CONCLUSION

From the early ventures in primitive user interaction with the OML mp3X and the formation of the Digital Forming® technology and UC3D™ co-creation platform, I have been working on the development of new ways and methods to embed personal user data and values into designed objects.

In Digital Forming®, O00 software allows designers to build an interaction experience that is delivered to the user using the C00D user interface. This new design method allows designers to design virtual, production-ready products with a user interaction to experience a setup that enables the users to personalize and co-design the products better for themselves.

My belief is that this ethos and design method should be adopted by the industry and further developed into a new industrial reality. I think that brands and manufacturers need to stay “in touch” with their user communities, demonstrate greater care and responsibility, and be better connected with their user communities (formerly called “consumers”). It is a move from a consumer to a user to a partner.

Consumers should be perceived as partners who participate in an exchange of information that, with time, will result in better products, with less waste and consumption. The exchange of information can be active or passive. This new industrial reality will provide a live stream of bidirectional information and a better way to connect directly with the users. In the end, it is all about owning less but with more value and enhanced performance.

ACKNOWLEDGMENTS


NOTES

1 Selective laser sintering (SLS) technology provides the manufacture of a single skeletal-like structure, a feat unachievable by any other manufacturing process at that time. The fundamental aspects of “no assembly,” together with the instant digital materialization of 3D geometry, reinforced my practice and were used as a foundation for further innovation and software development.

2 With thanks to my business partner Sia Mahadavi, formerly Compose Matters, today Within Autodesk, and to our sponsors EOS, The Odeon Chair is part of the Design Museum Barcelona’s permanent collection.

3 With thanks to our sponsors: 3T RPD, our manufacturing partners, for the SLS digital manufacturing and post processing, and Altair Inspire for the mathematics and FEA simulation. The Femur Seat is part of the Design Museum London’s permanent collection.

4 Fused Deposition Manufacturing.

5 With thanks to KIT and D-Lab, Kyoto, Japan. The bio-material, macromolecular science, and project development was done in collaboration with KIT professors Julia Cassim, Dr. Yoko Okada (bamboo microstructure and bio-material science), Dr. Yukihiro Ninomiya (microscopic scanning and macromolecular science), Dr. Kazuaki Masutani (PLA bio-material science), and Tomohiro Isoe (AMI and 3D printing).
In the last 25 years, we have digitalized almost every domain of our lives. The beginnings of this radically new development, which has changed the way we experience our world and is right now accelerating through our ability to handle big data by using artificial intelligence techniques, coincides with our architectural education. In the early 1990s, computers had yet to become consumer products, but were already found in universities and research institutions such as ETH Zurich. As architecture students, we had access to the computer labs and could experiment with these expensive and powerful machines, which not only visualized architecture in three dimensions and real time but – and this was the really exciting property – could be programmed. Belonging to the generation that learned programming in the mid-1980s in a playful way, with toys such as the Commodore 64, we believed that these machines were heralds of a paradigm shift that was soon to happen. We felt that the power of computation for architecture would go beyond the mere drafting and modeling of geometry; although the concept of computational design was not yet established, the possibility of moving beyond representation, toward the generation of form, was extremely seductive. While Greg Lynn was demonstrating the use of sophisticated techniques such as animation and kinematics in architecture, we felt that writing computer code, as an intellectual activity, was very close to designing architecture. Both implied the creative deployment of rules and logic, order and relationships, hierarchies and sequences. While we were excited by this relationship and were convinced that this new technique could be deployed in a truly creative manner and would allow us to do radically new things, we observed that these two worlds were interested in, physical and digital architecture, were dramatically drifting apart.

