3D-Printed Tabun Oven

Reinterpreting the Traditional Tabun through Additive Manufacturing

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Abstract. The discovery of fire is considered a foundational moment in the development of human society, marking the beginning of communal life and architectural expression. This connection between fire, social gathering, and built space is embodied in the tabun. This paper presents an innovative approach to fabricating a traditional tabun using 3D printing with cement and soil-based materials. It explores the thermal and structural potential of digital manufacturing techniques, utilizing a soil-printed inner dome that serves as a removable support during the cement printing process, offering an alternative to conventional support strategies. The research involved both 1:3 and full-scale (1:1) prototypes, requiring design adaptations and tool paths optimized for thermal performance, structural stability, and material efficiency. Thermal cycling tests evaluated material durability, and a full-scale prototype was used to assess real-use behavior. The project highlights the potential of digital fabrication to merge traditional thermal principles with contemporary technologies and local materials.

Keywords. Digital Fabrication, 3D Printing, Thermal Performance, Removable Support, Traditional Construction

1. Introduction

The tabun, a traditional oven rooted in local knowledge and built from natural materials, embodies the connection between fire, domestic life, and architecture. Guided by principles of thermal mass, insulation, and airflow, its design enables efficient heat retention and distribution. Traditionally, tabuns were built by hand from

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local materials, drawing on vernacular knowledge (Miscovich 2013; Denzer and Field 2000). This process was slow and labor-intensive, often taking several days to complete, as each oven was individually shaped, dried, and fired before use. Over time, the tabun has transformed from a handcrafted earthen structure into an industrial product made of synthetic materials, utilizing industrial manufacturing processes. Contemporary models, such as Ooni (Ooni 2012) and Gozney (Gozney 2010), emphasize portability and efficiency through hybrid assemblies of metal, ceramic fiber, and firebrick, while others like Valoriani (Valoriani 1890) and El-Mago (El Mago 2011) retain a more classic form and use traditional materials, yet they also rely on industrial components to enhance insulation and performance. This research proposes an alternative approach that merges traditional thermal logic with digital fabrication, employing a printable cement mixture and air as insulation. By 3D-printing and fire-testing a full-scale prototype, the study explores how the geometric potential of additive manufacturing can achieve thermal performance in high-heat environments. Beyond improving thermal and structural performance, this method also offers a significant advantage in fabrication time, enabling faster and more precise construction compared to traditional hand-built techniques. The paper moves from a traditional context, through digital strategies and tools, to full-scale implementation. It reviews 3D printing with soil and cement, focusing on temporary mold strategies that enable complex fabrication. The research then explores the digital fabrication of a full-scale functional tabun using parametric design, a printable cement–soil system, and a removable mold. This prototype demonstrates the feasibility of creating a thermally efficient and structurally resilient oven. This work advances digital fabrication by integrating local materials and cultural knowledge, revealing new possibilities for robotic fabrication for high-temperature architectural applications.

2. State of the Art

The research builds on two key currents in contemporary discourse: 3D printing with cement and soil-based materials and the development of temporary support strategies for complex printing processes.

2.1. 3D PRINTING WITH CEMENT AND SOIL IN ARCHITECTURAL AND DESIGN PRACTICES

In recent decades, interest in 3D printing with cement and soil-based materials has grown in architecture and design, exploring its cultural, material, environmental, geometric, and functional dimensions. Anton et al. (2020) demonstrated the potential of cement-based 3D printing to create complex architectural elements, expanding design possibilities beyond conventional limits. Precise toolpath control allows the formation of unique geometries and textures without molds or additional processing. Rael's Casa Covida (2020) consists of 3D-printed earthen dwellings built in the Colorado desert, combining digital fabrication with local material traditions and environmental sensitivity. Asaf et al. (2023) used locally 3D-printed soil to create biodegradable shelters for seedlings in arid regions, offering a sustainable alternative to plastic protection systems. These shelters blend into the environment and gradually decompose, allowing the soil to return to nature once their role is complete. AlZahrani et al. (2022) showed that toolpaths and infill patterns influence the thermal performance of printed concrete walls by modifying air-void distribution. While cement-based printing provides structural stability and geometric precision, soil-based printing enables natural biodegradability and environmental integration. Combining these two material systems allows the use of soil as a natural, temporary mold for more stable, cementitious materials.

