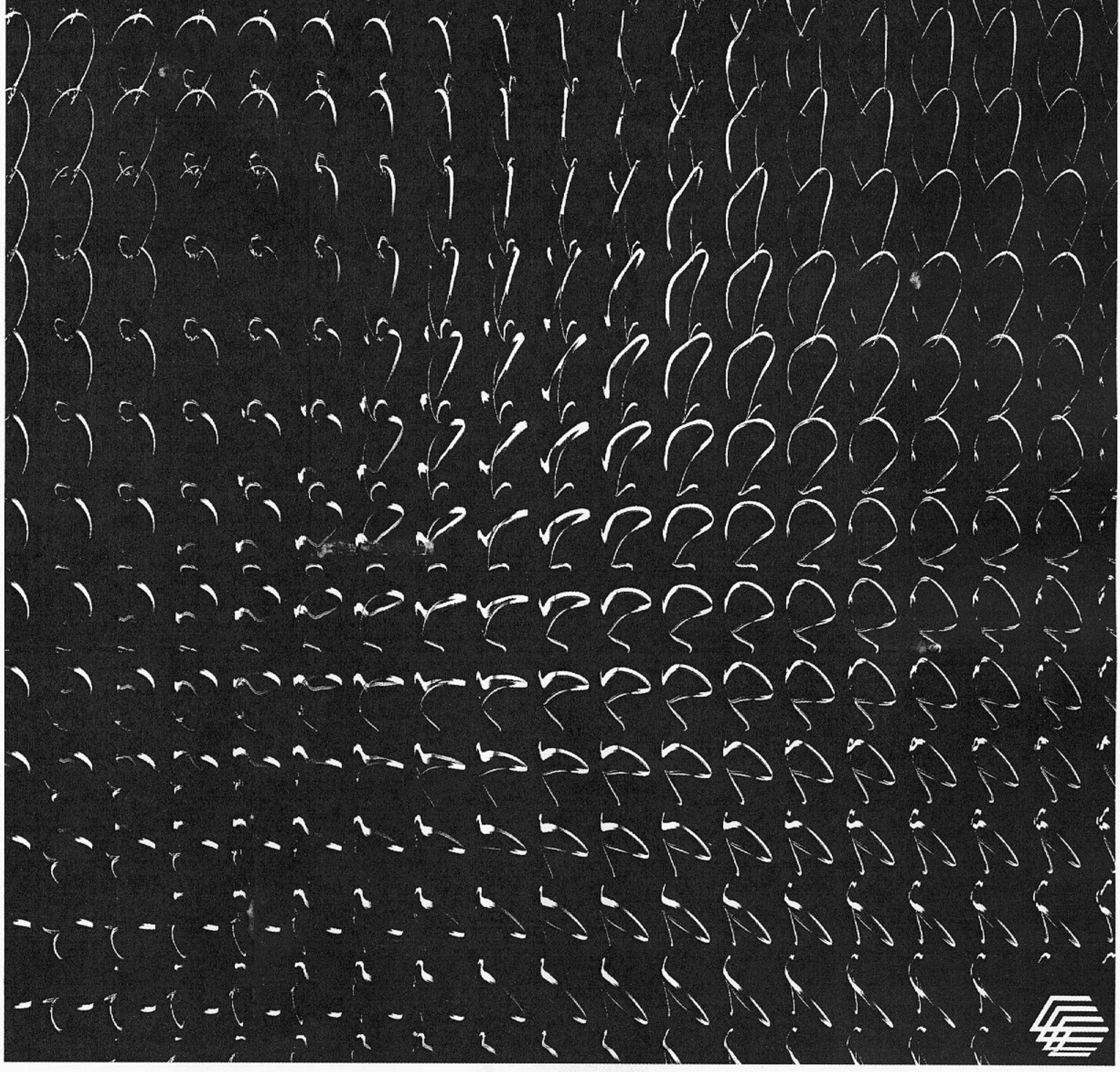
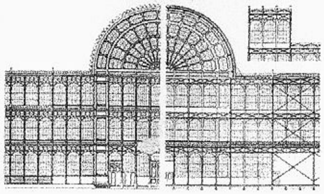
ARCHITECTURE IN THE DIGITAL AGE · DESIGN AND MANUFACTURING

