THEME I. INTEGRATION

DESIGN INTEGRATION (1A)

HOW TO MAKE A DIGI-BRICK

Design and Fabrication of a Masonry Module: material, construction, and craft

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Abstract. This project examines a non-traditional method of construction generated through a digital design process that leverages digital fabrication techniques related to masonry construction. Where as architects' use of computers first affected shape and structure, it is now additionally affecting material, construction, and craft. This design proposal explores these concepts through the production of a wall using simple configuration and reconfiguration of a repeated module adaptable to differing and unique contexts and site conditions. The masonry module is designed and built through the exploration of a CAD-CAM process. The prototypes produced investigate the repetition of a single module unit, manipulated and interlocked resulting in a continuous surface that is more than just the sum of its individual parts. The material, construction and craft of each unit informs and challenges the entire project to question the making of the masonry module into a wall.

Keywords. Digital fabrication, design theory, digital design methods.

1. Introduction

From their earliest inception, traditional methods of masonry construction have relied on the ability to consistently reproduce what might be considered the original building structure - the masonry unit. An example of the masonry unit can be found as early as the eleventh dynasty of ancient Egypt (2134 BC) in the Mortuary temples of Mentuhotep and Hatshepsut. (Trachtenberg, Hyman, 1986). In masonry construction, both structural and formal composition depended on consistency; a symmetrical six-sided polyhedron (a brick) meets both the needs of structure and is easily reproducable. It should be no surprise therefore that the geometry and proportion of the earliest known uses of masonry still resemble the bricks used in construction today.

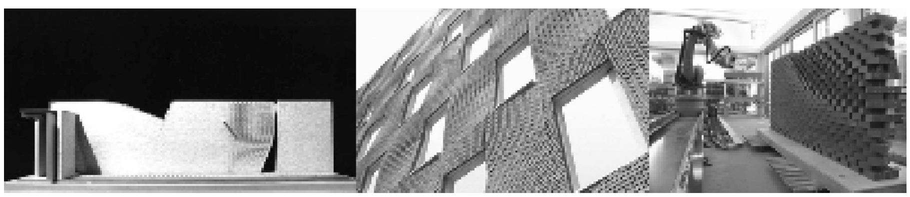

Figure 1. Tongxian art center (Office dA), 290 Mulberry Project (SHoP Architects), Winery Gramazio & Kohler).

In its simplicity, however, this elementary unit simultaneously allows for complexity of form through an increased complexity of unit-to-unit connections. Many, if not most complex applications of masonry also require novel or complex solutions to overcome the increased information required for the project. A historic example is the 15th century construction of the dome of the Santa Maria del Fiore in Florence. In this landmark project, architect Filippo Brunelleschi was required to invent entirely new methods of construction to organize the more than 4 million bricks that ultimately distinguish the completed structure, (King, 2000).

More contemporary examples of innovative masonry construction using digital processes can be found in work of firms such as office dA, SHoP Architects, and Gramazio and Kohler. For office dA's Tongxian Art Center proposal, the firm designed a brick facade that stretched into a screen of the same material (Figure 1), (Office dA, 2008). Because the effect was only designed for a localized area of the facade rather than the entire building face, office dA was able to use a printed template system extracted from a digital model to facilitate brick placement by the masons.

On the other end of the spectrum, SHoP Architects takes a different approach for their 290 Mulburry St. project (Figure 1) where their brick facade undulates uniformly across the entire building face, (SHoP Architects PC, 2008), Using

CNC milling to produce a mold, SHoP created precast concrete panels in which were set bricks rotated to create a pattern. By mass-producing the precast panel for application as the facade, SHoP was able to apply the tiled pattern uniformly across the entire building surface.

