THE BRICK SCREEN: PARAMETRIC APPROACH TO TRADITIONAL PAKISTANI *JALI* WITHIN THE DIGITAL DIVIDE

Muhammad Talha Muftee[1,2]*, Shaikh Abdul Basit[3]

[1]Doctoral Student, Department of Architecture and Urban Planning - Ghent University, BELGIUM, muhammadtalha.muftee@ugent.be
[2]Lecturer, Department of Architecture - COMSATS University Islamabad, Lahore Campus, PAKISTAN, talhamuftee@cuilahore.edu.pk
[3]Principal Architect, Fun-e-Tameer, PAKISTAN, architectshaikhabdulbasit@gmail.com
*Corresponding author

Abstract

With concerns regarding climate and need for more sustainable practices, practitioners try to appropriate advance design tools for their efficient problem-solving capabilities. In regions like Pakistan, architects are met with challenges of the digital divide due to which they must improvise and develop hybrid methodologies, bridging the gaps between digital tools and analogue construction techniques. While it imposes a limit on the selection of tools, it leads to new opportunities to embed performative qualities and novel tectonics in region specific material systems.

In this paper, authors explain the process and challenges behind a recent large scale parametric brick façade titled the *Brick Screen* in Karachi, Pakistan designed and fabricated for the ACPKHI (Arts Council of Pakistan Karachi) in 2022. Challenges consisted of local perceptions of risk, cost, sceptical attitudes regarding technology, and lack of existing examples of parametric design within the region. By using parametric design tools in a contextually grounded manner and optimization for manual fabrication, the architects were able to reintroduce the idea of the traditional *jali* (hence the name *Brick Screen* based on the Urdu word *jali* - جالی) which existed as an ornamental, climatically efficient device in the region interfacing with sunlight, natural ventilation, and privacy. Parametric design tools such as Grasshopper (a parametric design plugin for Rhino3D) helped develop not only brick patterns based on sunlight, spatial functions, and ornamentation, but a secondary script helped translate and optimize the generated patterns into human-readable fabrication drawings. This allowed linking of digital design process with existing construction practices that architects and stakeholders were familiar with. Constraints of manual brick masonry led to abstraction of thousands of bricks into simple sequences (or *chal* - چال as understood in colloquial construction terms), resulting in an efficient, economically feasible assembly process on site.

The project sets a precedent in the region for working at extremes of the digital divide and digital tools as means to transform existing practices. By using materials and building systems which are already accessible, digital tools can embed additional performative qualities in brick in a contemporary and regionally sensitive manner without the cost barriers of advanced materials or fabrication systems. Without access to advanced fabrication platforms ideal for transforming local practices at a fundamental level, architects can still work within limitations of technology, practice, and industry to achieve solutions that are more appropriate for the future.

Keywords: Parametric design, construction, digital divide, brick masonry, critical regionalism, sustainability.

1 BACKGROUND

Since advent of computational technologies, pioneers have commented on the profound implications of computers in any domain requiring some form of problem solving. As early as 1956, Ross Ashby wrote about digital systems which could amplify intellectual capabilities in the same manner as animals or industrial machines amplify physical capabilities of humans in laborious tasks (Ashby, 1956). With increasing access to computers and digital tools, many domains have depended on digital tools to solve complex problems. Architecture design, which deals with issues of the built environment is one of the key domains of application of digital tools since issues related to buildings and spaces can be complex depending on scale and nature of space.

Even when dealing with spatial issues without the use of sophisticated digital tools, architects rely of various types of drawing conventions and methodologies as strategies of problem abstraction in order to comprehend the countless variables involved (Alexander, 1964). Since the human mind has limited capabilities to process information (Miller, 1956), it makes sense that architects need to rely on whatever tools (whether digital or analogue) are available for solving complex problems.

With concerns of climate change, its impact on the built environment, and vice versa, there is an increasing awareness amongst architects about issues such as material performance, efficiency, carbon footprint etc. Recent COVID19 pandemic made the broader public even more aware of the delicate relationships between the natural and man-made environments. Such issues require cutting edge simulation tools to design buildings which are more efficient and sustainable for our future needs. However, availability of technology in design and construction industry is not straightforward. The construction industry is a complex and massive collection of sub-groups and stakeholders each evolving at a different pace according to material, social and economic factors within clusters of regions. As a result, the construction industry is one of the most lagging industries when it comes to adoption of innovative technologies (Bughin et al., 2016). In contrast, architects as designers and problem solvers are often detached from constraints of scale and material, at least while designing. They are more likely to explore and adopt new and better tools for their practice but are dissuaded due to the lack of stakeholders and collaborators willing to adopt new technologies for construction.