EDITED BY BRANKO KOLAREVIC

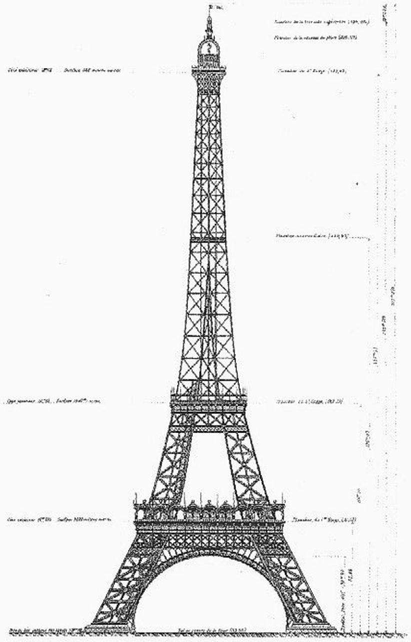


1 INTRODUCTION

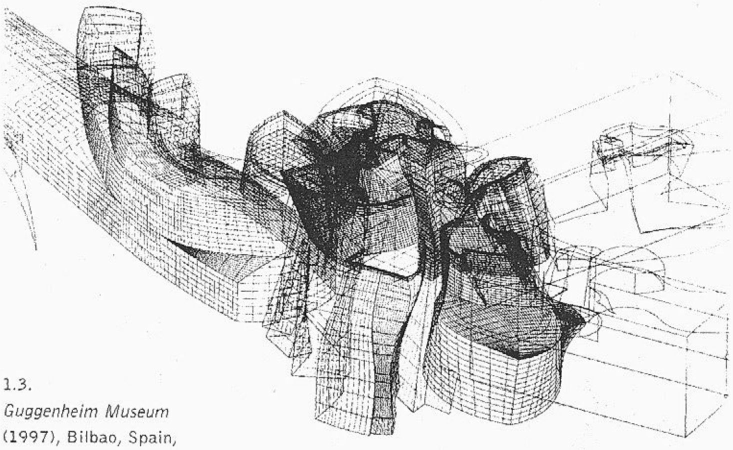
BRANKO KOLAREVIC



1.1.
Crystal Palace (1851), London, UK, architect Joseph Paxton: section.



1.2.
Eiffel Tower (1887), Paris, France, architect Gustave Eiffel: elevation.



1.3.
Guggenheim Museum (1997), Bilbao, Spain, architect Frank Gehry: the digital model.

Having abandoned the discourse of style, the architecture of modern times is characterized by its capacity to take advantage of the specific achievements of that same modernity: the innovations offered it by present-day science and technology. The relationship between new technology and new architecture even comprises a fundamental datum of what are referred to as avant-garde architectures, so fundamental as to constitute a dominant albeit diffuse motif in the figuration of new architectures.

— Ignasi de Sola Morales[1]

Joseph Paxton's *Crystal Palace* (figure 1.1) was a bold building for its time, embodying the technological spirit of the Industrial Age and heralding a future of steel and glass buildings. Gustave Eiffel's *Tower* in Paris manifested the soaring heights that new buildings could reach. It then took another 100 years for the glass and steel buildings to become ubiquitous worldwide, with gleaming skyscrapers part of every metropolis' skyline.

The first Crystal Palaces and Eiffel Towers of the new Information Age have just been built over the past few years. Frank Gehry's *Guggenheim Museum* in Bilbao (figure 1.3) is probably the best known example that captures the zeitgeist of the digital information revolution, whose consequences for the building industry are likely to be on a scale similar to those of the industrial revolution: the Information Age, just like the Industrial Age before, is challenging not only how we design buildings, but also how we manufacture and construct them.

Digital technologies are changing architectural practices in ways that few were able to anticipate just a decade ago. In the conceptual realm, computational, digital architectures of topological, non-Euclidean geometric space, kinetic and dynamic systems, and genetic algorithms, are supplanting technological architectures. Digitally-driven design processes, characterized by dynamic, open-ended and unpredictable but consistent transformations of three-dimensional structures, are giving rise to new architectonic possibilities. The generative and creative potential of digital media, together with manufacturing advances already attained in automotive, aerospace and shipbuilding industries, is opening up new dimensions in architectural design. The implications are vast, as "architecture is recasting itself, becoming in part an experimental investigation of topological geometries, partly a computational orchestration of robotic material production and partly a generative, kinematic sculpting of space," as observed by Peter Zellner in *Hybrid Space*.[2]

It is only within the last few years that the advances in computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies have started to have an impact on building design and construction practices. They opened up new opportunities by allowing production and construction of very complex forms that were, until recently, very difficult and expensive to design, produce and assemble using traditional construction technologies. A new digital continuum, a direct link from design through to construction, is established through digital technologies. The consequences will be profound, as new digitally-driven processes of design, fabrication and construction are increasingly challenging the historic relationship between architecture and its means of production.

New digital architectures are emerging from the digital revolution, architectures that have found their expression in highly complex, curvilinear forms that will gradually enter the mainstream of architectural practice in the coming years. The plural (architectures) is intentional, to imply the *multiplicity* of approaches – in fact, no monolithic movement exists among the digital avant-garde in architecture. What unites digital architects, designers and thinkers is not a desire to "blobify" all and everything, but the use of digital technology as an enabling apparatus that directly integrates conception and production in ways that are unprecedented since the medieval times of master builders.

FROM LEIBNIZ TO DELEUZE

Contemporary approaches to architectural design are digitally enabled and digitally driven, but are also influenced and informed by the writings of theorists and philosophers, ranging from the German philosopher, mathematician and logician Gottfried Wilhelm Leibniz (1646–1716) to Gilles Deleuze (1925–1995), one of the most influential French thinkers of the twentieth century. It was Deleuze who demonstrated that there are a thousand "plateaus" (*mille plateaux*),[3] a multiplicity of positions from which different provisional constructions can be created, in essentially a non-linear manner, meaning that the reality and events are not organized along continuous threads, in orderly succession. Such positions were eagerly adopted by a number of contemporary avant-garde architects to challenge the pervasive linear causality of design thinking.