DIGITAL MATERIALITY

While mainstream architectural practice was ignoring the challenges of digitalization, a new generation, to which we belonged, was enthusiastically embracing the new possibilities offered by the incorporation of the digital into architectural practice. This almost ideological divide between the material production of physical architecture and the manipulation of data through code, the two worlds we equally loved, felt artificial and unnecessary to us. In our minds, the question should not be addressed in terms of "either/or" but ought to be "as well as." We were striving for the establishment of a direct link between the digital and the physical realm in order to create what a few years later we would define as "Digital Materiality." By the end of the millennium, when we founded Gramazio Kohler Architects, CNC machines, mechanical devices controlled by digital information, were able to establish this direct link. They bridged the gap between the hitherto separated worlds of data and material, not just in conceptual but very practical terms and thus allowed the reach of the digital to extend into the physical dimension of architecture. Suddenly we were no longer limited to the manipulation of geometry in the computer but could eventually interact directly with the real world and focus our efforts on the materialization of the digital. Moreover, we believed that the potential of this process would definitely lead to the discovery of new and unexpected architectural qualities. In fact, the synthesis of digital and material properties would affect architecture in the same radical manner as the new physical building materials, such as steel, glass, and reinforced concrete, had done in the nineteenth century.

mTable

In these terms, one of the first projects we realized in our young practice was a speculative investigation of the potentials and challenges of parametric design and mass customization. mTable is a table (Figure 9.1) that can be designed by the customer on a mobile phone (Figure 9.2). On a custom design interface, the user defines points on the bottom surface of a table board and, with the pressure of his or her thumb on the joystick, deforms the surface by applying force to them (Figure 9.3). If the size of deformation leads to the intersection of two surfaces (top and bottom), a hole with a very thin and elegant
The CNC milling machine produces the table "landscape" directly from the data transmitted from a mobile phone.

edge appears in the table. Next, after having defined the dimensions, materials and color, the user sends the parameters of his or her design to our server, where our design algorithm generates a double-curved surface corresponding to the geometry of the table. Finally, a CAM software extracts the fabrication information from the geometry and sends the machine code to a CNC router that mills the surface in a massive wooden board (figure 9.5).

Around this time (the early 2000s) many people and companies were experimenting with online configurators which would allow their clients to customize their products according to their personal wishes. By short-cutting the process from the design at the lowest possible resolution of a 176 x 208 pixels mobile phone display directly to the highest thinkable definition of physical material and by eliminating the need — and possibility — of any form of human intervention along this workflow, we radicalized the question of mass customization and design democratization. We opted for a mobile phone as the design interface because we did not want the user to perceive it as a computer but as a personal accessory. In 2002, the Nokia 7650 was in fact the first mobile phone allowing third party developers to run custom applications on it and, in an irony of history, Nokia never understood the potential and implications of this invention until Apple released the iPhone in 2007 and disrupted the market with the concept of the App Store. However, what made mTable radically different, ambiguous, and ironic at the same time was the fact that it was not limiting the customer’s freedom to the definition of dimensions and material but extended it to the domain of form. By doing this, we deliberately immolated the holy grail of designers: the definition of form. Moreover, by allowing the customers to create holes in the surface of their table, we delegated the responsibility for the basic functionality of this simple piece of furniture to design nonprofessionals.

The eight mTables that we produced and sold, as well as the hundreds that potential customers designed (figure 9.5) but never ordered, are all very sophisticated and formally complex objects. Some of them are elegant and beautiful, others rather irritating and clearly dysfunctional. They are all different but still surprisingly similar because they share the same design genome. In fact, although the customer cannot emancipate himself or herself from the distinct rules set by the designer of the algorithm, the customer becomes a co-author in his or her own right. mTable is a statement about the complex relationship of freedom and control in design. In a playful and ironic way, it explores the potentials, limits, and implications of customization, both for the customer and the designer. While the former needs clear boundaries, the latter should not fear but embrace parameterization as an opportunity. As mTable demonstrates, parameterization does not necessarily imply "loss of control." If implemented in a proactive and self-aware manner, parameterization can move design beyond the static definition of form toward the authoring of processes and rules that generate controlled but still flexible formal results.
PARAMETRIC DESIGN AND COMPUTING

When we try to illustrate the role and significance of parametric thinking for our own architectural practice, we normally use a small private residence we designed and built in 2009 in Riedikon, Switzerland, as it offers two aspects where parametric processes play an interesting and critical role.

