Method For Construction Of Monolithic Structures Using Inflatable Air Form and Outside Membrane

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1 Field of Invention

This invention relates to methods for quickly erecting cost effective, easily replicable structures. Particularly, this invention relates to the erecting of monolithic structures via the use of an inflatable air form and an outer membrane. Specifically, this invention relates to a novel technique which utilizes an inflatable air form and outer membrane to create an air space into which various moldable mixtures (such as foam cement, or certain plastics) may be poured. Once the mixture has cured and become rigid, the air form may then be deflated and both the air form and the membrane removed, leaving a monolithic structure which can then be used for various purposes.

2 Prior Art

Structures built with conventional building techniques require a great deal of time, expertise, and capital expenditure to successfully erect. Furthermore, predominant methods of construction (such as timber, post-and-beam, steel, and others) are difficult and expensive to insulate effectively due to the presence of various gaps and thermal bridges inherent to their design.

What is needed is a construction process to produce structures that avoid the drawbacks discussed above. An ideal technique would produce well insulated, long-lasting structures that can be built quickly and cheaply, with low required expertise.

Despite evidence of clear, long standing work in the field (discussed below), such a construction technique has proven elusive.

2.1 Monolithic Domes: Construction Techniques and Physical Properties

Monolithic structures (such as the one presented in US5918438A) present a potential solution to the insulation problem. Due to the fact that monolithic structures are completely constructed from one piece, they eliminate the air gaps and thermal bridging associated with other construction techniques.

Briefly, a monolithic dome (as in US5918438A) is constructed by creating an inflatable air form which is to comprise the outer surface of the building to be constructed. Once inflated, workers enter into the inflated structure and spray insulation (usually polyurethane) onto the interior surface of the air form. After insulation has been applied, the workers then reinforce the inner structure with rebar and apply a layer of spray-on concrete. Once the concrete has cured, the resultant structure is largely complete and exhibits excellent longevity and thermal retention characteristics.

Monolithic domes constructed using this or similar techniques (as in USRE28689E, US4680901A [utilizes pre-cast members], US20170321438A1) effectively meet the challenge of providing long-lifetime, thermally regulated structures, but do not effectively meet all of the other challenges listed above — most importantly, they require capital expenditures roughly equal to those required when constructing a traditional building. The Monolithic Dome Institute (MDI), a leader in the field of monolithic dome construction domiciled in Italy, Texas, estimates the cost of using their construction methods (US5918438A) at "about $130 per square foot of floor area", or, roughly comparable per-square-foot to traditional construction techniques (http://www.monolithic.org/homes/home/how-much-does-a-monolithic-dome-home-cost).

MDI has also developed an alternate building technique which seeks to address the relatively high cost of constructing one of their monolithic domes. The technique to construct an "Eco-Shell" (http://www.monolithic.org/ecoshells) is similar to that of the monolithic dome in that it uses an air form, but, unlike the monolithic dome, the air form is reusable. In erecting an Eco-Shell, the first step is to pour a foundation. The air form is then affixed to the foundation and inflated. Once inflated, workers affix rebar *outside* of the air form and then proceed to apply a layer of shotcrete. Once the shotcrete is cured, the air form is then deflated and removed, leaving behind a free standing structure. The air form may then be re-used.

MDI's Eco-Shells effectively meet the challenge of providing a structure that meets several of the challenges discussed above. Importantly, an Eco-Shell is extremely cost effective to produce because one air form may be re-used. This is particularly effective for large projects, as the cost of the air form itself can be defrayed by the construction of many buildings. In fact, MDI, through their non-profit, Domes For The World, has successfully constructed large villages of Eco-Shells in various equatorial locations (https://dftw.org). MDI claims they are able to construct an Eco-Shell for as little as $1,500.00 in material costs (http://www.monolithic.org/in-the-media/the-next-big-future-ecoshells). The Eco-Shell can be erected quite quickly with minimal expertise, and it is exceptionally disaster resistant (http://www.monolithic.org/ecoshells/ecoshell-articles/more-about-monolithic-s-ecoshell-1). However, Eco-Shells, constructed with only a thin layer of structural concrete, do not effectively meet the challenge of having a high insulation value. Eco-Shells are therefore an extremely effective solution for low cost housing, but only in tropical or sub-tropical climates.

