080p Capable)
- Loud 2.1+ Stero
- 1080p Projector
- Power Cables
- Blender Software (Free)
- Black Blankets (Optional for Floor)

The best mirror to use in a planetarium is a primary surface mirror. These mirrors are optimal because they don't have any protection on the reflection surface and thus produce the best image, however, can easily exceed several thousand dollars in price. A cheaper safety mirror can be purchased (half-hemisphere) for approximately thirty-eight dollars.

Any 1080p projector will work in a dome, especially when a budget won't permit a higher end one. A current manufacturing trend shows that more expensive projectors have both higher contrast ratios and lumen counts, ideal for the best picture quality.

Anytime a dome is inflated, it is secured to the ground. As floors can be dirty and uncomfortable, black blankets provide a clean and relaxing way to view a show without decreasing the contrast ratio. Conversely, white blankets are a poor choice for floor coverage as they both show dirt easily and reflect projected light in the dome onto the rotunda.

Math

The math portion of this manual is the heart and soul of the dome construction process. The following information is needed to calculate the planetarium blueprints:

- Dome Diameter
- Width of Plastic
- Lateral Divisions[1]

The following equations will *generate* the planetarium blueprints based on the input parameters: dome diameter, width of plastic and the number of lateral divisions. It is important to note that numbers must be in the form of the

1. The number of lateral divisions should be by default, at least 20. Increasing this number will increase the accuracy of the dome's shape.

same unit. Numbers generate by formulas will be of this same unit. For example, if the chosen diameter is five meters, the width of the plastic needs to be listed in meters too.

Formula 1| Number of Gore Sections Needed:

$$number\ of\ sections = ceil\left(\frac{\pi \cdot diameter}{width\ of\ plastic}\right)$$

Note: ceil(x) means to round x up to the nearest whole integer.

Formula 2| Total Length of Plastic Needed

$$length = \frac{\pi \cdot (diameter) \cdot (number\ of\ sections)}{4}$$

For example, with a **5 meter** dome, and **1 meter** wide plastic, **16 gore** sections are needed. A total of **62.83 meters** of plastic, **1 meter** wide, would be required to build a **5m dome**.

Note*: the length as calculated in this function is also the total length of plastic needed to build a dome of the specified diameter.*

Formula 3| Calculating the Gore Sections

This formula is the most difficult. It will produce a *triangular* shaped section called a **gore**. The value *number of sections* determines how many gores are needed to build the dome. Gores have a base width (slightly less than the material width) and come to a point at the opposite end. In between, widths are calculated at even intervals called *lateral divisions* (lines of tape in the photos). The more divisions, the more accurate the gore will be. For most domes, 30 lateral divisions are sufficient. The following calculations and steps will produce a gore pattern:

Formula 4| Calculating the Gore Sections

$$angle(lateral\ division_n) = 90 \cdot \left(\frac{lateral\ division_n}{lateral\ divisions}\right)$$

For example, consider a dome with 30 lateral divisions. The first angle would be:

$$angle(lateral\ division_0) = 90 \cdot \left(\frac{lateral\ division_n}{lateral\ divisions}\right) = 90 \cdot \left(\frac{0}{30}\right) = 0°$$

The next lateral division angle would be

$$angle(lateral\ division_1) = 90 \cdot \left(\frac{lateral\ division_1}{lateral\ divisions}\right) = 90 \cdot \left(\frac{1}{30}\right) = 2.99°$$

This process repeats until you reach the final lateral division, 30

$$angle(lateral\ division_{30}) = 90 \cdot \left(\frac{lateral\ division_{30}}{lateral\ divisions}\right) = 90 \cdot \left(\frac{30}{30}\right) = 90°$$

Formula 5| Calculating the Gore Widths

The chart below will hold all calculations. Before proceeding, fill in the first column with angles calculated from Formula 4. ***Make sure to calculate all values in DEGREES, not radians.***

Table A

Formula 4 - Angles	Formula 5 – Widths	Formula 6 – Distance From Base
$angle(laterial\ division_0) = a_0$	$width\ at\ height(a_0) = w_0$	$dist\ from\ base(laterial\ division_0) = h_0$
$angle(laterial\ division_1) = a_1$	$width\ at\ height(a_1) = w_1$	$dist\ from\ base(laterial\ division_1) = h_1$
…	…	…
$angle(laterial\ division_n) = a_n$	$width\ at\ height(a_n) = w_n$	$dist\ from\ base(laterial\ division_n) = h_n$

