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*Research Article*

# The Versatility of using Bricks to Produce Generative Monolithic Surfaces using different Construction methods

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***Abstract***

*Designing a generative monolithic surfaces using a common construction materials like bricks have developed in design practice recently, especially with the widely use of parametric modeling by Architects. The real challenge here faced this development was how to construct these generative monolithic surfaces. However, CAD and BIM systems opened an opportunity for Architects to create parametric Monolithic surfaces using a traditional construction element like bricks, but there is still a challenge in how to develop or improve the construction methods to reach this generative walls. Now there are more developing construction methods used to produce the brick walls like digital templates, robotic assembly and 3d brick printed brick panels. The main goal of the paper is to relate the versatility of using bricks as a construction material with the parametric modeling of generative monolithic surfaces to verify the common methods of construction used to produce such kind of generative walls. The paper pointed out construction technologies that are compatible with the BIM systems to be integrated within to take it to a further step from virtual to reality. The paper concluded that new technologies of design and construction will influence the architectural definition of building components.*

***Keywords:*** *Digital fabrication, brickworks, parametric modeling, monolithic surfaces, associative parametric design and building components.*

## 1. Introduction

Masonry has a strong history in building construction in the Middle Ages as the most commonly used Building material. Masonry constructions are the great majority of the buildings in Europe's historic centers and the most important monuments in its architectural heritage. (Como, M 2014). This composite material consists of brick and mortar which is called brickworks and produced a traditional patterns. A few decades later, bricks was increasingly competing with concrete, steel and glass in building constructions and became a building material among many.

However, this small-scale construction element with its special texture and haptic feel of exposed masonry still have attraction depending on color and surface of the single stone arise in the Interaction with joint pattern and masonry bandage various design options. The widely spread of thermal performance analysis tools and its integration with the parametric modeling in the early design stages in order to achieve the thermal comfort inside the buildings and to optimize the building performance minimized the need for a multi-layered masonry Façade as the only mean as a thermal protection for the building (P.Massoud, 2008), and opened the opportunity to develop a thin wall monolithic construction with a better thermal performance in which it can be generated with the versatility of using the bricks as a construction element. A wall made of bricks is subjected to a rules of mathematics, meaning the relationships (i.e connections) between the bricks, and can be described by an algorithm and therefore digital production allows direct translation of digital files into physical artifacts.

The passion of producing this generative surfaces in the early design stage digitally needs the adoption of BIM technologies in order to obtain and construct these surfaces within the same digital stream to achieve what is defined by the American Institute of Architects (AIA) as Integrated Project Delivery (IPD) processes. (AIA,2007) which means the know how to construct such surfaces using the digital technologies in construction stage as well. This part that should be developed more by the stakeholders in the domain of building design (MacLeay AIA ,2007). Figure1

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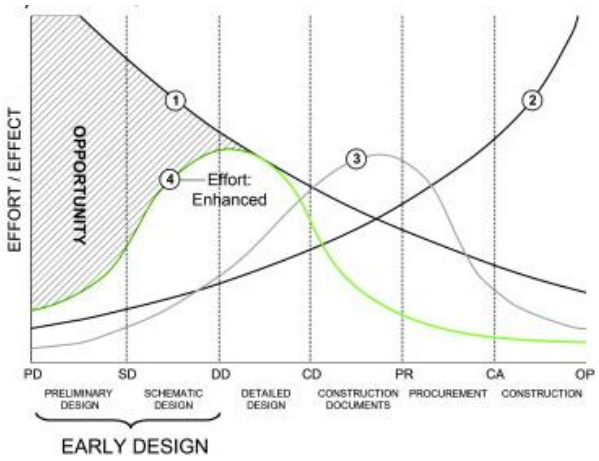



**Fig.1** MacLeamy (Patrick MacLeamy according to AIA, 2007) Curve 1 means the ability of decisions to affect costs and performance; Curve 2 refers to the cost of design changes; Curve 3 represents the traditional design effort distribution; Curve 4 represents a redistribution of efforts by an enhanced process.