The pointed geometry of the volume (figure 9.6), which results from two cutting operations on a simple rectangle, is at first glance irritating and needs some explanation. As the client actually is building the new house in its own garden, the first cut in the rectangle preserves the beautiful view on the nearby lake to his former house (figure 9.7). The angle of this cut negotiates between the generosity of the panorama and the size of the new house. The second cut allows parking behind the new house while keeping the garden facing the lake as generous as possible. Its angle directly depends on the minimal turning circle of a car accessing the property. This design strategy, which follows clear contextual parameters, could easily be formalized in an algorithm and the meaningful solutions calculated by a computer. However, we would never do so because the design space is simple enough to iterate the problem manually, in our head or on paper, fast enough to identify the ideal solution in an efficient manner. This is what we traditionally call “the design process.”

While the starting point of the second aspect, the design of the façade, is almost identical to the first one, its consequences for architectural practice are radically different. Here, 315 timber planks are mounted perpendicular to the façade a distance of 20 cm from each other, enveloping the whole circumference of the house (figure 9.8) and making it appear, in perspective, like a windowless timber barn (figure 9.9). From the interior, the contrast
between the front side of the thin planks in the foreground and the bright background causes the human eye to trip. However, this becomes apparent and to cancel out the façade (figure 9.10).

However, modulating the planks’ section relative to the glazing dramatically affects the width of the visual field. A simple set of parameters, such as depth, length, position, and inclination of the planks’ cutout (figure 9.11), governs the subtle visual effects of this sophisticated “perception engine” and allows the architect to control the nature and intensity of the visual relationship between the interior spaces and the surrounding environment. Yet, while the parametric logic is perfectly simple, its application to such a large number of elements, the geometry of which is different but mutually dependent, makes the development of a coherent design virtually impossible. Although manually modeling the geometry of the individual planks is theoretically possible, it would represent a Sisyphean undertaking. As designing implies iterating through multiple possible solutions, the only way to overcome this impracticality is to write a computer program, which permits fast computation and the visualization of specific solutions.

However, being able to compute the design information for the planks would still be irrelevant without a clear and robust strategy for their fabrication. To manually cut the 315 different profiles, or to manually program a machine to do so, would be inefficient and probably too expensive, at least in the context of a modest house. On the other hand, if we use an appropriate CNC machine, we can directly use the previously generated design information to guide a cutting head along each single plank by simultaneously varying its height and inclination. Because such an automated workflow does not need any manual intervention other than feeding the parts into the machine in the right order, the additional costs are, at least in relation to the architectural benefit, marginal.

Designing always involves parametric thinking. However, this becomes evident and computationally relevant only under very specific conditions. Recognizing this relationship is key to a meaningful discussion of the potential of computational design for architectural design that moves beyond its common association with spectacular form and iconic architecture. As the façade of this simple house demonstrates, the conceptual combination of parametric design with digital fabrication radically extends the traditional design tools and enriches architecture by fostering the emergence of a new kind of materiality.

HUMANS AND MACHINES

After having illustrated our general understanding of computational design and digital fabrication by means of these two rather different projects, we will introduce the industrial robot, which we selected as the hardware of choice to pursue our research on “Digital Materiality” in architecture at ETH Zurich. This iconic machine, which in the second half of the twentieth century has dramatically shaped car manufacturing and industrial production (logic in general), possesses a number of characteristics that make it interesting in architectural applications. First, the industrial robot is large, robust, and, as a mass-produced device, comparably affordable. Second, although in the past its field of application was mainly serial production, the industrial robot is fully programmable and thus not dependent on repetition. Third, and this is the most interesting property, the industrial robot’s nature is generic. When delivered, it comes without a tool in its hand, expressing the possibility as well as the need for process customization. This last property makes the industrial robot the ideal companion of the architect, as its openness extends the design to the very definition and customization of the fabrication process.

