Keynote Address

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Towards a Digital Materiality*

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The digital revolution had an unquestionable impact on contemporary architecture; it has changed the ways in which architecture is conceived, built, mediated, and used. This evolution has only just begun, and it is still too early to predict the long-term consequences for the architectural discipline. Already, a whole spectrum of polemical views on digital technology — ranging from unbridled enthusiasm, at one extreme, to reactionary fear, at the other — have dominated the debate and divided the professional community. Due to its intangible nature, the digital realm is generally mis-construed as being antagonistic to the analogue or physical realm. Our intention is to unite these seemingly opposing realms.

Since its foundation in 2000, Gramazio & Kohler has been exploring digital realities within architecture, working with the firm conviction that the digital paradigm will inevitably redefine the discipline. Human intelligence allows architects to take design decisions on complex issues using associative capacities and experience, yet unlike computers, humans are unable to process large amounts of discrete data. By understanding the fundamental concepts of digital logics and mastering its processing techniques, we expand our capacity to integrate information into the design process without losing control over it. The architect is engaged in the selection of relevant architectural parameters and the definition of subsequent rules and processes. The construct is created by a system that is entirely defined by the architect.

One of the most radical consequences of the digital revolution is the computer-controlled fabrication machine. As decades of artificial intelligence research have shown, a physical body is a precondition for every kind of intelligence. Architecture cannot be reduced to a conceptual, geometric, or mathematical phenomenon. Artificial intelligence in architecture can only manifest itself through a tectonic logic and a physical, material body. The application of a fabrication machine in architecture allows a direct coupling between information and construction. In digital fabrication, the production of building parts is directly controlled by the design information. This seamless link between data and material, design and building, dissolves the apparent incongruities between digital and physical realities and allows a new constructive understanding of the discipline. Thus, these issues are the primary focus of our research in the Department of Architecture at the Swiss Institute of Technology (ETH) in Zurich.

Robotic Additive Fabrication

In order to investigate the consequences of informing designs with the logic of physical materials and vice versa, we opened a research laboratory at ETH for the digital fabrication of full-scale prototypes and non-standard building parts (DFAB). For our first experiments, we chose a standard industrial robot. It extreme flexibility, both in terms of the software that controls it and its physical capacities, allows us to program its movements and design the actual construction tools it selects for operations. For us, it is a veritable “personal computer” for construction. With this robot, we investigated the logic of additive fabrication, using the most elementary architectural building block — the brick. The resulting projects, described below, confirm that digital logic, both in design and fabrication, will lead to profound changes in architecture, blurring and ultimately dissolving the boundaries between analogue and digital realities. We stand at the very threshold of an exciting development and believe that we should, as architects and authors of design information, actively lead this process towards a new, contemporary, and integral understanding of architecture that is relevant to our age.

Mtable

The mtable series project, completed in 2002, enabled us to examine the consequences of customer interaction when designing non-standard products. In the process, interrelated questions emerged: How much responsibility is the customer able to assume? How much does he or she want to assume? Who ultimately is the author? To what extent does the co-designer identify with the product? What consequences does this development have on architecture?

With Mtable, we created a table (figure 1) that customers can co-design. Modern communications and digital production technologies were used for its customized design and fabrication: we declared the mobile cell phone to be a personal design tool, and examined how it can be utilized to assist the individual to co-design his or her physical environment.

The design principle is simple. Customers choose the size, dimensions, material, and color of the table from their cell phone display (figure 2). Next, they place deformation points on the underside of the table and “press” them (figure 3); these points then “break through” the surface, creating holes with extremely thin edges, turning the table’s top and underside into two distinct “landscapes” (i.e. topographies). The program on the cell phone then verifies that the table with holes is structurally feasible.

Using a mobile phone is an enjoyable and inventive way to control the future physical shape of the table. The phone display’s low resolution and a deliberately simplified interface make customers focus on the most essential design features. As soon as the customer is satisfied with the design, he or she transmits the parameters that define the table as a simple series of numbers to the web-based platform at mtscape.com, where the designed table can be seen in high resolution, and compared with the designs by other customers (figure 4). Following the placement of the order, the table is cut by a computer-controlled milling machine...
The miföble project changes the task of designing form to defining the rules of a design system. The design concept and the formal consequences are carefully embedded in the software that provides a framework within which the customers can develop their own creative strategies, thus giving them control over the ultimate outcome of the design – the form. By deciding for themselves if and where the holes are placed, they assume partial responsibility for the aesthetic appearance, and functional efficiency of the tables. The designer, however, still retains control over which decisions are delegated to the customers and how freely they can intervene. This blurs the distinctions between designer and the customer, as the customer becomes a co-designer.

