**figure 27**

Final robotic plaster profile construct on site.

figure 27

of MAKER + MATERIAL in contemporary expanded practice" (Perez 2012). Attending to material constraints within this body of research has encouraged promising trajectories for architectural production. In particular, the research leveraged material feedback to inform the creation of variable robotic tools. Custom tools in turn provided a constellation of operations activated through the open-ended platform of robotic motion. Each operation required synchronization with the phase-changing properties of plaster as it transitioned from liquid to solid and relied on a multidimensional context where physical limits, durational constraints, and digital intelligence (from on-site singularities to tool geometry) were mapped into the procedural space of fabrication. While there are many topics worth further consideration and development relative to robotically applied plaster, the work also serves as an extendable model where new tools and machining operations can participate in the intelligent shaping of heterogeneous, synthetic materials (Figure 27).

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WORK IN PROGRESS

# DIGITAL VERNACULAR

## ABSTRACT


"In a computer-designed world the next logical step is to move straight from the digital models to 3D printed buildings" *(Kapoor 2009). In a computer-designed world "it is now possible to conceive customized prototypical architectures, which can be adaptable to differentiation with various inputs, distributed across global networks and for building in different parts of the world" (Malé-Alemany 2008). The research project Digital Vernacular has investigated the potential of using CNC technology for the production of housing, where the material system constantly feeds back into the loop with design systems. It has focused on the design of machinic devices as well as computational design tools, and revolves around the concept of fabrication on-site. Using an additive, layered manufacturing process and locally available material, the project proposes a revolutionary new digital design and fabrication system that is based on one of the oldest and most sustainable construction methods in the world. The main goal of this method is not to create complex forms for the sake of design, but to use parametric control to adapt each design to the specificities of its site. Guided by geometric rules found during many research experiments with real material behavior, a new architectural language is created that merges several environmental functionalities into a single integrated design.*



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## 1 INTRODUCTION

Architectural practice has been greatly impacted by technical innovations in the past. Usually new building types emerge as part of new ideologies. Yet the current revolutions in computer-aided design and fabrication are independent of each other, with architecture focusing on form—traditionally sequential in "form, structure and material" (Oxman and Oxman 2010).

The design system of this project uses an innovative fabrication method for the construction of housing. The method is based on an on-site, layered manufacturing process with a paste-like material. Developed from the customization of existing CNC technologies and incorporating CAD tools and scripting platforms, it bridges the gap between CAD and CAM and makes their relationship more explicit. The research was aimed at finding an equilibrium between materiality, design intent, and fabrication processes (Figure 1).

The project has the potential to serve society at large. Historically, when it comes to architecture, small and rural communities have been largely independent or self-sustaining. However, considering that our major interest lies in examining spaces and the different means of realizing them, we have the scope to examine societies strictly in the spatial context.

## 2 HACKING INTO CNC

In this research project, a traditionally subtractive process was converted into an additive process. CNC machines at two different scales were hacked. Initial tests were done on a print bed of .45 m × .45 m on a Roland MDX 540. This was successfully scaled to a print size of 1.2 m × 1.2 m on a Camtech router (Figure 2).

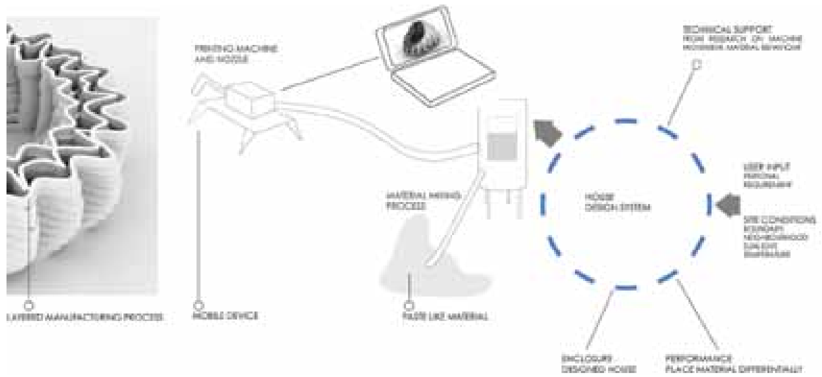


figure 1

figure 2

**figure 1**

Concept diagram of the overall system.

