V-INCA

Designing a smart geometric configuration for dry masonry wall

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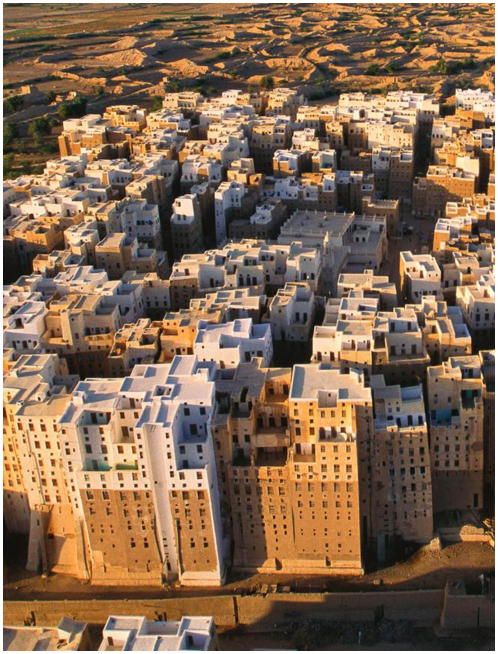
Soil is still used as a building material in many parts of the world, especially in rural areas. Approximately 30% of the world's population is still living in shelters made by soil (Berge 2009). One of the techniques is using soil in mudbrick form, which is sun dried instead of being fired in kilns. However, mud bricks have low compressive and tensile strength. Instead of enhancing the mix formula, we focus on designing the geometry of the brick itself to improve walls' overall compressive and tensile strength. The goal of the research is to explore an innovative way to build masonry walls through geometrical examination together with computer aided design. Unlike traditional horizontal laying of the rectangular brick elements, 3D designed blocks take advantage of gravity and foster an accelerated assembly without mortar. They create a balance point in the middle of the wall during the construction. The geometry of V-INCA blocks allows dry construction which will reduce the amount of time spent on the site. Load distribution and the friction between two surfaces are sufficient to have a dry construction. Thus, a wall built with V-INCA is stronger intrinsically due to its geometry.

Keywords: *Dry masonry construction, smart geometrical design, on-site material, compressed earth blocks, Inca masonry*

INTRODUCTION

Traditional context

Earth has been used by many civilizations throughout history all around the world. Many different techniques evolved depending on the climate, geology, vegetation cover, topography, orientation, history and culture of the region. There have been early examples of multi-story earth buildings in the history. Shibam in Yemen is known as "Manhattan of the desert" and renowned for its high-rise buildings built by unfired earth up to 14 stories height (see Figure 1) and the city's construction dates back to 9th century (Dobson 2015). In the following centuries, far from Yemen, Taos Pueblo in the semi-desert plateaus of New Mexico and Arizona were being built by the Pueblo Indians (Schoenauer 1981). Considering the earth buildings were rising in different parts of the world independently, earth has functioned as a universal building material for thousands of years; mainly due to being a low-cost and on-site material and requiring little skilled craftsmanship.



Compression forces and the interlocking system together create an integrity for a dry stone wall (Dipasquale et al. 2016) By exaggerating the angles of faces and making them repetitive, V-INCA can benefit from the inclined surfaces and produce two type of bricks supporting each other for faster installation. Meanwhile, it avoids the labor intensive masonry work of Inca's with the help of computer-aided design.

Figure 1
Mud-brick high-rise buildings in Shibam, Yemen

Figure 2
Wall from Inca masonry in Machu Pichu

Nevertheless, today's increasing world-wide interest in earth is because of environmental awareness, ecomorality and search for energy efficient building materials which is expressed in the increased number of conferences, institutions, building codes, research studies and the new products. As interest in earthen building techniques increases, it requires more research design initiatives to meet today's demands.

Dry masonry. One of the early examples of dry masonry wall building method was ashlar technique in Tiahuanaco and Inca. Structures made by this technique were strong enough to stand until today. (see Figure 2) Stone walls were built with Random-Range work, which means laying stones with different heights and widths (Protzen 1986). The structures made with this technique could resist to seismic forces. The method was a labor intensive work and it required skilled masons. When examined, the stones of Inca walls exhibit convex and concave faces and create different angled bedding and lateral joints.

