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BARZAKH – Earth construction and participatory Design with Mixed – Media

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Abstract. This article explores earthen materials in particular mudbricks (adobe), a traditional material in Egypt and the Middle East, as a contemporary building material by integrating local craftsmanship, engineering, and advanced digital technology. Although often perceived as a low-tech option in under-resourced communities, the project BARZAKH برزخ – aims to reposition earth bricks within a contemporary architectural, structural and social context. By incorporating mixed-media-tools such as Virtual and Augmented Reality the project fosters collaborative design and building experiences, enhancing shared awareness of sustainable practices. The project's methodology reconnects people with the handmade craft of mudbrick construction through immersive digital tools.
In New Gourna (Luxor) – alongside Hassan Fathy's pioneering sustainable architecture – students and locals co-designed and collaboratively built BARZAKH – a curvelinear mudbrick wall constructed using a digitally guided assembly strategy. The project's digital workflow seamlessly linked the immersive architectural design process (VR) conducted in the design studio with structural design and on-site construction of this public seating element. Following Hassan Fathy's Principle "Construire avec le people" (1) BARZAKH fosters a participatory methodology embedding collaborative engagement throughout all project phases. By reimagining mudbrick as a viable and per se resilient alternative to CO_2-intensive materials, the project advocates for its relevance in contemporary architecture.

1. Material Responsibility Design

There is a growing awareness of using natural and renewable materials, particularly earthen materials, in both practical applications and academic research. As a vernacular solution, earth-based construction has evolved over thousands of years. However, knowledge of its inherent qualities and relevance has faded, along with the skills needed to work with it, as modern, CO_2-intensive materials take precedence. While the Global North debates how to initiate a construction shift, our primary concern in Egypt is not only how to realize this transformation but how to convince people of its value and sensitize them to its potential. This undervaluation persists despite the fact that Hassan Fathy, a pioneer of sustainability and earthen architecture, taught and built with local materials nearly 80 years ago, advocating for vernacular architecture

Figure 1. Market building in New Gourna (today) by Architect Hassan Fathy (1946-1952)
Photos: Hussein Elsarnagawy (left), Christian Schmitt (right)

at the height of the global modernist movement – already addressing today's shifting paradigms in architecture (2). His New Gourna project remains a landmark example of sustainable design, integrating climate adaptation, material reuse, low emissions, and participatory planning.

Yet, his pioneering approach in New Gourna, centered on building with mudbrick (adobe), is scarcely valued by the inhabitants and has partly fallen into disrepair (Figure 1).

"Although 'mud-brick' is the term most often used in Egyptology, 'adobe' has a more widespread currency. The ancient Egypt word for mud brick, *djebet*, passed, via the Coptic word ⲧⲱⲃⲉ into Arabic الطوب tub(a) and thence probably into Spanish to give the word adobe" (3). The word *barzakh* زخ, derived from Quranic verses, is often described as a liminal zone – a threshold between two states, realities, or realms. The project explores contemporary perceptions and tries to improves the narrative of mudbrick in the local communities. It reframes discourse at the intersection of:

- Vernacular and the contemporary – bridging traditional craftsmanship with modern architectural approaches.
- Analog and digital design methods – combining hands-on material experimentation with computational design tools and processes.
- Standardized construction practice and digitally driven workflows – investigating how emerging technologies can coexist with and enhance non-industrialized building techniques.

To enable a fully participatory and immersive workflow, we connected a parametric design process – developed in Rhino and Grasshopper within a virtual reality (VR) environment - with a digital fabrication (assembly) setup, using the same 3D model in augmented reality (AR) through Rhino, Grasshopper and Fologram. Because both models are identical, BARZAKH seamlessly bridges design and execution. Contextually, the chosen location embodies a unique spatial dialogue, between Hassan Fathy's Villa and the Temple of Hatshepsut (ca. 15th century BC) (4), positioned between two historically significant landmarks. The Genius Loci amplifies the project's conceptual framework, as it physically situates users within a (liminal) space where history and modernity, tradition and innovation, converge. As a mudbrick landscape wall, the project provides sitting elements with two oppositional orientations, overlooking these two landmarks.