Using the angles calculated in the first column, **Formula 4 – Angles**, calculate the values for the next column, **Formula 5 – Widths**, using the formula below. For each width calculated, plug in the *angle* value from the same row.

$$width\ at\ height(angle) = \frac{cos(angle) \cdot diameter \cdot \pi}{number\ of\ sections}$$

***Tip**: The first width calculated should be slightly less than the width of the material. The next width a little less than the first (for the first several widths, this value may not change). The closer you get to the final angle, 90º, the smaller the widths should become, until the final width is calculated at 90º, which will always be 0.*

Formula 6| Calculating the Width Distance From Base

$$distance\ from\ base(lateral\ division_n) = \frac{length \cdot lateral\ division_n}{lateral\ divisions}$$

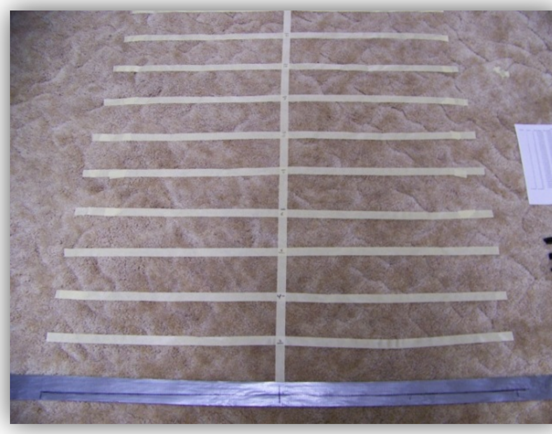
Consider the dome example earlier, 5 meters wide, 1 meter plastic, with 30 lateral divisions. The first calculation would look like the following:

$$distance\ from\ base(lateral\ division_0) = \frac{length \cdot lateral\ division_0}{lateral\ divisions} = \frac{3.927 \cdot 0}{30} = 0$$

This means the first width is 0 meters from the base – because it is the base of the gore. The next width would be placed .131 meters up from the base, and so on to the tip of the gore.

Fill out these calculations in the 3rd column, **Formula 6 – Distance From Base**.

Using tape as a marker on the ground, make a straight line a meter longer than the width of your plastic. Lay down a second piece of tape perpendicular to the first one meter longer than the gore length, positioned in the center of the first strip. Using a tape measure, mark along the second piece (strip b) the values from **Formula 6 – Dist From Base** as they occur in *Table A*. At each distance from base marker, lay a piece of tape corresponding that row's width (centered) – **Formula 5 – Width Values**. The created pattern should now look like the picture on the right.



Once this pattern has been created, the dome will come together quickly. Place some tape along the contour of the outer tape fingers to give the gore section a clear edge. A different color can be helpful as an edge.

Roll the plastic over the pattern on the ground and trim the excess using scissors slightly open. This technique slices easily through the plastic. Books work well to hold the plastic in place. Cut as many gores as calculated in the number of sections formula.

The next step is trickiest: taping the sections together. An optional method to cutting each gore to the tip is to stop one section before the width reaches zero and make a circle to fill the top with a radius equal to the width closest to zero times the number of sections. Holding two sections together on a table, tape them in small pieces to ensure the curvature is taped along evenly. It helps to have a partner for this step.

Seen in the photos below, the gore sections do not all come to a single point at the pole. Instead, the gores are truncated one division early, and a circle is used at the pole.

Taping the top circle.

Inflating the dome, notice bottom of dome is taped down.

Tape in the filler circle last if the whole-top method was chosen.

Using remaining plastic, create a tube around the box fan at least ten feet long. Cut a hole in one gore section and mount the fan chute through this hole using tape. This hole will allow the dome to be inflated. Tape the dome to the floor and turn on the fan; the dome will inflate. Lift a flap of tape to crawl under the planetarium to enter it. To “close the door,” an operator outside the dome must reattach the tape to the floor.

In the photo below, the fan inflation unit is located on the left. Its length reduces noise inside.