2.2 Techniques Using High Porosity Concrete

While this invention is agnostic as to the moldable medium used in the construction of any particular structure calling for the use of the process — one possible moldable mixture that can potentially be utilized in the process is that of high porosity (foamed) cement.

Foamed cement has a number of advantageous properties including compressive strength and density (55 PSI at a density of 19 pounds per ft^3) sufficient to be viable as a structural, load bearing building material in low rise construction. Further, foamed concrete has a significantly higher R value (up to approx. 2.5 per inch) than that of structural concrete (http://www.litebuilt.com/English-T3.html). These properties make it a potentially near ideal candidate as a moldable mixture. Foamed concrete has successfully been employed by DomeGaia (http://www.domegaia.com) as the primary load bearing construction material in completed buildings.

The technique utilized by DomeGaia differs from those discussed above in that the structure is not monolithic. In this process, foamed concrete is made by mixing cement with foamed soap, which is then poured into moulds. Once cured, the concrete blocks are removed from the forms and individually shaped with hand tools before being stacked into a domical structure. For the purposes of description, this process of stacking blocks is readily comparable to that of building an igloo. Once the blocks are in place, the structure is sealed with a layer of plaster.

The DomeGaia technique produces a structure that meets some of the challenges discussed above. Namely, higher insulation value, and (perhaps) longevity. However, this structure does not meet the constraints of being quickly erectable and it is not easily erected without the labor of skilled masons. The protracted length of construction along with the requirement for skilled labor inflates the costs associated with construction. While this technique is likely still more cost effective per ft^2 than traditional building, it is not optimal. Further, the fact that DomeGaia domes are not monolithic leaves the potential for some thermal bridging between the blocks which comprise the final structure.

3 Summary of Invention

The method and system proposed in this patent application revolve around the novel concept of utilizing an inflatable air form together with an outer membrane to produce a "negative" airspace between them. That space can then be filled with a moldable material which, upon curing, leaves a rigid, self supporting, monolithic structure. While work has been done using air forms in the past, using them to create a large "air mould" in this fashion has not been attempted and represents an innovation that can facilitate a structure meeting the criteria discussed above.

> **Note:** For the purposes of expediency, the detailed description of the invention will, (a) assume (and reference) the use of foamed concrete (discussed above in 2.2) as the moldable mixture added between the air forms & (b) assume (and reference) that the structure to be constructed is a structure of revolution (in this case a half dome atop a cylinder). Neither (a) nor (b) need necessarily be the case as other mixtures may prove more efficacious, and other shapes are obtainable with air forms.

List of Figures

3 Cutaway drawing of the small air form and the larger membrane (100 & 200, respectively) from figure 1 and 2 attached to a concrete pad (300). A vent (600) is passed through the outer membrane and used for inflation. This an orientation of the air form and outer membrane prior to introduction of the moldable material.

4 Cutaway drawing of the small air form and the larger membrane (100 & 200, respectively) from figure 1 and 2 attached to a circular stem wall (400). Vent not pictured. This an orientation of the air form and outer membrane prior to introduction of the moldable material.

5 Cutaway drawing of the small air form and the larger membrane (100 & 200, respectively) from figure 1 and 2 attached to the ground, on top of a trench rubble foundation (500). Vent not pictured. This an orientation of the air form and outer membrane prior to introduction of the moldable material.

6 Cutaway drawing of the completed structure (700) after the air form and outer membrane have been removed. In this instance the structure is depicted atop a concrete pad (300), though this is not the only option for a foundation.