The first experiment we did back in 2005 was set up as a proof of the concept, whereby we equipped the industrial robot with the simplest
tool possible, a hand, allowing it to grip the most basic architectural building element ever: a brick. This simple setup, which we can describe as a "pick-and-place" operation, becomes very powerful when the "placing" can be different for each brick (figure 9.12). Suddenly what held true for the human mason, namely, the direct dependence between the complexity of the bond and the efficiency of the building process, fails to make sense. The industrial robot does not need to measure but simply "knows" its position in space at every given moment in time and as such, as in a low-resolution 3D printing process, complexity no longer has an impact on the execution time.

Before addressing the architectural potential of this paradigm shift, we would like to discuss its impact on the relationship between human and machine. While in pre-industrial times the artisan not only mastered but also was continuously refining the use of tools, which he – and it was a he – normally personally owned, the Industrial Revolution of the eighteenth century radically disrupted this relationship. Tools became machines, complex mechanical devices that got bigger and so expensive that they were only affordable to capitalists. At the same time, following the principles of Fordism, the division of the production process into several simple steps alienated the human from the process of making and eventually turned the craftsman into a factory worker. This separation of labor and capital, which starts with the industrialization of weaving during the eighteenth century, created a deep divide between humans and machines, whereby the latter expose humans to the permanent risk of becoming the victim of further automation steps. While in such a historic perspective this deep distrust is comprehensible, we argue that the advent of the numerically controlled machine necessitates a reassessment of the human-machine relationship.

In fact, this new type of machine needs humans as much as humans need it. In the case of our proof of concept, the machine needs instructions from a human while the human needs the machine's indifference to complexity in order to be able to materialize the design. At once, historic antagonists turn into strategic partners in a process to which each one contributes with their unique strengths, which fortunately are the other's weakness (figure 9.13).

In terms of programming, the fabrication of a brick wall can be described by two "nested loops" in which simple rules are repeated a specific number of times. This very basic algorithm does no more than what the mason would execute if asked to build a brick wall with a running bond. He would just take a brick, place it next to the previously placed one and then repeat this action until the wall reaches the desired length. Then he would move to the next row, shift the first brick by half in order to assure proper bonding and start over again until the wall reaches the desired height. However, while a mason can easily perform this simple and repetitive process, as soon as we add some simple calculations to the algorithm, which modify the position or rotation of each brick, the execution complexity explodes. What previously was just the repetitive execution of a simple rule turns into the sequential placing of bricks according to an endless list of complex spatial information. However, what is difficult for the mason is easy for the robot, whereby this division of labor is nothing else than perfect team play that can directly connect the human act of designing with the mechanical process of building.
20,000 BRICKS

This early proof of concept prototypes directly led to an architectural commission of a 400 m² brick façade for a vineyard in Filis, Switzerland (figure 9.14). Board & Deplazès Architects designed the project, and it was ready under construction when they invited us to design and build its façade. The initial design proposed a simple concrete skeleton filled with bricks. The masonry acts as a temperature buffer, as well as filtering the sunlight for the fermentation room behind it. The bricks are offset so that daylight penetrates the hall through the gaps between the bricks. Direct sunlight, which would have a detrimental effect on the fermentation, is, however, excluded. Polycarbonate panels are mounted inside to protect against wind. On the upper floor, the bricks form the balustrade of the roof terrace.

While we had to solve many technical questions to manufacture 72 façade elements, which were transported to the construction site by lorry and installed using a crane, the main challenge was indeed the development of a suitable design strategy. We were practically able to design and construct each wall to possess the desired light and air permeability, while creating a pattern that covers the entire building’s façade. According to the angle at which they are set, the individual bricks each reflect light differently and thus take on different degrees of lightness. Like pixels on a computer screen, they add up to a distinctive image and thus communicate the identity of the vineyard. In contrast to a two-dimensional screen, however, there is a dramatic play between plasticity, depth, and color, depending on the viewer’s position and the angle of the sun.