In his essay on "Architectural Curvilinearity,"[4] published in 1993, Greg Lynn offers examples of new approaches to design that move away from the deconstructivism's "logic of conflict and contradiction" to develop a "more fluid logic of connectivity." This new fluidity of connectivity is manifested through "folding," a design strategy that departs from Euclidean geometry of discrete volumes represented in Cartesian space, and employs topological conception of form and the "rubber-sheet" geometry of continuous curves and surfaces as its ultimate expression.

Folding is one of the many terms and concepts, such as *affiliation*, *smooth* and *striated space*, *pliancy*, and *multiplicity*, appropriated from Deleuze's work *The Fold*.[5] Deleuze's writing, aimed at describing baroque aesthetic and thought, reintroduced fold as an ambiguous spatial construct, as a figure and non-figure, an organization and non-organization, which, as a formal metaphor, has led to smooth surfaces and transitional spaces between the interior and the exterior, the building and its site. The fold, or *le pli*, as defined by Deleuze, posits a post-structuralist notion of space "made up of platforms, fissures, folds, infills, surfaces and depths that completely dislocate our spatial experience." The effect of folding is a new distinctive architecture of formlessness that questions existing notions of built space, its aesthetics, and utility.

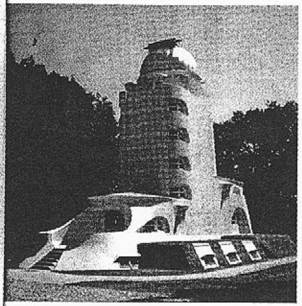
FROM BAROQUE TO GEHRY

Digitally-generated forms evolve in complex ways and their free-form surfaces curve complexly as well. As exceptions to the norm – as formal transgressions challenging the omnipresent, fundamentally rectilinear conventions – these new forms raise profound and necessary questions of an aesthetic, psychological and social nature.

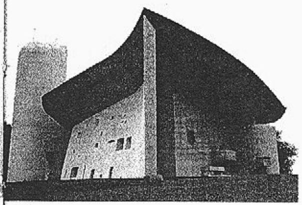
The contemporary digital architectures appear to reject any notion of urban and structural typology, continuity and morphology, and historic style and perspectival framework – they represent an ideological, conceptual and formal break much like Walter Gropius's *Bauhaus* in Dessau, Germany. They seem to prefigure an entirely new way of architectural thinking, one that ignores conventions of style or aesthetics altogether in favor of continuous experimentation based on digital generation and transformation of forms that respond to complex contextual or functional influences, both static and dynamic. The new digital architectures might be non-typological, discontinuous, amorphous, non-perspectival, ahistoric... But they are not without a precedent.

Since Baroque, architects have been trying to go beyond the Cartesian grid and the established norms of beauty and proportion in architecture. The parallels between contemporary and Baroque thought are indeed multiple, as contemporary reading of Deleuze's *Fold* shows, leading to labels such as "Neo-Baroque" being applied to new architectures.

The biomorphic forms are, of course, not new, from the excesses of Baroque to organic design vocabularies of the early- and mid-twentieth century. At a purely formal level, the precedents abound. Rafael Moneo speaks of "forgotten geometries lost to us because of the difficulties of their representation."[6] The forms of Gehry's recent projects could be traced to the Expressionism of the 1920s; one could argue that there are ample precedents for Greg Lynn's "blobs" in Surrealism. Earlier precedents could be found in the organic, biomorphic forms of Art Nouveau or, more specifically, in



1.4.
Einsteinturm (1921), Potsdam, Germany, architect Erich Mendelsohn.



1.5.
Chapel at Ronchamp (1955), architect Le Corbusier.

the sinuous curvilinear lines of Hector Guimard's Metro Stations in Paris. And then there is Gaudi's oeuvre of highly sculptural buildings with complex, organic geometric forms rigorously engineered through his own invented method of modeling catenary curves by suspending linked chains.

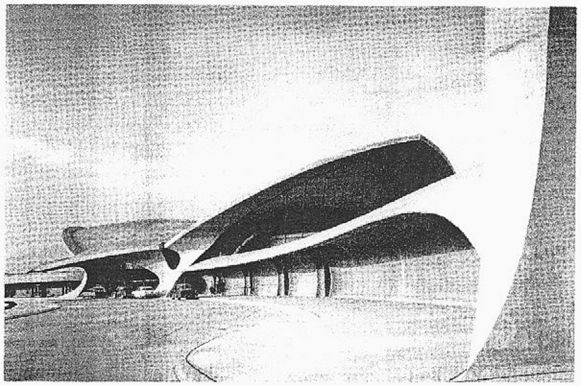
There is a range of expressive precedents from the early 1920s onwards, from Erich Mendelsohn's *Einsteinturm* in Potsdam, Germany (1921, figure 1.4), to Le Corbusier's *Chapel at Ronchamp* (1955, figure 1.5) and Eero Saarinen's *TWA Terminal* in New York (1962, figure 1.6). It is worth remembering that it was Le Corbusier's "free plan" and "free façade" that allowed for elements of variable curvature to emerge in the modernist projects of the mid-twentieth century. Eero Saarinen attributed the reemergence of the plastic form to the advances in building technology, while acknowledging that "it is the aesthetic reasons which are [the] driving forces behind its use."[7] Alvar Aalto broke with the pristine geometries of the International Style fairly early, applying sinuous curves to his designs from furniture and glassware to buildings. His *Finnish Pavilion* at the 1939 World's Fair in New York (figure 1.7), one of his best known projects, featured dramatic undulating curves in the interior of a modest, rectilinear shell.