**figure 2**

Hacking the CNC, including a .45 m × .45 m Roland MDX 540 and a 1.2 m ×1.2 m Camtech router, successfully transformed a subtractive process into an additive process.





As technology becomes more accessible to areas that have not had access to it or the infrastructure to support it, this system (which was tested with clay) has the potential to be deployed to various parts of the world where earth is used widely as a material for construction.

## 3 MATERIAL STUDIES AND DESIGN APPLICATION

"The most abundant building material known, the earth around us has been used for house construction since early times. Adobe is perhaps the most popular and oldest form of earth construction" (Shelter 1973). The material system explored was with a paste-like material—clay—which has many qualities that were tested and understood.

### 3.1.1 Test and Studies

One aspect that became clear immediately in the material testing phase was that when printing with a paste-like material, the material was structurally more stable when built in curves rather than straight lines (Figure 3).

- The testing was done under the following categories.
- Geometrical analysis: to understand angles to build and geometrical limitations.
- Central wall: printing in multiple layers, and its geometrical implications.
- Standability of a straight surface: walls with various numbers of curves were tested.
- Standability of a curved surface: walls with various numbers of curves were tested.
- Rotated angle: geometrical possibilities were explored.

The development of the design system and digital tools was based on the knowledge acquired during the material testing phase. In this manner, material studies directly fed back into the process.

### 3.1.2 Openings

To proceed with meaningful architectural design, it was necessary to look beyond surfaces and start considering surface perforations and openings. The geometrical tests suggested what kinds of openings were possible (Figure 4).

Materially, it seemed that more than one option was possible. Investigations were carried out to determine the various possible outcomes, which can be classified as:

- Inverted triangle openings
- Oval openings
- Stopgap print openings
- Openings through material effects

With the creation of openings, it also became apparent that the position and size of the openings had an impact on the printing sequence. Thus the final printing is broken up as different set of sequences (Figures 5a and 5b).

figure 3

figure 4

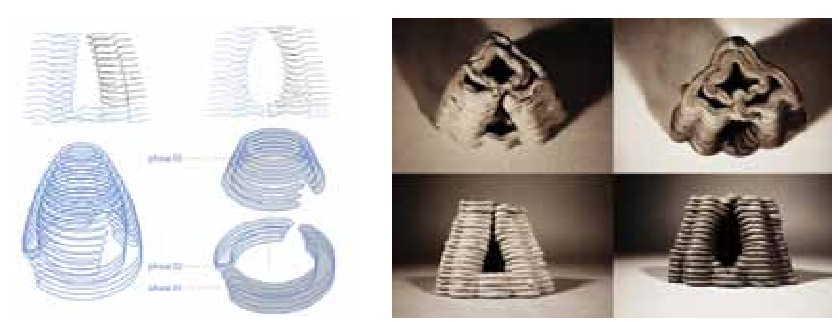

figure 5

**figure 3**

Standability of single wall tests: single walls with varying degrees of sine curves were tested to understand the relationship between the strength of the surface to the number of troughs and crests in the wave.

**figure 4**

Typical opening strategy.

**figure 5**

(a) Printing diagram / G-code; (b) opening tests, using the angle limitation derived from the geometrical tests. These can be used for large view opening.

