MASS Customization

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INTRODUCTION

By definition, a brick or masonry unit embodies standard repetition of standard construction. Much like the 1950s IBM Plant in Poughkeepsie, New York, mainstream masonry facades tend to embody a design intention of low-maintenance brickwork structures where the brick is a standard size and is placed in a standard configuration with occasional variation in color, texture, position, pattern, and joint finish (Figure 1). The expanse of façade is typically homogenous, and in this case outlines an orthogonal form as a pedestal for its marquee to house a major force in American industry.[1] The IBM Company at the time of this construction (and publication) had just introduced new products that included the IBM Card-Programmed Electronic Calculator (CPC) and signaled its commitment to electronic computing with the introduction of the IBM 701, the company's first watershed production in the computing industry.[2] In this instance, architecture was as technologically advanced as the computing industry it served. To date however, computation has advanced immeasurably from that IBM 701 and yet the architectural discipline has only recently engaged the capabilities of computer-based numerically controlled (CNC) techniques for innovative masonry production and fabrication.

Despite CNC developments, the standard for brick and stone facades are generally still constructed with the same technique and economic rationalism as the manner of this IBM facility. Many cities require that a building's exteriors adhere to a certain percentage of brick or stone, and yet the standard paradigm prevails. Is the reality of hand labor the issue? Mark Burry pointed out almost a decade ago the revival of architect as 'maker' brought on by the discipline's recent relationship to CNC. He also reminds us of Ruskin's exhortation that the architect need not devolve fully, that they "work in the mason's yard with men." Is the masonry product itself restricting the inertia to mass-customize thermal mass for the masses? How does the nonstandard then become the standard? And should it? Cost effectiveness and the potential for these masonry walls to do more than the average brick will be the impetus for furthering mass customization in masonry.

This paper highlights two case studies that underscore the dialectic between the prevailing paradigm (within mainstream architecture) of masonry standardization and the emerging practices of unique, nonstandard masonry veneer. The case studies, termed assemblage and product, propose practical opportunities and theoretical implications through the use of standard parametric design and digital fabrication technologies—practices that could ultimately become standards in building tradition. The first case study will refer to the additive robotic standard brick assemblage of the *Gantenbein Winery*—a collaboration between Bearth & Deplazes Architekten and Gramazio & Kohler. The second discloses this author's current research and production of nonstandard, stone building components that rely on conventional hand labor to form mass-customized patterns and effects. These case study models describe innovative strategies of labor and production of a nonstandard, mass customizable brick or masonry façade and give new meaning to the term "hands-on" masonry craft. This paper asks from each model how the emerging fabrication technologies have continued or furthered the idea of the architect as 'maker,' as opposed to 'manager,' in the context of mass-customization of the particular masonry construction.3 These projects suggest that variety need not be compromised for mass production to be viable.

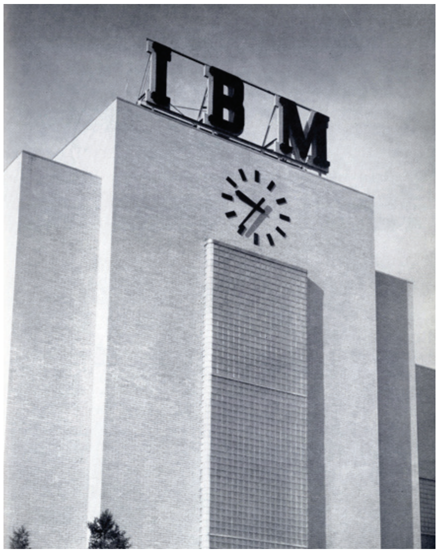

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Figure 1: The 1950s IBM Plant in Poughkeepsie, New York, where the brick is a standard size and is placed in a standard configuration (photo by *Brick and Tile)*

STANDARD PRACTICE

Researching the domain of the nonstandard assumes a standard. The constraints of mainstream masonry architecture typically derive from economics, regional material structures, skill of labor, desire of clients and environmental considerations. For instance, new brick construction might never occur in places that are prone to earthquakes, however in other areas masonry may be merely a stylistic status symbol (to the point that cheaper houses use masonry facades like wallpaper).