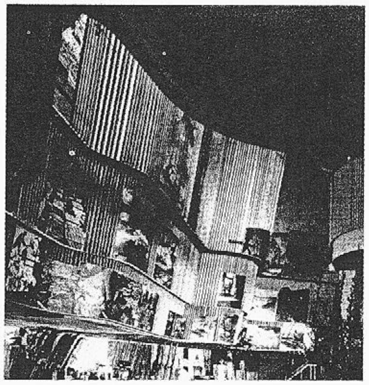
It is interesting to note that Saarinen is rather cautious in his use of plastic form, implying that it has a rather limited applicability, and warning that the "plastic form for its own sake, even when very virile, does not seem to come off."[8] Saarinen's cautious approach to plastic form is exemplary of the apparent ambivalence of the modernists towards the curvilinear, an attitude that is still widely present. While it enabled them to break the monotony of the orthogonal and the linear, it also heralded the emergence of a new unknown geometry, about which they were still not sure, as noted by Bernard Cache;[9] the modernists "knew that they had, above all, to avoid two opposite pitfalls: a dissolution into the indefinite and a return to the representation of natural form,"[10] the former manifested in "the loss of form," and the latter in "the organicist maze into which art nouveau had fallen."[11]

The utopian designs of the architectural avant-garde of the 1960s and early 1970s brought a certain state of formlessness, which, in strange ways, resembles the contemporary condition, as observed by Peter Zellner in 2001.[12] It was Reyner Banham's seminal book on *Theory and Design in the First Machine Age*[13] that provided a significant ideological shift which led to the emergence of various groups and movements, such as Archigram, Metabolism, Superstudio, etc. Archigram's "soft cities," robotic metaphors and quasi-organic urban landscapes were images of fantasies based on mechanics and pop culture. Expanding on Buckminster Fuller's work, pop designers were creating "blobby" shapes throughout the 1960s and 1970s; "formable" materials, such as plastics, and concrete to a lesser extent, inspired a free and often unrestrained treatment of form. More importantly, the works of these architects, designers and thinkers offered a new interpretation of technology's place in culture and practice, transgressing the norms of beauty and function. Archigram, for example, explored in projects, such as *Plug-in City*, *Living Pod* and *Instant City*, the continuity of change and choice afforded by new technologies, going beyond the superficial appearance of novel forms.

As was the case in the past, the contemporary digital architectures find their legitimization in their exploitation of the latest technological advances, new digital means of conception and production, and the corresponding aesthetic of complex, curvilinear surfaces. As a manifestation of new information-driven processes that are transforming cultures, societies and economies on a global scale, they are seen as a logical and inevitable product of the digital zeitgeist.

1.6.
TWA Terminal (1962), New York, architect Eero Saarinen.





1.7.
Finnish Pavilion at the 1939 World's Fair in New York, architect Alvar Aalto.

SMOOTH ARCHITECTURES

The use of digital media by avant-garde practices is profoundly challenging the traditional processes of design and construction, but for many architects, trained in the certainties of the Euclidean geometry, the emergence of curvilinear forms poses considerable difficulties. In the absence of an appropriate aesthetic theory, the "hypersurface" forms (a term coined by Stephen Perrella[14]) often seem to be utterly esoteric and spatially difficult to comprehend, and are often dismissed as just another architectural "fad."

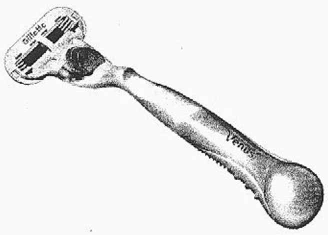
What is often overlooked is that these new "smooth" architectures are tied intrinsically to a broader cultural and design discourse. Rounded contours have been omnipresent in our lives for a good part of the past decade, from toothbrushes, toasters, and computers to cars and planes (figures 1.8–1.10); somehow, perhaps in the absence of a convincing framework, the curves were widely ignored by the architectural culture until a few years ago. This formal ignorance of wider design trends also stems from yet another ignorance – the technological one – of three-dimensional digital modeling software that made the smooth curves easily attainable by industrial designers, who used them widely on everything from consumer products to airplanes. Historically, the building industry was among the last to change and adopt new technologies; CATIA (Computer Aided Three-dimensional Interactive Application) had been in use for 20 years before it was discovered by Gehry's office (and is currently used by very few design offices).

Why this sudden interest and fascination with "blobby" forms? Three-dimensional digital modeling software based on NURBS (Non-Uniform Rational B-Splines), i.e. parametric curves and surfaces, has opened a universe of complex forms that were, until the appearance of CAD/CAM technologies, very difficult to conceive, develop and represent, let alone manufacture. A new formal universe in turn prompted a search for new tectonics that would make the new undulating, sinuous skins buildable (within reasonable budgets).