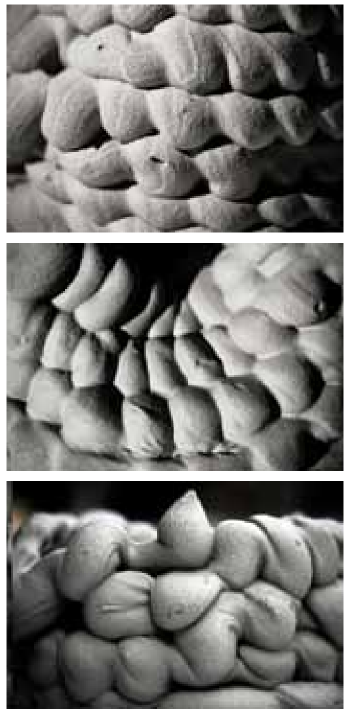

figure 6

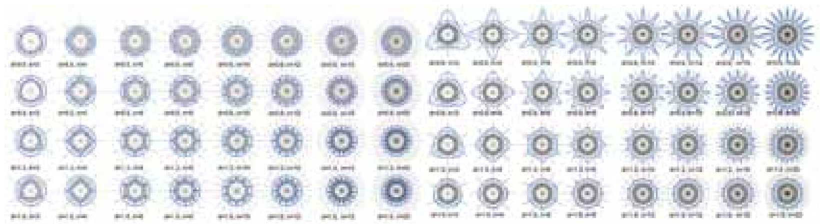

figure 7

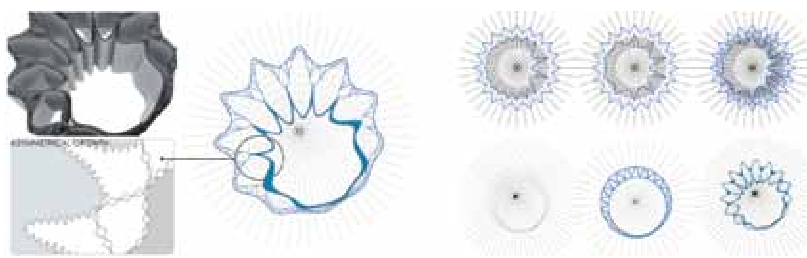

figure 8

### 3.1.3 Material Events

Inconsistency of the material formations and material properties can be viewed as material interruptions. These interruptions can be used for design advantage if they are controlled, since they can be predicted; they would not be surprises, but would be controlled noise created particularly to address specific issues. They would be generated through the integration of construction and programming in the design process (Gramazio and Kohler 2008). The applications of this kind of noise can range from aesthetic to purely functional (Figure 6).

### 3.2.1 Printing Logics—Learning from Tradition

Traditional single-material enclosures were created primarily to build domes. This aspect of construction was explored from a design point of view while using the data from material studies (Figure 7).

One solution was buttress-like fins supporting the dome. Two-layer membranes intersect with each other to produce more strength.

A triple-layer membrane can also perform as a cavity wall—something that is already used in vernacular houses around the world to provide thermal insulation. With a triple-layer membrane, the potential of continuously printing a high-performance membrane integrated with structure and functions emerged. This directly led to the discovery of spaces within space, and the potential for architectural design immediately became immense (Figure 8).

### 3.2.2 Printing Logics—Learning from Nature

Single surfaces can easily become a double or triple surface with an increase in distance between them. This method is inspired by and modeled after nature's pattern of bone growth, where material is deposited where it is required based on function. The fabrication method similarly provides a great advantage in that material can be deposited only where it is needed, allowing optimization of traditional structures and reducing the amount of material used during construction.

**figure 6**

Different effects caused by unpredictable events.

**figure 7**

Stability of single wall tests.

**figure 8**

Stability of single wall tests.





### 3.3 Scale of 1:1

A primary concern about all of the tests was whether tests conducted at a smaller scale were scalable. From a printing bed size of .45 m × .45 m, the process was scaled to a printing bed size of 1.2 m × 1.2 m. Tests of the same geometry—a cavity wall section—on the two printing beds illustrated the capacity to scale up the entire process (Figure 9).

## 4 MACHINE DEVELOPMENT

The proposed machine is a five-axis machine. It can be broken into three-axis for general movement in X, Y, and Z directions and two-axis at the nozzle level to control rotation and orientation (Figures 10 and 11).

Other issues under development are reliability and calibration of pumping and the precise mechanisms needed for it. Especially when building at a scale of 1:1, machine precision plays a larger role.