Architects and designers have historically looked for expression and decorative effects through the masonry unit. This originates out of the most economical means through to plastic treatment of whole walls or fields of molded brick. Unlike the Gaussian roof vaults in single-thickness brick achieved by Eladio deEste, or more currently the Block Research Group at ETH Zurich[4] and Defne Sunguroglu in Helsinki,[5] the selected case studies propose façade applications of mass-customized masonry, accept traditional materials like brick and stone, and prefer to mass-customize within that known palette. Both case studies are just skins and not load bearing, although the thickness implies the reverse. This indicates a trend toward material thickness for purposes of the nonstandard becoming the standard. Basically, Gramazio + Kohler alter the rotation of the brick stretcher face. In contrast, this author's research and production carves the brick into unique components and configurations.

ASSEMBLAGE

Gramazio & Kohler Architects have developed a language of variety and variation through the design of processes rather than final forms.[6] Their desire is to code the process by which a brick wall is assembled. For them, a familiar material, like a brick (of standard shape and size), can be programmed into particular positions in order to construct a mass-customized design. For the *Gantenbein Winery* in Fläsch, Switzerland, regular bricks are irregularly placed, giving texture to walls that infill a conventional concrete frame (see Figure 2). Each displaced brick is thrown into relief as the bricks overlap and wall perforations create a pictorial "grape-like" pattern. This drama playfully communicates the function of the winery and reveals a subtle changing message as the sun rakes across the wall at a shallow angle.[7] A super-graphic relief as such is effortlessly driven from a bitmap image and efficiently resolves itself through algorithmic capabilities. It is no longer a nonstandard endeavor in practice.

The ordinary brick has reached the limit of its potential in this rotation displacement and the wall is pierced. The façade then acts as a screen wall, using a combination of horizontal and vertical sinusoids. The code governs the displacements—controlling a dramatic dappled light effect into the fermentation rooms. Another function is then added to the purely visual effect, that of ventilation. The screen acts as a double skin of brick with polycarbonate panels behind to protect the interior from the wind. What is unclear is whether the curves of brick wall are determined at all by the rigidity resulting from the waving contour of the wall and the consequent economy in material by using a standard brick? Does the graphic variability overrule these constraints?

A very general rule in masonry states, if you can lift it with one hand, it is a brick, and if you have to use two, it is a block. The innovation in this project occurs from the fact that there are no human hands involved in the building component assembly. The scale, precision, and vast number of units necessitated an automated process based on script and robotic construction (see Figure 3). The *Kuka* Robot used requires data input to direct its "manual skills." The two automated moves are 'efficient hold' and 'placement of the brick,' alongside the precise application of a bonding agent. The robot expects to grab the standard brick size and the bonding agent registers the standard brick surface to lay the adhesive. The efficiency uncovered with this procedure reduced necessary reinforcement normally required of prefabricated walls.[8] This "hand" procedure follows Kolarvic via McCullough's argument that the machines, not the hands of the maker, touch the material directly.[9]

Using parametric design, each one of the seventy-two façade elements in the project is effortlessly unique and each of the 20,000 bricks is precisely placed according to those programmed parameters—at the desired angle and at the exact prescribed intervals.[10] Is robotic assembly absolutely necessary? *SHoP Architects* of New York prefabricated a façade with similar brick displacement gestures for the 290 Mulberry Street Project. In those panels, brick usage responds to contextual cues and landmark requirements. Using CNC routed sections, the individual bricks are placed in the routed jig framework and then mortar is poured from behind,[11] without the expense of a robot assembler.

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Figure 2: Regular bricks are irregularly placed, giving texture to walls that infill a conventinal concrete frame (photo courtesy of Gantenbein Winery)

Figure 3: The Kuka Robot requires data input to direct two automated moves are 'efficient hold' and 'placement of the brick', alongside the precise application of a bonding agent (photo courtesy of Gantenbein Winery)

As the robotic industry becomes increasingly more accessible to not only specialized research and design laboratories, but also to standard practice, efficiency will be matched with economy. And the production of robotic or pre-fabrication will extend throughout an entire project, as is the case for the winery. After the bricks become nested into a precast unique panel by the robot, they then get transported and lifted into place by a crane. The three-month timeframe given for design, assemblage, and site placement of the façade demonstrates the effectiveness and efficiency of the mass-customization of the standard brick in this process.