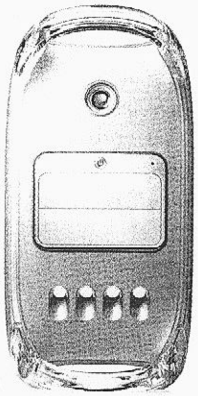
Inspired by the writings of thinkers ranging from Leibniz to Deleuze, as discussed earlier, some architects are exploring the spatial realms of non-Euclidean geometries, and some are basing their spatial investigations on topology, a branch of mathematics concerned with the properties of objects that are preserved through deformations. Thus, topological forms, such as torus (figure 1.11), the more complex Möbius strip (figure 1.12) and the Klein bottle (figure 1.13), have entered the architectural discourse; in some instances, projects are even directly named after their topological origins, such as the *Möbius House* (1995, figure 1.14) by UN Studio (Ben Van Berkel and Caroline Bos) and the *Torus House* (2001, figure 1.15) by Preston Scott Cohen.

The appeal of the topological geometries is in part aesthetic, in part technological, and in part ideological. Topology is ultimately about relations, interconnections within a given spatial context, and not about specific forms – a single topological construct is manifestable through multiple forms (and those forms need not be curvilinear). Topology is, in other words, less about spatial distinctions and more about spatial relations. Because topological structures are often represented by mathematicians as curvilinear forms, one might think that topology is synonymous with curved surfaces, a fundamental misunderstanding which is now more or less widely adopted. Thus, in (uninformed) architectural discourse, "topological" often means "curved" and vice versa.

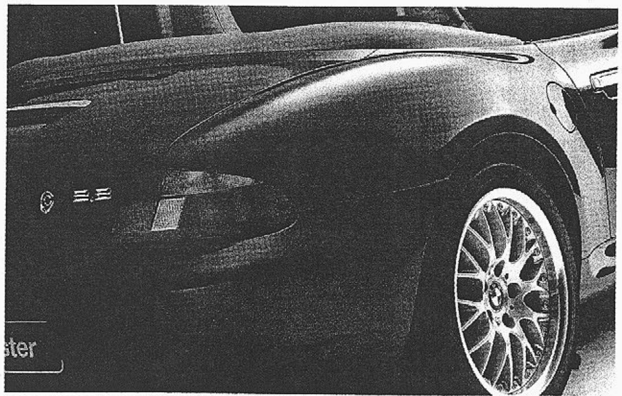
What should make the topology particularly appealing are not the new forms but, paradoxically, the shift of emphasis from the form to the structure(s) of relations, interconnections that exist internally and



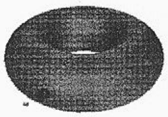
1.8.
Gillette Venus razor.



1.9.
Apple PowerMac G4.

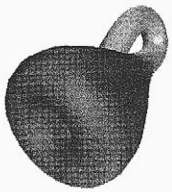


1.10.
Detail of *BMW Z3 Roadster.*



1.11.
Torus.

1.12.
Möbius strip.



1.13.
Klein bottle.

externally within an architectural project. Whether an architectural topological structure is given a curvilinear ("blobby") or a rectilinear ("boxy") form should be a result of particular performative circumstances surrounding the project, whether they are morphological, cultural, tectonic, material, economic, and/or environmental.

Admittedly, there is a considerable degree of novelty in complex, curvilinear forms (in spite of numerous precedents) and the new digital means of creating and physically producing and constructing them. The strong visual and formal juxtapositions created between "blobs" and "boxes" in traditional urban contexts, as is often the case, add to their "iconic" status, and their perception of being exceptional and marvelous.

The "boxes" and "blobs," however, should not be seen as architectural opposites, but rather as instances on a sliding scale of formal complexity, that could even coexist within the same building, as was often the case in the notable modernist projects of the twentieth century and in some recent projects of the digital avant-garde. It is important to note that dissimilar forms – "blobs" and "boxes" – are not necessarily oppositional and that formal differences are not that essential (this does not mean that all geometries are alike). In the future, as buildings become more "intelligent," it will be the information the surface transmits to and from the surrounding environment – and not its form – that will matter more.

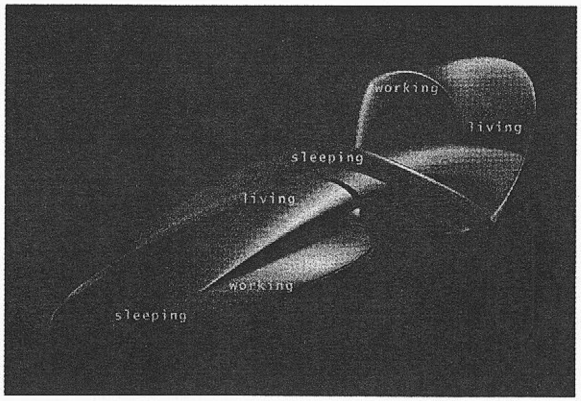
DIGITAL CONTINUUM

The use of digital modeling (three-dimensional) and animation (four-dimensional) software has opened new territories of formal exploration in architecture, in which digitally-generated forms are not designed in conventional ways. New shapes and forms are created by generative processes based on concepts such as topological space, isomorphic surfaces, dynamic systems, keyshape animation, parametric design and genetic algorithms – discussed in more detail in the following chapter.

