Weeping Brick

The Modular Living Wall System Using 3D Printed Porous Ceramic Materials

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Abstract. The goal of this research is to design and fabricate a modular living wall brick system that purifies and cools air for various indoor environments. The research utilizes ceramic 3d printing techniques for fabrication; and living plants in conjunction with evaporative cooling techniques for indoor air quality control. The brick is made of soil which become porous after firing or drying. Water from the reservoirs slowly weep through the porous brick, creating a layer of water on the surface of the brick. The air movement around the saturated brick creates evaporative cooling and the hydro-seeded plants absorb water from the surface. The shape and texture of the Weeping Brick maximizes the cooling effect via large surface area. As an aggregated wall system, the water circulates from unit to unit by gravity through interconnected reservoirs embedded within each unit. The plants and moss transform the Weeping Brick into a living wall system, purifying and conditioning the indoor air.

Keywords: Living wall system · Modular brick · Ceramic 3D printing · Evaporative cooling

1 Introduction

This research describes the design and fabrication process of the Weeping Brick, which is a modular living wall system that can house vegetation for both aesthetical and functional purposes. Inspired by traditional irrigation methods and evaporative cooling techniques, Weeping Brick can serve as passive air conditioning system for various indoor environments.

Olla, a traditional unglazed pottery used for irrigation is an excellent reference for utilizing weeping as a mechanism for slowly distributing water to the outer surface in a controlled way. Furthermore, Muscatese, a traditional evaporative cooling window system, serves as an inspiration for utilizing evaporative cooling for indoor environments.

1.1 Traditional Ceramic Technology

Traditional ceramic products such as pottery or mud brick is among the first material technology invented by humanity. The production techniques such as hand-building,

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wheel-throwing, and casting has been developed and refined throughout the history and continues to be utilized to this day (see Fig. 1). Olla and Muscatese, which will be discussed in the following, utilizes these conventional ceramic production methods. However, in order to utilize the weeping mechanism, the ceramic is not glazed before firing to maintain its porous characteristic.

Fig. 1. Conventional ceramic production including hand-building, wheel-throwing, and slip-casting method in sequence. (Source: Shepherds Grove Studio)

Olla is an unglazed clay pot traditionally used for irrigating as well as cooking in the tradition of Northern Africa and is still practiced as an irrigation system in certain countries such as Brazil and India (see Fig. 2A). Once the unglazed clay pots are buried in the ground, the contained water slowly leaks out through the porous enclosure saturating the soil adjacent to the Olla. The plant roots absorb moisture from the wet soil around the Ollas [1]. Since the water weeps out from the pots in a consistent and extremely low rate, the water conservation is significant compared to other irrigation methods. Furthermore, the water distribution relies on weeping which is a passive process that does not require any external power sours of mechanisms (e.g. water pump or spray).

The Muscatese evaporative cooling window system has been used in Oman since the ancient era (see Fig. 2B). A porous-surfaced pottery is placed outside of Mashrabiya, a lattice screen window made of wood, controls the air temperature using the evaporative cooling effect. As the breeze from the outside enters the indoor space through the Mashrabiya screen, the air is cooled by the evaporative cooling that occurs at the moist surface of the water-saturated pot [2]. Similar to the Olla irrigation system, there is a water usage is optimized and the water distribution is passive.

In the current research, these traditional irrigation and cooling systems provide a basic understanding of the porosity of clay materials that can play significant role in water distribution and evaporative cooling.

