# Seismic Design of Masonry Structures: Droneports for Africa

Callum Fleming

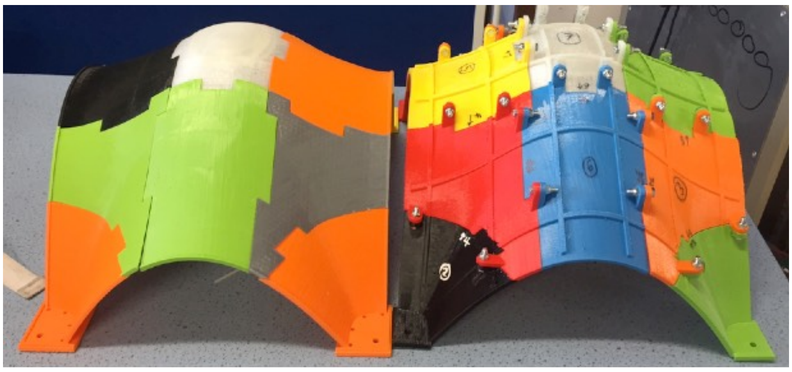
## Project Summary

The Droneport is a Foster + Partners design for a timbrel vault which is designed to be constructed across the African continent, particularly in Rwanda. The structure is designed to house supplies and services whilst also providing a base from which supply drones can be deployed. These drones can carry large payloads of food and aid to regions of the continent which are currently difficult to access due to a lack of infrastructure.

*Full scale prototype of the Droneport as displayed at the Venice Biennale*

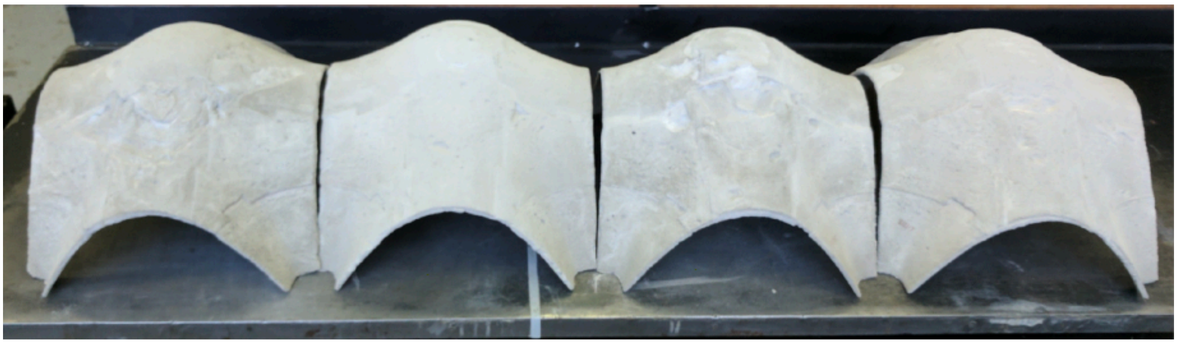
Timbrel vaults are comprised of tiles and mortar, and are self-supporting even during construction. This allows particularly complex forms of shell to be assembled which are in pure compression under most loading conditions. The Droneport measures 12 m by 10 m in plan and has a shell thickness of between 100 and 120 mm, a span to thickness ratio of 100. Finite Element (FE) models have been used to quantify the seismic capacity of these shells, but prior to this project no physical models had been tested.

This project concerned the production of a 1:25 scale model of the Droneport and the testing of this model in the beam centrifuge at the Schofield Centre, Cambridge in an attempt to support the FE results. To model the structure, a segmented mould was designed in AutoCAD which was then 3D printed. The funding for this part of the project came primarily from the Dyson Bursary, as the total cost of the plastic parts and failed prints came to over £200. The 26 parts of the mould were designed to fit together perfectly before being bolted to secure them, however inaccuracies inherent in the printing process including warping of the plastic meant the alignment of pieces was not perfect.