A machine or machines can be deployed to a site and can be customized according to the local conditions and available infrastructure. The machine can potentially be a size that can be mounted onto a tuk-tuk or onto a large truck—similar customization as with existing machinery such as cranes. And the size of the machine directly determines the size limitations of the homes or buildings that can be built, meaning that the machine plays a vital role in design strategy and customized design solutions.

## 5 HOUSING

### 5.1 Design

The housing system that was developed used a simple geometry—the dome, which is taken as an initial shape for a single space. The points at which multiple spaces intersect are understood to be a common space. According to the rule setup, the smaller geometries always support the larger ones at these intersection points. These intersecting spaces become extremely complex geometrically with the increase in the number of spaces intersecting (Figure 12).

figure 9

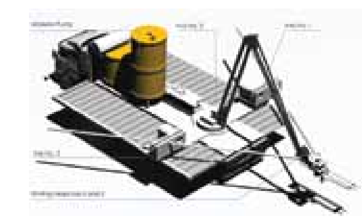

figure 10

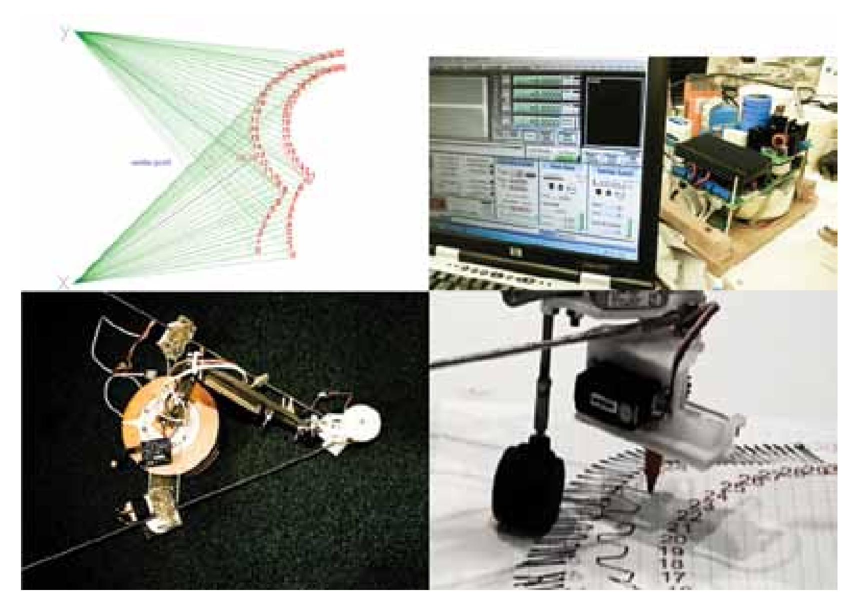

figure 11

**figure 9**

The same model printed by two different machines: a .45 m × .45 m Roland MDX 540 and a 1.2 m × 1.2 m Camtech router.

**figure 10**

Concept machine on truck. The proposed machine is a five-axis machine made of multiple parts. It can be assembled and disassembled while deploying on-site and is fully capable of being remote controlled. Three axes charge the overall geometry; the other two control nozzle movement.

**figure 11**

Sending G-code and embedded nozzle movement. The nozzle movement is embedded so that curvature generation is visible and is calibrated to create control amplitude.

figure 12

figure 13

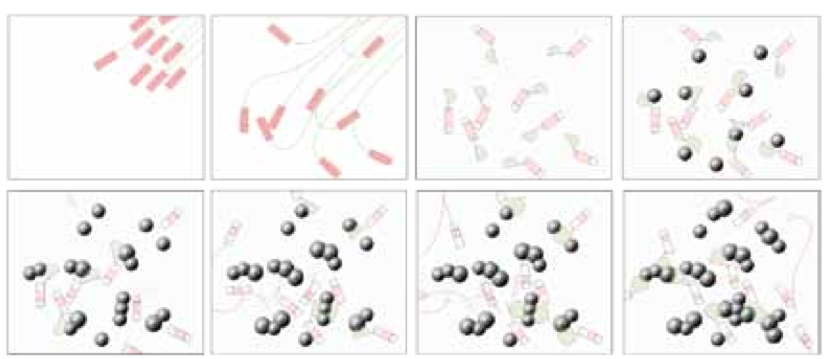

figure 14

### figure 12

The intersecting space in between.