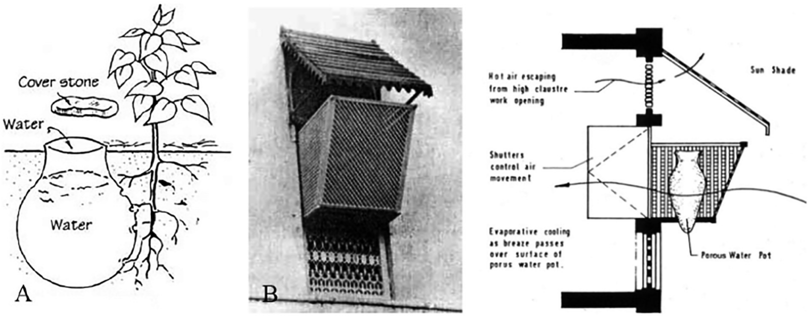


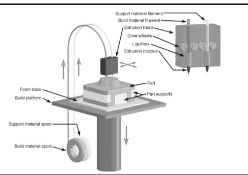
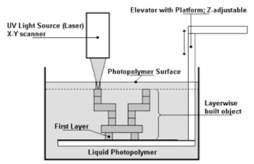
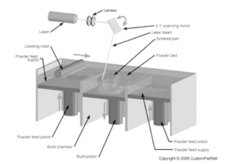
Fig. 2. A; Ollas irrigation B; Muscatese evaporative cooling (Source: A; Vukasin et al., B; Cabin et al.)

1.2 Contemporary 3D Printing Technology

With the wide spread interest in 3d printing ranging from artists to scientists, techniques to print objects beyond plastic (e.g. metal, glass, ceramic) has been in great demand. In this context, ceramic 3d printing technology has also been a focus for many researchers and developers. Currently, ceramic 3d printing can be achieved using all three platforms including fused deposition modeling (FDM), stereolithography, and selective laser sintering (Table 1). Depending on the platform, ceramic is used in the form of powder or in the plastic state (i.e. ceramic powder suspended in water or liquid plastic).

Ceramic 3d printing technology allows artists, designers, and architects to fabricate complex geometry with ease, and allow mass customization [3]. This research utilizes the FDM platform due to the simplicity of the system and the capacity to scale-up more effectively compared to other 3d printing platforms. Clay in a plastic state (clay powder mixed with water and ethyl alcohol) is used during the printing process and compressed air is used to force the clay mix through the nozzle. The viscosity of the clay mix, air pressure, print speed, and nozzle diameter needs to be optimized based on the complexity and size of the brick.

Table 1. Types of contemporary ceramic printing technology (Source: Snikhovska, K)

	FDM	Stereolithography	SLS
Mechanism			
Product	DIY Printer Delta Wasp Lutum	Formlab	Tethon3d VTech

There are a plethora of research and design utilizing ceramic 3d printing techniques. Cool Bricks (see Fig. 3A) designed by Emerging Objects utilizes evaporative cooling via micro-structured ceramic bricks [4]. The lattice structure enabled by the 3d printing process significantly increases the surface area of the bricks which enhances the rate of evaporative cooling.

Also, Ceramic Morphologies (see Fig. 3B) designed by Material Process + Systems Group, Harvard GSD investigates novel ceramic 3d printing processes for building applications. Their research pavilion not only showcases the geometric possibilities of ceramic 3d printing but also implements thermal design strategies [5]. These two precedents highlight the potential of ceramic 3D printing as an enabling technology for creating expressive ceramic components which functions beyond aesthetics.

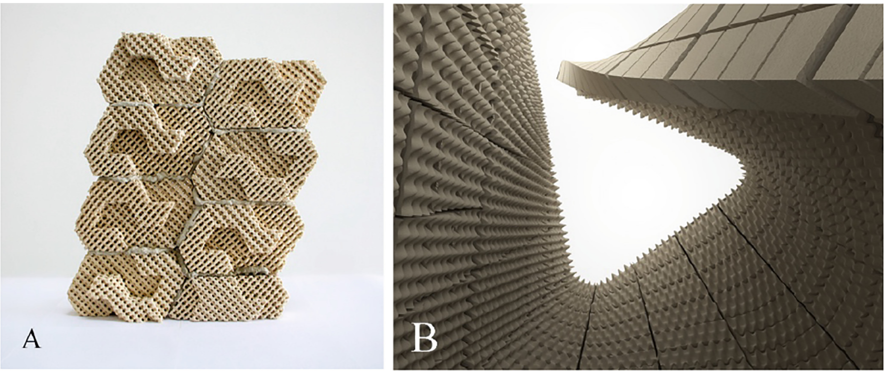


Fig. 3. A; Cool brick and B; Ceramic morphologies (Sources: A; Emerging objects, B; Material process + systems group)

