Digital Materiality in Architecture

Fabio Gramazio and Matthias Kohler

We use the term *digital materiality* to describe an emergent transformation in the expression of architecture. Materiality is increasingly being enriched with digital characteristics, which substantially affect architecture's physis. *Digital materiality* evolves through the interplay between digital and material processes in design and construction. The synthesis of two seemingly distinct worlds—the digital and the material—generates new, self-evident realities. Data and material, programming and construction are interwoven. This synthesis is enabled by the techniques of *digital fabrication,* which allows the architect to control the manufacturing process through design data. Material is thus enriched by information; material becomes "informed." In the future, architects' ideas will permeate the fabrication process in its entirety. This new situation transforms the possibilities and thus the professional scope of the architect.

Sensuality of Digital Order

Digital materiality leads to a new expression and—surprisingly enough, given the technical associations of the term "digital"—to a new sensuality in architecture. Digital and material orders enter into a dialogue, in the course of which each is enriched by the other. *Digital materiality* is thereby able to address different levels of our perception. It is characterized by an unusually large number of precisely arranged elements, a sophisticated level of detail, and the simultaneous presence of different scales of formation. Despite its intrinsic complexity, we experience and understand it intuitively. *Digital materiality* addresses our ability to recognize naturally grown organizational forms and to interpret their internal order. Its expression is novel, but not alien. *Digital materiality* is not rooted solely in the material world and its physical laws such as gravity, or in material properties. It is also enriched by the rules of the immaterial world of digital logics, such as its processual nature or calculatory precision. Digital orders intensify the particularities of materials. Materials do not appear primarily as a texture or surface, but are exposed and experienced in their whole depth and plasticity. Even familiar materials—such as bricks, which have been known for over 9000 years—appear in new ways.

For the observer, a tension spans the intuitively understandable behavior of a material and the design logic, which may not be immediately obvious. The logic can be sensed, but not necessarily explained. This obscurity seduces our senses, sending them on a voyage of discovery and inviting us to linger and reflect.

Programming Constructions

Digital materiality is generated through the integration of construction and programming in the design process. We use the conceptional affinity of the produc-

tion of building components and computer programming. Today there are 700 million personal computers in use, in addition to 1.7 billion mobile phones, the latest generation of which are essentially mobile computers, plus countless other microchips built into various electronic devices. There is much that a computer cannot do; but certain things that it can do very well. It cannot substitute for the architect in the creation of designs, but is an invaluable design tool. A computer program describes the processing of data as a sequence of individual calculation steps. Similarly, the manufacturing of a building component takes place as a temporal sequence of individual steps in fabrication.

The sequence of construction steps—which step is first, which step follows—is usually not arbitrary, since they build upon one another and thus determine successive steps. This sequentiality is possibly the most radical analogy between construction, the knowledge and art of putting individual building components together as a built spatial ensemble, and computer programming. By mapping the *savoir-faire* of construction into a programmed process, we gain immediate control over digital fabrication. From now on, we are no longer designing the form that will ultimately be produced, but the production process itself. Design and execution are no longer phases in a temporal sequence—design sketches do not need to be converted into execution drawings anymore. The design incorporates the idea and knowledge of its production already at its moment of conception. In turn, the understanding of construction as an integral part of architectural design takes on greater significance. Digital craftsmanship thus continues the tradition of construction in architecture.

Does it make sense to formalize designs completely or partially in computer programs, to write down architectural logics, instead of drawing or modeling architectural forms? As architects we have had little experience of the unfamiliar "language" of programming. Many architects find it constricting, because it requires precise settings from the outset. To allow oneself to be limited by this precision would however be as pointless as capitulating before a freshly sharpened pencil. Because in reality, it is precisely programming that provides the necessary instrumental basis for liberating oneself from prevailing images of digital architecture production.

The practical, "hands-on" experience of programming demystifies digital technologies and fosters a liberated, autonomous approach to the computer. Through these practical skills we emancipate ourselves from existing CAAD tools and the passive application of their built-in paradigms and menu functions, which are mostly programmed simulations of traditional drawing processes. Instead, it is necessary to develop programming languages suitable for architecture that account for the fact that when designing, the exception is often just as important as the rule; or that hierarchical dependencies can change throughout the design process. Like spoken languages, programming languages and their paradigms are also subject to continuous change. Architects can intervene in this evolution by developing their own dialects that take up the subjects of construction, materials and space.

Building with Robots

The robot connects the digital reality of the computer with the material reality of built architecture. The simple insight that architecture is largely built through the addition of parts or the aggregation of materials allows us to advance digital fabrication. As we accumulate materials precisely at the point where they are needed, we can weave form and function directly into building components, and are not limited to the design of their surfaces. The industrial robot enables us to implement this additive principle on an architectural scale.

Worldwide, there are currently more than a million multifunctional robots in use, predominantly articulated-arm robots, and their numbers have risen steadily since the 1980s. The industrial robot has become standard in automation precisely because, like the personal computer, it has not been optimized for one single task but is suitable for a wide spectrum of applications. Rather than being forced to operate within the predefined parameters of a specialized machine, we are able to design the actual "manual skills" of the generic robot ourselves. We do not just steer it to a particular point in space, but also determine its capacities for physical manipulation and processing. By defining the robot's hand—also called the "end-effector"—and determining its movements, we teach the robot a desired type of construction. We teach it to register its surroundings through sensors, and to affect the environment through the robot hand. The robot thus connects the world of immaterial logic with that of material construction in the most direct way.

