

Equity In Practice: Digital Architecture's Role In Maker Culture

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Low-tech building methods have been gradually developed according to the actual needs of a community and the demands of location-specific requirements. High-tech digital design has advanced the level of precision and control over material applications and has increased the possibilities for studying design options. But where might the two meet? How can innovation in construction carry forward the lessons learned from vernacular and low-tech building solutions? How can contemporary technology be used to create new solutions that are as context-aware and affordable as low-tech solutions in places that low-tech solutions are still generally practiced? This paper explores the relationship between digital design and low-tech application by local labor looking for opportunities to advance the exchange between both the design process and the practice. The goal is to study and advance the linkage between the precision and design innovation of computational technology with traditional building systems in a context-aware and universally applicable manner.

The study process starts by observations from designing a screen brick wall which leads to developing an modeling tool that allows the users to design brick masonry wall systems in a digital world and to create construction guides for building the wall in the physical world, allowing for back and forth communication between the designer, the community and the mason during the design and construction process. This process is not only a form finding exploration, it rather focuses on the communication between team members and the ease of construction. The designer can simultaneously study form, pattern, and solar exposure and can communicate the process and the result with the mason and the users using simple paper guides called "DNA guide". This approach advocates a collaborative process where the form-making, prototyping and building is a shared experience between the designer, the community and the layperson.

INTRODUCTION

Architecture should reflect the culture, climate, and resources of the time and place¹. Because of complexities of the contemporary societies, the number of factors that should be considered during the design and construction process can't be easily understood and controlled by one party. More than

often the architect, the builder and the client are not in the same location and therefore there is a clear gap of communication between them specially when the architect design projects oversee. In fact, today more than 70 percent of the architectural projects are designed by foreign architects² and many are designed for locations with limited access to high tech technology. This phenomenon raises a question that how one should mediate the impact of global civilization considering elements derived from distinctive characters of a place and how should the process be represented and evaluated by the users and local builders. Even when the architects are not foreign, they are not inherently aware of all the peculiarities and problems of a place or project³.

This gap of communication can be filled by introducing mathematics to the design process to study and control a network of factors. Computational tools can transfer data and design ideas to create an interactive and clear communication language between the designer, the builder, and the community. The task here is to identify the pattern of the problem and the process of designing a prototype which responds to that problem. Achieving such a logical structure to represent design problems brings with it the loss of innocence in design because a rational process is easier to understand and criticize compared with a fuzzy design approach⁴.

In order to create cost-effective, performative prototypes that are derived from the local culture and benefit from the advancement of universal technology, architects should identify patterns that reflect various factors in an integrated way. This network of factors as discussed in the paper include using low-cost local material, achieving energy efficiency, working with the community to reflect on their desires, and reshaping the construction techniques using cost-effective methods. By parametrically relating these factors during the design process, each can be adjusted and improved, leading to better overall options.

Instead of presenting an image of a complex form and imposing a digitally fabricated foreign form in a traditional setting, the users are presented with a tool that allows them to engage with the designer and the mason and achieve a contextual artifact. This approach seeks to link digital design with traditional making techniques and builds upon existing low-tech methods for greater global implementation at smaller

costs. The design tool connects high-tech digital methods with traditional brick masonry practices to create a “high-touch”, more responsive process.

This paper explores an alternative approach to the practice of digitally designed artifacts by looking at brick screens as a manifestation for projects of bigger scale. To develop the digital design algorithm and the practice toolkit a full-scale brick screen prototype was first designed and built using smart construction guides, then the toolkit and the guides were applied in designing and building a Compressed Earth Block (CEB) screen wall, constructed in Western Africa by local labor as part the facade of a multifamily housing project. A third prototype is also designed to test the application of the toolkit at a larger scale.

PROJECT BACKGROUND: BRICK AS THE MATERIAL AND SCREENS AS PROTOTYPES

The problem stated in this work was raised during the design and construction process of a school project. Located in the center Mazar-I-Sharif, Afghanistan’s fourth largest city, the Gohar Khatoon Girls’ School opened on June 2nd, 2015. The school was commissioned by the Balkh Province Ministry of Education with a U.S. based non-profit organization and was designed by Robert Hull + a team from the University of Washington including the author, in the US. The project was designed and built with brick as the main material. The challenge of consideration of environmental and cultural factors and virtual communication with the community and the local masons, in the process of first designing and then building the screen brick walls (figure 1), raised the problem for this research. How could we find more culturally and environmentally aware options within the short period of the design process and study them before making final decisions? How could we find a cost-effective methodology for communicating the design with masons from far away?