Dome Technology

Compared to a conventional movie screen, planetariums vary in one fundamental way: their content is projected onto a hemisphere instead of a flat screen, often utilizing 5 or 6 projectors in a fulldome theater. This requires a special projection method called a fisheye render. Planetarium projectors utilizing fisheye projection are *very* expensive yet produce good results. An example of a fisheye projection is presented at right.

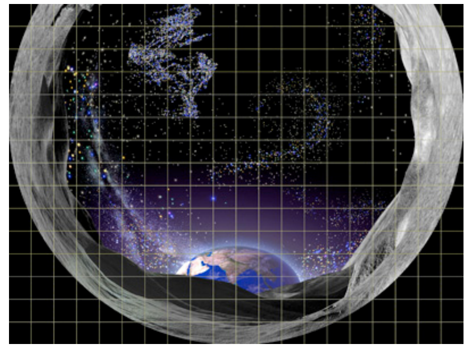
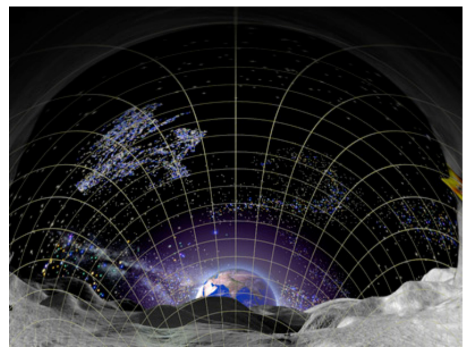


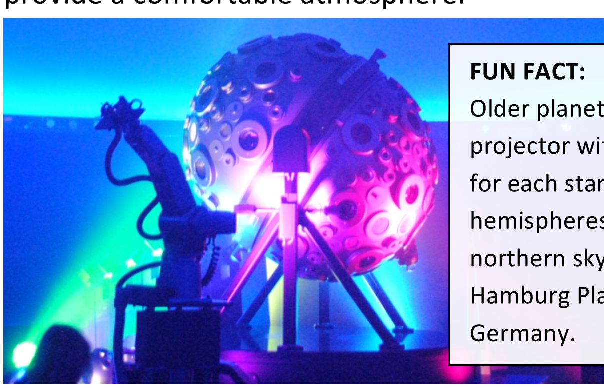
Image Credit: Paul Bourke (both images)

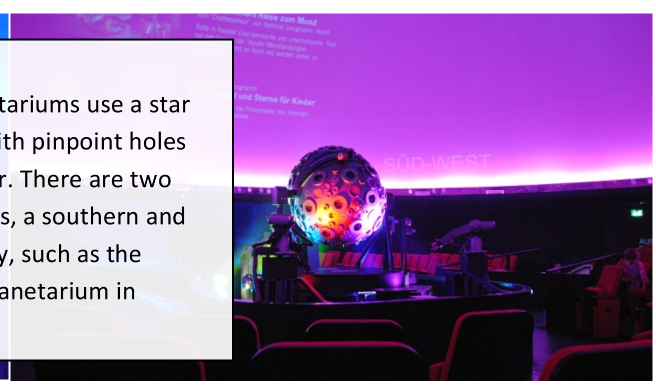


A cheaper alternative to this projection technology is a truncated fisheye projection used to project onto a hemisphere using a mirror dome. The resulting image can be projected with decent 1080p resolution using a single cheap projector. An example of a distorted fisheye can be seen below the original. By changing merely the *projection method*, the cost is reduced by over fourteen thousand dollars or a 15x reduction.

A single table can house all of the planetarium electronics. Point a table (3'x6') towards middle of the room. Against the dome, position the mirror with the curvature touching that of the domes. Shine the projector at the mirror and connect the laptop input. Load a file such as the truncated image on the bottom of page seven to keystone the projector and mirror.

Audio speakers should be positioned on the "opposite" side of the mirror facing the table. Blankets can be laid around the floor to help protect cables underneath, keep viewers clean and provide a comfortable atmosphere.





FUN FACT:
Older planetariums use a star projector with pinpoint holes for each star. There are two hemispheres, a southern and northern sky, such as the Hamburg Planetarium in Germany.