1.3 Porosity and Absorption Rates of Ceramics

At the beginning of research, choosing the proper types of clay was significant to get a porous surface after fabricating, which is dependent on the mineral components and size of the particle. Therefore, the investigation into characteristics of several types of clays was required to find the appropriate material. Clay which is used for pottery or brick can be broadly divided into Porcelain, Stoneware, and Earthenware [6]. Each classified clay has its own traits such as color, porosity, absorption rates, texture and strength (Table 2).

Table 2. Broad classification of clay type and characteristics (Source: Kiln Art)

Earthenware clay	Porcelain clay	Stoneware clay
Color range from white to brick red	Color range from white to brown	Color range from gray to dark brown
Various texture	Various texture	Various texture
Porous surface	Non-porous	Slightly porous
Relatively fragile	Relatively less fragile	Relatively strong

This paper studies the three types of clay, porcelain, earthenware red, and red terracotta clay, to identify the correlation between porosity and water absorption rate. These clays have different levels of water absorption rates depending on their porosity. Also, each clay has appropriate firing temperature to get stable outcomes [7]. Table 3 below shows proper firing temperature and the characteristics of fired potteries made from each clay type. Earthenware has highest absorption rate but, porcelain barely absorbs water [8]. Accordingly, among the attributes of each clay type, porosity and water absorption rate plays a significant role in evaporation.

Table 3. Proper firing temperature and absorption rate of clay pots (Source: Zamek, J)

	Earthenware clay	Porcelain clay	Stoneware clay
Firing temperature	Cone06 (1,828 °F)	Cone09 (2,300 °F)	Cone06 (1,828 °F) Cone09 (2,300 °F)
Porosity	Porous	Non-porous	Slightly porous
Absorption	12–14%	0.5–2%	1.5–3%

2 Design and Fabrication Process

2.1 Design Parameters

The primary components of the Weeping Brick include water reservoirs, evaporative surface, structural elements and water vessels. The undulating top surface of the brick functions as a reservoir to capture water as well as provide a large surface area for evaporative cooling (see Fig. 4).

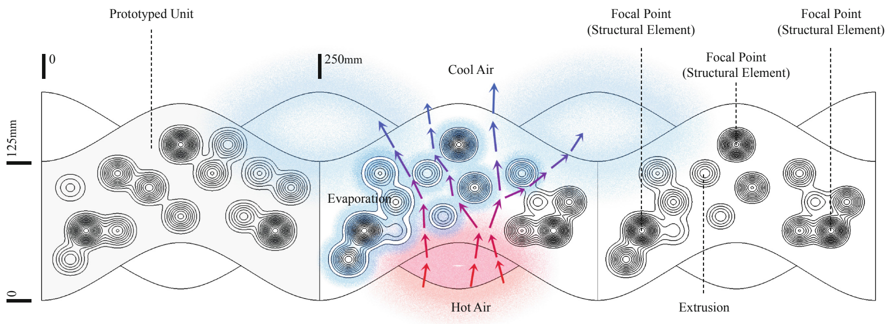


Fig. 4. Basic elements and evaporation mechanism

The structural elements consist of three vertical hollow tubes located to distribute the load evenly. These elements also serve as water vessels that circulate water (excess water after the reservoirs are full) from one unit to another. This design allows the aggregated wall to have interconnected system of water vessels that can passively distribute water using gravity and overflow (see Fig. 5).