As technology is neutral, the challenging question is how to make use of the unconventional degree of freedom and generate the information needed for the placement of the bricks in space. Instead of resorting to a pictorial strategy, which could have depicted the company’s logo on the façades, we decided to design a generative process. We interpreted the concrete frame construction by Board & Deplazès as a virtual basket and, with digitally simulated gravity, filled it with abstract, oversized “grapes” of varying diameters. Then we looked at the result from all four sides and transferred the digital image data to the rotation of the individual bricks. On the built façades, the visitor discerns gigantic, synthetic grapes, which were virtually inside the building as we developed our design. On closer view—in contrast to its pictorial effect at a distance—the sensual, textile softness of the walls dissolves into the materiality of the stonework. The observer is surprised that the soft, round forms are actually composed of individual, hard bricks. The façade appears as a solidified dynamic form, in whose three-dimensional depth the viewer’s eye is invited to wander. In the interior, the daylight that penetrates creates a mild, yet luminous atmosphere. Looking toward the light, the design becomes manifest in its modulation through the open gaps. However, the architectural implications of this brick façade are more elaborate and diverse than those of a two-dimensional image. To the human eye, able to detect even the finest difference in color and lightness, the subtle deflection of the bricks creates an appearance and plasticity that are constantly changing along with the movement of the observer and of the sun over the course of the day.

THE LINE OF NEGOTIATION

Two years later, we radicalized this experience by designing an installation for the Swiss contribution to the 11th Venice Architectural Biennale. We proposed a 100-meter-long, robotically fabricated brick wall to run as a continuous ribbon through the Swiss pavilion (figure 9.15). With its looped form, the wall defines an invariable central space...
and an interstitial space between the brick wall and the existing structure of the pavilion. The first conceptual innovation was to transport the robot instead of the individual prefabricated parts (figure 9.16). By reactivating the concept of the field factory and producing in situ, we gained a huge degree of formal freedom as the transportation costs no longer related to the geometry of the elements.

The radical difference from the winery façade was in the chosen design strategy. In order to avoid any additional elements, we activated the form of the elements by inscribing the structural logic directly in the parametric engine generating the design. We gave the wall a “structural behavior” which would guarantee its feasibility, and we defined which additional properties would be non-negotiable. The course of a single, continuous curve carried all the generative information necessary to determine the design. This curve functioned as a conceptual interface, which enabled the curator of the exhibition to negotiate between the individual spatial requirements of the exhibited groups. As the curve (figure 9.17), which we named “the line of negotiation,” was, for whatever reason, modified, the three-dimensional, undulating wall could be automatically re-generated. Its complex shape was determined by the constructive requirement that each single, 4-meter-long segment should stand firmly on its own. Where the course of the generative curve was almost straight, meaning that the wall elements could possibly be tipped over by the visitors, the wall’s footprint began to swing, thus increasing its stability (figure 9.18). Each curvature in the lower layers was balanced by a counter-curvature in the upper layers, thus giving the wall its architectural expression. In addition, the 15,000 bricks were rotated according to the curvature—the greater the concavity of the curve, the more the bricks were rotated. The wall thus adapted its shape according to its course, widening and narrowing, producing tension-rich architectural spaces.

We created a parametric design system, which involved the user, in this case, the curator of the exhibition, in the design process. In a strong analogy to the mTable strategy, we separated the design into hard and soft parameters, where the hard ones guaranteed the quality of the design, both in functional as well as in aesthetic terms, while a co-author would be free to customize the soft ones until shortly before the production started. This freedom is of particular value in an exhibition context, where the curator has to ideally stay open and flexible to changes in the spatial layout until very late in the process.
CONCLUSION

In summary, the question of where authorship manifests itself in contemporary digital design practice and how this relates to the alleged openness and democratization of design is key to many of our architectural and research projects. The profound structural change ahead of us not only will overcome the nonlinear relation between complexity and costs that has governed the logic of twentieth-century architecture, but also will facilitate the production of difference, which is a prerequisite to a successful industrialization of the building trade. We believe that the architect should spearhead the development of a novel digital building culture, yet this movement will have to involve all stakeholders in the building industry and eventually reshape the relationship between humans and their tools with the aim of making the machines our best allies.

NOTES