"The World's Largest Timepiece"

The project for the Christmas lighting on Bahnhofstrasse in Zurich, Switzerland (2005), is based on a winning entry in a competition that called for a contemporary interpretation of the lighting installation designed over thirty years ago by Willi Walter and Charlotte Schmid. Their project was described as “distinctive, generous, unique” and these were qualities the new design was naturally expected to incorporate.

We designed a continuous band of lights with a dynamically changing pattern (figure 7). The main premise behind the time-based light installation is that light is not static, but fundamentally dynamic in nature. Light can now be used as a highly flexible and interesting information medium, due to contemporary digital technology that can provide control over its intensity. By changing its appearance during the Advent season, “The World’s Largest Timepiece,” as the installation is called, accentuates the passing of time and creates a constantly changing “lightscape” on Bahnhofstrasse, and provides every visitor with a truly unique experience.

Fig. 4
miföble: many different designs can be produced effortlessly.

Fig. 5
miföble: the CNC milling machine produces the table "landscape" based on the data transmitted from a mobile phone.

Fig. 6
miföble: each table features opening in the top, curved edges, and a spectacular underside.

Fig. 7
Christmas lighting on Bahnhofstrasse in Zurich, Switzerland (2005).

Fig. 8
Christmas lighting: a visual backbone of the city.

Fig. 9a/b
Christmas lighting: a section and an elevation drawing.
The installation is conceived as a single illuminated line running from the railway station to the lake, emphasizing the urban “boulevard” atmosphere of the Bahnhofstrasse and accentuating its two slight, yet distinct turns in direction as it negotiates the heart of downtown Zurich (figure 8). Its simple, linear course turns the band of light into a visual backbone of the city. The vertical shaft of light in the middle of the street contrasts with the surrounding building façades and points upward to the night sky. Depending on where the viewer is standing, the Christmas lighting can either look like a slick series of individually lit tubes or a glowing, constantly changing curtain of light.

The installation consists of 275 tubes of light, each 7m high, and placed at 4m intervals (figure 9a,b). Each light tube has 32 small LED bulbs and contains the electronic equipment necessary to regulate 256 brightness levels within each bulb. There are 8,800 LED bulbs in the 1km-long band of light. The intensity of each bulb can be controlled in real time, using custom-made software written in C++ called XMAS Generator (figure 10). Approximately 26,000 lines of code were necessary for the creation of this software. Different light patterns were generated and transmitted to the light tubes via an optical database at the rate of 17 times per second.

The changing patterns of light are generated by an algorithm controlled by the dates associated with the holiday season and the street activities that were recorded using sensors. An increase or decrease in the number of visitors affects the character of the lighting pattern and the frequency of change. Hence, the light patterns not only reflect the passing of time, but also the daily activities on the street itself. In this way, each passer-by can alter the street’s ambience by influencing the lighting patterns. In a form of collective interaction the Christmas lighting becomes the city’s inner timepiece, and creates an unpredictable, dynamic, and immaterial architecture, similar to clouds in the sky.

Each of the 7m-long tubes had to illuminate in all directions, withstand wind and water, and be lightweight. We had to find a sufficiently rigid material for the shell of the tubes that allowed the transmission of light; a supporting aluminium core would have created unattractive shadows on the outer shell and thus compromised the effect. After several trial and error experiments, we stumbled upon the manufacturing technique for woven glass fibers used in high-tension insulation, in which glass fibers are soaked in resin and spun around a mandrel (figure 11). We were fascinated by the additive logic of this process. The winding controls the stacking of the fibers via two computer-coordinated movements. A sliding carriage drives the wound glass fibers back and forth along the spinning mandrel. This creates an extremely stable multi-layered shell. The stacking winder and the number of tiers and overlaps determine the flexural rigidity and torsional stiffness, as well as the transmission of light.