### figure 13

Interior circulation-driven space layout of flats from two to five bedrooms.

### figure 14

In this scenario, multiple machines go on-site. The printing sequence is dependent on machine limitation, site condition, and the structure of the community.

Interior circulation is always along the edge of the smaller geometries. The arch as a symbol of structure is attached to the interior circulation path that goes through the whole unit, giving us the opportunity to make openings like doors, which could also contribute at a structural level. When these rules operate at the community level, spaces start to deform and the distinction between inside and outside space becomes unclear (Figure 13).





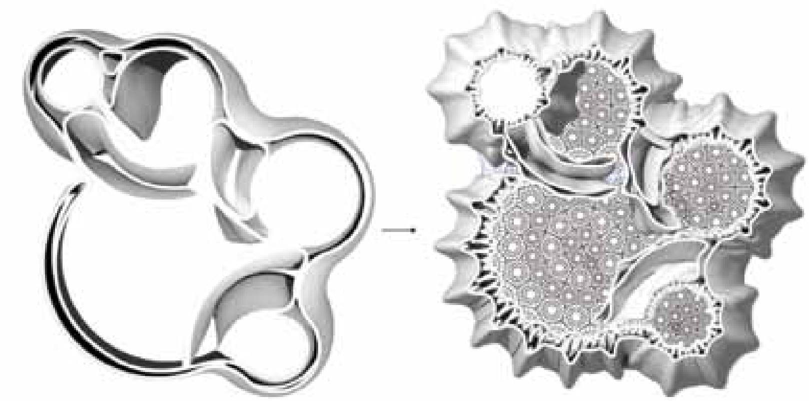

figure 15

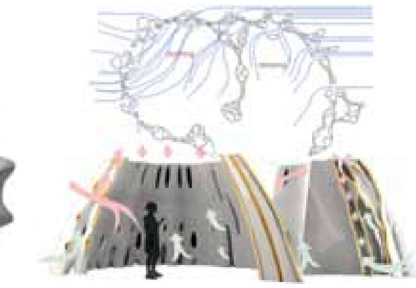

figure 16

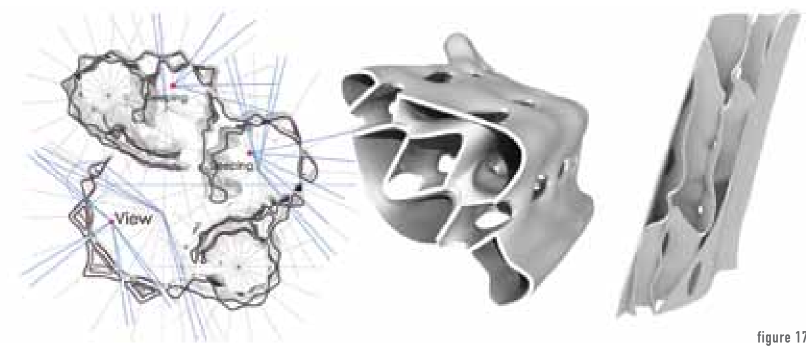


figure 17

The system further develops into a larger community, with a range of homes. Circulation at the community level can clearly be demarcated as three different spaces due to the intersection of volumes. Some spaces will become completely open, a shared territory for social life and a public thoroughfare. Others are semiprivate and private spaces. Machines can be deployed to build the community; homes can be constructed simultaneously, and as a structural system, homes and community are interdependent (Figure 14).

The architectural design system proposed at this stage of study was largely based on the material studies and machine limitations. A further layer of detail is added to this design: the performance layer that translates into the printing logic (Figures 15–18). Also explored was the potential of a flooring system that is accommodating to site conditions (Figures 19 and 20).