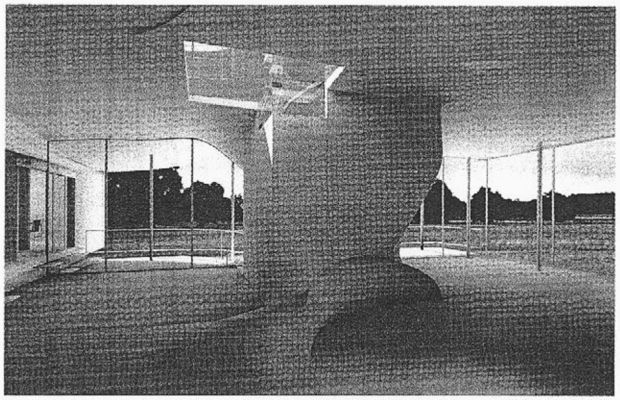
The changes are not purely formal. As noted earlier, by using digital technologies it is now possible to generate complex forms in novel ways and also to construct them within reasonable budgets. In other words, the processes of describing and constructing a design can be now more direct and more complex because the information can be extracted, exchanged, and utilized with far greater facility and speed; in short, with the use of digital technologies, the design information *is* the construction information.

This process-based change is far more significant than the formal change. It is the digitally-based convergence of representation and production processes that represents the most important opportunity for a profound transformation of the profession and, by extension, of the entire building industry. Much of the material world today, from the simplest consumer products to the most sophisticated airplanes, is created and produced using a process in which design, analysis, representation, fabrication and assembly are becoming a relatively seamless collaborative process that is solely dependent on digital technologies – a *digital continuum* from design to production. There is (the usual) one glaring exception – the building industry, which is bound to change as well, albeit very slowly, but change nevertheless.

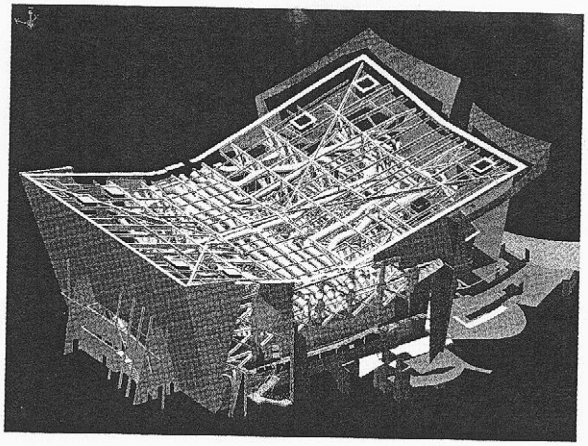
It is interesting to note that it is the complexity of "blobby" forms that is actually drawing architects, out of sheer necessity, back into being closely involved with the making of buildings, thus giving them, perhaps surprisingly, more control of the building process. This position of greater control over the construction stems from the digitally-produced design information becoming construction information through the processes of data extraction and exchange.



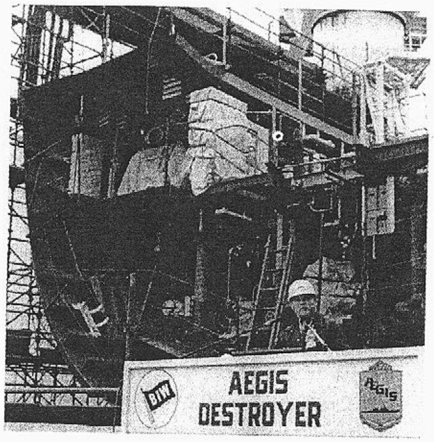
1.14.
Conceptual diagram of the *Möbius House* (1995), Het Gooi, the Netherlands, architects UN Studio / Ben Van Berkel and Caroline Bos.



1.15.
Torus House (2001), Old Chatham, New York, architect Preston Scott Cohen.



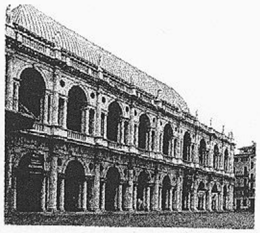
1.16.
Walt Disney Concert Hall (2003), Los Angeles, architect Frank Gehry: four-dimensional model of the concert hall volume.



1.17.
The Winston Churchill Aegis-class destroyer being built in the shipyard.

Thus, when applied to architecture, the use of digital technologies raises not only the questions of ideology, form or tectonics, but also the questions of the significance of information, and, more importantly, who controls it.

The ultimate goal becomes to construct a four-dimensional model encoded with all qualitative and quantitative dimensional information necessary for design, analysis, fabrication and construction, plus time-based information necessary for assembly sequencing. The result is a single, cohesive, complete model that contains all the information necessary for designing and producing a building (figure 1.16). This single source of information would enable the architects to become the coordinators (master builders) of information among various professions and trades involved in the production of buildings. By digitally producing, communicating and controlling the information exchanged between numerous parties in the building process, architects have an opportunity to place themselves in a central, key role in the construction of buildings and perhaps even regain the absolute powers of the medieval master builders. Whether they want to do that is a complex issue, as there are numerous social, legal and technical barriers to the complete restructuring of long-ago established relationships among the various building professions and trades.



1.18.
Basilica, Piazza dei Signori (1617), Vicenza, Italy, architect Andrea Palladio.

The main technological issue is how to develop an information model for the building industry that facilitates all phases of building design and construction, and that can synthesize information produced and exchanged between various parties. This was a long-standing and yet unattained goal of the computer-aided design research community.