Based on this premise, this work outlines a parametric digital design, representation, assessment and construction process for designing masonry walls that can have flexible forms, patterns and openings. Adding openings to the wall creates a screen, providing a platform for testing the parameters of energy performance, occupant comfort and privacy based on natural light, view and air. The patterns can reflect the cultural preferences of the community. By giving the team control over the placement of each brick within a brick masonry wall, it is possible for the users to become masons in the digital world and to quickly study and visualize design options based on the properties of the masonry blocks and mortar joints.

The principles of this work can be applied to any masonry units however the prototypes that are presented here are made of brick, as a generally low-tech and low-cost material that is available in many regions of the world and is widely used in building construction. The simple, symmetrical form of brick allows for a multitude of complex unit-to-unit connections that can create a variety of forms, patterns, and openings in a wall⁵. Brick can create both load-bearing and non-load-bearing systems. The focus of this work is to study the design

and construction process of a self-supporting, reinforced, single-layered brick wall that can have flexible forms, patterns and openings.

GLOBAL IMPLEMENTATION

In more recent projects, parametric design and digital technology has been used in various ways to create innovative masonry systems. One example is in the area of robotic fabrication and form-finding for complex masonry fenestration systems. This linkage results in high precision in the fabrication process⁶. Also Numeric Control (NC) and robotics have become firmly grounded within architectural practice⁷. The research methodology for these approaches is often heuristic and experimental. Robotic brickwork developed by Swiss architects Gramazio and Kohler Pike Loop project in New York is one example of such systems. Gramazio and Kohler used a robotic system which included a programmed robotic arm to create a non-uniform pattern across the entire facade of their Gantenbein Winery project⁸. Other examples for direct implementation of digital design and fabrication is creating 3D printed bricks like the work of Ronald Rael and Virginia San Fratello at Berkeley. Each 3D printed brick can have a particular shape as part of a bigger system and the bricks can interlock to create a



Figure 1. Figure 1: Brick screen wall at the Gohar Khatoon school project . Image credit: Nic Lehoux

tration systems. This linkage results in high precision in the fabrication process⁶. Also Numeric Control (NC) and robotics have become firmly grounded within architectural practice⁷. The research methodology for these approaches is often heuristic and experimental. Robotic brickwork developed by Swiss architects Gramazio and Kohler Pike Loop project in New York is one example of such systems. Gramazio and Kohler used a robotic system which included a programmed robotic arm to create a non-uniform pattern across the entire facade of their Gantenbein Winery project⁸. Other examples for direct implementation of digital design and fabrication is creating 3D printed bricks like the work of Ronald Rael and Virginia San Fratello at Berkeley. Each 3D printed brick can have a particular shape as part of a bigger system and the bricks can interlock to create a

