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CANADIAN MUSEUM OF ARCHITECTURE

IN PERSPECTIVE

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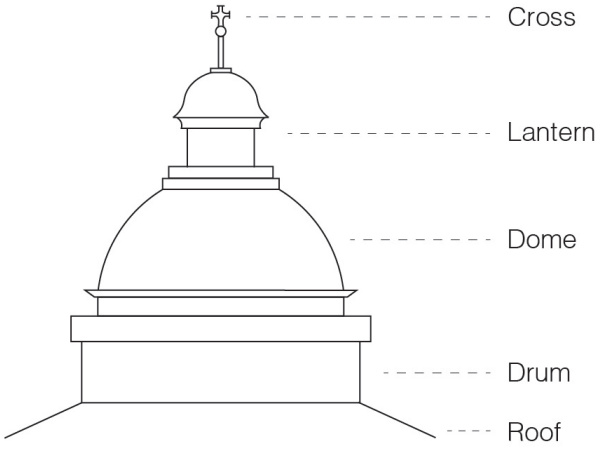
HOOKE, LINE & ARCHITECT

> "As hangs the flexible line, so but inverted will stand the rigid arch." - Robert Hooke

Although Robert Hooke was not an architect, the consequences of this observation made by him in 1675 were seminal to the architectural design of the dome of St. Paul's Cathedral.

The ascendancy of the British Empire was well underway in the seventeenth century. Though the population of London was increasing rapidly, its infrastructure was still largely medieval and in need of remediation. The Great Fire of 1666, which burned the city to the ground, compelled its rebuilding.

At this time, aside from a palace, the cathedral would be the most consequential building in a city. The commission to design and build one for London was given to Sir Christopher Wren. As the city was on its way to becoming the capital of the largest (as it turned out) empire ever created, he proposed an imposing structure with a very large dome that would dominate the skyline. And, it was to be surmounted by a prominent lantern.

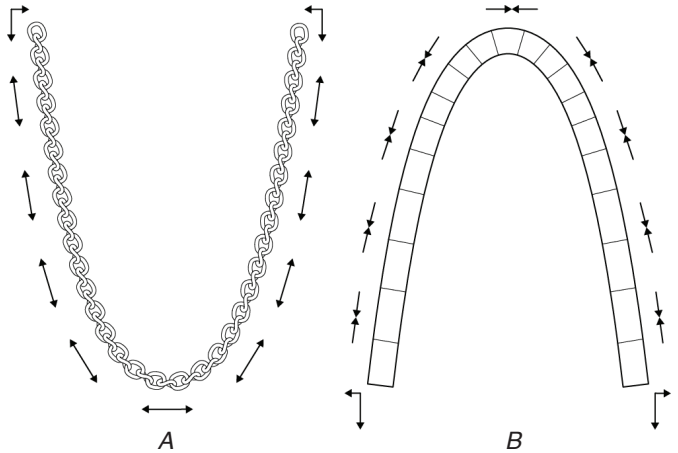


The principal parts of a cathedral dome.

Construction started in 1672, however the design of the dome was still up in the air twenty years later. At issue was the fact that a conventionally designed dome of sufficient size that could support itself and the lantern was too heavy for the cathedral walls.

A SOLUTION

Hooke deduced from his observation of a freely hanging chain (line) that the direction of the tension force arising from the weight of the chain was shown at each link by its lengthwise orientation. He inferred that if the arrangement was inverted it would represent an arch wherein the direction of the compression force through the units of which it is built would follow a corresponding curve.



A) A freely hanging chain takes the shape of a catenary, with its links in tension. B) A catenary arch, with its blocks (voussoirs) in compression. Note the lateral forces at the ends of both.

This line of thrust, roughly a parabola, is the shape of the arch that would use material most efficiently in its construction. Rotating this arch about its vertical axis defines a dome that makes similar economical use of material, providing strength for relatively less weight.

Wren's final design incorporated a brick dome designed in this way, sufficiently light and strong enough to carry

The CMA's model of St. Paul's dome, showing both its internal and external structure.

a 700 ton masonry lantern. It plays a vital structural role but is shielded from view by traditionally shaped inner and outer domes that provide the cathedral's aesthetic characteristics. The elaborately decorated masonry inner dome creates much of the atmosphere customary in a Christian place of worship. The lead covered wooden outer dome, together with the lantern, is the visual hallmark of the church.

THE CATHEDRAL

St. Paul's was completed in 1711, as a richly ornamented geometric structure in the baroque style, symbolic of the English Enlightenment. It remains a notable landmark.

St. Paul's Cathedral dominating the London skyline in 1746.

Early in the construction of the cathedral there were, apparently, several non-catastrophic structural failures reflective of the trial and error method of building practised at the time. The use of mathematics in the structural design of the dome to predict its performance is an early example of the incorporation of formal engineering into architectural practise. This trend continued as science and technology developed, leading to the establishment of architectural engineering as a discipline and, hence, to safer buildings.

MATHEMATICS

When Hooke made his observations, it was believed that the shape of a freely hanging chain was a cubic parabola. But in 1691 it was shown to be a catenary.

The hanging chain method, using suspended weights, allowed forces and their directions to be estimated in asymmetrically loaded arches. Antoni Gaudi famously used it in his design of the Sagrada Familia Basilica.

Gaudi's model using the hanging chain method to determine force distributions during structural design. The model is inverted.

- Peter Brueckner

References

Gerbino, Anthony and Stephen Johnston. *Compass and Rule: Architecture as Mathematical Practice in England 1500 - 1750.* New Haven: Yale University Press, 2009.

Zhang, Myles. "St. Paul's Cathedral Dome." Myles Zhang. April 16, 2020. myleszhang.org/2020/04/16/st-pauls-cathedral/

Image Citations

Image 4: Canaletto. *The River Thames with St. Paul's Cathedral on Lord Mayor's Day.* 1746. Oil on canvas, 26.8 x 37.6 cm. Lobkowicz Palace.

Image 5: Maqueta polifunicular. Photo by Canaan. 2009. https://commons.wikimedia.org/wiki/File:Maqueta_funicular.jpg