The bands of glass fibers are woven into a rhombus structure: the thick areas are responsible for the stability of the structure, and the slender necks create optical brilliance. In order to optimally join both light diffusion and rigidity, we developed software that simulates the fabrication process, enabling us to test weaving variations with different bandwidths, angles, and tiers. Using more than thirty physical prototypes, we tested effective optical qualities such as brilliance, light transfer, and surface structure for both night and day conditions. We also tested wind resistance. The final tube was 7m long and 15cm in diameter; its shell was only 2 mm thick. It weighed less than 23 kg, including lighting and control technology. An intense involvement with the computer-operated production process allowed us to integrate two normally incongruent requirements into one single material, and thus implement for the first time wound glass fibers for lighting on this scale.

Gantenbein Winery Facade

The new service building for the Gantenbein Winery in Fläsch, Switzerland (2006), was already under construction when Bearth & Deplazes Architects invited us to design the façade (figure 12). The building had three stories: a cellar for storing the wine barrels, a large fermentation room for processing grapes, and a terrace-like lounge for wine-tasting and receptions. The fermentation hall had to be windowless, because constant temperatures and subdued lighting are required to ferment the grapes properly. To provide natural lighting despite these preconditions, we designed a façade in which the bricks were laid with gaps between them to allow daylight to enter the fermentation hall (figure 13). The façade itself has two layers: outside, the masonry layer functions as sun protection, light filter, and temperature buffer; inside, polycarbonate panels protect against wind.

We decided to imbue the façade with a pattern that looked from afar like a basket filled with grapes (figure 12). To create this effect, we designed an information generation process that produces an impression of a precisely controlled result by applying purely systematic chance. We interpreted the Bearth &

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Deplaces’ concrete frame structure as a massive basket, and filled it with abstract balls (the “grapes”) that varied in diameter (figure 14). The balls fell into a virtual container via digitally simulated gravity, until a specific density was reached (figure 15). The elevation images of the digital “basket” were then used to create the “grape-like” brick wall patterns (with gaps), using an automated layout process (figures 16a,b).

The brick wall patterns are three-dimensional. Bricks are rotated slightly, and thus reflect light differently, resulting in slightly different tonal values on the surfaces (figure 17). In this way, bricks function like pixels that form the “grapes” image pattern on the façade, and thus brand the identity of the vineyard. Unlike a two-dimensional image, however, there is a subtle interplay between plasticity, depth, and color in a three-dimensional brick pattern, producing not one but many material effects that constantly shift during the course of the day (figure 18). The result is a dynamic surface that possesses a sensual, tactile softness.

On closer view, the walls reveal a materiality that resembles stoneWORK, and one is surprised that the soft, round form is actually composed of individual, orthogonal, hard bricks (figure 18). The façades appear as solidified dynamic forms, whose shallow three-dimensional depth invites the viewer’s eye to wander. Once inside, the transparency of the brick wall surface becomes evident. The daylight creates a mild, yet luminous atmosphere in the fermentation hall (figure 19); the design intent becomes manifest through the subtle light modulation by the gaps between the bricks. The superimposed image of the landscape glimmers through in various ways.

A three-dimensional brick façade, therefore, is far more affective than a two-dimensional image. To create subtle visual and tactile effects, bricks were rotated in two counter-directions, with a maximum deflection of 17° (figure 19). Each façade was balanced, so bricks would progressively rotate as much in one direction, as in the other. Where there is no visible “grape” (meaning where a gap is created in the virtual “basket”), bricks are in a neutral position and thus form a simple running bond.

The construction technology we developed at the ETH enabled us to lay each brick precisely using an industrial robot (figures 20a,b). Not only did the robot lay the bricks, it applied a special bonding agent onto each brick (figure 21) rather than traditional mortar. With this new digitally driven, additive production method, we were able to construct each wall differently, so that each would possess the desired light and air permeability and thus create the overall pattern that covered the entire façade. We designed 72 different brick wall panels using a computer program created expressly for that purpose. The program generated the production data directly from the design data and calculated the exact rotation for each of the 20,000 bricks that comprise the 400 m2 façade. The bricks were then laid out automatically by the robot according to programmed parameters, at prescribed angles and at exact intervals.