Examples of a standard setup can be seen pictured below:

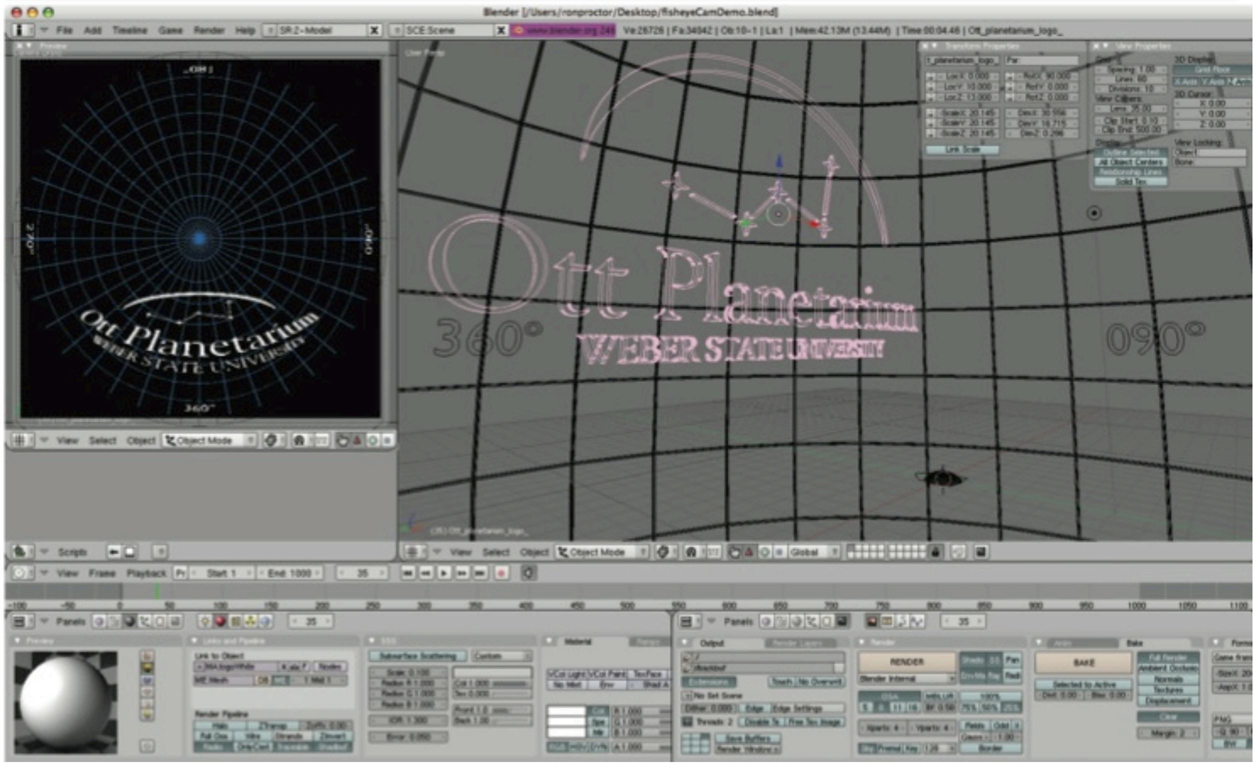
The above image shows a typical mirror, projector, computer setup. The right image shows viewers inside.

Many shows are *extremely expensive,* with some annual licenses costing well over twenty thousand dollars. An alternative to purchasing shows is to create content manually using a program called Blender. For planetariums with a budget, below is a list of industry leaders in affordable pricing and quality programming:

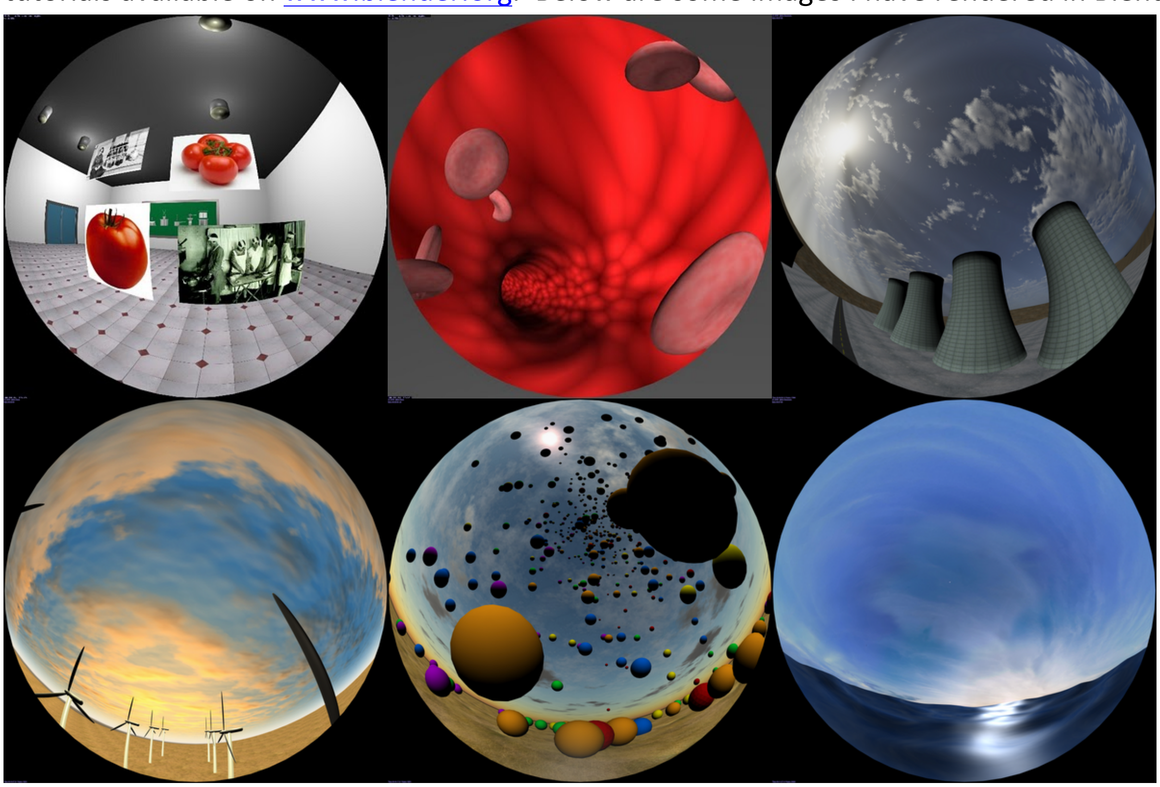
- Weber State Planetarium
- Loch Ness Productions
- Denver Museum of Nature & Science

Rendering Technologies

As mentioned earlier, the projection method for a planetarium is the use of a fisheye image. Render clients such as Maya and Studio 3DS Max have fisheye 'cameras' but these programs cost thousands of dollars, many with an annual license fee. Blender is a free open source alternative that provides fisheye rendering thanks to a rig developed by Ron Proctor at Weber State University. This camera rig is available upon request from the Weber State University Ott Planetarium. **2013 Update:** Blender now natively supports fisheye rendering via Cycles.



Blender is an extremely powerful yet complex tool to learn. Its functionality cannot be shown documented in this manual, but the Blender Foundation sponsors hours of free lectures and tutorials available on www.blender.org. Below are some images I have rendered in Blender.



Glossary

1080p — Dome Technology
- Standard HD resolution. (1920 pixels x 1080 pixels).

Ceil — Math
- A function that rounds a number up to its nearest integer value.

Contrast Ratio — Dome Technology
- A property of a display system, defined as the ratio of the luminance of the brightest color (white) to that of teh darkest color (black) that the system is capable of producing.

Gore — Math
- A bulging triangular shape that comprises a "side" of the planetarium

Half-Hemisphere — Math
- A hemisphere in halves, think of a quarter of an orange or an apple.

Hemisphere — Math
- Half of a sphere.

Lumens — Dome Technology
- The brightness of a projector.

Keystone — Dome Technology
- A process in which an image is tilted or distorted to achive a perfect orientation.

Primary Surface Mirror — Math
- A type of mirror that has no coating on its reflective surface, making it great for optical precision, bad for durability.

Rotunda — Math
- The dome of a fixture.

Works Cited

All images in this manual are photographed by me, Adam Goss. All digital images and renderings have been rendered by me in Blender. The exceptions are the fisheye/mirrordome maps on page eight, created by Paul Bourke of Swinburne University in Australia. These images were taken from his website, www.paulbourke.net. All other content including the math is my own original work. Credit to Justin Overton for pointing out mathematical errors.