As an example, in countries like Pakistan, only a handful of practitioners and firms have adopted BIM (Building Information Modelling) as a design and construction platform (Ismail et al., 2017). Architects who are still motivated to employ more sophisticated tools to create sustainable buildings must improvise and work with industry limitations beyond their control.

2 DIGITAL DIVIDE AND ARCHITECTURE

Digital divide is defined as the inequal access to communication and technology based on social, cultural, economic factors causing global divisions between developed and developing regions or sectors when it comes to participating in global economy and development (Ragnedda & Muschert, 2013).

In terms of digital divide, what sets architecture apart from most engineering or scientific domain is its relation and proximity to technology. Architects and designers are often early adopters of computational tools, but they are seldom creators of such tools. Even though in recent decades, there have been examples of architects learning how to code in order to create their own tools and API (Application Programming Interface) for robust design methods (Loukissas, 2012), and architecture schools have always implemented courses related to digital tools with Harvard Graduate School of Design and MIT (Massachusetts Institute of Technology) being one of the first (Mcmahon, 2013; Upitis, 2013). On the other hand, as architectural projects are often prominent because of their presence in the public sphere, architects and designers are also responsible for popularizing innovative technologies of design and fabrication such as Frank Gehry's famous Guggenheim Museum Bilbao which in 1994 made use of CAD (Computer Aided Design) software originally designed for the aerospace industry (Carpo, 2017), as one of the first prominent examples of computational design in architecture.

While architecture is subject to the digital divide around the world, architects can strive for improving the technological landscape within architectural design. However, the phenomenon of the digital divide is composed of several layers and factors (global and regional), requiring a deeper understanding to develop strategies to overcome it. Some of the crucial factors are explained in the following sub-sections.

2.1 Historical Factors

2.1.1 Industrial Revolution and Evolution

Any major development in technology whether for communications, transportation, or production of goods can have profound impact on social and political structures in a very short amount of time. This leads to collective displacement of communities and human capital. Consequently, this also means inequal distribution of capabilities to benefit from newly restructured systems of production. Historically, using machines to produce with higher efficiency have led to restructuring of occupations (Gombrich, 2005). In similar manner, digital technologies have had equally profound impact on social structures and practices.

But these changes never occur all at once globally. Industrial developments are incremental and specific to regions which means that architects in different parts of the world have access to very different platforms (hardware or software). One example of this phenomenon is emergence of additive manufacturing and robotic fabrication systems. Their accessibility and usage in architecture is directly related to the local state of manufacturing and engineering sectors since these machines were originally developed for other purposes, over time becoming ubiquitous enough for architects to implement in novel ways (Carpo, 2017).

In developing regions like Pakistan which lacks similar industrial breakthroughs, it is not justifiable for architects to make use of similar manufacturing tools for architectural design or fabrication when compared to very low costs of manual labour. Thus, the possibilities of tools for innovative design methods stemming from local industrial development is a direct outcome of the digital divide.

2.1.2 Institutional and Bureaucratic Forces

Even in developed regions with favourable conditions of the manufacturing sector, technological access for architectural researchers and practitioners can vary and are subject to organizational, social, political, or financial forces operating within the region. What technologies end up shaping architectural practices or vice-versa in hindsight can be a matter of happenstance and illusion of choice.

One example exists during early stages of computer development within academic institutions during the 1960s involving two key figures i.e., Christopher Alexander and Ivan Sutherland. Christopher Alexander is often considered as one of the first architects in history to make use of computational tools to solve complex issues within the built environment, while Ivan Sutherland is most famously known for his development of the first digital drawing tool known as the *Sketchpad* (Upitis, 2013). Both researchers were working at the same institution (MIT) around the same time. However, due to funding and organizational differences both had access to very different hardware in separate domains. Ivan Sutherland developed *Sketchpad* using the TX-2 computer with much better processing capabilities and a graphical user interface while Christopher Alexander in the same vicinity had access to a much inferior IBM 7090 mainframe limited to numerical input using punch cards. Furthermore, *Sketchpad* was primarily developed for electrical engineering and CAD software was adopted in architecture practice later. Had Christopher Alexander access to the TX-2 computer, the development of computational design would have been drastically different (Upitis, 2013).