2.2. TEMPORARY SUPPORTS FOR COMPLEX 3D PRINTING

The idea of a removable mold, which forms the basis of the current research approach, appears in both architectural and design projects. Zumthor's Bruder Klaus Field Chapel (2011) was cast around a wooden mold later burned out, while Ensamble Studio's Truffle (2010) used a straw mass consumed by a cow to reveal the interior. Rael's Tres Hornos (2022) employed an inflatable mold, demonstrating how air can act as a reusable support structure, and Sitnikov (2019) used CNC-milled ice molds that melted after casting to eliminate waste. In 3D printing with concrete and soil, the main challenge is forming complex geometries without permanent support. Nan and Vigorito (2024) used robotic sand molds, and Meyuhas et al. (2025) printed soil as a temporary mold for concrete, which was later removed with water. Building on this strategy, the current research applies the removable mold concept specifically to the printing of a tabun oven, using natural, biodegradable soil as a temporary mold that supports the cement structure during fabrication, and can be returned to the environment after removal.

While most studies on 3D printing with cement and soil focus on geometry, sustainability, and efficiency, few explore high-temperature performance. In particular, the fabrication of thermal structures such as ovens using digital manufacturing remains largely unexplored. This study fills that gap by testing how soil-supported, digitally fabricated cement structures respond to direct fire and repeated heating cycles. In this context, reinterpreting the tabun positions it as an active architectural component, demonstrating how additive manufacturing can integrate functional elements, such as ovens or fireplaces, into building systems.

3. Methods

This research explores the fabrication of tabun using additive manufacturing techniques, combining cement-based materials, following Asaf et al. (2024) guidelines. The matrix includes: CEM I 52.5R White Cement, siliceous sand, and polycarboxylate admixtures, with soil-based material developed by Asaf et al. (2023), consisting of sand, water, and local kaolinite clay. The study focused on three aspects: testing material durability under thermal cycles, developing a fabrication strategy, and analyzing thermal performance during controlled firing. All the experiments described in this chapter were carried out using the same printing setup: robotic printing with a KUKA Iontec KR30-70 R2100 arm (6 DOF), with a dedicated extrusion head for cementitious and soil-based materials. A 10 mm nozzle was used for printing the soil dome, and a 15 mm nozzle for printing the cement. Soil-based mixtures were extruded using a MAI®2PUMP-LYRA, while the MAI® MULTIMIX-3D pump delivered the cementitious mixture. Designs were modeled in Rhinoceros 8, with parametric toolpaths generated in Grasshopper and KUKA|PRC to control layer height, infill, speed, and density.

3.1. MECHANICAL DURABILITY OF THE MATERIAL UNDER HEATING CYCLES

To evaluate the cement mix's durability under repeated heat exposure, mechanical tests were conducted under thermal cycling. Two specimen types were prepared: 50×50×50 mm cubes for compression and 160×40×40 mm beams for flexural testing (Figure 1), according to ASTM C109 (Standard Test Method for Compressive Strength of Hydraulic Cement Mortars) and C348 (Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars) standards. After curing, one set was tested without prior heating, while another was tested after undergoing three heating cycles at 400 °C in a Nabertherm oven to simulate active tabun conditions.

Figure 1. Cast beams and cubes for flexural and compressive strength tests

3.2. DEVELOPING FABRICATION STRATEGIES

The tabun's development explored multi-stage printing strategies using a removable soil mold, tested at different scales. These strategies aimed to balance structural strength, thermal mass, and insulation while dividing complex geometries into segments without disrupting their visual continuity.

3.2.1. Printing at a 1:3 scale

At this stage, the tabun was printed in two main phases using two materials: soil for the inner dome and a cement-based mixture for the outer body. First, the soil dome was printed, dried, and used as a temporary mold. Then, on a separate print bed, the base and first layer of the cement body were printed to mark the dome's position. The dried dome was placed on the base, and printing continued above it to complete the structure (Figure 2). After curing, the dome was dissolved in water, softening the soil for easy manual removal, after which the material was reused or returned to nature.