Gramazio and Kohler depart from a 'managerial' role or editors of code but instead offer a cost effective fulfillment of variability through the digital.[12] Ultimately, the curving gestures position these programmers as designers and makers, in control of code, material, and geometry. Does this case study place architecture on the path of the mythical cyborg—part machine, part organism? So how does this become standard and should it? In keeping with the open-source nature of the current digital realm, this process of mass-customized brick production is now available for mass (re)production. The code, rightfully called "designing the-brick-wall-of-the-future," comes from an application for computations with possible effects to investigate: displacing bricks, rotating them, leaving gaps between them, creating ledges of various depths for shadow effects, combining bricks of various colors, and so on.[13] Alternatively, *BrickDesign* was initiated by the company Keller AG Ziegeleien, who assisted in the production with Gramazio + Kohler at UT Zurich. *ROB Creator,* the predecessor to *BrickDesign*, is a standalone program, which anyone can download and allows the user to apply desired patterns and images on straight brick walls. The created designs can then be directly ordered and prefabricated from Keller. This controlled fabrication process allows for the realization of highly informed building elements to happen like an online co-design purchase in an economic and efficient process. Designers are enabled to map patterns or images on a facade, or realize complex wall geometries as efficiently as a standard mode of production.

PRODUCT

Despite its general efficiency and suitability, a rectangular brick can be restrictive for mass-customization of a masonry façade when accepting standard (i.e., human) means of assembly. The technology for creating variation and difference is already a well-established process, but is not always integrated into projects because of the conventions of labor and the accepted standardization of masonry units. This case study, referred to as *Petals*, relieves the severity of a standard brick repetitive pattern through research of alternative stone milling with CNC technology. The project eliminates carving *in situ,* or cutting gauged pieces by a bench-mounted disc-cutter of the past. The geometry of the brick plays upon an accepted tradition, like gauged brick and stonework. Through the use of emerging technology, the standard brick is reconsidered to ergonomically reflect the mason's hand with its bulges and deep valleys.

Gauged brickwork is a masonry craft where bricks are cut or rubbed to fine tolerances. Historically, it originated through guilds of the 15th century

Medieval and Tudor masonry. This form of finish detail became prolific in the 1870s due to the influence of the 'Arts and Crafts Movement' and relationships of highly skilled master bricklayers to Victorian apprenticeships. The advance in technology at that time also prompted the use of twisted wire-bladed bow saws and cutting or moulding boxes to shape rubbers. 'Rubbers' are the bricks used for these purposes and consist of finely sieved brick. As a consequence, rubbers are relatively soft compared to a standard brick. For the purpose of this research, soft limestone is used as rubbers.

Heavy patterning and moulding in masonry construction is now said to be all but obsolete.[14] There has been something of a revival of the carving of standard stock bricks by eminent sculptors like Walter Ritchie with "The Creation" at Bristol Eye Hospital. This, however, has been mainly of the low relief, sculptural variety and rarely the extensive architectural carving of the past. The '*petals*' of this research project are CNC milled from 1' x 2' x 6" deep units of stone and recognizes the capacity of parametric modeling to rethink all parts of a standard brick: the frog, the bed, the arris, and the stretcher. Each carved piece is derived from the same genus or family type, meaning a trapezoidal footprint divides and bulges in form to create one unit. Although similar in form, each petal is unique and varies in its curvature, peak height, valley depth, and profile shape (see Figure 4). The stone is maximized to produce five unique bricks from one unit.

The nonstandard shapes provide material effects that together give expression to an inner revolt against the monotony of mass production. Plastic treatment of the building component produces interplay of light and shade as it breaks the emphasis of either typical horizontal or vertical patterning. The natural stone, with its individuality of color and texture features, also enriches the surface variation and dissolves easily away under the force of the CNC. The technology highlights variation in the material with its imbedded shells and irregularity of organic makeup. The CNC creates a tertiary pattern where the drill bit had executed its finishing passes in the X- and Y-axis direction. The time required for each of these X and Y passes across limestone is negligible for a result of crafting texture.

Can the geometry of a "brick" add to its already exceptional thermal and acoustic properties? Variation in form has potential to open up an entire realm of exploration for greater performance from these individual elements.