2.2 Sociological Factors

2.2.1 Limited Understanding of Digital Divide in Developing Post-Digital Regions

Due to cost and ease of access regarding consumer technologies such as smartphones and internet, cities and communities all over the world are part of the global information system. Rural communities in developing regions lacking in substantial public services and infrastructure are still able to form online communities, interact digitally and extend commerce. When developing an understanding of the digital divide, one must acknowledge that even developing regions are now post-digital regions where physical and virtual spaces inform one another. Multiple projects regarding digitalization have failed in such regions because of false assumptions and denial of existing local digital cultures (Arora, 2019).

For example, in cities like Durban, Africa, informal spaces of commerce are constantly shifted to avoid displacement by law enforcers using communication applications. There is hardly a city present today that is not shaped by its virtual dimensions and a lack of understanding of the post-digital context means that architects are unable to design interventions for public good in a meaningful manner (Odendaal, 2008). The simplistic definition of digital divide simply in terms of infrastructure and access is not sufficient anymore as was also evident during the COVID19 pandemic when parts of the world despite having internet access were unable to sustain activities in isolation (Esteban-Navarro et al., 2020).

For architects, it means that local context for possibilities of computational design must be understood with regional digital cultures and relations to technology. Implementing innovative digital tools developed for a different set of users elsewhere is not sustainable and may in fact contribute to digital divide. Architects motivated to transform design and building practices using digital tools need to start at the fundamental level, developing new methodologies in harmony with local stakeholders, context, and existing practices.

2.2.2 Alienation and Aversion to Technology

Any new radical development in technology not fully understood is often met with scepticism and resistance by public which is one of the biggest challenges of introducing digital tools in design of the built environment. Tectonics and complex aesthetics consisting of complex surfaces, splines, and fractal details which are often outcome of generative tools, because of their apparent sense of unfamiliarity contribute to feelings of alienation and distrust when it comes to computational design (Carpo, 2017). If the users and stakeholders are made to understand its benefits to the built environment there can be a sense of empowerment but it requires public discourse, open participation and awareness on part of the architects involved (Claypool et al., 2020).

Since technologies evolve at an exponential rate as compared to local cultures, it is not unusual for even local practitioners to be vary of societal implications of technology. One of the primary fears is the potential of unemployment and job displacement because of technological advances. However, studies suggest that such fears are not based on empirical data and in fact, technological shifts bring about new opportunities in terms of employment with new roles and broader scope of participation in global economy (Bughin et al., 2016).

In countries like Pakistan, while practitioners are aware of the advantages of digital tools such as BIM, perception of clients regarding ROI (Return on Investment) is one of the reasons for its slow adoption. Architectural projects demand a lot of time, material, labour, and monetary investment so from the clients' perspective, any untested methodology or novel tool carries inherent financial risk (Akdag & Maqsood, 2020). Likewise, any design proposal based on mass-differentiation, parametric, or complex design elements is seen as costlier due to assumed longer times of fabrication especially when there are no existing precedents in the region which can be used to convince stakeholders of the environmental, performance, or cost benefits of sophisticated design and construction tools.

3 CASE STUDY: THE BRICK SCREEN

Considering the complex scenario of digital divide in Pakistan, it is important to set a precedent for architects to contribute to the technological landscape within architectural practice. The authors found such an opportunity in 2019 to develop a large-scale (144 ft. by 39 ft. for northern façade and 94 ft. by 39 ft. for southern façade) parametric brick façade for the ACPKHI situated in Karachi, Pakistan. The project, which was part of a larger renovation project replaced the existing façade using parametric design tools to create a more efficient façade with conventional materials and systems. All aspects of the design and construction process were dependent on challenges and factors of digital divide previously discussed.

Fig. 1. The *Brick Screen* (north façade), Academic Block, ACPKHI, Karachi, Pakistan.

3.1 Setting a Precedent

3.1.1 Traditional Jali

Clay bricks are one of the oldest and most ubiquitous building materials in Pakistan with earliest examples dating back thousands of years in archaeological sites such as Harappa and Mohenjo-daro (Mumtaz, 1985). Even today, the brick is commonly used as a low-cost building material due to easy availability of suitable clay as compared to modern materials such as concrete. Meanwhile, *jali (*جالی) which translates to a perforated screen has been part of regional architecture for centuries, gaining widespread popularity as a climatic and ornamental device during the Mughal era (Lerner, 1984). While many *jalis* have been made using materials such as terracotta, marble and limestone, the principle of the perforated screen has survived till date as a passive device suitable for the local climate and culture. The *jali* can diffuse direct sunlight, allowing for natural light and wind while offering a cooler indoor climate and allowing for varying degrees of privacy. The traditional screens as ornamental elements consisted of highly intricate patterns, often geometrical and modular as a derivative of Islamic architecture and design (Abbas, 2016).

