Digital Fabrications
Architectural and Material Techniques
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Architecture continually informs and is informed by its modes of representation and construction, perhaps never more so than now, when digital media and emerging technologies are rapidly expanding what we conceive to be formally, spatially, and materially possible. Digital fabrication, in particular, has spurred a design revolution, yielding a wealth of architectural invention and innovation. How designs use digital fabrication and material techniques to calibrate between virtual model and physical artifact is the subject of this book.

In "Translations from Drawing to Building," Robin Evans expands on the inevitable separation architects encounter between drawing, the traditional medium of design, and building, the final outcome of their work. As he describes it, great invention occurs in this gap. Like traditional drawing, digital production is a generative medium that comes with its own host of restraints and possibilities. Digital practices have the potential to narrow the gap between representation and building, affording a hypothetically seamless connection between design and making. As with any design process, however, there are invariably gaps among the modes of making. And, as with all tools of production, the very techniques that open these investigations have their own sets of constraints and heighten particular ways of working. In the best cases, such as those shown in this book, innovation is born out of this fissure and advances design.

**Digital Fabrications: Architectural and Material Techniques** documents architecturally innovative projects realized through digital design and constructive processes. By way of several groundbreaking projects, it offers a brief and informative overview of the digital fabrication processes on a small scale. The means by which these projects were realized are within the reach of many practitioners and students. Here, the architectural project is a form of applied design research. These architects seek to leverage digital design and manufacturing for perceptual, spatial, and formal effect. The projects center on a mode of inquiry whose method of making ultimately forms the design aesthetic. Many of the practitioners teach as well and bring their interests into the classroom, offering the architecture student an opportunity to "do it" as well. For this reason, some excellent student projects have been included in the pages that follow.

The book is organized according to types of digital fabrication techniques that have emerged over the past fifty years: sectioning, tessellating, folding, contouring, and forming. Each section introduces the basics of the featured technique through a description of pioneering case studies, after which there is a collection of projects demonstrating how architects have manipulating the tectonic method for design. Naturally, the projects overlap the chapter definitions: many combine two or three techniques. The distinctions nevertheless structure and contextualize the work, so that the projects gain specificity in light of the others.

Lastly, this book aims to show both working methods and final results, documenting working drawings, templates, and material prototypes. Books on digital design tend to be highly technical, focused on documenting a few large building projects in great detail or else providing a visually exciting description of pioneering case studies, after which there is a collection of projects demonstrating how architects have manipulating the tectonic method for design. Naturally, the projects overlap the chapter definitions: many combine two or three techniques. The distinctions nevertheless structure and contextualize the work, so that the projects gain specificity in light of the others.

Architects have been drawing digitally for nearly thirty years. CAD programs have made two-dimensional drafting efficient, easy to edit, and, with a little practice, simple to do. Yet for many years, as the process of making drawings steadily shifted from being analog to digital, the design of buildings did not really reflect the change. CAD replaced drawing with a parallel rule and lead point, but buildings looked pretty much the same. This is perhaps not so surprising—one form of two-dimensional representation simply replaced another. It took three-dimensional—computer modeling and digital fabrication to energize design thinking and expand the boundaries of architectural form and construction.

In a relatively short period of time, a network of activities has grown up around digital fabrication. Inventive methods have emerged from project-specific applications developed by a handful of architects and fabricators. This inventiveness has to do in part with restructuring the very process of construction. The work of Gehry Partners and its associated firm Gehry Technologies has played a pivotal role in this regard. For them, digital integration was largely necessitated by the complexity of the building geometries.

Gehry's office began using CAD/CAM processes in 1989 to develop and then test the constructability of a building system for the Disney Concert Hall. As is usually the case in design, the process was iterative and nonlinear. Initially, physical models were reverse-engineered using a digitizer to take coordinates off a model's surface and import it into a 3D digital environment. The design subsequently moved back and forth between physical and digital surface models—physical models for aesthetics, digital models for "system fit." For this purpose Gehry's office adapted software from the aerospace industry, CATIA (Computer Aided Three Dimensional Interactive Application), to model the entire exterior of the concert hall. At that time the skin was conceived as...
stone and glass, and the office successfully produced cut-stone mock-ups, using tool paths for computer-controlled milling machines derived from digital surface models. In other words, the digital model was translated directly into physical production by using digitally driven machines that essentially sculpted the stone surface through the cutting away of material. This building method revealed that the complexities and uniqueness of surface geometries did not significantly affect fabrication costs, and it is this realization, that one can make a series of unique pieces with nearly the same effort as it requires to mass-produce identical ones, that forms a significant aspect of the computer-aided manufacturing that has since been exploited for design effect.