## 5.2 Prototype

A prototype is tested in which all the various aspects of the system are applied. The site chosen for the test is Timbuktu, due to the culture's tradition of using earth as a construction material, local knowhow in maintaining earth structures, and the availability of earth in the river delta to carry out the potential experiment (Figures 21–25).

## 6 FUTURE

With advanced CAD tools, efficient and unique structures can be generated in response to variable local conditions. As architectural elements evolve, are understood, and redefined, they can be intelligently

### figure 15

Applying material and printing logic to the housing unit (structure).

### figure 16

Applying material and printing logic to the housing unit (opening and performance).

### figure 17

Applying material and printing logic to the housing unit (opening and performance).(detail section). Material is gradually reduced from the bottom to the top of the leg.

figure 18

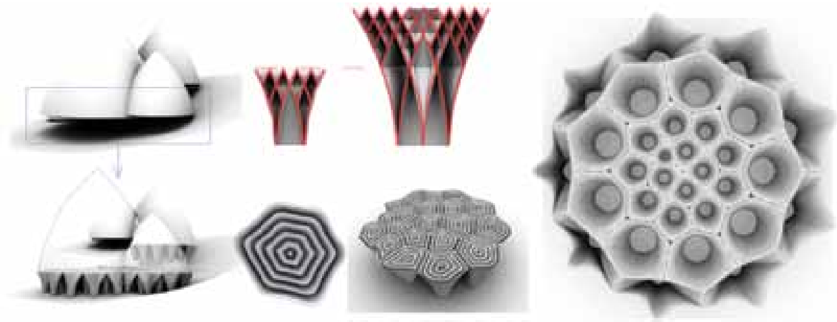

figure 19

figure 20

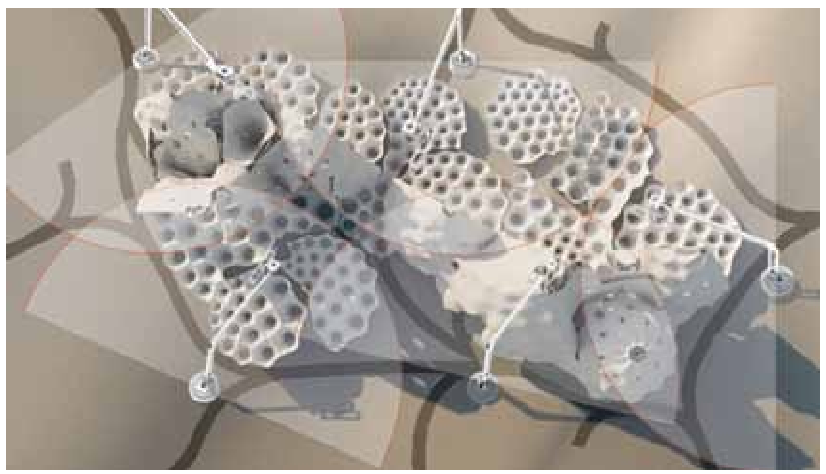

figure 21

embedded in structures due to the developed fabrication method. For an entire community generated in this way, floors, walls, and roofs can function differently than they used to. Openings, used space, and unused space become intertwined. When spaces grow, spaces within spaces begin to emerge. The relationship between a user and a space has a new meaning, yet the old meaning has not entirely changed.

The fabrication method also gives users the power to create and customize their living space—yet this personal space fits perfectly into the larger community that it is a part of.

This research represents the first steps in understanding a system in which machine and material cannot really be separated from each other, a system that will be further aided/pushed with computer-aided design playing a decisive role in their relationship.

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**figure 18**

An STL model of "high performance skin."

**figure 19**

Cone-shaped legs provide a unique floor system that is highly customized and has the flexibility to deal with site conditions.

**figure 20**

An STL model of a cone-shaped leg (detail section). Material is gradually reduced from the bottom to the top of the leg.

**figure 21**

Machine on-site and printing area.

figure 22

figure 23

figure 24

figure 25

**figure 22**

Prototype of two units.

**figure 23**

Prototype of two units (section).

**figure 24**

Prototype of two units (interior and exterior spaces).

**figure 25**

Prototype of two units (STL model).