Weeping Brick also utilizes hydro-seeding method to transform the ceramic wall into a living wall system that is attractive to the eye and contribute to air purification. Hydro-seeding is normally used for sowing seeds on irregular surface of ground efficiently by spraying a viscus mix of seeds, nutrients, water, and organic glue [9]. The textured surface of the brick facilitates hydro-seeded plants to stably root at the surface.

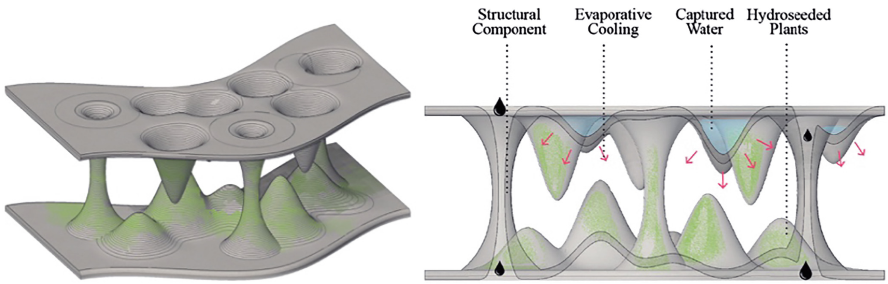


Fig. 5. Prototyped Weeping Brick unit and section which shows the basic components of unit and how water can circulate internally.

Weeping Brick is a modular system that can be flexibly configured and stacked. As an assembled system, the curvatures in the front and back of each individual unit create a wall that undulates in multiple directions (see Fig. 6). Once the units are joined horizontally and stacked vertically, air can flow between the top and bottom plate of each unit creating evaporative cooling effects through the extended undulating surfaces.

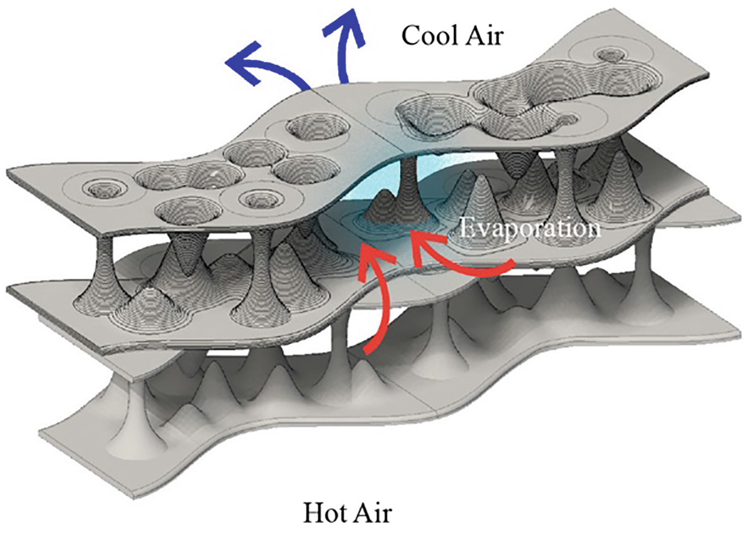


Fig. 6. Prototyped modular brick system and basic concept of evaporative cooling.

Weeping Brick living wall system can be applied to the exterior as well as the interior wall and enhance the aesthetical and environmental aspects of the space (see Fig. 7). The large porous surface saturated with water passively controls the indoor temperature by the evaporative cooling effect and the hydro-seeded plants contribute to air purification.

Fig. 7. Application of weeping brick to living wall brick system

2.2 Fabrication Process

After finishing the design process, the physical experiment, which uses Delta Wasp 2040 with a clay extruder, is conducted to fabricate actual brick units. In the beginning the fabrication process, two types of clays are prepared to compare the cooling performance. This depends on the porosity and absorption rate of each material. Each type of clay is mixed with the appropriate portion of water and ethyl alcohol to get proper softness and adhesiveness.