In 2002, Gehry Partners created Gehry Technologies to further develop Digital Project, a version of CATIA adapted and specialized for the unique demands of complex architectural projects. Digital Project integrates numerous aspects of the construction process, including building codes, and mechanical, structural, and cost-criteria aspects. Gehry Technologies now acts as a consultant to Gehry Partners, as well as to other architects, assisting with digital construction and management. The company is revolutionary in that it expands the role of the architect to include oversight of the building and construction-management process, much as it was in the age of the master builder. In addition to Gehry's, architectural offices such as Foster & Partners, Nicholas Grimshaw, and Bernard Franken are forging similar integrated project-delivery methods for large, complex projects. The focus of this book, however, is less on integration with the construction industry and more on another avenue of investigation taken by architects relative to digital fabrication: design-build experimentation at a one-to-one scale.

Recent Experimentation

We have experienced a fertile generation of architecture focused on the expanding possibilities of material and formal production. Digital methods have fundamentally shifted the discipline of architecture, and many paths now characterize this design arena. The architects included here are committed to employing the fluid potentials of technology to inform the design process and gear the evolution of their designs, while their experimentation is remarkable for being on a one-to-one scale. This approach recognizes what Michael Speaks has termed "design intelligence": "Making becomes knowledge or intelligence creation. In this way thinking and doing, design and fabrication, and prototype and final design become blurred, interactive, and part of a non-linear means of innovation." As it does for the large-scale work of Frank Gehry and others, the digital environment allows architects to take control of the building process. Several groundbreaking projects helped instigate this avenue of design research and shape a new generation of architects.

Within a span of about five years beginning in the mid-1990s, a host of projects appeared that clearly demonstrated the aesthetic merits of using digital devices. These include, among others, William Massie's concrete formwork, Greg Lynn's waffle typologies, and Bernard Cache's surface manipulations, all of which will be discussed at greater length in the chapter introductions. In seeing these projects, one cannot deny that, in addition to the professional, industrial, and economic benefits associated with CAD/CAM, building with the computer achieves unprecedented visual, material, and formal results. While the ingenuity of the following projects goes far beyond the outward appearance, the strong visual aspect nevertheless plays a significant role in sparking the imagination of young designers. These early projects are the achievement most notably of architects with material know-how and a will to experiment—traits that have now increasingly permeated design culture.

To move from design to construction, it is necessary to translate graphical data from two-dimensional drawings and three-dimensional models into digital data that a computer–numeric–controlled (CNC) machine can understand. This demands that architects essentially learn a new language. Some aspects of this translation are relatively automatic and involve using machine-specific software; others are very much in the purview of design. Decisions as to which machine and method to use must marry design intent with machine capability. It has therefore become necessary for digitally savvy architects to understand how these tools work, what materials they are best suited for, and where in the tooling process the possibilities lie.

Along these lines, architects have begun to couple form with method and revisit tectonic systems as a means to produce material effect. They seek to elevate standard building materials perceptually through nonstandard fabrication processes. Surfaces form buildings, and they can do so through smooth, undifferentiated expanses, or they can be constructed, textured, assembled, patterned, ornamented, or otherwise articulated. Digital fabrication opens onto a sea of possibilities. Punching, laser cutting, water-jet cutting, CNC routing, and die cutting are just some of the automated processes fueling this design domain.

Practically speaking, because buildings are made from a series of parts, their assembly relies on techniques of aggregating and manipulating two-dimensional materials. Computer fabrication has opened a realm for architects to perceptually heighten and make visible the nature of this accretion through constructed repetition and difference. The subtle variation of a system of elements, the transformation of recognizable materials, and the visceral response, no less, to viewing the result of intensive material evocations of abstracted images at mural scale—and all achieved through the aggregation of simple building materials.

The following chapters discuss architects who have honed digital-fabrication techniques on specific projects. Each discussion is accompanied by a detailed breakdown of the fabrication technique, providing insight into the recent projects featured in each chapter. These are projects that concentrate on the fertile realm of one-to-one-scale experimentation, which demands reciprocity between design and empirical innovation. The final outcomes hinge on the ability to reconcile the developmental shifts in material and working method. While the individual projects naturally take on different emphases, the work consistently elucidates provocative liaisons between digital production and making. Compelling design projects in and of themselves, they are both testaments to smaller-scale experimentation and the testing grounds for buildings to come.