Unlike both previously mentioned projects where non-traditional coursing was either locally confined or uniformly or applied, Gramazio and Kohler use highly complex means to to create a non-uniform pattern across the entire facade of their Gantenbein Winery project (Figure 1), (Gramazio and Kohler, 2008) To manage the complexity of the project, the firm programmed a robotic arm to precisely build a series of unique masonry panels. When the panels were installed as the facade, the composition when produced a pattern resembling a basket of grapes — a highly complex pattern that could only be constructed efficiently through highly complex means.

These examples of contemporary design and production based on the brick are all carefully controlled and complex processes that the architect must be present to direct from the initial design to construction. The more complex the project, the more that the architect has to oversee the project to be certain that it will be built according to certain design intent. The craft is the orchestration of the process by the architect and the construction is the physical combination of the bricks into a final design.

Rather than continue up this ramp of increasingly complex construction, our project inverts the historical approach. As seen in the aforementioned applications, a traditional approach to masonry construction employs a primitive geometric unit to allow for a complex variety of unit-to-unit connections. For our project — a memorial pet wall for an animal shelter — we use contemporary methods of fabrication and digital design to create a new unit of masonry that simultaneously responds to design constraints while greatly reducing the

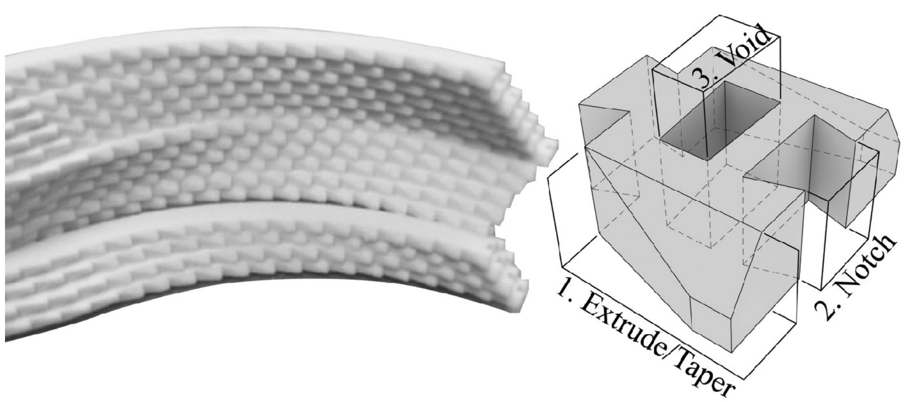

Figure 2. Studies of Masonry Module, development and combination.

complexity of construction and the necessary involvement of the architect. The reduction of the complexity of construction along with the decreased direction necessary from the architect, allows the client to carry on, or expand the design over time (as needed) independent of additional engineering or design expenses.

2. brick|mold|brick|wall

Contemporary methods of brick construction occur in the combinations of a typical six sided bricks to construct patterns on various scales—panel, wall, and building. The construction of a digi-brick occurs on the scale of a brick, through the manipulation of its faces in relation to program and site considerations. A six-sided brick on its own cannot respond to performance and culture. It can only respond to those conditions through a combination of bricks. The digi-brick, however, has inherent in it a design, and with it, a reaction of performance and culture. The craft is the design of the brick to reflect performative and cultural considerations. The construction is the fabrication of the formwork to produce the brick.

The digi-brick, explored in this paper was a reaction to a program from an animal shelter in the American Southwest: to design a memorial/fundraising wall to which plaques would be attached. Additionally, the wall needed to be designed in such a way that allowed for expansion after the initial construction without the aid of the designer; rather it would occur incrementally, constructed as needed by employees of the Animal Shelter. The digi-brick was a reaction to these internal and external forces, transforming from a 6-sided non-orientable block, to a multi-sided, directional module.