Because each brick is rotated differently, every single brick has a different and unique overlap with the brick underneath. We had to find a method of applying the bonding agent so that it fits precisely every overlap (all of which were dimensionally unique) and, at the same time, distributes the adhesive evenly. Working closely with an engineer from the brick manufacturer, we devised a strategy whereby four parallel bonding agent paths could be applied at pre-defined intervals to the center axis of the wall panel. This strategy allowed us to attain consistent dimensions. Load tests performed on the first manufactured prototypes revealed that the bonding agent was so structurally effective that the reinforcements normally required for conventional prefabricated walls could be completely eliminated.

Manufacturing 72 façade panels was a big challenge, both technically and in terms
of deadlines. Due to the advanced stage of construction, we only had three months to complete the design and production before installation on-site. Because the robot could be directly driven by the design data, we were able to work up to the last minute on the façade design, while developing simultaneously the production methods. In the end, the façade panels were produced over just two weeks (with the robot working double shifts). They were then transported by truck to the construction site and installed on-site with a crane (figure 22). The procedure was developed in collaboration with a brick manufacturer who, as an industry partner, was subsequently able to take on the system guarantee on our manufactured panels.

Perforations
What is the spatial effect and architectural significance of a perforation in a wall, in the form of a diagonal, round hole? Openings regulate the amount of light and air that enters a building. Moreover, by allowing one to look into or out of the building, they also create visual relationships between the interior and exterior. Qualities such as dimension, position, depth of a reveal, and geometry determine their architectural expression. The complexity is heightened if an opening (i.e., perforation) passes through a wall at a non-orthogonal angle; the reveal’s visual presence is emphasized and the wall acquires more depth. Besides formal qualities, the number and arrangement of the holes also affect the architectural effect of a perforation.

Today, complex, perforated architectural components can be created using digital design methods. In contrast to industrially manufactured elements, such as a punched perforated metal sheet, the digitally designed perforations do not need to be based on a repetitive, regular grid. The individual openings can be different in shape or diameter, and the material can be perforated not only orthogonally, but also at different angles through the surface. Moreover, given that each element can have a unique pattern of perforations, larger constructs made of different perforated components, such as façades, can be designed without repetition.

What is the best way to design using a large number of openings? What would it mean if each individual opening was at a different angle to the surface? In several elective courses at the ETH in Zurich, the students were asked to examine the spatial potential of highly perforated wall elements. These wall elements had to be developed using innovative digital tools, which we encouraged to be seen as more than simple technical aids to manage geometric complexities. In each course, students produced full-scale prototypes of perforated wall panels, concentrating on the materialization and development of a self-devised production technique. Designing with large amounts of information and “informing” the material in the process – required the development of computational tools as an integral element of the design process. The students altered and expanded the digital tools in an agile, creative manner, based on the feedback attained through the iterative processes of design and production.

In the “oblique hole” course (Das schief Loch), students had to allocate 2,000 holes over an irregular polygonal volume (figure 23). The objective was to examine the architectural potential of spatial perforations pro-
duced by distributing a large amount of circular openings in an irregularly shaped form. The production tool was a milling spindle mounted on a robot hand; the robot’s ability to drill holes at any angle to the surface expanded the design possibilities from merely distributing the holes to also defining their direction. Various algorithmic tools for distributing the holes had to be developed, as it was impractical to process such a large number of perforations with conventional computer-aided design (CAD) technology.

The digitally generated design data was translated into production data for the robot by a custom-developed post-processor. The production data for each individual hole consisted of its position in space and a vector that described the tool’s drilling path through the material (figure 24).

Surprising architectural artifacts were created despite the fact that design options were intentionally limited to a single hole (i.e. drill size of 10 mm in diameter). It was the thickness of the material, which transformed a supposedly two-dimensional hole into a complex three-dimensional design task, that revealed the project’s full architectural potential. Orienting fields of holes towards a certain point in space caused the physical depth of the material to collapse into an abstract, almost immaterial surface when seen from a particular vantage point. The openings created new spatial and visual paths between the interior and exterior that were independent of the volume’s physical geometry. For the viewer moving about the room, the three-dimensional nature of the perforations changed the effects of the architectural volume.