Contemporary context for earthen architecture

Previous studies were made to investigate interlocking wall systems with dry construction or using less mortar. One of the early attempts was Walter Burley Griffin's knitlock system (see figure 3) which was designed in 1916. Even if his attempt was to design a dry masonry construction, the vertical holes were grouted with the reinforcing bars (Johnson 1970). On the other hand, Armo Block System is using a similar approach to Griffin's knitlock system, this time with a metal rod inserted every 80 centimeters. [1] Both are using a geometrical design strategy which is a horizontally interlocked wall system. In the early 1990s, Musaazi developed a block called "Interlocking stabilised soil block (ISSB)" which is a variation of compressed earth block. Manually operated press machines are used for the production of ISSBs (see figure 4). With manual labor, production of 400-600 blocks with 2-4 workers in an 8hr work is possible (Pérez-Peña 2009). This technology is gaining recognition especially in East Africa. Less cement is used because interlocking faces require less mortar.

Figure 3
Students at the Melbourne School of Design are rebuilding Pholiota, a project built with Knitlock system by Walter Burley Griffin and Marion Mahony in the 1920s.

Figure 4
The steel press in the image is used by UN-Habitat for ISSB's manual production. It is a modification of first steel press machine CINVA-RAM.

Figure 5
Quake Column by Emerging Objects with interlocking 3D printed units using traditional Incan ashlar techniques.

Overall, all three examples are promising solid and more resistant wall systems than traditional masonry alternatives together with time-saving and sustainable properties. Based on these examples, the argument is that there is a recent demand for innovative wall systems that will save time, cost and the amount of material used together with a promise of low-carbon footprint. Another promising research on interlocking components is quake-column which has 3D-printed interlocking blocks for an earthquake resistant column. Rael and Fratello, researchers of quake-column project argue that mortar free construction is more earthquake-resistant than the ones have used mortar [2]. Considering the earlier innovative examples and traditions of masonry wall systems, V-INCA is investigating a reliable performance and a smart geometrical application for a masonry wall.

Material Properties

Interlocking of neighboring blocks create an interdependency between wall elements and functions as a monolithic wall. Blocks can be manufactured with compressed soil, lightweight concrete or clay. We are focused on compressed soil because it is a ubiquitous on-site material with a low-embodied energy. Soil mixtures used for block making typically consist of silt, clay, sand, gravel and an addition of a fibrous material such as straw. Another advantage of soil is that it has no transportation costs if it is manufactured on-site with compressed earth machines. When earth is compressed, its density changes between 1700 to 2200 kg/m3 (Minke 2012). Earth materials support a balance of indoor humidity due to its moisture regulating properties (Minke 2012). However it also have some limitations such as high cost of labor and difficulty of making tall buildings. [3] V-INCA blocks are also designed to overcome these limitations. In addition to material research and smart geometric configurations, other possible strategies to increase the performance of the blocks are self-shading surface, recycled aggregates, channels embedded for an airflow. Self-shading surface can be developed to prevent heat accumulation in warmer climates. An air-flow can be supported throughout the gaps created between diagonal joints. The end product as a vertical element (partition wall, building envelope etc.) will expose its elements and logic behind the geometry. Thus, building technique will be read through the surface which will give an insight to its users.

DESIGN AND FABRICATION

Mainstream approach for a brick wall is multi layer-based wall assembly. Since the building envelope is constructed using material layers that are developed and manufactured by various entities, the performance as a system is susceptible to defects caused by detailing, workmanship, and maintenance. V-INCA is seeking the possibility of a one-layer monolithic wall system whilst preserving multi-layered wall system's features, such as heat insulation, water-tightness and ventilation. It is also a thermal mass which provides direct heating and cooling effects. Blocks imitate the logic of Incan ashlar techniques from 15th century as discussed above. Thus, in case of an earthquake or under strong winds, the forces will be diffused through interlocking faces. Walls are intrinsically stronger and can support more load than traditional mud brick walls. Exploration of geometry is conducted through 3D modeling on Rhinoceros. A seismic vulnerability study can be done by using digital model of different buildings designed with V-INCA bricks. Other advantages of digital modeling are that it allows all block types to derive from each other and total number of bricks needed for a construction can be calculated within the model. Digital modeling also allowed us to 3D print the blocks in various scales in order to have control over the geometry and spot where modifications needed. 1/1 scale production of the bricks is designed to be low-tech and practical. Both types of mid-bricks are each other's derivatives; they have surfaces with matching angles (see figure 6). Steel manual press machines will be used in the production of V-Inca bricks. In this case, molds need to be designed with certain angles. In order to have a simple on-site construction only one type of mold unit is designed. When 4 identical mold units are placed with particular combinations, different types of blocks can be produced (see figure 7). It is possible to create all kinds of blocks (2 types of mid-blocks, half and quarter blocks, top and bottom blocks) within the same machine by using same mold units (see figure 8).