Fig. 2. Example of a Mughal era perforated marble *jali (Lerner, 1984).*

Both elements of architecture are part of public consciousness in Pakistan, hence it was an appropriate choice to design a parametric perforated brick façade to avoid issues of alienation and perceived risks of cost pertaining to complex digital tectonics.

3.1.2 Precedents in Neighbouring Regions

At time of conception and commission of the project in 2019, there was a lack of large-scale parametric brick facades as was being proposed for renovation of the Academic Block of ACPKHI. By time of its completion there existed another notable example of parametric brick façade by Ali Arshad Associates in Toba Tek Singh, Pakistan (Abdel, 2020). However, back in 2019, it was necessary to investigate examples of similar typology in neighbouring regions. Iran, sharing cultural, and traditions of Islamic art and architecture with Pakistan, was an important case study since many contemporary Iranian architects have successfully developed brick facades using parametric tools in combination with local masonry techniques (Canepa, 2022). The aesthetic association with Iran was an important point while collaborating with the stakeholders in this project.

3.2 Design

3.2.1 Performative Layer

The primary algorithm for generating the brick patterns was developed in Grasshopper as it allows for an approachable interface for computational design which is relatively easy to understand for stakeholders and collaborators. The main parameter for the new façade was based on required amount of natural light and wind in the newly planned spaces behind the façade. All primary studio spaces and corridors were denoted as spaces requiring the maximum amount of light during the day while secondary and private spaces such as storage, private meeting spaces (requiring more control over lighting conditions) needed lesser or no natural light. Each floorplan designed for the renovated building was mapped in terms of degrees of lighting and transposed over the façade to generate a vertical planar map of high, medium, and low intensities of light.

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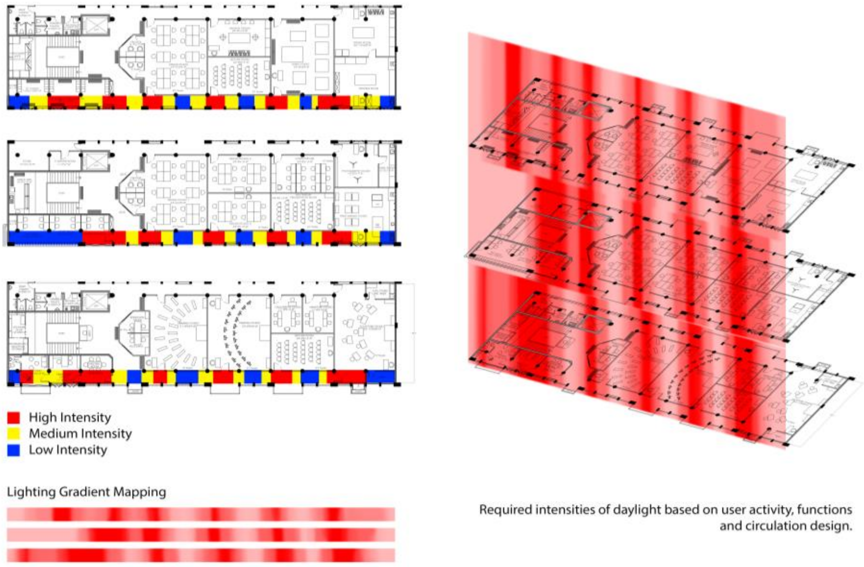

Fig. 3. Transposed values of required natural light over northern façade based on internal spaces.

3.2.2 Communicative Layer

Once the limits were defined for the façade, the mapping was used to generate an image using digital painting to create a fluid surface. This was done to create smooth transitions between various values of lighting while at the same time affecting the materiality of the brick *jali.* The fluid pattern also harkened to Karachi's proximity and identity associated with the Arabian Sea. The digital painting technique, while a subjective approach to conventionally objective computational design allowed for bridging local traditions of painting and technology which improved its acceptance on behalf of all stakeholders. As ACPKHI is an esteemed institution for art education and engagement in Pakistan, the stakeholders were able to take creative risks compared to others. As practitioners, architects are intermediatory agents and not the sole authors which is an overlooked fact in conventional histories of architecture. Without clients, collaborators, and stakeholders' role in shaping the built environment, mainstream narratives surrounding prominent buildings overlook the social aspects of design and construction (Gosseye, 2019).