The exploration of perforations continued in the “perforated wall” (Die perforierte Wand) course. The students examined the potential of “informing” large styrofoam panels (1 x 2 m in size) with a large number of round holes; the panels were considered full-scale components of a larger wall or façade design (figure 25). As in the previous project, the holes could be defined using five different parameters: the X and Y position on the wall, the “alpha” directional (deflection) angle vector into the wall mass, the “beta” cut-out angle around the central axis of the hole, and the radius of the hole. The holes were distributed using dynamic force fields of attraction and repulsion, in which parameters defining the location and intensity of the forces could be interactively changed. The holes could produce different perforation patterns on two sides with the use of “target” points to define the “deflection” of the holes. We also used the custom-developed “color mapping” tool that translated the red, green, and blue (RGB) color values of pixels into a chosen image into the “alpha” directional vector, the “beta” cut-out angle, and the radius of the hole, respectively.

Working with images provided the students with the intuitive and direct way to “inform” the material.

With another group of students, we worked on developing a method to cast a large (3 x 2 m in size) perforated wall in concrete. We used a robot to cut the geometric extensions of the holes into the formwork boards (figure 26), in order to transfer the perforation information onto the concrete formwork. After assembling the formwork, standard plastic pipes were inserted into the holes as block-outs (figure 27ab). The design information was thus indirectly transferred to the material via the formwork design.

Manufacturing the formwork presented a particular challenge, because, due to the irregularly distributed holes and the narrow breadth of the web, neither a conventional reinforcement, nor a mechanical re-densification of the concrete was possible. Also, we were unable to use the self-compacting steel-fiber concrete that had recently been developed by the ETH Zurich. After a successful casting, we used various load tests (figure 28) to check the structural effectiveness of the wall element. We tested wall elements with different densities of perforations and demonstrated that even highly perforated walls could be used as bearing walls in a building structure. We also demonstrated that the load-bearing capacity can be locally controlled with a density of perforations and the deflection of the holes. Our prototypes revealed the multiple architectural potentials of a perforated wall. By moving from Styrofoam to concrete, we created not only complexly “informed” concrete panels with some very interesting potential for light and sight modulation (figures 26ab, but also produced actual load-bearing, structural components.
The Programmed Wall

A key assumption underpinning our work is that new digital technologies of design and production will influence the architectural definition of building components. Our research interests are not limited to the technology only. Examining the robotic additive fabrication of brick wall panels, we asked our students to explore social and cultural implications of that technological possibility. What does it mean to digitally fabricate a brick wall using a robot rather than a person? A robot is not only quicker, more precise, and more productive, but it also allows complex designs that are impossible for a human to build with that level of accuracy. The robot does not need an optical reference or an identifiable pattern in order to lay bricks precisely. It also allows complex walls to be built without relying on repetition.

We chose to work with bricks, because a brick is perhaps the most highly developed module in building history. For over 9,000 years, human hands have optimized the brick’s dimensions, proportions, weight, and material. The sequencing, the joint detail and the type of bonding agent used determined the specific structural qualities and appearance of the brick wall. Despite the long history and well-established traditions in the building industry, the brick walls today aren’t nearly as ubiquitous as they were not long ago: the brick is now mainly used as a single-layered facing on a building. Due to the high cost of labor, walls today are mostly made of large, industrially manufactured blocks or reinforced concrete.

If the brick walls are too expensive because of the high cost of labor, to continue working with this material, the assembly of brick walls could be programmed and automated. A wall made of brick is subject to the rules of mathematics, meaning the relationships (i.e. connections) between the bricks, and can be described by an algorithm and therefore, “programmed.” In turn, digital production allows direct translation of computer programs into physical artefacts. A robot can build a wall: it can lay each brick in the exact prescribed position, at the exact angle, and at the exact interval, as described by the author of the program, i.e. the designer. The robot can also position each brick differently with no additional time and effort, which is not possible for humans (figures 30a-c).

New spatial and architectural possibilities open up with “programmed” brick walls. Continuous, procedurally controlled variations of the position and rotation of each brick could create flowing transitions between open and closed areas. Some walls can be formed three-dimensionally by bricks receding or projecting out of the surface plane of the wall; even if the bricks are laid on one plane, the wall can still appear three-dimensional. Structural patterns, plasticity, and transparency can change dramatically depending on where the viewer is standing or the angle of light (figure 31).