## 2. Originality and Versatility

Originality is rare, because to be truly original means to have done something that no one has ever done before, and that no one could have anticipated. Most masonry creations will not meet that condition, most Masons who make creative surfaces are making creations that are based on commonly used brickworks bonds table1 as a constraint or a rule, part of the ingenious quality of bricks is that it is a system of construction, fundamentally based on interconnecting sets of bricks/blocks.

**Table 1** types and description of most common brickworks

| Type of bond | Description |
|---|---|
| English bond | A combination of the stretcher and stack bond. Two courses are laid in stack bond and the next two courses are laid while staggering by half a brick. |
| Flemish bond | All courses consist consecutively of a header and a stretcher. An often used bond that includes a little more cutting work. |
| French bond | Every course alternately consists of a stretcher and two headers. |
| Stretcher bond | This is the most common and used brickwork method. The vertical joints are staggered each time by half a brick. There is hardly any loss of material because the bricks do not have to be grinded to size. |
| Header bond | All the courses consist only of headers that are staggered by half a brick. The header bond is sometimes combined with the regular stretcher bond in order to create a curve in the wall in an easier way |
| Stack bond | This bond visually emphasizes the vertical aspect of the masonry. The facing bricks are laid one on top of the other so that not only the horizontal edge joints, but also the vertical head joints are continuous. This can be done with stretchers as well as with headers. However, the latter will up the price due to all the grinding and cutting work. |
| Block bond | A combination of the stretcher and stack bond. Two courses are laid in stack bond and the next two courses are laid while staggering by half a brick. |
| Brazilian bond | The facing bricks are laid in such a way that empty spaces are created. An elegant solution to partially show an underlying construction or to let more light in. |

The way in which a brick is laid also strongly influences the appearance of the monolithic surface it gives the monolithic surface style and character. Brickwork versatility not only have an aesthetic effect; but it can also influence the budget, the structure and the construction method itself. More complicated brickwork bonds, which usually necessitate more grinding work, can substantially change the traditional way of constructing the monolithic surface. So in order to achieve the versatility in producing a monolithic brick wall there are two major factors;

## 3. Versatility In designing brick wall

There has been a long history of brickworks in the built environment, which indicates that there are limited possibilities for the traditional techniques that can be applied on wall design to produce a generative surfaces. In this regard, parametric techniques in designing brickwork and digital technologies can assist in developing proper methodologies (Al-Haddad, Gentry and Cavieres, 2011). Brick walls consist of uniformly shaped and sized bricks that are laid in courses with mortar joints (Lynch, GCJ, 2007). This feature makes the parametric design of the brick walls possible to provide designers with the ability to parametrically test formal concepts and also to manage continuous changes of the design. Associative Parametric design software affords manipulation of both geometry and relationships it allows the architect to create design tools without having to start from scratch each time. This software requires a very specific approach and a thorough recorded of choices that are made in the process of evolving the design

solution. And by exploring most of the trials to achieve this versatility of using the bricks parametrically it was found that there are significant parameters that can generate the required monolithic wall; The size of masonry units, The type of bond that is going to be used and adopting a computational operation as introduced by (Kereshmeh Afsari, Matthew E. Swarts, T. Russell Gentry, 2014) "select", "corbel" and "yaw". Table 2,

**Table2** the major computational operations that are done for the brick as a construction element inside the monolithic wall

| Type of operation | Description |
|---|---|
| Select | Upon selection of the base modules, the units can be combined to generate a chosen pattern either through mapping a traditional or other bonding pattern or by mapping a digital image onto the wall |
| Corbel | a solid unit in the wall protruding from it, can create several patterns on brick walls by offsetting successive courses of bricks |
| yaw | is a rotation that is an aviation term for this particular rotation around one of the Euler axes |

These computational operations were applied on several monolithic wall designs with subtraction and extrusions as shown in figure 2, 3, 4 where the versatility appeared in the gaps in between bonds or extruding the bricks with same amount of extrusions.