For this instance of the digi-brick, six orthogonal sides do not suffice. The first deformation of a typical 6-sided brick was an angling of one of the sides (figure 2), making it adaptable to different spaces (flipping the brick changes the directions of the curve), giving it a specific orientation. Next the digi-brick developed ten sides in reaction to the need for plaque space and site conditions. The extruded and tapered sides (step 1. figure 1) of the brick allow the plaques to act as a system separate from the wall, navigating the curve of the wall while taking advantage of the intense Southwest sun. As the day progresses shadows made by the protrusions and plaques will transform and move across the face of the wall. The interlocking notches created by the sixteen sides (step 2. figure 1) narrowed the possible connections of each brick to two choices, the same orientation or a flipped orientation, while providing horizontal structural rigidity with in each course. The seemingly binary connection (a finite condition) of each individual brick (the decision to flip a brick or keep the original orientation) still allows for an infinite number of combinations as the course of bricks expands, allowing for unique responses to specific site conditions. Finally, the void introduced in the now twenty sided digi-brick (step 3. figure 1) reduces the weight of each individual brick making construction easier, and allows for steel reinforcement to improve vertical stability.

The proposed twenty-side digi-brick is only one possible solution given this specific set of program and site conditions. Given additional or different cultural and perfomative conditions, the digi-brick would necessarily react with different shapes, sizes and configurations. The six-sided brick has inherent in it none of the qualities of the intended design. It only takes on those qualities, reacting to performance and culture, through the complex combination of many bricks. The design is the composition of the bricks. The brick is also the design. The focused qualities of the digi-brick provide a DNA style (re)combination that allows for infinite arrangement within a structured system that creates a framework so that anyone can continue and expand the wall, while still operating within the intended design objectives. The design intent becomes independent of the oversight of the architect.

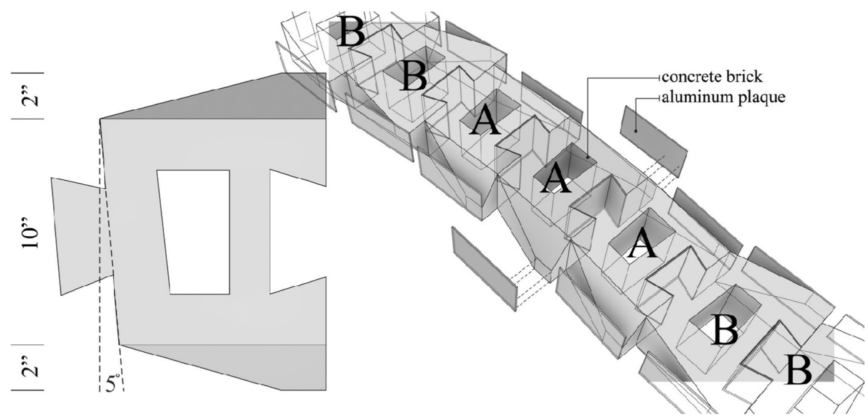

Figure 3. Masonry Module–dimension, shape, and connection. BBAAABB connection illustrated.

Figure 4. Digital representation of a wall constructed of digi-bricks

3. digital|physical|making|thinking

Architecture is being transformed through the digital tools, processes and applications we use, allowing the conceptual designs of our mind's eye to be transformed into the tangible, and ever-buildable world of today. Digital fabrication methods, techniques and processes are additionally affecting material, construction, and craft. This design proposal explores these concepts for the production of a wall using simple masonry methods based on traditional craft and materials translated through digital thinking and making of the masonry module by the collective and individual study of surface. Surface, understood here as that of the brick and simultaneously the surface of the wall, is developed through the geometric development of the six faces of the masonry module in response to a given set of internal and external forces and conditions. The novel aspect of this project is that the digital, computational tools have been applied to the making of the masonry module, not the composition or construction of the wall.