The appearance of the wall is not only affected by a purely surface effect, but by its depth. The qualities of this third dimension cannot be designed two-dimensionally or described pictorially. The geometry of the walls has to be programmed, i.e. algorithmically, procedurally defined; it can only be experienced in physical space in time, through movement of the body through space.

We asked students to design a “different” brick wall and to produce it using an industrial robot in our research lab. The wall had to be 3m in length and 2m in height (containing about 400 bricks). Students developed algorithmic design tools to define the spatial disposition of the bricks according to procedural logic. These tools drew upon the knowledge that the layout of a brick wall is based on a system of rules that describe the sequence of operations needed to build a wall. A brick is laid next to another brick, shifted, and perhaps rotated until the end of a row is reached. The next row is then shifted by half of the brick width, and the previous procedure repeated, and so on, until the desired height is reached.

Fig. 31
Different "programmed walls"

Fig. 32
The "programmed wall" is defined by two nested loops, one for the horizontal direction and one for the vertical direction.

Fig. 33
The concepts were first tested manually.
reached. When programming, this process can be described with two nested loops, one for the horizontal direction and one for the vertical direction (figure 32).

Students examined different brick bonding schemes along with various criteria for brick laying, stability, and overall bonding effect. First, they manually tested the feasibility of the concepts (figure 33). Afterwards, they transferred their findings to a simple computer script, which they could expand and refine through an iterative, step-by-step process. The students did not design a geometric system, but rather constructive logics that created an architectural form by organizing material in space and this directly provided the production data for the robot.

In the end, the walls—products of a digital, highly rationalized, design process and built by a robot—contain both the archaic presence of the material as well as the differentiated qualities of their procedural design. Adding information created a new, different kind of a brick wall, of previously unknown forms coming from a familiar and trusted element of the construction industry (figures 34a,b).

Screens

The German writer Kurt Tucholsky once said, "A hole is where there is nothing." Around the hole is a material from which it has been carved. If the holes (i.e., perforations) increase in size, a grid structure develops in the material between the holes and the attention shifts from the holes to the resulting mesh-like structure or screen.

Screens are a common and rich architectural device that can separate spaces, while maintaining a certain visual (and often audible) transparency. In contrast to glass, screens have a strong spatial presence and offer great potential for variation in material, color, texture, etc. The architectural definition of the screen mesh, i.e., its width, alignment, and form, can guide the eyes' glance, obstruct it selectively, or allow full views.

Grid-like structures make the structural depth of a building layer tangible. According to where they are positioned, hybrid structures like screens can assume other functions, such as passive shading (sun protection) on façades. Screens have been used throughout the history of architecture in very different cultures; they have developed in many different ways due to a wide variety of available technological means. As an example, consider the screens in Islamic religious architecture: highly perforated grid structures separate women from the main room of prayer. Besides a purely ornamental value, these highly sophisticated devices allow observation of the events in the main prayer hall without the viewers being seen.

Our work with screens is in many ways a continuation of the previous experiments with the perforated walls—with a shift in focus from the openings to the material remaining between them (figure 9.35). We asked students to produce full-scale prototypes (2 x 1 m in size) in styrofoam. We also varied the forms of the openings, i.e., we didn't limit the explorations to the round holes only. With the help of algorithmic tools, we were able to manipulate the contours, dimensions, angles, and the sequence of openings, which could take any regular or irregular form (figures 36a-c).

Moreover, in addition to being at an angle to the surface, the openings could also be distorted three-dimensionally, meaning that the front and the back of the screen-wall element could be different in appearance.

Conclusion

The projects presented express our empirical approach to the physical and constructive reality of architecture as well as our understanding of the digital as a tangible and sensual reality. We believe that a truly substantial discussion on "digital architecture" can only arise from built projects that physically manifest the underlying logic of this technology. We want to know how it looks, feels, smells, sounds
and how much it costs. To do this, we adopt a strategy of operating in small steps and experimenting, finding ways (or creating them if necessary) of integrating this technology into projects we are actually building, testing their architectural potentials as well as their limits in terms of technological and economic feasibility. We work, whenever possible, at full scale, using the real materials and construction methods. This provides us with substantial feedback for our design process, both at a conceptual and technological level and allows us to understand the real consequences of digital technologies on architecture.