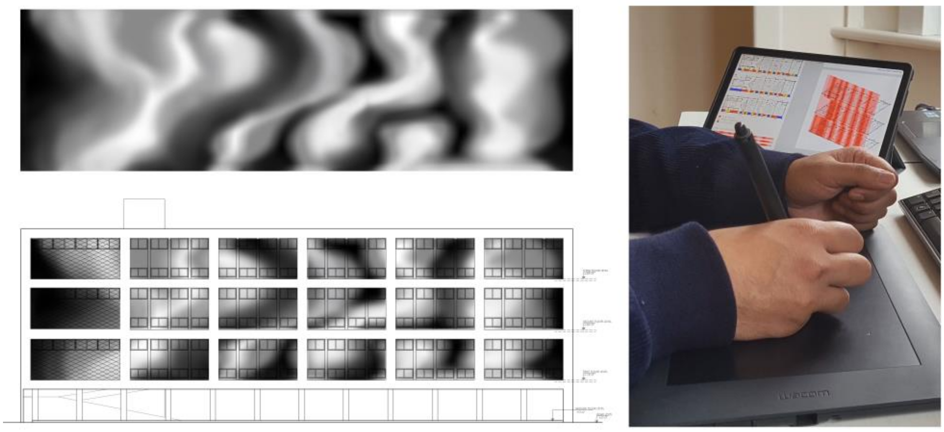

Fig. 4. Painting values of light and shadow over predefined limits of required relative amount of lighting.

During conception of the façade, it was felt that the building, enjoying a prominent scale and placement within the campus of ACPKHI visible from the main roads could also benefit from added layers of visual identity that represented the institution. Thus, another layer was added in the lightmap with the southern façade (facing a large open public space and a major entrance) including the logo of the institution and the northern façade a portrait of Sadequain; as a tribute to a famous modern painter of Pakistan known for his innovative approach to painting and calligraphy. In both instances, lighting simulation and raytracing helped in ensuring that the images and text added to the patterns did not affect the overall lighting conditions previously defined.

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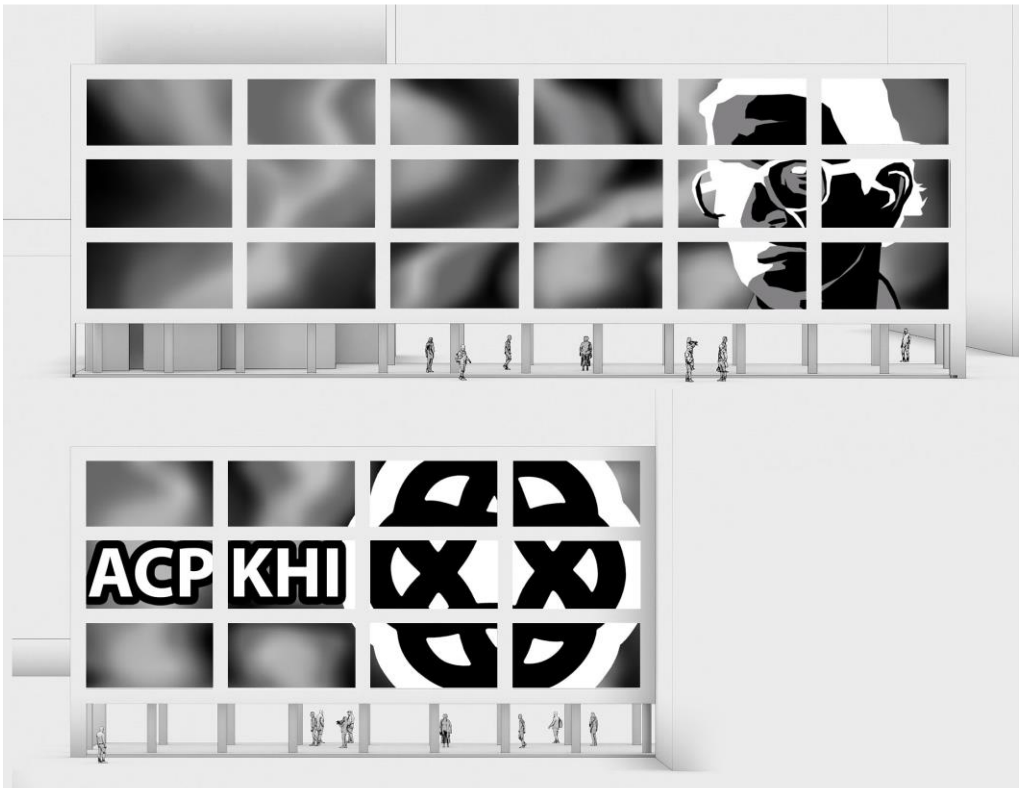

Fig. 5. Lightmaps with performative and communication layers with northern (top) and southern (bottom) façade.