In this proposed digi-brick, the geometric manipulation of the masonry unit and increase in the number of facets, simultaneously reduces the number of connection possibilities resulting in a new masonry module where connection is now a binary condition based on the orientation of the module. The making of the wall (Figure 3) is developed through the sequencing of the binary connection as a contextual relationship, developed and defined as the digi-bricks are placed in the site. The digital fabrication of the mold or formwork of the digi-brick (Figure 5) allows a formal manipulation that eases the physical requirements of the construction. The investigation of the brick as a module of craft and construction yields two variables conditions, module facets and connection type. Most masonry modules balance these conditions in a numerical equilibrium. Formal diversity is achieved through the craft of placement; orientation and connection is developed course by course to achieve a pattern across each course of brick. The digi-brick developed here is connected in such a way as to be crafted in the course by connection variation in each course. In current methods of brick construction complexity is introduced in the combination of a simple brick into an intricate whole that the architect must carefully orchestrate. The increased complexity of a digi-brick results in a reduction in the number of potential connections, making possible easy construction that the architect no longer has to carefully oversee.

The design of the digi-brick enables a process driven method of brick design to provide transformative effects on the physical making of the wall by emancipating the digital thinking that was employed in the design of the digi-brick form. Such a technique acts on and influences the object, which in turns modifies the culture of craft (Rahim, 2002) and material in the masonry construct. In this project the material is not the concrete, but the masonry module. The constriction is that of the formwork not the wall. The craft is the geometric manipulation of the faces of the digi-brick not the brick laying itself. It is a redefinition of traditional preconceptions of material, craft and construction, instigated by the development a new process of brick design: the digi-brick.

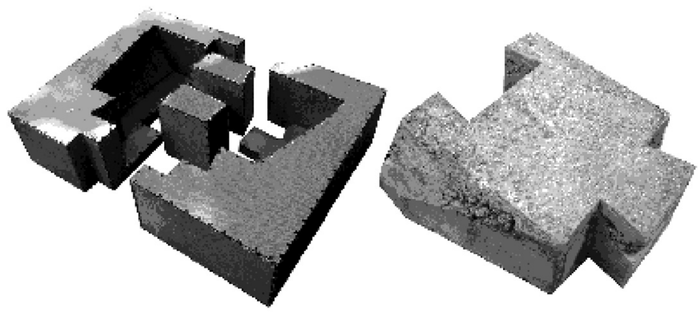

Figure 5. Masonry Module – the digi-brick mold (formwork) and the digi-brick.

4. Material|construction|craft

Just as the digi-brick's incorporation of program and geometric considerations has altered the process of design, it has similarly effected the methods required for construction. Whereas the precedents mentioned in section 1 required complex and top-down management models for construction, the digi-brick has no requirement for construction drawings or measurements or even architect oversight. The result is a construction process that is transparent and understandable to the client who may have little to no knowledge of architectural construction. In the small-scale example of the memorial pet-wall, both client and architect will choose the location and extent of the wall's foundation on site. With this method, the first coursing of digi-bricks are laid out on the site (physically) while simultaneously and parametrically modified digitally to reflect the physical layout in the digital model. Once the client is confident in the design, the layout is marked on the ground, the digi-bricks removed and the foundations poured. Because the foundations are poured to the specific layout that physically existed on site, the risk of errors in measurement or communication are greatly reduced. Additionally, since the digital model reflects the physical condition, design can be modified literally as the wall is built, course-by-course through the direction of the client. In this way, the digi-brick provides a new model for design build that is more flexible than previous models.

5. Conclusion

The digi-brick is not significant in its specificity of form, but rather in the process that it proposes. By reevaluating the traditional masonry unit through digital design and fabrication, the proposed digi-brick is a single iteration in an ongoing research effort to capitalize on the synthesis of traditional and contemporary design within construction methodologies. The case study of the memorial pet wall has shown that with this novel approach there are strong implications for the design and construction process, as well as the client-architect relationship. Inherent here is a redefinition of material, craft and construction that is a response to digital methods of design and fabrication. Where traditional definitions of material, craft and construction refer to discrete elements; the design process of a digi-brick addresses the issue of craft at multiple scales focusing on the discrete element to the programmed whole, and of performance and culture.

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