By the 12th century, the popes could see that rough calculations of the sort made by their predecessors did not furnish Easters in harmony with the heavens. "In that emergency," says Heilbron, "the popes encouraged the close study of the apparent motions of the sun and moon." Fortunately, ancient Greek mathematical texts by Ptolemy and others were just then being translated into Latin from Arabic versions.

"The key piece of data for making the Easter calculation was the period between successive spring equinoxes," Heilbron writes. "The most powerful and precise way to measure that cycle was to lay out a 'meridian line' (usually a rod embedded in a floor) from south to north in a large dark building, put a small hole in the building's roof or facade, and then observe how many days the sun's noon image took to return to the same spot on the line." Cathedrals were the most convenient large, dark buildings available, and over the centuries they were turned into solar observatories throughout Europe, says Heilbron.

Though the edict against Galileo obliged Catholic astronomers to identify the sun as the "orbiting" body, that made little difference in scientific practice. And since church officials "tended to regard all the systems of mathematical astronomy as fictions," Heilbron says, Catholic writers remained free "to develop mathematical and observational astronomy almost as they pleased."

"The first church meridian built to modern ideas of precision," Heilbron says, was created in 1655 in the great basilica of San Petronio, in Bologna, in the heart of the papal states. Observations made there by astronomer Giovanni Domenico Cassini, and confirmed by independent observers, notes Heilbron, "amassed unimpeachable evidence" in favor of the Copernican theory that had been condemned by Pope Urban VII and the Inquisition only a quarter-century before.

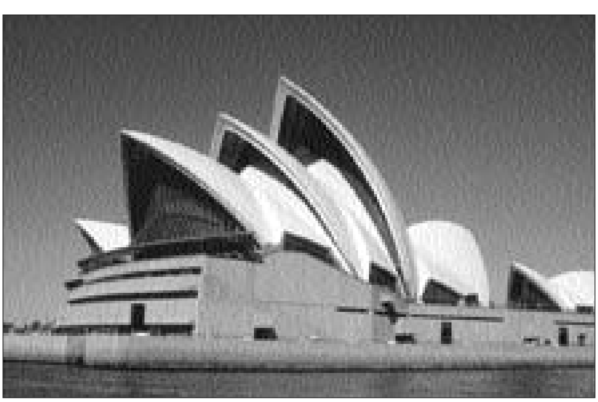
SCIENCE, TECHNOLOGY & ENVIRONMENT

Architectural Liberation

"A Tale of Two Cities: Architecture and the Digital Revolution" by William J. Mitchell, in *Science* (Aug. 6, 1999), 1200 New York Ave., N.W., Washington, D.C. 20005.

Four decades ago, Danish architect Jorn Utzon's winning design for the Sydney Opera House, featuring free-form curved concrete shell vaults, presented an extraordinary structural challenge. After heroic labors, the architect and a London engineering firm figured out how to build an approximation of the spectacular curved surfaces. But other parts of the design were discarded as hopelessly impractical. Ultimately, Utzon was forced to resign from the project. Aside from the magnificent shells, the completed building had little of his design's freshness and originality.

Today, that story would have a much happier ending, writes Mitchell, dean of the School of Architecture and Planning at the Massachusetts Institute of Technology. For architects, the computer has dramatically narrowed "the gap between the imaginable and the feasible."



The Sydney Opera House's shells were hard to build, but other parts of the architect's vision proved impossible.

In the past, designers of large and complex buildings were severely limited in the geometric and material possibilities they could explore, Mitchell points out. "Traditional drafting instruments—parallel bars, triangles, compasses, scales, and protractors—largely restricted [them] to a world of straight lines, parallels and perpendiculars, arcs of circles, and Euclidean geometric constructions." The limitations of the analytical techniques (based on precedent and rule of thumb) used to predict the building's performance and ensure its structural adequacy further reduced the range of acceptable designs.

But not any more, Mitchell writes. "Modern CAD (Computer Aided Design) systems allow designers to create very complex three-dimensional geometric models with ease." And cheap computer power allows sophisticated analyses and simulations to be done to predict, reliably and precisely, the performance of even the most imaginative structures.

Architect Frank Gehry's initial sketches and model for the Guggenheim Museum in Bilbao, Spain, had "an even more audacious assemblage of free-form curved surfaces than Utzon's," Mitchell says. But thanks to the digital revolution, Gehry did not have Utzon's problems. "The completed building—remarkably true to the architect's first visionary sketches—opened in 1997 to universal acclaim."

The Genetic Genie

"The Moral Meaning of Genetic Technology" by Leon R. Kass, in *Commentary* (Sept. 1999), 165 E. 56th St., New York, N.Y. 10022.

Are popular fears about genetic technology the product of ignorance? Many scientists say so—but not Kass, a physician-philosopher at the University of Chicago. "The public is right to be ambivalent" about genetic technology, he argues.

Genetic technology differs from conventional medicine. When the technology is fully developed, genetic engineers will deliberately make changes that will be passed on to succeeding generations, and may even be able to alter particular future individuals. Genetic enhancement may allow creation of new human capacities. "The genetic genie, first unbottled to treat disease, will go its own way, whether we like it or not," Kass believes.

Genetic engineering aside, gaining advance knowledge of an individual's likely or possible medical future by "reading" his genes may not always be a good thing, Kass observes. "Should we welcome knowledge that we carry a predisposition to Alzheimer's disease [or] schizophrenia?" Such knowledge could prove inhibiting, even crippling. Without "blind hopes," human aspiration and achievement may be diminished.

Most genetic technologists imagine themselves to be enhancing people's freedom in making decisions about their health or reproductive choices. But in reality, Kass contends, genetic power may well curb the freedom of most people, subjecting them even further to "the benevolent tyranny of expertise." Already, in many cases today, he says, "practitioners of prenatal diagnosis refuse to do fetal genetic screening in the absence of a prior commitment from the pregnant woman to abort any afflicted fetus." In other situations, pregnant women are pressured to undergo genetic testing. Eventually, Kass believes, strong economic forces are likely to develop that will work to compel genetic abortion or intervention. "All this will be done, of course, in the name of the well-being of children."

At the root of popular anxiety about genetic technology, Kass says, is the challenge it poses to human dignity. It puts scientists in the role of God, standing "in judgment of each being's worthiness to live or die." And the road from in vitro fertilization "leads all the way to the world of designer babies." Producing genetically sound babies will mean "the transfer of procreation from the home to the laboratory," turning it into "manufacture." This new arrangement, he says, "will be profoundly dehumanizing."

As genetic engineering progresses, Kass contends, the standard of health by which it is guided will become increasingly vague. "Are you healthy if, although you show no symptoms, you carry genes that will definitely produce Huntington's disease?" And with the inevitable arrival of "genetic enhancement," he continues, the standard will vanish along with "our previously unalterable human nature. . . . Because memory is good, can we say how much more memory would be better? If sexual desire is good, how much more would be better? Life is good; but how much extension of life would be good for us?"