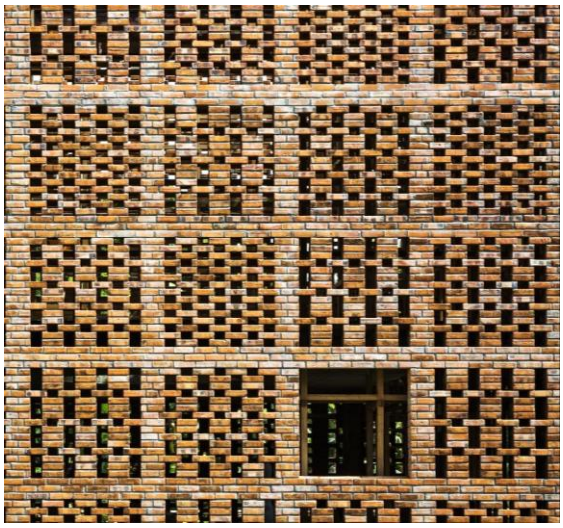


**Fig.2** Selective and corbel operations were done to create the gap in the wall

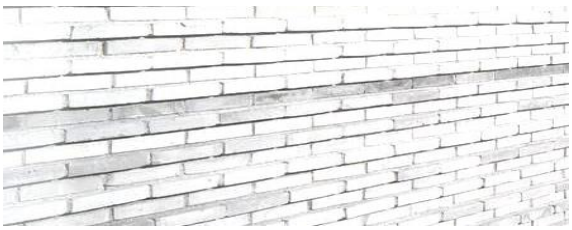


**Fig.3** Corbel operation was done by extruding the odd courses. For the whole wall

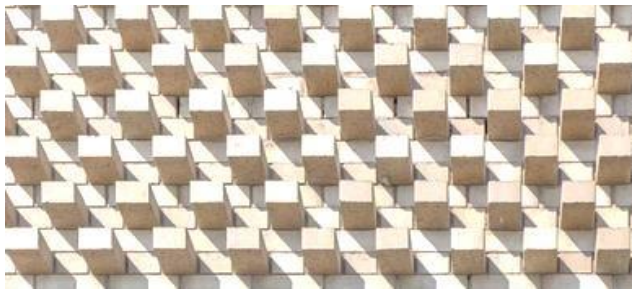


**Fig.4** Corbel operation was done by extruding a selective bricks in the wall

Other projects used digital environmental simulation software on the wall resulting a unique monolithic surface Using the commonly used brickworks bond as a start then playing on rotating the brick/ block to produce the variation of the final surface to generate shadows an entering light inside the space. Figure 3

**Fig.5** Yaw operation was done on the brick unit to allow light and shadows

## 4. Versatility in constructing brick wall

The versatility in constructing such a creative monolithic walls designed using Parametric modeling using bricks/blocks as a construction element experienced a lot of challenges due to the nature of the construction element itself and its traditional manual low cost way of construction. Brick Walls construction depends mainly on human craftsmanship and introducing any other techniques may lose this construction method its gained quality as a low cost

construction method especially in developing countries where manual labor, local materials and conventional methods are preferred, this is the main challenge. As previously mentioned in order to achieve integrated project delivery IPD the construction/ fabrication method should consider in the early design stage. Different strategies were done for materializing parametric masonry designs by using;

*4.1 Hands-on and low-tech construction method;*

Which does not necessarily need any digital aid for construction it only depends on a well-trained mason to construct the monolithic surface of brick. Figure 6, 7 the mason was talented to achieve the different patterns generated by same masonry bond, most linear brick walls done by the parametric operations; select and corbel and constructed by a well-trained mason.