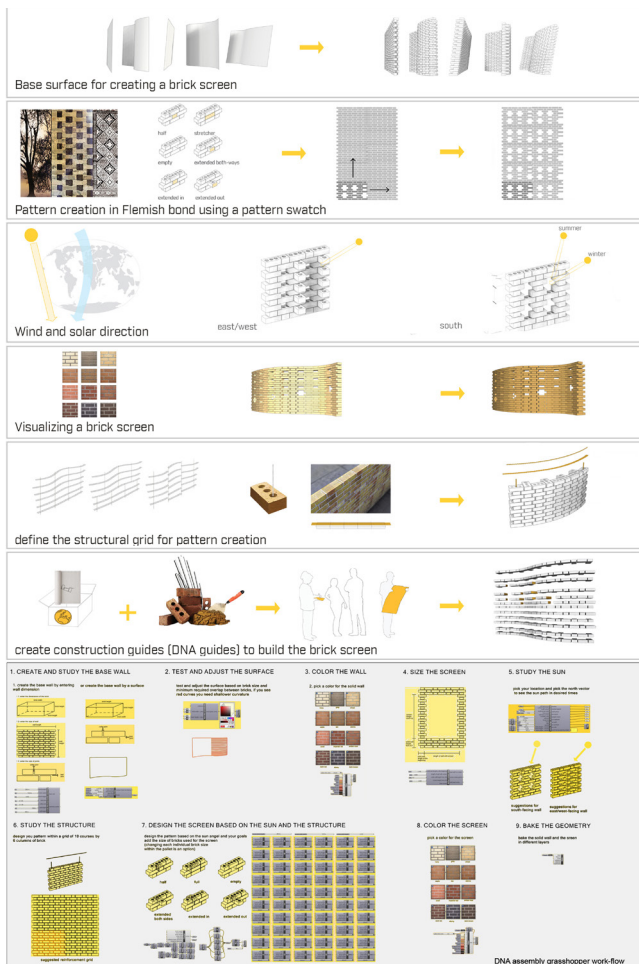


Figure 2: DNA design and construction toolkit

specific form⁹. There are also few parametric tools that enable complex form-making with bricks. Some examples are Brick Design Rhino plugin and Fologram application for bricklaying.

These approaches have complex and generally expensive outcomes, which require access to either highly skilled mason or costly digital tools and technologies and automation. The price and complexity of such systems means they are currently available in a few locations. Therefore, in locations with limited access to high-end technology and unpredictable site conditions, relying on traditional and low-tech construction methods can be more useful than solely relying on digital technology.

This work addresses the challenge of lack of masonry skill by creating low-cost digital diagrams that clearly show the layout of the masonry system and the process of assembly. The properties of this guide depend on the brick dimensions, mortar thickness, brick type and the type of bonding. Based on the guides, less-skilled masons can create more complex, responsive forms and patterns. The focus of this work is not on the form itself, but on the process of communicating the design



Figure 3: The paper guides and the process of building a full-scale prototype

with the users and implementing the form on site in locations with limited access to high-end technology and automation. In such locations, improving low-cost masonry techniques can have a great economic gain for the community.

Another helpful part of this construction kit is a set of simple sketches that can show the builder how to build the wall step by step (figure 5). Like the sketches that were developed by architect Lauri Baker about constructing a low-cost brick house¹⁰, simplicity of these sketches makes them understandable by unexperienced masons and encourage those with little or no experience in masonry to build or repair their own artifacts.

At the design stage, the toolkit is visually clear, acting as a design communication tool for the community. (figure 3) This approach advocates a collaborative process where the form-making, prototyping and building is a shared experience between the designer, the community and the mason.

To test this toolkit, a full-scale brick screen prototype was first designed and built using smart construction guides, then the toolkit and the guides were applied in designing and building



Figure 4, the process of digital design, and construction of the brick screens in Niamey, Niger. Image credit: united4design

a Compressed Earth Block (CEB) screen wall, constructed in Western Africa by local labor as part the facade of a multifamily housing project. A third prototype is also designed to test the application of the toolkit at a larger scale.

DESIGN PROCESS: DNA-DESIGN WORKFLOW

The nano-fabrication technique, DNA-Brick Self-Assembly, uses short, synthetic strands of “DNA” that work like interlocking Lego bricks. The system capitalizes on the possibility to program DNA to form pre-designed shapes. The same process can be applied to the design and construction process of a brick screen system that will inform the builder on how to place the bricks. Various design criteria—based on the information gathered by the designer and response from the community and the builder—are considered when creating a parametric workflow that aids in the design of more efficient solutions.

The proposed tool uses Rhino, Grasshopper and Ladybug to create a DNA Brick Design Workflow. Ladybug is a highly optimized daylighting and energy modeling plug-in for Grasshopper and allows users to carry out a series of environmental performance evaluations during the design process. Before using the workflow, the designer should gather the

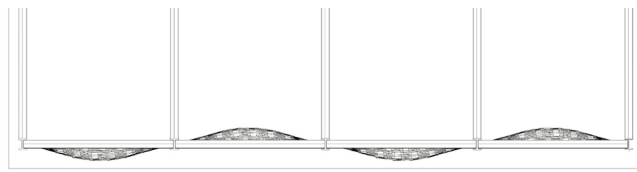
information that is needed to operate the tool. This information includes the size of brick and thickness of mortar, size and form of the wall and size of the screen and location-specific parameters including latitude, longitude and time zone. The DNA Brick Design workflow is interactive and visually clear and diagrammatic. The designer can go back and forth in between the design steps and adjust the initial inputs at any point (figure 2). Outside information will inform the organization of the screen. Below, the steps of the design/construction process are explained.