3.3 Brick Pattern Generation

The lightmaps were then used in Grasshopper as input for image sampling, mapping all grayscale values to rotational values between 0 and 90 degrees. Based on documentation on site, the ideal number of bricks and their courses were calculated using a digital twin (also considering tolerances for mortar). The mapped rotational values were then used to rotate each brick around its z-axis in counter clockwise motion.

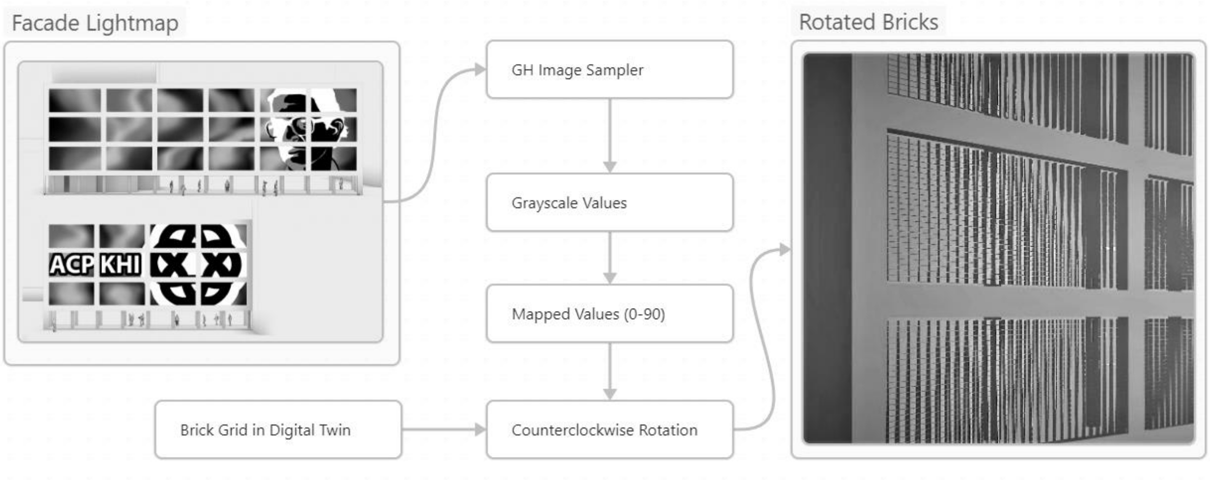

Fig. 6. Grasshopper script description to rotate each brick in façade with respect to lightmaps.

3.4 Optimization

Optimization was required to transform the generated brick pattern into a set of assembly instructions which could allow for cost effective, precise, and approachable workflows on site using standard masonry techniques. This was done in the following two stages using a secondary grasshopper script which optimized the mass differentiated bricks and generated annotated drawings to be used on site.

Fig. 7. Grasshopper script description to optimize brick pattern and generate assembly drawings.

3.4.1 Resolution

The first phase of the optimization process was based on resolution of rotation. The original generated pattern consisted of thousands of bricks with angles between 0° and 90°. Manually rotating each brick to precision of one degree would have been not only time consuming or costly but in terms of performance would have had diminishing returns. Several lower resolutions were tested to find optimal values which were not only easy to work with on site but also from a user's perspective did not lose the intended fluidity in the façade. After several trials, each brick's angle was set to the nearest 15°. This was an angular increment that could be easily set by hands by masons using custom wooden jigs (seven jigs in total to adjust bricks efficiently).