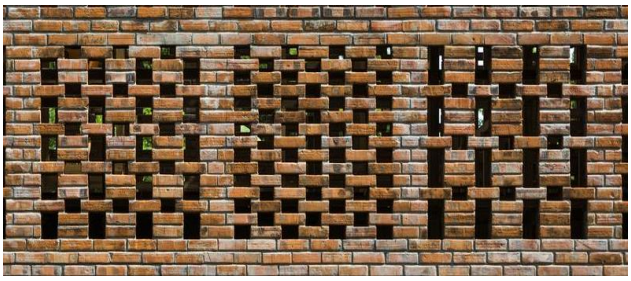


**Fig.6** Terra Cotta Studio, Vietnam Brazilian bond used with a gap between each brick and the other in the same course to create a space and combining it with the block bond with gaps as well which help the wind ventilating and air conditioning the studio using a traditional clay bricks

**Fig. 7** while in Westkaai towers, the diversity and range of Flemish bricks used in this project allow a subtle color difference between the pair. Tower 5 is yellow and tower 6 red, the classic colors of brickwork, but chosen in tones that make their color highly ambiguous. Using different types of bonds stretcher and English bonds and extruding one of the headers.

*4.2 Digitally generated templates and adjustable scaffolding construction method;*

Historically the mason's construction tools were physical elements that are not related to digital files by any mean; in this construction method they are often connected to digital files, allowing the designer to visualize the design of brick wall without getting limited by traditional mason tools; that if the tools doesn't suit the required wall design the tools can be changed. Which makes making tools is an order of magnitude more powerful than making the end object. This on site construction method where digital fabrication is not directly applied on the construction material but on the construction method itself as a kind of adjustable scaffolding or templates where a digital file is generated for these instructional templates to control the individual rotation of each block in a parametric masonry wall or a joint templates that can be used by the mason to construct each course of the masonry wall. Figure 8

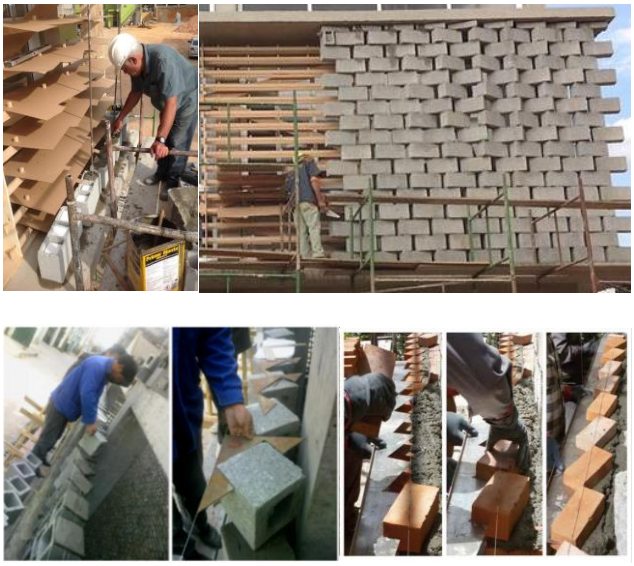
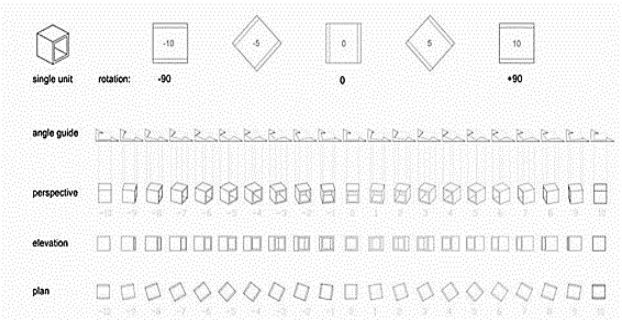


**Fig.8** shows how templates aid the mason to construct the parametrically generated brick wall

This technique in construction depends on both the mason and the template generated by the digital file of design figure 9, it is considered a low tech. method as it still depend on labor but with a low cost digitally generated templates that allow the assembly of bricks into a geometric pattern. The templates and guides during the construction, still show that the ancient craft of setting out drawing lines on site with strings is very much alive.