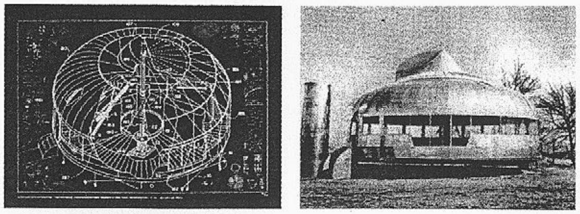
FROM SHIPS TO BUILDINGS

The processes developed by the shipbuilding industry over the past two decades to coordinate and connect design and construction are an example of the ways in which various parties from the building industry – architects, engineers, fabricators and contractors – could potentially integrate their services around the digital technologies of design, analysis, fabrication and assembly.

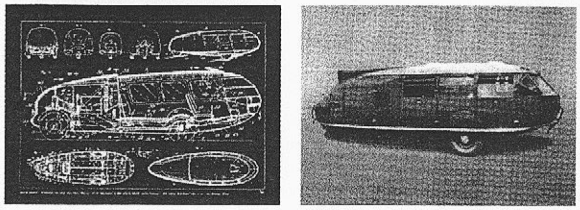
Ships, just like buildings, are objects of considerable technical complexity (figure 1.17). Just in terms of scale and use, there are sufficient similarities that warrant comparison (there are, of course, significant differences); it is precisely the similarities that offer opportunities for technology transfers. Both ships and buildings are large objects, with similarly complex service systems and interconnected spaces inhabited by people (in the case of passenger ships) and serving specific functions. Both have to respond to similar environmental influences and functional requirements. Both represent significant undertakings that require substantial financial and material resources. Both rely on similar principles, methods and processes of design, analysis and production.

Differences do exist, but do not negate the notion of similarity. Designing and building ships is, in fact, more complex. Structurally, ships have to resist not only gravity and wind loads, but also complex external hydrodynamic pressures. There are then additional stresses caused by propulsion systems and the motion of heavy loading equipment with which many transport ships are outfitted. Service systems in ships are more numerous, more complex, and need to operate with greater reliability. In short, ships have to perform in more ways than buildings.

Architects have relied historically on the building expertise of the shipbuilders. Palladio designed the roof of the Basilica at the *Piazza dei Signori* in Vicenza (1617, figures 1.18a–b) as an inverted ship hull and had to bring shipbuilders from Venice to construct it. This reliance on the building skills of shipbuilders has continued to modern times. Buckminster Fuller in his *Dymaxion House* (1946, figures 1.19a–b) co-opted the production methods from aircraft and shipbuilding industries. Fuller's design for the *Dymaxion Car* (1933, figures 1.20a–b) employed methods for framing and cladding modeled after the ship hull construction, and was fabricated by a shipyard in Bridgeport, Connecticut.



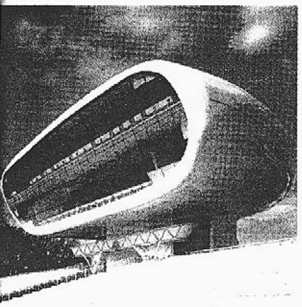
1.19a–b.
Dymaxion House (1946), architect Buckminster Fuller.



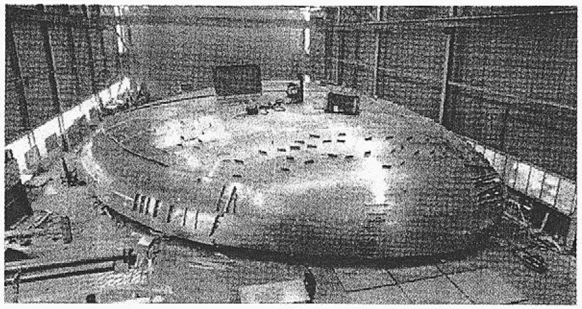
1.20a–b.
Dymaxion Car (1933), designer Buckminster Fuller.

Frank Gehry's *Guggenheim Museum* in Bilbao would not have been possible without the local steel and shipbuilding industry. A number of other recently completed projects, of widely varying scales and budgets, made creative use of shipbuilder's expertise. The *NatWest Media Centre* at the Lord's Cricket Ground in London (1999, figure 1.21), designed by Future Systems, was manufactured in a small shipyard in Cornwall, England (figure 1.22), and then transported in segments for assembly at the building's site. The shipbuilder's expertise in making aluminum yacht hulls was essential in designing and manufacturing the first semi-monocoque building structure from aluminum (figure 1.23). The conference chamber in Frank Gehry's *DG Bank* building (2000), Berlin, Germany, with its complex, curvilinear form, was clad in stainless steel plates produced and installed by skilled boatbuilders.

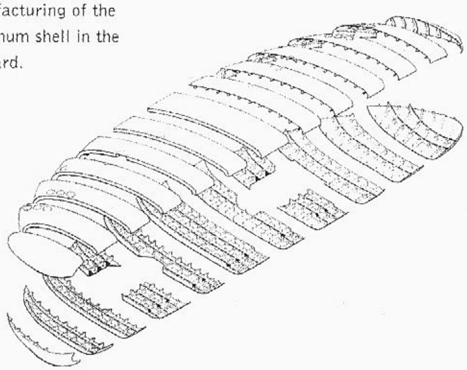
Architects and builders have much more to learn from the shipbuilding industry. Shipbuilders have almost entirely eliminated drawings from the design and construction of ships, and are working instead with complete, comprehensive three-dimensional digital models from design to production (figure 1.24). Similar process changes have also taken place in automotive and aerospace industries. As in the building industry, they all work with numerous subcontractors to produce and assemble a large number of components with a high degree of precision. If we look beyond the complex, curved geometries of cars, planes and ships, which are increasingly becoming common in architecture as well, and focus on the centralized three-dimensional digital model, which is at the core of the transformation in those industries, the opportunities for architecture and the rest of the building industry become too apparent to ignore.