Increased volume and surface area make for a greater thermal protection and acoustic barrier. Extreme contours reside within each individual brick and also when placed next to neighboring bricks. For plastic effects, the projecting bricks form a pattern whereby each building component, with its varying depths and curvatures, has potential to direct and divert wind or water coming down the surface of a façade, as shown in CFD analysis (see Figure 4). Alternative functions of this brick might match that of the University of Aarhus, Main hall interior where brickwork details perform acoustically, scattering sound waves much more than the absorption qualities of a standard brick or stone unit. The parameters of angle, depth, and chamfer angle can be modified to produce a particular percentage of sound

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Figure 4: Bricks carved from stone block unit using CNC mill. *below*: Individual brick with a trapezoidal footprint divides and bulges in form. CFD analysis discloses unit control. (images by Briscoe)

diffusion, like the research panels of Brady Peters. Alternative configurations could adhere to pursuits like the *Brick Biotope,* whereby a set of brick typologies is designed as a natural living environment for birds and other ecological habitats.[15] Similarly, a *Biowall* project creates nonstandard stone modules with a cavity space to hold plant and earth medium to act as a living wall for hot and dry climates.[16]

Traditionally, brick carving is rarely the work of the bricklayer, but instead generally the preserve of the “trade carver,” who could work in brick, stone, or wood. The carver manipulates the bricks himself by sawing, cutting, or rubbing them on site. The success of the outcome would then rely solely on the skillset of this mason. Carving requires the ability to naturally think and create three-dimensionally. Part of the training of a carver is now being passed down to architects through digital technology and fabrication. Building upon the skills of a new generation, the architect can now play the role of a most prestigious artisan carver and highly skilled craftsman with whom the virtuoso bricklayer enhances an ambitious façade. In the same vain, these peaks and valleys of the unit also conform to a more ergonomic hold of the bricklayer’s hand and exist to be picked up, placed and potentially made into alternative, novel configurations (see Figure 5).

The “petal-like” bricks of this façade can stack together neatly into a predetermined digital pattern. Assuming a specific pattern is desired, hand labor could adopt a parcel tracking system, like that of a barcode or tagging identity, in order to direct and assist each brick’s accurate position in space, like the *Mero Space Frame System*. The project can also vary in pattern composition according to the placement by the bricklayer on site, given that clusters exist in the brick typology. (See Figure 6.) Therefore, customization of composition might ultimately further a nonstandard brick through a traditional laborer’s hands-on decision making, putting the finish quality out of the control of the said designer.[17] Does the design control made available through the CNC allow for this design relationship between architect/carver and bricklayer/designer to flourish? Does this relationship enhance craftsmanship of the nonstandard moreso than the use of advanced robotics? It is challenging to argue against the future of advanced technology to interpolate nonstandard pieces into an assembly, like “singulation”—a range-image system guided by an *AdeptOne Robot* used by the US Postal Service for recognizing irregular packages from a moving conveyor at 36 pieces per minute with more than 95% efficiency.[18] Although this system can recognize, size, and locate highly diverse materials and objects in space, greater chance of outcome diversity might occur out of the human selection for mass assemblies. There is the opinion that “mass customization is only relevant when the custom elements are massed together, rather than deployed as discrete elements, because they release an unprecedented richness in assemblies that even traditionally have required thousands of pieces.”[19] This relevancy suggests an entail then of a standard (re)production of the nonstandard unit.

Is stone milling an economically viable and practical use of precious material? The project recognizes parametric capabilities for a generative process