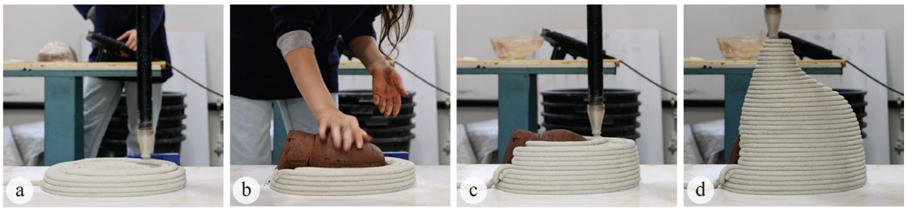

Figure 2. 1:3 scale tabun fabrication: base printing (a); dome placement (b); body printing on soil support (c); final structure (d)

3.2.2. Printing at a 1:1 scale

At this stage, the full-scale printing strategy was refined based on small-scale experiments to address large-scale challenges. The tabun's geometry followed defined parameters (Figure 3): 68 cm base, dome height 15% above the radius, door height 63% of dome height, and a chimney 20–25% of the baking surface radius (Denzer & Field 2000). The printing toolpath was parametrically designed as a radial grid converging toward the chimney, maintaining the thermal logic of traditional tabuns by enhancing heat storage and insulation while preventing thermal bridges. This toolpath created internal air pockets that improved insulation without compromising structural stability. As before, the process was divided into printing the soil dome and the tabun body. However, each component was further broken into sub-steps to reduce the risk of printing inconsistencies and to maintain greater control over material behavior. The soil dome was divided into segments that were printed separately and assembled after drying (Figure 4), in order to reduce the weight and volume of the print on one hand, and to provide sufficient structural support for the tabun body on the other. The soil dome was printed in segments over a total duration of approximately 30 minutes. The body was printed directly on the dome in separate three segments: base (one hour), dome perimeter (one and a half hours), and chimney perimeter (one hour). The base was printed as a single unit, while the dome and chimney perimeters were each printed in two phases. The dome perimeter was printed in two stages to optimize the printing process and ensure consistent material application through adjustments to parameters such as print speed, pump pressure, and nozzle size. The chimney perimeter was also divided into two stages to accommodate the object's proportions and to ensure the material could gradually support its own weight during the process.

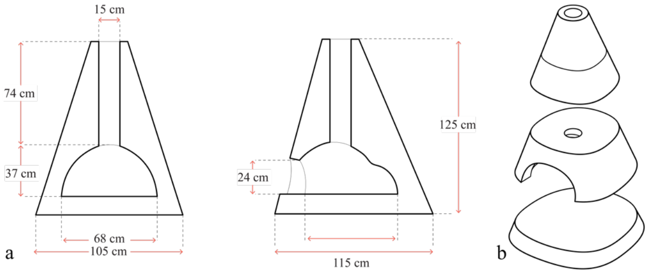

Figure 3. Tabun structure: dimensions (a); The three parts of the tabun (b)

Figure 4. Assembly of the soil dome from the separately printed segments

3.3. EVALUATING THE THERMAL PERFORMANCE OF THE TABUN

The tabun's thermal performance was tested through a controlled burn inside the printed dome to simulate real use and observe heat behavior. Temperature and fire spread were measured using a Uni-T UTI260B thermal camera and a VICTOR 303B digital thermometer. This experiment compared the printed model's performance with the traditional thermal logic of tabun ovens and assessed the potential of the chosen materials and geometry (Miscovich 2013).

4. Results and Discussion

This section presents the experimental results, examining how the printing process, temporary mold, and material performed under simulated tabun use. It also reflects on the project's contribution to digital design and fabrication, addressing whether a cement-based tabun can be produced using digital tools and a removable natural mold.

4.1. MECHANICAL DURABILITY OF THE MATERIAL UNDER HEATING CYCLES

Mechanical tests showed that after three heating and cooling cycles at 400 °C, the cement-based mix increased in strength. Compressive strength rose from 54.5 MPa to 89.8 MPa- an improvement of about 65%. Flexural strength also increased from 10.7 MPa to 13.8 MPa, a gain of up to 35% (Figure 5). These results confirm the material's suitability for a functioning tabun oven, demonstrating strong resistance to repeated heat exposure.