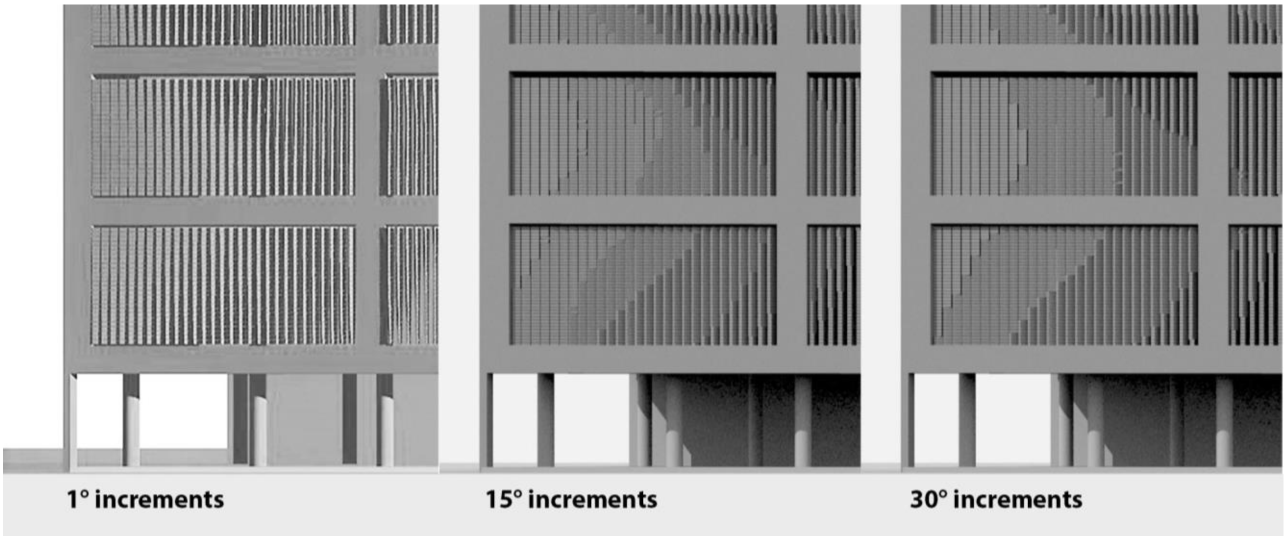

Fig. 8. Varying angular resolutions for brick rotation.

3.4.2 Vertical Chal

In colloquial Pakistani construction terms, a *chal* is defined as a continued sequence of one brick course from one point to another. *Chal* is how masons on site coordinate brick laying. For each *chal,* the mason follows the demarcated centre lines to lay bricks in a straight line when constructing walls. In case of the Brick Screen, the idea of the *chal* was used to denote vertical sequences of bricks instead of horizontal. Each vertical *chal* was optimized in Grasshopper similar to a smoothing algorithm: if in a vertical sequence, a single brick was rotated at a unique angle, it was readjusted to match the angle of the brick below. In this manner each *chal* contained fewer groups of bricks in successive sequence. The motivation behind this method of optimization was to minimize any errors in manual fabrication and turning complex sequences of bricks into easy to remember compressed sets of information (e.g., 10 bricks of 30° followed by 27 bricks of 60°). Thus, there was no need to continuously consult drawings and allowed for ease of communication amongst construction teams. Each angle was also denoted by a letter i.e., A=0°, B=15°, C=30°, D=45°, E=60°, F=75°, and G=90°. It was observed that such optimizations had no perceivable impact on the overall materiality of the Brick Screen.

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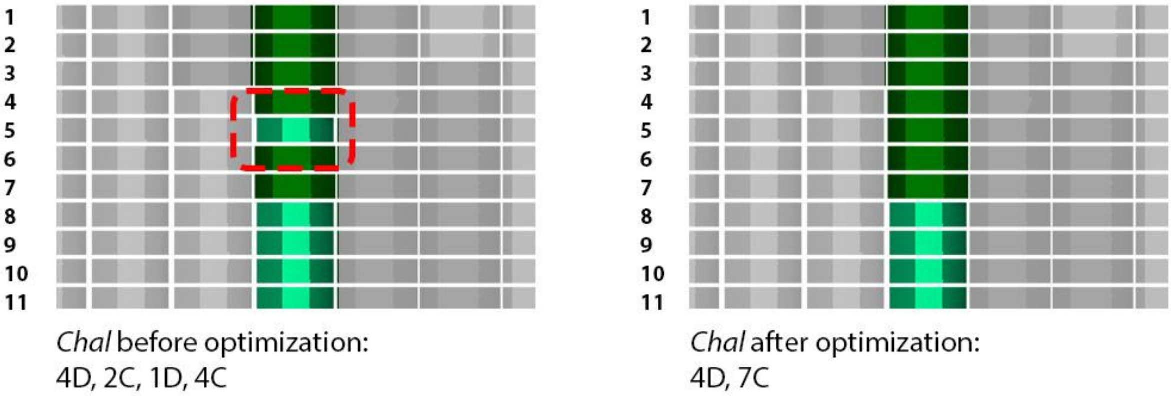

Fig. 9. Example of *chal* optimization to reduce complexity of information on site.