One might ask whether and why architects should use industrial robots or even computer programming, tools that can appear architecturally irrelevant. In our opinion it is crucial that architects, now and in the future, choose their means consciously and master their tools. Accessing these generic tools enables architects to create their individual design instruments and thus generates diverse forms of expression. They will thereby be in a position to answer contemporary demands with contemporary means and concepts. The fact that no new conventions have arisen in the design and building world in recent decades shows that built architecture has so far benefited only marginally from digital technologies. Through its link to the tradition of construction, *digital materiality* changes the culture of architecture, both in its expression and in its productive capacity. Architects are predisposed to forge links between technology and the built environment.

Variation and Multiplicity

Through *digital materiality*, architecture becomes increasingly rich and diversified. This diversification affects different scales, from materials and building components to spatial sequences and loadbearing structures, to houses and urban development zoning. Variation emerges as it becomes possible to design large numbers of elements in differentiated ways using digital means. Such designs would have made very little sense before the availability of computers and digital fabrication, but their realization has now become a matter of course. The potential of digital design and production processes can best be exploited where a very large number of parts must be combined. Here they extend the architect's human capabilities; they improve his or her overview and multiply the possibilities for control of the design. In order to design a façade with hundreds of windows, for example, or a large building volume with mixed forms of housing, the architect has until now had to turn to the classical manual aids such as the grid, or to develop repeatable types. Repetition makes it possible to organize variation manually, to control and construct it with simple procedures. With the rise of *digital materiality*, the frontier between system and variation is renegotiated. As a consequence, architectures develop that place diverse, complementary logics in relation to one another.

In the digital age, our concept of serial repetition, which was the product of industrialization, is being transformed much in the same way as the opposing romantic conception of the "natural" uniqueness of craftsmanship. A language of diversity is emerging that gains its identity through the design of processes rather than final forms. In these processes, different elements combine adaptively into a coherent, harmonious whole. The multilayered, sometimes complex arrangements that constitute the aesthetics and expression of *digital materiality* may be reminiscent of the organic structures of the animal or plant world. But this comparison, though appealing, falls short: it masks the fact that digital systems do not arise out of biological conditions, and are not rooted in them either. The digital is an independent cultural achievement resulting from centuries of human engagement with logic. Precisely for this reason the computer is a fascinating instrument, one that motivates a designer to exploit the human potential for associative thinking in order to discover new organizing principles, and establish new relations with the built environment. The multiplicity that attends a design of digital processes seems novel, but not entirely strange, since it refers to familiar experiences of perception. The forms in all their variety appeal to the senses while continuing to assert their distinctly inorganic derivation.

Designing Processes
Digital materiality leads us from the design of static forms to the design of material processes. In doing so we give up geometry, whether drawn or modeled, as architecture's actual building plan and its primary basis for design decisions. Instead, we design the relationships and sequences that inhabit architecture and that emerge as its physical manifestation. But once we begin to invent such material processes, a new way of thinking about architecture reveals itself. It is a conceptual way of designing with architectural parameters, conditions, relationships, and degrees of freedom.

We ask ourselves: which parameters determine the design, and which do not, but still have an effect on its form and function? Using digital logics we define relationships and intentions in the form of rules. We weigh the influences that the design-generating factors have on each other. Through the medium of programming we can model complex decision processes, checking and refining them iteratively. Architectural expression thus takes on a different character, because new conventions emerge in the medium of programming.

In this way of conceiving architecture, processes are not mere metaphors for a process-oriented approach to design, but are concrete sequences of operations, procedures that have to be designed. These procedures are determined, they have a beginning and an end. They produce directly tangible results, the qualities of which can be tested intuitively and analytically, as we can with sketching or building models. We exploit the advantages of programming by integrating them into our traditional methods of design.

When architecture becomes the design of material processes, we no longer have a static plan in front of us, but a dynamic set of rules. We design a behavior. A set of rules like this has the advantage that even very fundamental interventions can still be implemented even late in the process, as long as they are anticipated as an open parameter in the design. We can work in a determined manner, but with open conditions that will be set only at an advanced design stage. This even offers the possibility of intentionally ceding partial control over selected design parameters to customers or partners. We thus design architecture

itself as an open system with different active participants. This type of design, detached from a drive towards form, does justice both to the ever more complex conditions of our profession, and to the material substance of architecture, including its sensual qualities. Designing architecture as processes thus strengthens the central role of the architect as proactive author.

The Changed Physis of Architecture
Design using digital technologies interests us because it delineates the boundaries of rationality and of predictable reality. In our opinion, designing architecture is not an activity that can be reduced to performance optimization—it is a multifaceted cultural production. It is precisely *digital materiality* that shows us quite plainly the essentially human dimension and quality of this production. Under conditions of apparently extreme rationality, which range from computer programming to fabrication using the industrial robot, we discover associative, manifold and tangible ways to think, build and experience architecture with all our senses. We realize that the probability of encountering discoveries and innovations is increased, not limited, by using rational means of design and fabrication. Our senses are taken by surprise, as we cease designing by means of visual representations intended to be converted into buildings. Architectural expression is instead produced only in the course of the design and materialization process, and takes on its character little by little. *Digital materiality* changes the *physis* of architecture; changes the *Gestalt*, and ultimately the image that society has of architecture.