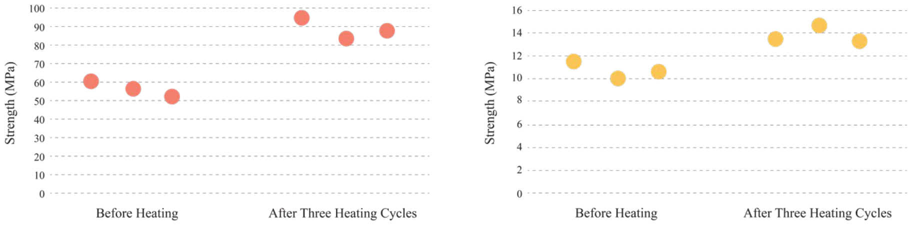

Figure 5. Mechanical tests. Compressive tests (a), Flexural strength (b).

4.2. DEVELOPING FABRICATION STRATEGIES

This section describes the move from small to full-scale fabrication. The workflow was refined to address challenges in material behavior, geometry, and process control. Printing at full scale offered clearer insight into the structural and material performance of the cement-based mix. The initial experiments for the tabun's structure were conducted using soil as part of an iterative design process aimed at testing printing toolpaths, flow parameters, and geometric accuracy. The soil material was chosen because it does not harden as quickly as the cement-based mix, allowing multiple iterations and repeated trials until the desired parameters were achieved. Insights from these experiments informed the final design of the tabun, which was divided into three main parts (Figure 3). Key parameters, like infill density, speed, and nozzle size, were optimized to balance insulation and stability. In the chimney area, a geometric adjustment to the tabun allowed stable printing with roughly half the material (Figure 6).

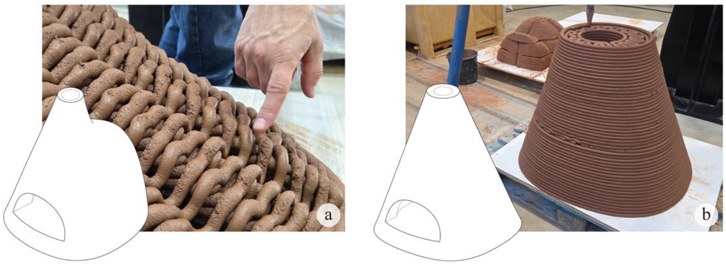

Figure 6. Printing the chimney perimeter. Collapse between supports due to horizontal back angle (a), Geometry adjustment to prevent collapse (b)

During dome perimeter printing, two main issues arose: robotic arm collisions with the soil dome, which caused print interruptions, and insufficient wrapping material that affected the dome's sealing and stability (Figure 7).

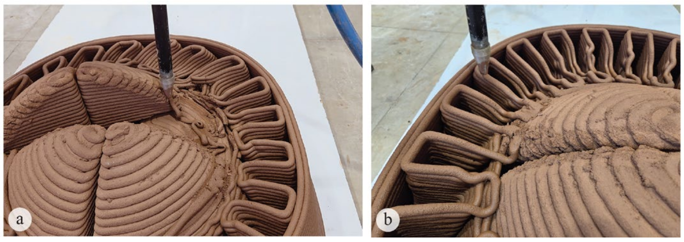

Figure 7. Dome perimeter printing failures: robot collision (a); insulation loss at support interface (b)

To address both issues, two changes were made: increasing print resolution and splitting the file into two parts. A 15 mm nozzle and 12 mm layer height replaced the 10 mm setup used for the soil dome (Figure 8a). The file was divided into a perimeter path forming a thick layer and a second file printing the tabun body above it (Figure 9). This approach resolved collisions, as impacts were absorbed by the soft perimeter layer without harming the structure (Figure 8b).

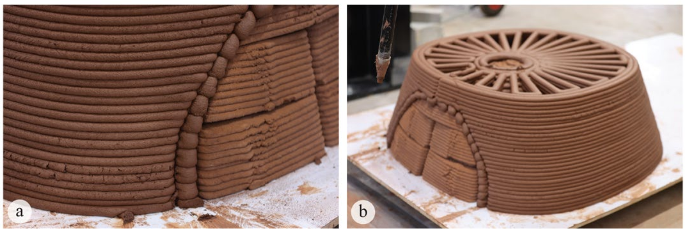

Figure 8. Printing the dome perimeter. Change in resolution between dome and perimeter (a); two perimeter layers printed on removable support (b)