The beauty and power of digital technology lies in its universality and its generic quality. Binary data is an abstract entity that can contain anything we want. We consider it a raw material in our hands that we can creatively manipulate in an infinite variety of ways with a degree of complexity we would not dare attempt by hand. It is like a brick, its generic nature does not impose one given architectural form but rather offers the potential for an infinite variety on a given theme. Programming thus becomes an open and self-evident exploratory technique like sketching and model building.

While the technology necessary to change from mass-produced serial parts to mass-produced custom parts certainly does exist, and is thriving in other industries, it is not yet available to architects. This is largely because architecture-specific interfaces for digital fabrication do not yet exist. If we want to take full and creative advantage of the amazing technological possibilities at our hands and finally fuse the seemingly separate worlds of analog construction and digital data design we have to get involved in the conception of these interfaces and directly link the design data, we produce and the machines that are actually able to fabricate architecture in both directions, technically and conceptually. We should be able to “get our hands dirty,” so to speak, and proactively develop a technological savoir faire that directly relates to the way architecture is conceived, processed, built and used today. Technology needs to be demystified and re-integrated into the architectural discipline, not just as a source of inspiration but as an integral part of the professional vision.

The fundamental architectural potential of the “digital materiality” we have been describing here remains of course to be explored through more built projects and at larger scales. One can still question whether or not the deterministic and rational nature of digital logics really is compatible with the creative and subjective practice of architectural design. Our work attempts to dispel this doubt and we hope that our projects will convince others who will in turn make their own contributions to this effort. Indeed, we feel that our own experience proves that digital technologies do not contradict the architectural process. If we understand its nature and use it as a complementary tool to our intuition and intelligence, digital technology will unleash its systematic, aesthetic, and poetic potential.

Notes

1 The project’s clients were Zurich’s Bahnhofstrasse Association and the Electric Utility Company of the City of Zurich.
2 The project’s clients were Marth und Daniel Ganzenbein. The façade was designed in cooperation with Bearth & Deplazes Architects.
3 Despite the relatively slight deviation from linearity, the human eye could detect even the finest rotations with the subtlest light reflection, making them architecturally readable.
4 The wall panels for the Cantonswineyard were manufactured within the framework of a pilot project at our research facilities at the ETH in Zürich.
5 While we were testing the interior of the space using prototypes, we realized that it would be difficult to read the design if the openings between the bricks were too large. For this reason, we laid the bricks as close as possible, so that the gap between two bricks at full deflection was nearly closed. The eye reads this as maximal contrast value.
6 The robotic brick-laying production method was initially developed for an elective course entitled “The Programmed Wall.” We had to optimize it for the 400m2 façade, so that the production time and the quality of the elements could be guaranteed. Besides further developing the picker arm and the feeding chute, this mainly involved developing an automated process to apply the two-component bonding agent. We installed a pneumatic, hand-held, hot glue gun as a fixed external tool onto the robot, linked its activation mechanism with an interface to the robot’s control unit, and integrated the application of the bonding agent into the automated process.
7 The courses were: Das schiefen Loch (The oblique hole) elective course offered in the winter semester in 2005/2006 academic year, Die perforierte Wand (The perforated wall) elective course offered in the summer semester in 2006, and Die perforierte Wand (The perforated wall) graduate elective course, also offered in the summer semester in 2006.
8 There were other difficulties too: the forces resulting from the pouring of concrete had to be dealt with by geometrically complex braces in the formwork.
9 These themes were explored in the “Programmed Wall” (Die programmierte Wand) graduate level elective course, offered in the winter semester in 2005/2006 academic year and also during the seminar week in 2007 at the Domotemos Swiss Pavillon.
11 The screens were first explored in the “disintegrated wall” (Die Aufgelöste Wand) elective course offered in the winter semester of the 2006/2007 academic year; the explorations were then continued in an elective course during the summer semester in 2007, when we asked the students to design a safety fence that surrounded the construction site for the new Science City Campus at the ETH Zurich.