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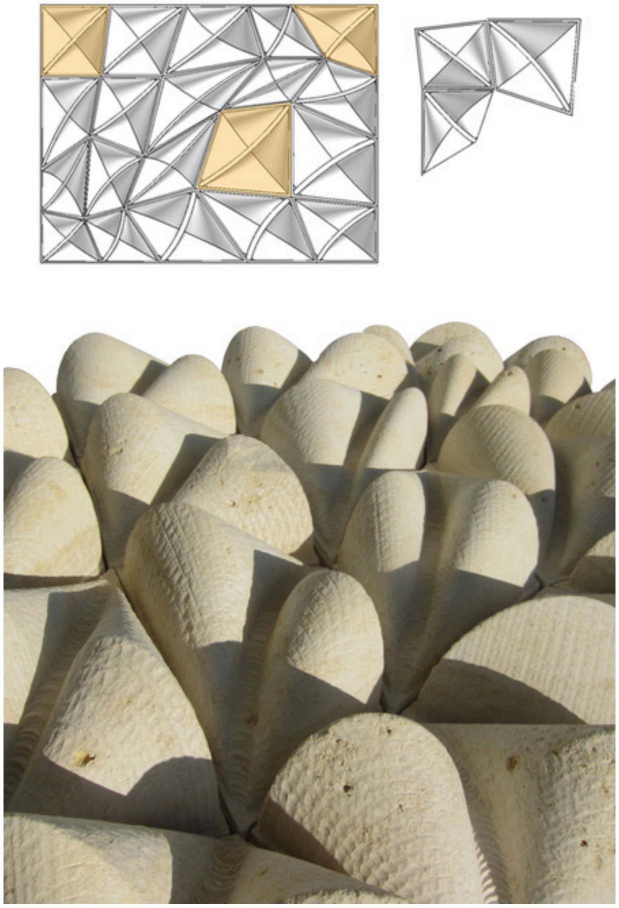
Figure 5: Peaks and valleys conform to a more ergonomic hold of the human hand and exist to be picked up and placed. (drawing/photo by Briscoe)



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of variability (i.e., once file to CNC has been separated for milling, anything can change at the last minute). In so far as to say, the geometry of the pattern and its intended material are linked associatively to the fabrication process. Variations are 3D printed to test-pattern making to recognize many ways can they all fit together. The process redefines relationship between design and production, as it no longer adapts a static state in the conception process just before fabrication is meant to take place. Alternatively, the work of *Stone Spray Robot*, 3D, prints architecture out of soil—preferably the soil on location where it needs to be printed. This research project is aimed at finding means of proposing new eco-friendly, efficient, and innovative systems using additive CNC fabrication.[20]

OUTCOMES

It is known that great thickness and weight of masonry walls provide enormous advantages in heating and cooling as a thermal mass. Such a thick mass certainly also allows for various design options as a façade. Is the custom mass integral to future standard practice or might it easily be viewed as uneconomic for standard building processes? As technology continues to become more and more ubiquitous and generations of architects have this “carver” training as part of their pedagogy, economy will not be

Figure 6. Pattern can vary according to the clusters that exist in the brick typology. Arrangements can either be radial or linear (drawing by Briscoe)

an issue for the use of nonstandard customization. Guided by the work of Abraham Robinson's nonstandard analysis community, perhaps nonstandard products and production are not meant to be translated into standard ones because the intuitive content is greater or clearer when left in nonstandard agendas. The use of nonstandard building components in architecture describes the behavior of singular economies, and the use of nonstandard methods give meaning to concepts that do not classically make sense, such as certain products of infinite and equally many independent, equally weighted random variables.

Nonetheless, carved brickwork is a natural progression from gauged work and has moved beyond being considered purely an art to an architectural craft via digital fabrication and advanced technology assemblage.[21] Variation in the carved surface can give not only aesthetic appeal but can be crucial for future innovation and qualitative transformations.[22]

The case studies point out modifications to existing methods of production within the discipline that allows for a destabilization of labor. Does robot replace bricklayer or conflate the role of the designer? Can material behavior be hybridized with its production? These are questions that could potentially be answered by modes of nonstandard (re)production in masonry construction.

CONCLUSIONS

Brick masonry façade serves as an intermediary between the Cartesian standard frame and a new expression of variety. Transformation of wall surfaces displays variability of process, material usage, labor, and fabrication, which affords maximum emphasis to the transformations effected by surface modeling. One process is an evocative display of the standard brick while the other glorifies the traditional hand of the craftsman.

Today, if Kahn were to ask the Brick, 'What do you want Brick?' The Brick might have changed its mind or even forgotten about the arch and say with equal confidence 'I like variation.' And if you say to the Brick 'Look, customization is expensive, and it's okay to be just like all the rest. What do you think of that?' Brick says: 'I like variation.' ◆

ENDNOTES

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7. The technique of robotic construction for this project was manufactured as a pilot project at Eidgenossische Technische Hochschule Zurich.
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13. http://blog.wolfram research.com. Christopher Carlson Mathematica software
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