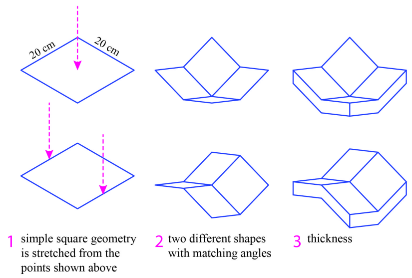


Figure 6
Blocks' geometry is designed on Rhinoceros software.

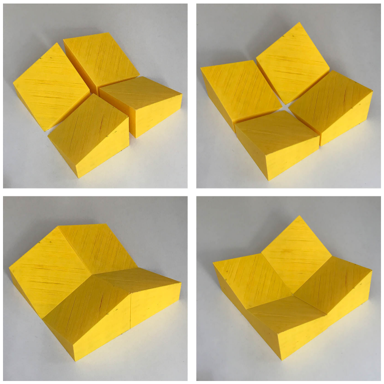


Figure 7
Four identical units create the mold's form. Other type of bricks can be produced by a different combination of the same units.

Figure 8
Here are all necessary block types for a building envelope's construction.

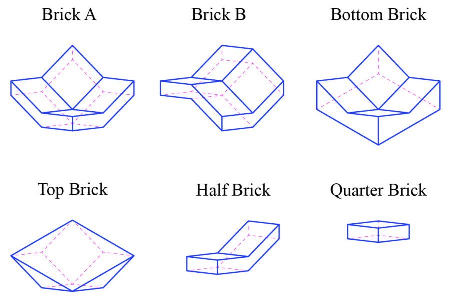


Figure 9
Concrete mix is used in production of 1/2 scaled blocks.

During our initial tests on a physical model, we 3D printed the solid shapes to create the mold's base geometry. A concrete mix is used instead of soil mix during the first production. We have casted concrete in a mold which has 4 identical 3D printed units (see figure 9). Four types of combinations are used to produce all blocks necessary. Using the mold horizontally would be an imitation of the compressed earth machine, however, we used it vertically since it is more practical for casting concrete. Once concrete is cured, the mold is easily detached and the blocks are taken out. The sample wall consists of twenty 1/2 scaled concrete blocks. For 1/1 production, the subsoil found on site will be the main material of the soil mix. A mold that can be easily adapted for different block types is significant for efficient block making on-site. Four identical but solid shapes will be placed in a simple square prism. Soil mix is filled from the top and pressing is made by a plate that geometrically matches the form created beneath. Due to blocks' geometry, they allow a compact stacking and thus they can be stored efficiently. When used on site, they are simply laid on top of each other, held by gravity and the friction between corresponding faces (see figure 10).

DISCUSSION

The key goal of V-INCA blocks is to investigate geometry's role on dry masonry systems that will contribute to development of existing compressed earth block (CEB) technologies. In order to utilize this system as a safe and economic manual labor in rural areas, steel manual press machines should be introduced and made accessible. Since earth buildings have low social acceptance [3] and usually correlated with poverty, the role of combining old technologies (compressed soil) with recent ones (computer aided design) is greater in social context.

CONCLUSION

Summary

One third of the world's population is living in earth buildings made by traditional techniques especially in rural areas. A new approach to building with earth blocks is investigated by altering the geometry of the units of a masonry wall. Inspired by Inca masonry, the proposed research investigates iterations and alterations of the brick members' geometry by using Rhinoceros 3D. Possible forms are first 3D printed and then casted in molds to test the integrity of a sample wall to be used in either load bearing wall or non-load bearing system.

Future Steps

(1) In addition to rural context, investigation of utilizing V-INCA building system in an urban environment which includes developing a model for utilizing excavated soil which are usually discarded in construction sites. (2) Material research will be conducted in order to suggest a low-carbon technology; comparisons will be made between soil, clay, concrete and such. Additives will be explored those have the potential to improve performance. (3) The size of the brick element, user experience of the brick wall will be investigated on a 3D digital model. Visual effects

Figure 10
A sample wall made by V-INCA bricks

will be tested under different light conditions within the physical and the digital model. (4) 3D printing will be used to test different surface properties. Ultimately, this research utilizes digital designing tools into 1:1 production of a building element in order to investigate geometry's impact in designing dry masonry walls. 3D designed bricks foster rapid installation and allows mortar free construction.

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[3] http://www.earth-auroville.com/compressed_stabilised_earth_block_en.php