DIGITAL DESIGN STEPS:

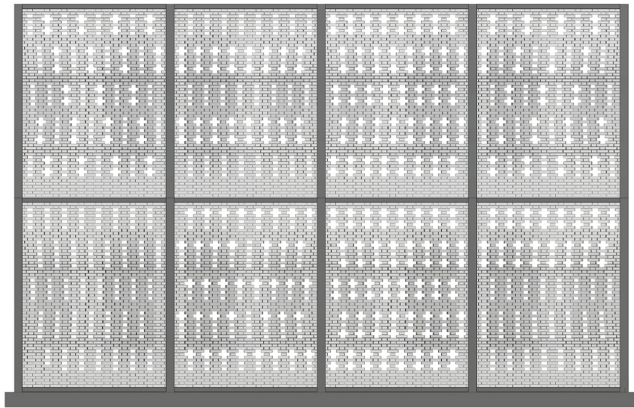
1. **Low-Cost Local Material: The Base-Wall:** The first step of the DNA Brick Design process is creating the base-wall. This step is directly related to the type of brick bonding and each bonding pattern can create different types of brick screen systems. To define the form of the base-wall the user can create a flexible surface and use it as an input for the component. Another method is to define the length and the height of the wall. The next step is to define the brick size and mortar thickness. Once all these data are entered in the component, the base brick wall is created.

In order to build a curved surface, there should be enough overlap between the bricks to have enough area for the mortar. The tool tests the curvatures of a surface and gives live feedback and identifies those areas of the wall that don't meet the defined criteria. The 3D representation of the wall in the Rhino workspace lets the user get a general feeling about the brick wall in a fast and easy way. In order to better visualize the bricks, the users can pick the color and the texture of the bricks.

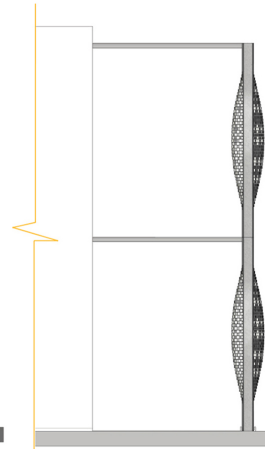
2. **Environmental factors: The Sun and The Wind:** The next component of Grasshopper workflow lets the users set the sun position, the geographical location and time of the year and the prevailing wind information. After inputting the geometry of the wall to the component and other required data, the sun path and the wind rose for that specific location are applied to the system. This can help the user understand how to design the screen to control natural light and air flow throughout the year. This component also suggests the appropriate opening height based on direction.
3. **Community and the Patterns:** The next step of the design process allows the users to design various patterns within the brick screen. For each brick there are six options to choose from or the brick can be removed. The main rule of thumb for the designer to remember while picking an option for the brick is that the span of the opening shouldn't be larger than the brick length. The pattern can be drawn based on the community's desire for privacy and other cultural preferences.