7 Rendering of the air form and membrane assembled atop a concrete pad, prior to pouring.

8 Rendering of the air form and membrane assembled atop a concrete pad, after pouring.

3.1 Detailed Description Referencing Figures

Figure 1 is a drawing of the inner air form, figure 2 is a drawing of the outer membrane. The air form and membrane are built such that

$$r_{outer} - r_{inner} = x \qquad \text{(eq. 1)}$$

where r_{outer} is the inner radius of the outer membrane in figure 2, r_{inner} is the outer radius of the small air form in figure 1, and x is the thickness in units of length of the resultant wall, once poured. x can be varied based on the size of the air form and outer membrane to produce a structure with sufficient strength and insulation value so as to be appropriate for the given conditions.

Figure 3 is a cutaway drawing of the smaller air form and larger membrane (100 & 200, respectively) in position atop a concrete pad (300), there is a built-in vent used to inflate the inner air form (600). Figures 5 & 6 show the air form and membrane erected and ready for pouring atop a circular stem wall (400) and a trench and rubble foundation respectively (500) these figures illustrate that the system may be employed using various foundation methodologies. In Figures 2, 3, 4, & 5 the hole in the top of the outer membrane where (in this case) the foamed concrete will be introduced to the air mould is not pictured.

The moldable mixture, once cured, will comprise the final shape of the structure and the air mould will be removed (Figure 6).

Figures 7 & 8 are provided for illustration and are renderings of the building assembly atop a concrete pad, both before and after pouring (respectively).

The air form and membrane are generally made from PVC-coated nylon or polyester fabric. The air form is inflated with a heavy duty construction inflator fan. Besides a dome-on-cylinder shape, the forms can be made in a plurality of shapes such as rectangular or square prisms, triangular prisms, pyramids, cones, domes, cylinders, elliptic cylinders and others. As in the provided example, two or more shapes can also be combined, such as a rectangular square prism and a triangular prism to produce a more traditionally shaped structure with a peaked roof.

3.2 Stepwise Description of Process & Assembly

The invention proposed herein seeks to combine the advantages of the various structures discussed in section 2 via an innovative new process of "air molding." The air mould described in 3.1, is deployed and utilized as follows:

1. The site is compacted and prepared using any of a variety of foundation techniques. Depending on the local circumstances the foundation may be a poured concrete slab, a trench rubble foundation, a stem wall, or other appropriate technique.

2. The inner air form (figure 1) is centered on the site, inflated and appropriately affixed to the foundation. Depending on the circumstances, the air form may be held down with weights, strapped to anchors in the ground, or tied to rope cleats or other securing points built into the foundation. If necessary, structural reinforcement (e.g. a web of rebar or basalt rebar, or other appropriate reinforcement wrapped around the inner air form) may be applied at this point to increase the tensile strength of the final structure.

3. The outer membrane (figure 2) is then suspended around the inner air form and, as above, appropriately affixed to the foundation, completing the air mould (figures 4 & 5).

4. Foamed cement (or other mixture) is mixed and introduced into the mould, in this case via the hole in the peak of the outer mould. As the mixture is added to the mould, the outer membrane is stretched to shape via the hydraulic pressure of the cement. Various fibers may be added to the mixture to increase tensile strength. The foamed cement is subsequently allowed to cure. The foam itself is produced on site using a continuous foam generator and one of several foam concentrates such as dish soap — as used in DomeGaia domes — or one of many proprietary formulations such as Drexel F.M.-160™ (http://www.drexchem.com/products/f-m-160/)). The foam is mixed with the concrete or cement from a ready-mix truck to create the foamed cement (the cement and foam can also be mixed by hand, or with portable cement mixers). Other mixtures may also be added, such as different concrete/cement formulations (e.g. hempcrete or other formulations infused with fiberglass or polymers), epoxies, plastics, or curable liquid insulators.

5. Once the cement is cured, the outer membrane may be removed from the site. The inner air form is removed by cutting a hole (to be used as a door way) in the newly formed structure, the air form is deflated and removed through the hole. This leaves a single, monolithic structure. The air forms may then be used to construct another structure.