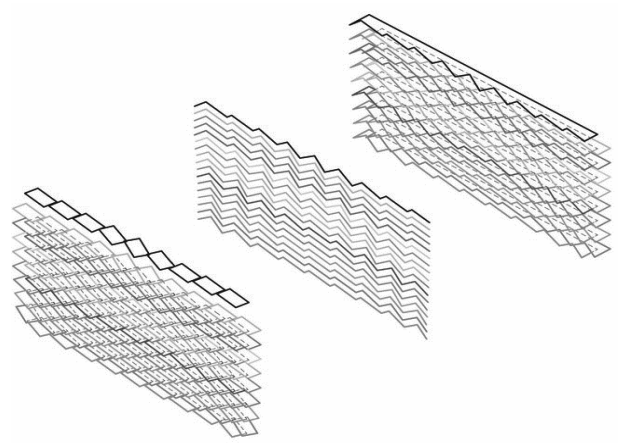


**Fig. 9** the digital file generated for the templates used by mason to construct the wall. Either a guide for each block or for the whole course

It is difficult and very labor -intensive to go over every block in the model to verify that the data actually describes the block to be built. It must be done, so the agreement between the designer and the fabricator has to make clear who is responsible to do it, and to avoid on site problems there is no substitute for good communications early on and open collaboration throughout the wall construction. The integrated project delivery here requires skill and judgment to check the validity of the data and examine the entire data set to find buried problems.

*4.3 Advanced digital fabrication technology construction method;*

It can be considered as an additive fabrication technique this type of construction technique depends totally on digital technology in manufacturing and fabrication. Dry brick wall fabrication without traditional mortar masonry, 3D printed prefabricated brick panels and robotic manufacturing process like ROB made are used to achieve the parametrically designed brick walls and allowing fast assembly on site. Prefabricated panels figure 10,11.

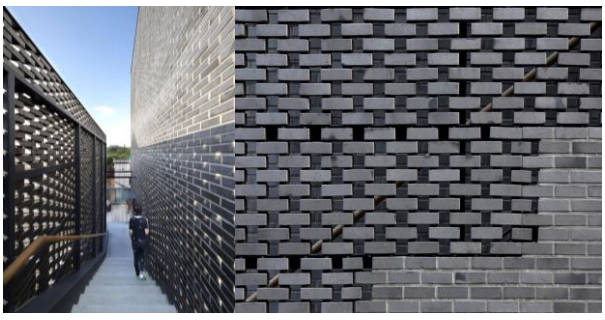


**Fig. 10**.The ABC Building is located in Korea used the dry brick wall fabrication

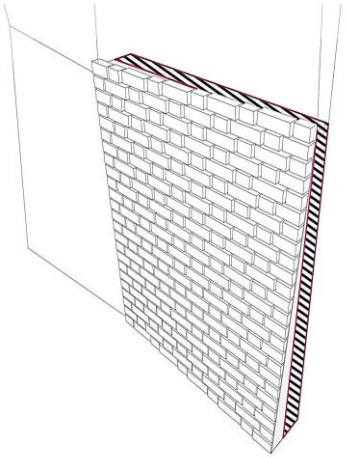



**Fig. 11** 290 Mulberry building the prefabricated brick panels were used

ROBmade is a type of glued masonry that opens up brand new possibilities in façade and wall design. Create a structure that is truly 3D through building block rotation, open butt joints, vertically offset elements or formation of horizontal and vertical curves. Figure 12