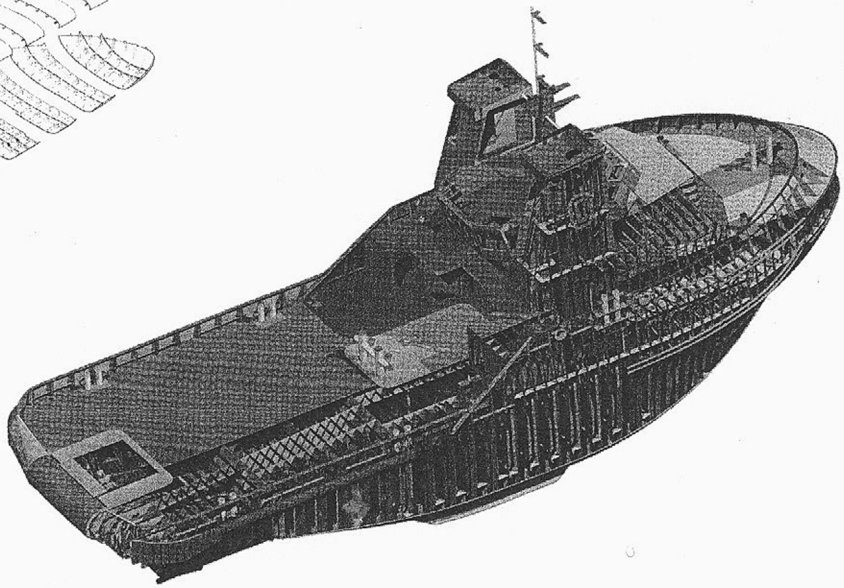
1.21.
NatWest Media Centre (1999), Lord's Cricket Ground, London, UK, architect Future Systems.



1.22.
NatWest Media Centre: manufacturing of the aluminum shell in the shipyard.



1.23.
NatWest Media Centre: the semi-monocoque aluminum shell was made from 26 segments.



1.24.
An example of a comprehensive three-dimensional model used in the shipbuilding industry.

LEARNING FROM OTHERS

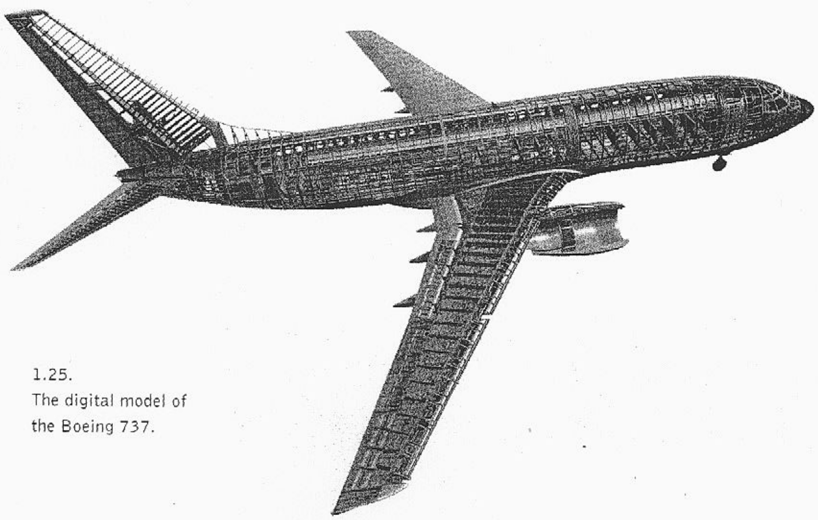
CAD/CAM systems, used by architects whose work is featured in this book, were actually developed for the consumer product industry. Animation software, such as *Softimage, Alias,* and *Maya,* were developed for the special effects needs of the film industry.

This interest of architects in the re-use of technology and methods from other industries is nothing new. Architects have always looked beyond the boundaries of their discipline, appropriating materials, methods and processes from other industries as needed. Historically, these technology transfers have been at the core of many successful advances, widening the scope of innovation and continually affecting the prevalent norms of practice.

Today, much of the innovation and change stems from the adoption of digital design and production processes based on CAD/CAM processes, and from new materials invented for, and widely used in, the product design, automotive, aerospace and shipbuilding industries.

The impact of the adoption of innovative technologies in those industries was profound – there was a complete reinvention of how products were designed and made. Today, various appliances, cars, airplanes and ships are entirely designed, developed, analyzed and tested in a digital environment, and are then manufactured using digitally-driven technologies. Boeing 777, "the first 100% digitally designed aircraft," is probably one of the best-known examples (figure 1.25).

Buildings have that same potential to be digitally conceived and produced. While the CAD/CAM technological advances and the resulting changes in design and production techniques had an enormous impact on other industries, there has yet to be a similarly significant and industry-wide impact in the world of building design and construction. The opportunities for the architecture, engineering and construction (AEC) industries are beckoning, and the benefits are already manifested in related fields.



1.25.
The digital model of the Boeing 737.

NOTES

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