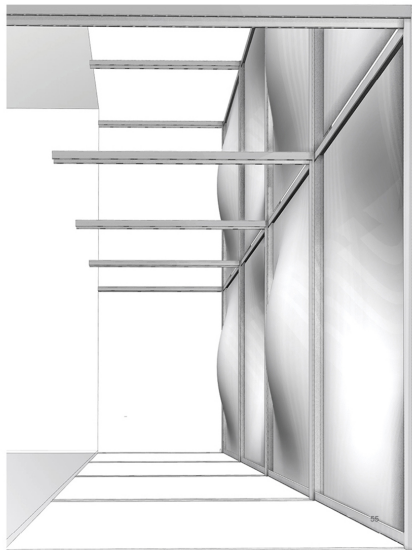
PLAN



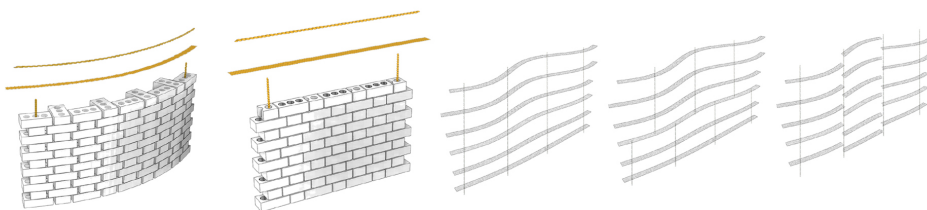
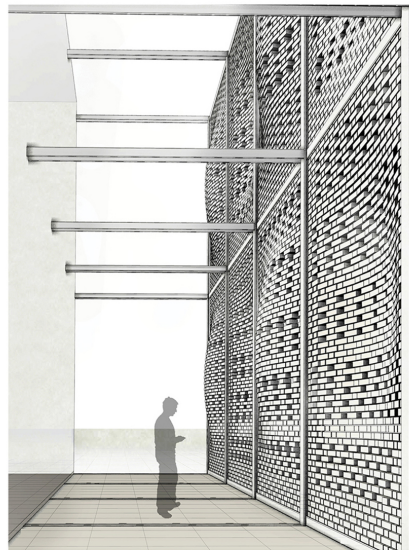
FRONT ELEVATION



SIDE ELEVATION



BASE SURFACE



SMART GUIDE ACTING AS THE REINFORCEMENT GRID

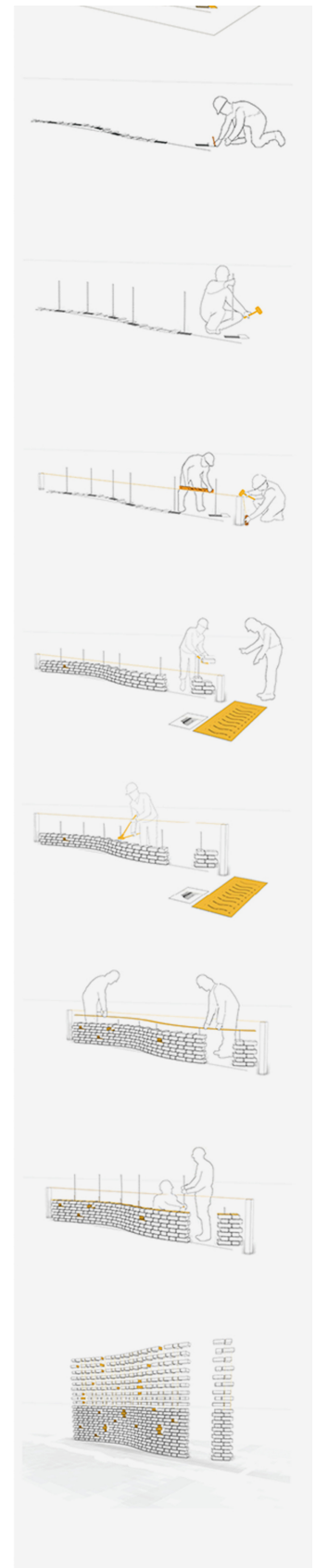


Figure 5: The third prototype, construction diagrams and smart reinforcement guides

Instead of automating the process of pattern creation, the DNA Brick Design tool allows the users to choose any form and size of the opening by having the control over each brick in a defined patch of bricks which is repeated in other parts of the screen. Repetition of a pattern within a screen is proper for ease of construction and for visual comfort. Also, the screen wall needs a reinforcement system in order to be self-supporting and the grid of the reinforcement can be a guide for creating repeating patterns.

4. The reinforcement grid: In the current form of this workflow, the grid is designed using a rule of thumb, assuming to have vertical reinforcement in every seven bricks in a row and horizontal reinforcement in every ten courses of bricks. The actual number of bricks in a unit of the grid can vary depending on the structural requirement in each location and factors like the type of brick and seismic requirements. The required reinforcement can be less if the wall form is not flat because of the improved lateral support. In this methodology one unit of the structural grid acts as a swatch that the user designs. If the user prefers more than one swatch pattern, the screen can be divided to sections and each section can be designed as a separate brick screen.
5. Cost-effective construction guides for masons: After digitally designing a brick screen wall, the drawn patterns are used for construction. The challenge of communicating the design to an average-skilled mason is addressed by creating a set of paper guides (called DNA guides) that are drawn with Grasshopper/Rhino. The DNA guide tells the mason where to place each brick, where openings are located, and how to position the bricks to create a curved or straight form. One section is drawn for each unique course of brick screen. The section guides and the elevations visually guide the mason.