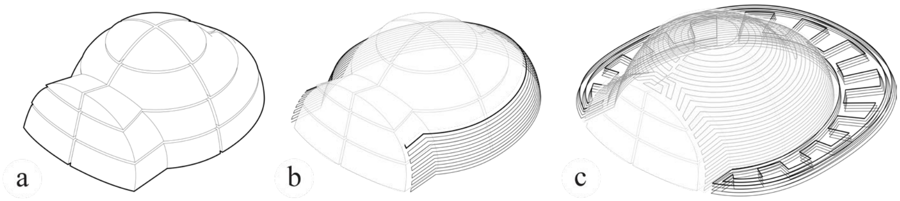

Figure 9. The two files defining the dome's perimeter. The dome is divided into segments (a), First file- dome perimeter (b), Second file-Tabun body (c)

The cement-based printing phase introduced new challenges: the material had limited self-support, requiring the chimney to be printed in two parts, and the dome perimeter cracked as the soil mold rapidly absorbed moisture from the cement. These observations suggest the need to refine the process, either by using a temporary mold made from a less absorbent material or by adopting a slower, more controlled drying approach. The assembly phase involved dissolving the soil dome and stacking the printed components on top of one another (Figure 10).

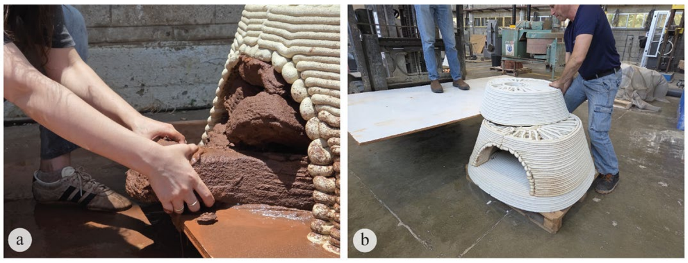

Figure 10. Assembly process. Mold dissolved in water (a); stacking segments (b)

4.3. EVALUATING THE THERMAL PERFORMANCE OF THE TABUN

The fire in the tabun burned for about an hour (Figure 11), reaching 250°C on the baking surface, below the 400°C target. This was mainly due to the short distance between the fire and chimney, which disrupted airflow, and the small gaps between printed segments that created thermal bridges, allowing heat to escape. Future work should focus on improving heat retention by refining the print path to reduce heat loss, expanding the inner dome's surface area, repositioning the chimney for better airflow, and developing interlocking joints to trap heat more effectively. The outer shell showed strong insulation performance, with surface temperatures between 30–50°C above the baking area. Air pockets formed during printing provided effective thermal insulation, achieving performance comparable to multi-layered ovens while reducing material use and carbon footprint. The front of the oven insulation was less effective, suggesting the need to optimize the print path for improved air distribution (Figure 12). Although the material showed durability after thermal cycling, direct fire exposure caused cracks due to uneven, rapid drying. Despite the faster fabrication time compared to hand-built ovens, a controlled drying process remains necessary. Future research should develop faster-drying, heat-resistant mixes and align testing with fire-resistance standards such as ASTM E119 and EN 13501 to ensure long-term thermal stability.

Figure 11. Fire ignition inside the printed tabun

Figure 12. Thermal tests. Insulation of tabun shell (a); thermal imaging of heat loss at joints (b); temperature measurement (c)

5. Conclusion

This research demonstrates the potential of digitally fabricating a functional tabun oven using a cement-based mixture, air as insulation, and a temporary soil mold. By combining traditional thermal logic with parametric design and robotic fabrication, the project reinterprets the tabun as a contemporary architectural element. Future work will focus on improving thermal performance through the development of heat-resistant mixtures and the refinement of printing toolpaths. Improved mixtures can help prevent cracking, while enhanced toolpath control will support optimized infill patterns, intentional shaping of the inner dome surface, and precise seam adjustments to reduce thermal bridge. The study highlights an integrated system in which printer, material, and air jointly produce thermal performance without industrial insulation. More broadly, it outlines a framework for sustainable, locally sourced, fire-resistant design through digital fabrication, suggesting directions for future fire-adaptive architectural applications.

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Attribution Statement

ChatGPT (OpenAI, 2025) was used to improve flow, translation and correct errors in spelling and grammar.

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