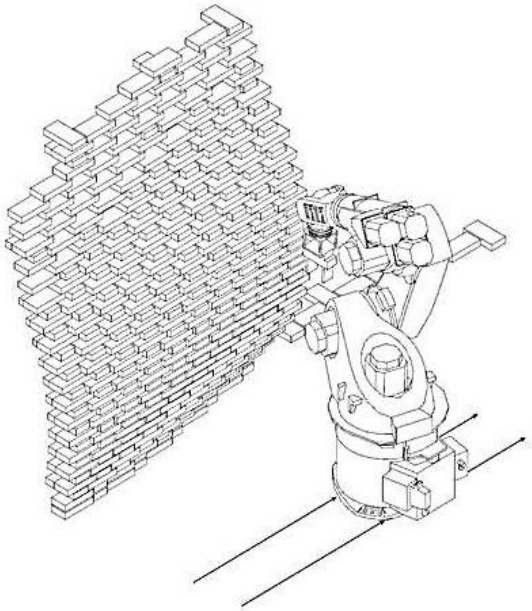


**Fig. 12**. The robotic masonry fabrication technique gives a precise positioning of bricks with the stretch display of the curving walls

Digitally fabricated brick wall using a robot does not only mean that the robot is quicker, more precise, and more productive, but it also enables complex designs that are impossible for human to build with that level of accuracy. The robot doesn't need an optical reference or an identifiable pattern in order to lay bricks precisely. It also allows complex walls to be built without relying on repetition.

## Conclusion, Discussion and limitations

The complexity of designing the surfaces and the construction method itself has led to increasing levels of specialization as well as delivery methods that promote separation of disciplines rather than efficient integration meaning that should be a digital interface for each discipline in constructing the wall, therefore applying the Associative parametric modeling approach in designing the monolithic surface using bricks as construction material; requires that everyone involved in the process must treat the digital geometry as a real physical brick/ block because most of the recent parametric design tools with BIM authoring capabilities define a wall as a single entity and cannot provide access to the geometry representation of the units of the wall so that the designer can create patterns/brick bonding. Associative parametric modeling is working directly from digital files as a BIM platform used in architectural design and digital fabrication as well. Figure 13. The concurrency of different levels of mason expertise who choose the suitable construction techniques which is crucial at early design stages. Digital fabrication and traditional techniques are compatible and complementary. Even more they are interrelated and enable us to build a new hybrid toolset. Knowing the right tool for the designed wall is a sign of a skilled craftsman. So in construction field today it is found that digitally controlled tools, conventional power tools and many manual tools are all complementary and used. The Digital fabrication and construction provides an accurate precision, which is not necessarily visible to the human eye. Digital fabrication technologies, such as 3D printed panels and ROB made have entered the construction field, but they are not a replacement for the traditional construction methods.

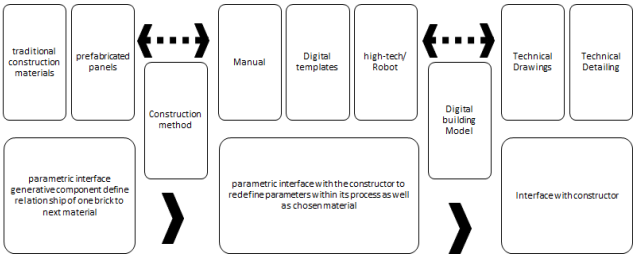



**Fig. 13**. Associative parametric modeling flow diagram

## Further work

A complete discussion of the physical, structural or aesthetic judgments resulting from such patterning is beyond the scope of this paper.

Current software design tools that can provide techniques to design a parametric brick wall such as Brick Design plug-in for Rhino (ROB Technologies, 2012) have limited capabilities when it comes to the brick bonding and brickwork patterns which needs a further research with structure engineers to provide stability and strength for the proposed wall.

The currently BIM tools like Revit and sketch up are limited as they do not allow the selection of the construction material unit of the wall (brick/ blocks) separately , so there is little possibility to access the basic components like the brick and permute their geometry representations while preserving the linked definition of the whole assembly. To embed design expertise, the basic unit that is required is a parametric component that holds internal geometric relationships and deals with external rules to represent the assembly of masonry components. If the design changes, these parametric relationships will allow constant application of changes automatically in order to organize the assembly within the coherent topology and geometry of its components. Thus, the components have to be modeled both by their appearance and by their semantic relationships within their specific domain.

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