The centerline of the wall stays identical in each guide and can help the mason as a reference to find where to start and where to finish each course. It can also be a visual reference relating to the string guides that masons use on site to keep the wall leveled. The base level (guide 0) only shows the bricks of that level. Starting from level one up, each guide shows the bricks in that course and the bricks in one course below. Figure 3 shows the guides and the process of building a full-scale prototype for testing the DNA Brick Design and construction tool.

The base level of the DNA guides can be printed large in the location that the wall is going to be built or can be mailed if there is no access to large printers in project location. The next levels can be printed on smaller papers. In this process the high-tech piece of the project is the DNA guide, which is a light-weight paper guide. The low-tech is the brick and mortar. The construction kit includes the DNA guide, the process sketches, the brick, mortar and the reinforcement.

REAL-WORLD DEMONSTRATION

This workflow was tested and applied in a multi-housing building project in Niamey, Niger (figure 4). The masonry units of this project are compressed earth blocks (CEB). CEB blocks are made of mostly of dry soil, include a small amount of clay and aggregate, and roughly 7-10% cement ¹¹. The CEB units act as thermal mass and perform very well in the heat of Niamey; in addition, they are much cheaper than cement blocks. CEBs are much more brittle compared to fired bricks and therefore should be protected from weathering and act better in a flat surface. The screens designed for this project face south, east and west. The design considers the required privacy for the residents and take visual cues from the local vernacular architecture. Based on the seasonal position of the sun the best size of each opening had to be only as high as one brick to keep the terrace spaces shaded throughout the year in this the hot climate. In order to communicate the digitally designed brick screen, a DNA paper guide was developed by the tool. The guide was used for constructing the mock-up on site and the final screen.

SUMMARY AND FUTURE WORK

This paper presented a process for designing a contextually appropriate and cost-effective single-layered brick screen system and creating simple paper construction guides for average-skilled mason to build the artifact. Brick, a low-cost and widely available material, along with low-tech construction techniques, was used to create the artifact. The tool allows the users to work with bricks in a digital realm and to control their position within the assembly and work with the community to find the appropriate design by making custom brick patterns for the wall. By defining a location, the orientation and the time zone, the user can study the sun's location during the design process and adjust the screen's form and pattern according to cultural preferences and environmental factors. Therefore, with this tool, a high level of flexibility and collaboration can be achieved in creating design options that can be constructed in different locations around the world.

The challenge addressed in this paper is the development of a process that is applicable in different conditions by average skilled masons. This is particularly important because many architects today are working internationally. After customizing the design, the tool creates a DNA guide that, along with construction diagrams and drawings, instructs the mason on the assembly of the wall. DNA paper guides let the average-skilled mason understand the design requirements and build a digitally designed screen with low-tech materials and hand tools. In order to test this design and construction process a prototype screen wall was made. Also, the real-world application of the process was tested during the design and construction process of CEB screen walls that were designed in Seattle and built in Niamey, Niger.

An area for future investigation in this research, is to study the possibility of using smart guides that also act as horizontal reinforcing elements in the wall. Such guides can be made from different types of mesh material including fabrics, plastic or

metal. The guide can be printed with plasma-cutter or fabric-cutter and mailed to construction site. It can be embedded in the bed joint of the wall if it allows the mortar pass through its holes. The shape of the guide can add to the precision of wall form and help the mason make sure he is creating the right curvature. Figure five shows a third prototype designed to test the application of the toolkit at a larger scale which also diagrams the use of smart guides.

This digital design tool and its future iterations creates a flexible process that makes it possible to bridge the gap between the high-tech digital design tools and the builder who works with low-tech techniques in locations with limited access to high-end technology. It also simulates the environment of various locations and allows for cultural interpretation in order to create an adaptive artifact.

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