3.5 Construction

The script designed for optimization above in Grasshopper was also used to generate drawings for each opening of the façade. This was done in DWG (Drawing) format since AutoCAD is the conventional drawing software used for construction drawings in Pakistan.

3.5.1 Procedural drawings

Directly generating drawings using Grasshopper components allowed for a precise translation process to avoid any errors in the hundreds of drawings (plans and sections). Grasshopper also allowed for directly exporting annotations and visual information such as values of rotation, unique colour codes for each type of rotation and respective assigned letters. This allowed for color-coded elevations drawings that could be easily understood at a glance by anyone involved on site.

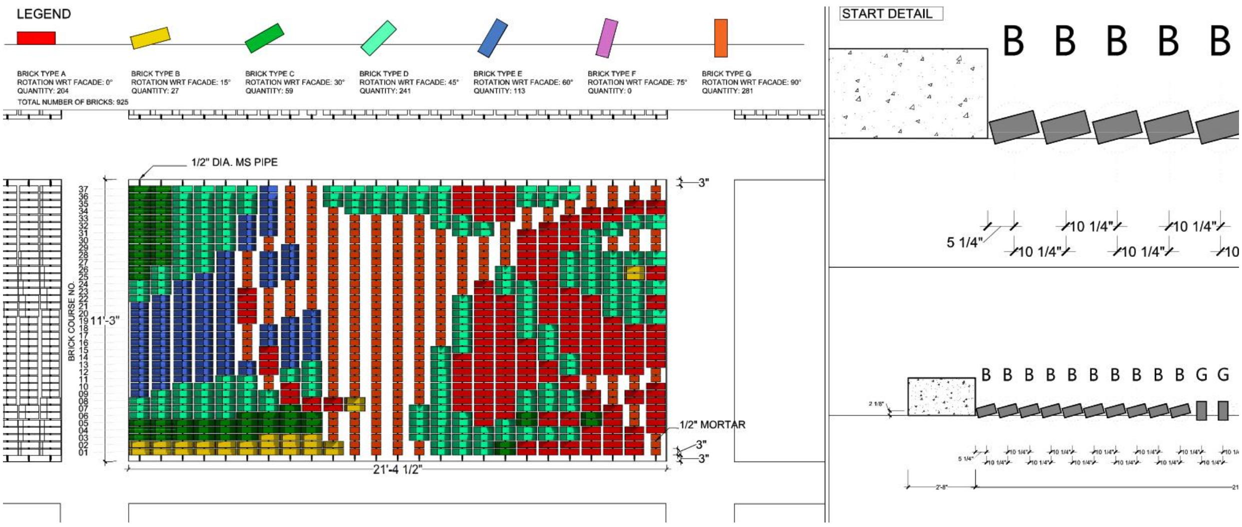

Fig. 10. Example drawing exported from Grasshopper to AutoCAD with annotations.

3.5.2 Fabrication

For fabrication procedure, stainless steel rods were installed in each opening for added stability and precision for assembling bricks. After surveys it was concluded that drilling bricks on site was more feasible compared to custom moulds or using alternative modular materials. With optimized drawings containing simpler sequences of bricks the project assembly was quick and efficient considering the complexity of the overall design. By using custom wooden jigs, masons could swiftly rotate bricks according to their respective colour/letter code. Plans for each course was generated with every colour-coded elevation as a means of redundancy and supervision.

Fig. 11. Conventional brick masonry using custom wooden jigs based on colour codes.

4 CONCLUSION AND FUTURE DIRECTION

With a design and fabrication process derived from an understanding of the technological limitations, standard practices and constant collaboration with stakeholders, the project was not only completed within expected margins (despite affected by COVID19 lockdowns) but was able to achieve a very high level of accuracy with manual fabrication. Considering the lack of precedents at time of conception, the authors hope that by documenting the process, the Brick Screen can serve as a necessary precedent not just for similar architectural projects but also in broader sense, with the necessity of understanding post-digital cities and practices that are often overlooked with the limiting dichotomies established by notions of digital divide around the world.

Fig. 12. Southern façade of the Brick Screen at ACPKHI, Karachi, Pakistan.

For future direction, the research and practice will investigate regional digital cultures closely to allow for future methodologies that are not only more appropriate for the material conditions of the region but also help in developing localized digitally enabled practices that local stakeholders, collaborators, practitioners, and public can claim ownership of. By claiming regional ownership and moving away from linear conceptions of technological progression, future emerging technologies such as artificial intelligence, robotic fabrication or generative algorithms can be better understood and critically analysed.

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