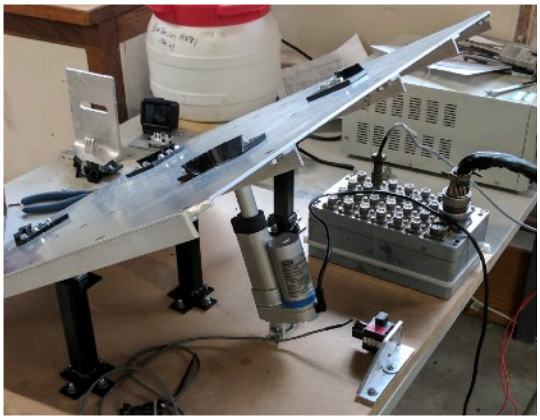
*3D printed mould used to cast model shells of the Droneport*

Mortar was cast into the shells in order to produce models which had similar structural properties to the actual Droneport. Much like the mould design, this proved to be more difficult than anticipated, and several casting processes were trialled (including injection moulding and extrusion) before it was found that a piecewise assembly of the outer half of the mould was the most effective method. Four shells were cast successfully amongst a plethora of failures, though one of these shells did not survive to be tested.



*The four successfully produced shells, after smoothing*

The tests on the shells were intended to be conducted in the centrifuge at 25 g such that the stresses found in the actual structure were replicated in the model, though accelerations of 35 g and even 45 g were required to cause collapse. The shells were mounted on a pivoted table which was designed to rotate slowly, resolving the centrifugal force from the centrifuge into 'vertical' and 'horizontal' components relative to the structure. The results were recorded using a draw wire and a MEMS device to measure the angle of tilt at failure, and three GoPro cameras to observe the collapse mechanism. The Dyson Bursary also provided the funding for the production of the tilting table and the apparatus used to measure the results. The readings from the measuring instruments were riddled with noise, making interpretation of results rather difficult, and the collapse of the structures happened so quickly that the fastest frame rate of the GoPro cameras could only make the collapse span four frames.



*The designed tilting table with connected apparatus including the driving actuator*

The results from the tests were unfortunately inconclusive due to a lack of repeatability, imperfections in the shells, and cracks which formed in two of the tests during the spin up phase. Whilst the form of collapse mechanism was a reasonable match to FE results, the collapse loads were inconsistent and difficult to compare. Further FE tests using a variation of thicknesses and mortar strengths, performed as part of Eftychia Dichorou's PhD thesis, showed that the collapse loads were not as far from the model as previously expected, but there was still some discrepancy.

The results for different thicknesses were required because the mean thicknesses of the shells were measured to be almost twice the 4 mm thickness that was desired. The distribution of the thickness also meant the structures were top heavy, an imperfection which may have influenced the results. The excessive shell thickness was attributed to the design of the mould: the connection between segments was not as secure as desired; the edges of the mould did not form a seal; and the PLA plastic used to create the mould was flexible and liable to fracture.

Refinements of the modelling and testing processes are necessary to produce reliable results to support the use of FE modelling for masonry structures. Several suggestions for the refinement of the mould were outlined, including a more secure row of bolts integrated into continuous walls, preventing rotation between adjacent pieces and providing more areas for securing segments together reliably. With regards to the test itself, tighter control on the rotation speed of the table is required to mitigate dynamic effects, and a high speed camera capable of withstanding centrifuge conditions should be procured in order to better understand the collapse of the models.

**Outreach Activity**

Year 10 students from the Corby Technical School were invited to the Cambridge University Engineering Department to take part in an outreach activity to be introduced to some basic engineering concepts. These concepts spanned several areas of engineering, including structural design. Daniel Blower and I organised a brief presentation which introduced concepts of bridge and truss design as well as discussing our individual projects. Simple ideas regarding dynamic responses of structures were discussed, and the students were asked to consider how to design against earthquakes, wind, and other events. The students were then challenged to build a bridge out of bolts and rolled paper tubes, spanning approximately half a metre and able to support a centrally applied load of baked bean cans.

The activity seemed to be engaging and entertaining for most of the children, particularly when the structures were tested. Some of the students clearly understood the basic concepts of triangulation with regards to truss design, though the time to complete the activity was underestimated, even with a large number of tubes pre-rolled the night before. In general, the concepts of structural design appeared to be well understood, with very few corrections required to sketches made by the students before construction. The bridges themselves were generally able to support a substantial load, with one group exceeding the eight cans of beans available.

A brief discussion of dynamic effects showed the students understood the basic principles and consequences of such events and appreciated the challenges involved in designing against these effects. The video of the Tacoma Narrows bridge collapse was shown to the students at the end of the session in order to show that not every design is perfect, and that relatively low wind speeds acting in the right manner can cause devastation if not designed for.