These prepared clays are loaded into the clay chamber that is connected to a compressor and printer. A compressor is required to squeeze the material from the clay chamber to the extruder. By using Delta Wasp 2040 3D printer and LDM (liquid deposit modeling) extruder, the prototyped unit of Weeping Brick is printed using each material, porcelain and earthenware red clay for the purpose of evaluating the materials' evaporation performances (see Fig. 8).

Fig. 8. 3D printing clay materials and 3D printer (Color figure online)

Once the printer is set up, the manual setting in the slice tool plays a significant role in the quality of outcomes. This research uses Slic3r as the main slicing tool. Since the outcomes can vary significantly depending on the setting in slicing tool, manual settings were utilized to find the proper parameters (see Fig. 9). During this phase, multiple samples with different variables (e.g. printing speed, infill density, and material extrusion width) were fabricated and tested.

Fig. 9. Outcomes of ceramic 3D printing

The final phase in fabrication process is to plant the vegetation on the surface of the brick. Hydro-seeding method, which is a mix of seeds, nutrients, and organic glue, is utilized so that the vegetation adheres to the textured surface (see Fig. 10). The water from the reservoir weeps throughout the body of the brick providing moisture to the vegetation as well as the evaporative cooling surfaces (see Fig. 11).

Fig. 10. Hydro-seeding

Fig. 11. Weeping brick

3 Discussion

The purpose of this research is to produce a modular brick living wall system which performs evaporative cooling and air purification. At the beginning of the research, this paper looked at the inspirational ceramic precedents in the tradition, the Olla irrigation and Muscatese window. These cases utilize the porosity of unglazed ceramics for consistent water distribution and evaporative cooling which optimized for certain environmental conditions [1, 2]. This research converts the traditional ideas of ceramic technology into contemporary interpretation by using parametric modeling, ceramic 3d printing, and hydro-seeding.

The brick can be assembled as a modular living wall system which allows nature to enter the indoor space as well as contribute to better control the indoor air quality for the habitants. Water channels and structural components embedded within each individual unit interconnect when the modules are put together for distributing the load and water throughout the assembly. Since water is distributed down the walls via gravity and overflow, the occupant can replenish the entire wall by supplying water to the top row of the assembly. After the water from the top reservoirs are full, the overflow of water trickles down to the next row via the hollow vessels embedded within the vertical structural components.

There were some challenges and limitations in the fabrication process as well as the proposed system itself. Due to the large number of variables that affect the outcome of the samples such as clay viscosity, air pressure, and print settings (speed, extrusion dimension) it is challenging to get consistent outcomes. The hydro-seeding process works in principle but similar to the delicate 3d printing setup, it is necessary to optimize the mix (seed, nutrients, water, glue) and surface texture to ensure that the batch will adhere to the brick surface properly.

Furthermore, although it is apparent that the porosity of the clay type dictates water content of the brick, it is not apparent how air flow, indoor air temperature, and vegetation covering will affect the evaporative cooling effect of the system. Therefore, further experiments are necessary for optimizing the porosity and absorption rate of the brick for both evaporative cooling and water distribution to the vegetation.

Finally, the scope of this research included prototyping of several modules for refining the 3d printing process and hydro-seeding process. During the next phase of research, it is necessary to fabricate a full-scale partition wall or a pavilion to further investigate the connection methods (e.g. mortar, gravity, or mechanical connector), and test the performance of Weeping Brick as an assembled system (e.g. structural integrity, water network, evaporative cooling performance, and aesthetics).

4 Conclusion and Future Work

This paper describes the design and fabrication process of Weeping brick, a modular living wall system made of 3d printed ceramic. This research explores the potentials of ceramic 3d printing as an enabling technology for creating both aesthetical and functional components for building applications.

Future investigations will focus on (1) further refining the 3d printing and hydro-seeding process for fabricating consistent and reliable modules; and (2) conduct physical experiments using different types of clay and firing process to optimize evaporative cooling; and (3) fabricate a building-scale prototype (e.g. partition wall or pavilion) for testing the overall system performance in terms of structure, water distribution, evaporative cooling, and aesthetics.

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