6. In the case of foamed concrete, the resultant structure can be worked with hand tools. Holes for doors, windows, and utility connections may thus be cut out easily and without a requirement for a high level of expertise.

7. The structure is then dried in by installing windows and doors, and sealed appropriately for local conditions. Depending on conditions, the structure could be sealed with any of a variety of products such as paints, resins, epoxies, cement formulations, plasters, or clays.

The structure produced by this process is monolithic and thus avoids thermal bridging or gaps. The walls can be made as thick as necessary to provide the insulation required for local conditions. The process requires very little expertise and can be completed in a matter of days. The monolithic nature of the structure gives it inherent longevity. Finally, the structure is extremely cost effective to produce. In the case of foamed concrete, the volume of the concrete expands by as much as a factor of 5, and the relatively high R-value of foamed concrete (2.5 per inch) eliminates the need for other insulating materials. This structure requires only 7.6% the amount of concrete that would be required to make a structure with a similar square footage and R-value built with non-porous, structural concrete. These factors combine to produce a structure with a cost per ft^2 an order of magnitude cheaper than traditional building techniques. The resulting structure thus meets the criteria identified above.

Figure 1

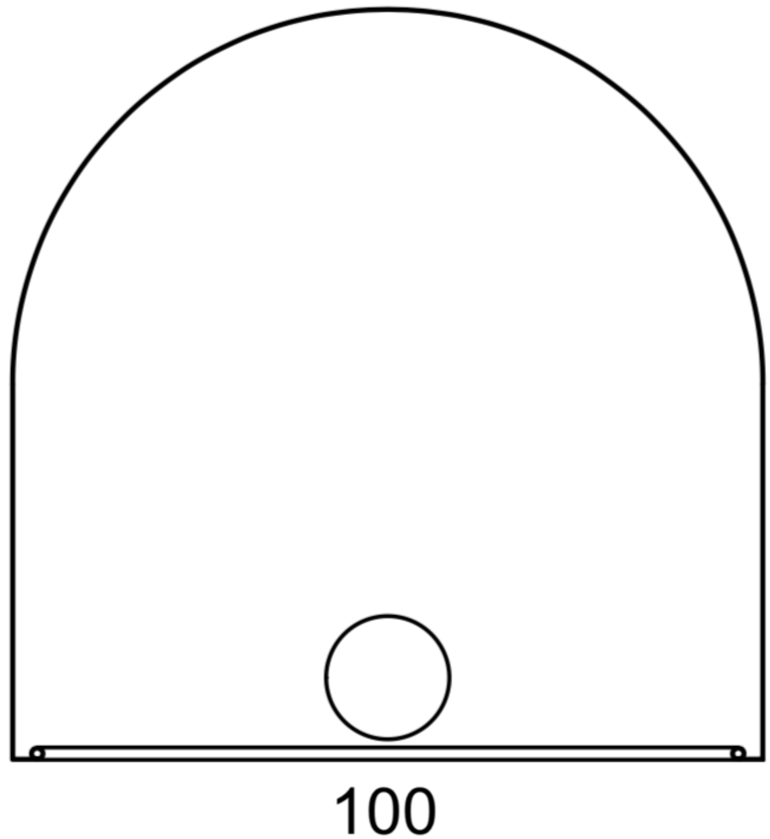

Figure 2

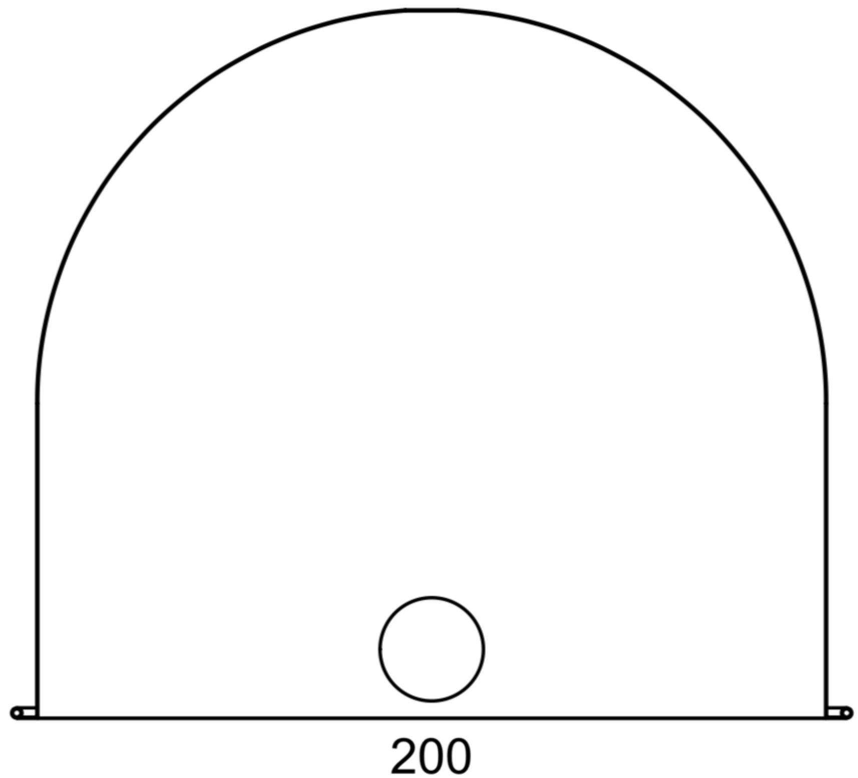

Figure 3

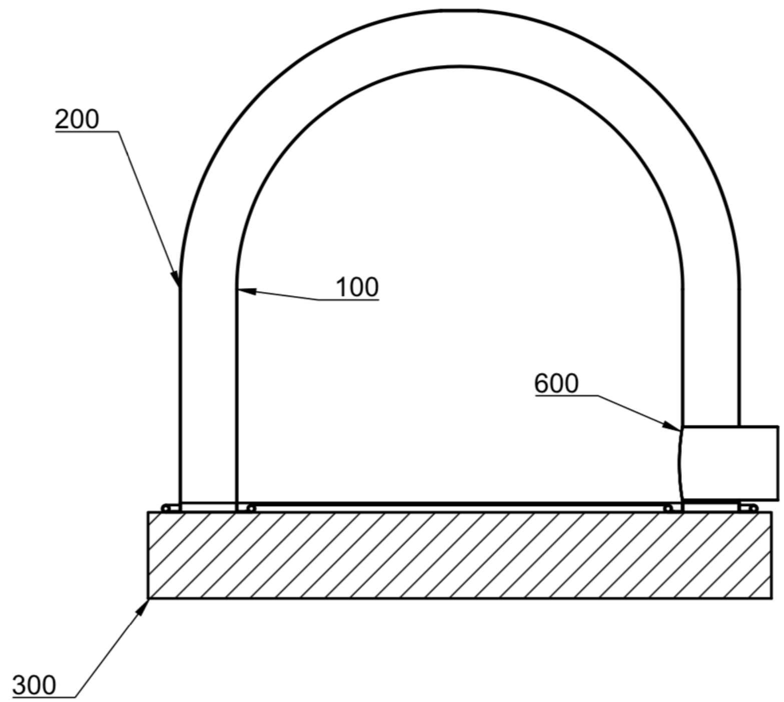

Figure 4

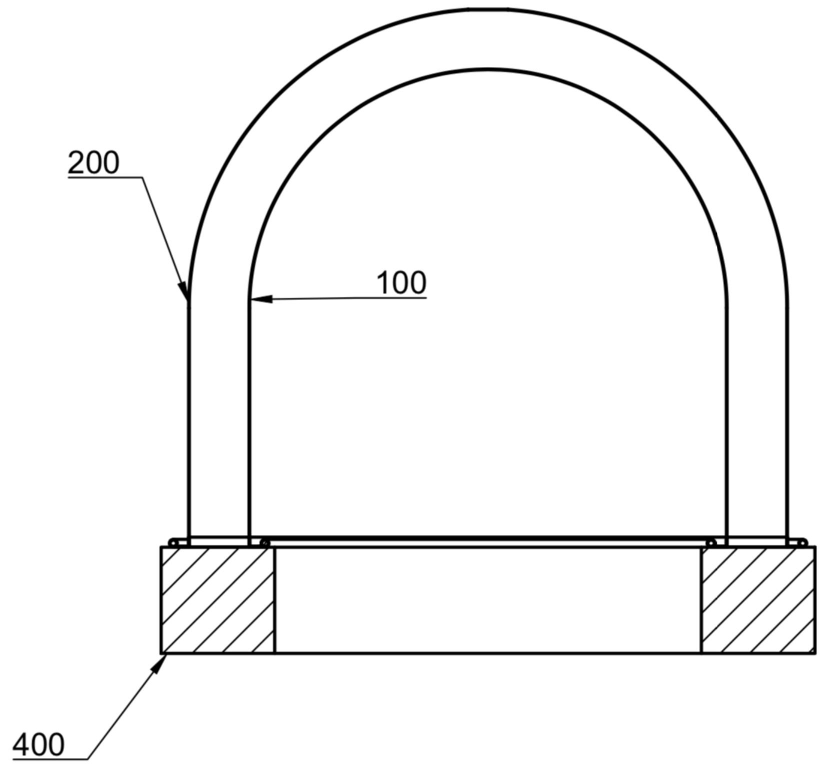

Figure 5

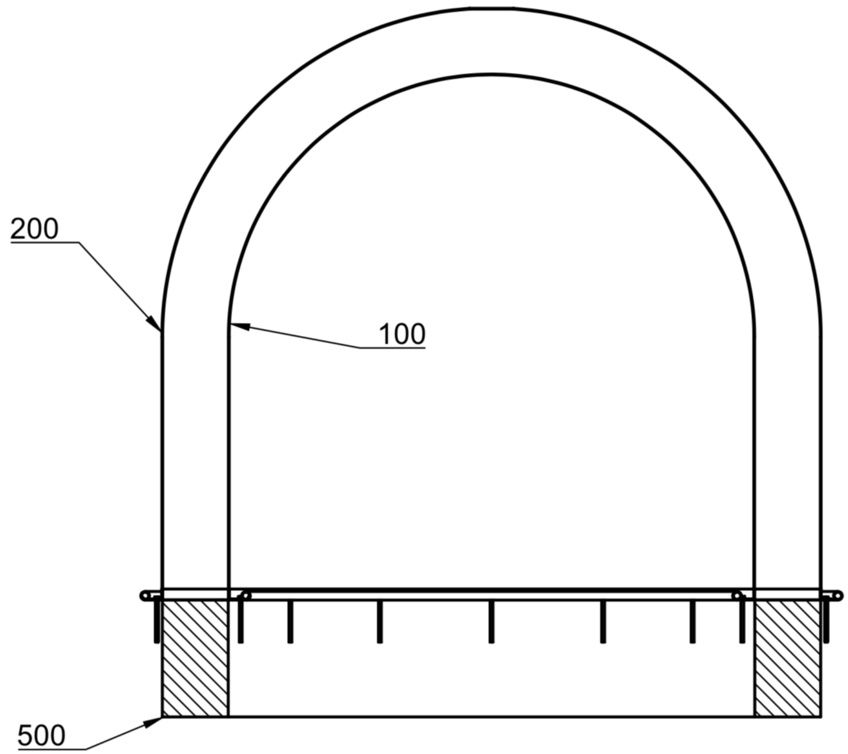

Figure 6

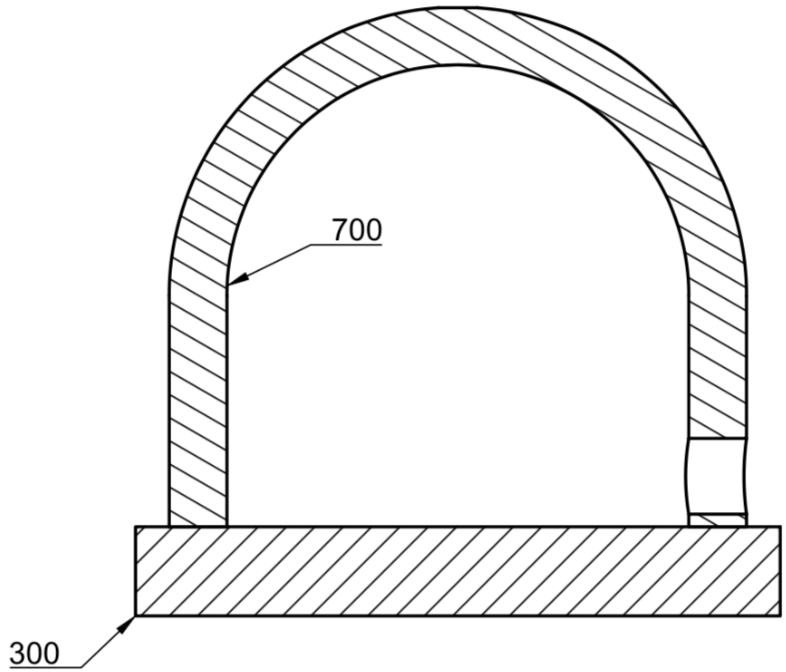

Figure 7

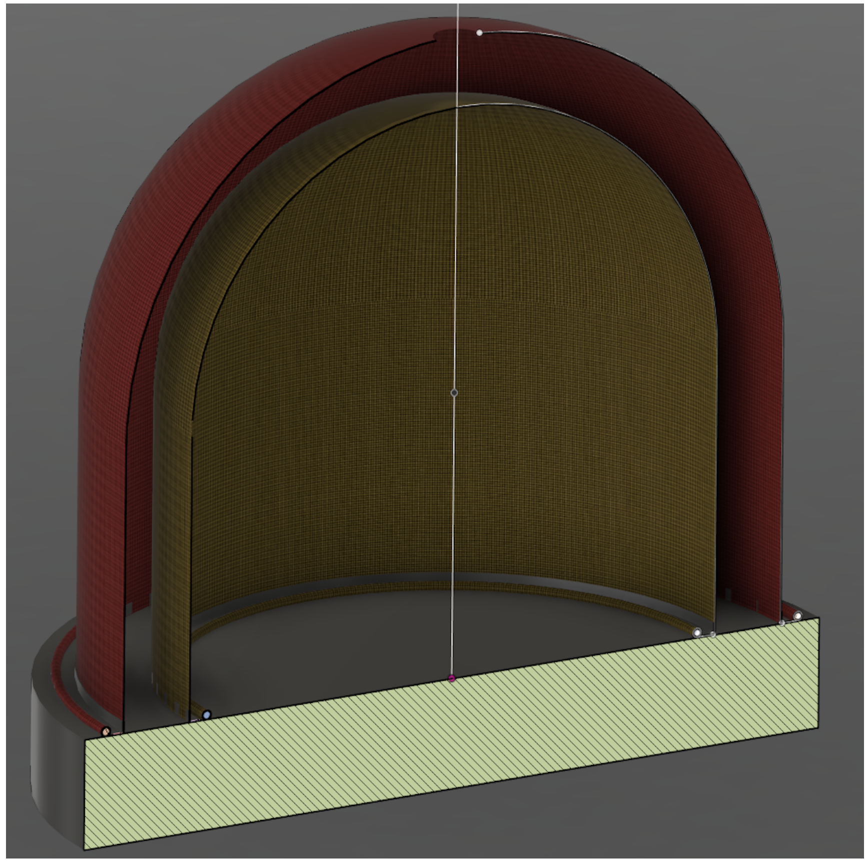

Figure 8