2. Immersive Architectural Design with Mixed Reality and Mudbricks

The project was conducted at German University in Cairo (GUC) from late October 2024 until the building workshop in January 2025, as an extracurricular initiative involving 18 students from the 7th and the 9th semester. It built on the previous experiments DIGITAL IMPERFECTION (2021) (5) and IMMERSIVE imPERFECTION (2023) (6), where we explored brick structures assembled

Figure 2. Immersive design approach by (VR) Virtual Reality Illustration Students, Photos: Hussein Elsarnagawy

from of self-made bricks with intentionally varying (imperfect) brick heights. These bricks were arranged based on a parametric design process that generated a real-time construction sequence streamed directly to a HoloLens device. This system guided the worker in picking up specific bricks (of two different heights) and placing them precisely. While the 2021 experiment relied only on the HoloLens technology, the 2023 iteration tried to replace it with smartphones and tablets, using more universally available (ubiquitous) devices. Both experiments emphasized human-centred assembly process, instead of mere robotic automation.

BARZAKH also utilized parametric design software in combination with the augmented reality plugin Fologram to stream directly to a mixed reality headset on-site. To foster a seamless workflow, we used the same tools already for the design process and tried to let the 3D model get influenced by all possible expressions that the different participants tried to co-design with.

Starting in November, the student team experimented with the digital wall setup, formulating ideas and exploring their spatial consequences in the virtual model. During this concept phase, the villa owner, the supervisor and students identified a design idea, which was refined and optimized in size and number of mudbricks through regular workshops until late December. During the winter break, the OST (Eastern Switzerland University of Applied Science) and GUC teams, along with students, and an involved Postdoc researcher of KIT (Karlsruhe Institute of Technology) travelled to New Gourna, where the design process was further developed – not only through VR visualization but also by overlaying the wall model with (Augmented) Reality. Through iterative adaptations, discussions, and augmented interventions, the team integrated the wall into the existing landscape, positioning it directly between the surrounding trees and dialogue with both historic architectures (Figure 3). While architecture students engaged

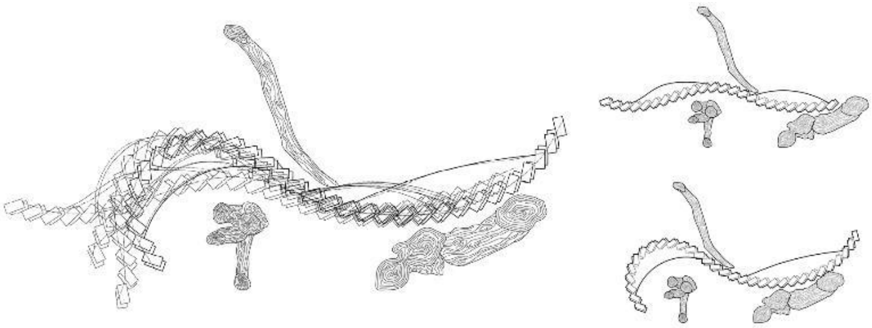

Figure 3. Overlay of adaptation process (left), two exemplary options (right)

playfully with the free form curves in the VR environment, participants without architectural training begun by sketching possible forms directly on the ground. Together they tested spatial configurations by physically sitting on mock-ups, which students coordinated back into the 3D model using the VR headset. Mixed reality served as a bridge between these "realities" – sketching, physical modelling, and embodied spatial testing – creating a shared experience that enabled all participants to collaboratively refine the structure in real time, testing views, spatial relationships, ergonomics and spatial usability. We primarily used the Meta Quest 3 headset, which supports both VR and AR (by passthrough). This transition to the Quest 3 enabled a design approach in VR that seamlessly connected immersive design phase with AR-assisted construction (Figure 4).

Rooted in the philosophies of Hassan Fathy BARZAKH reinterprets his legacy, focusing on material, craft, sustainability, architectural representation, and, most importantly, participation. Central aim was to embody the principle of "Construire avec le people: Histoire d'un village d'Egypte, Gourna" (1) – for the people, with the people – and to expand upon it already during the design process. It quickly became clear that a traditional architectural workflow – moving from sketches to physical models, schematic design, and printed plans – was not suitable for this participatory setup involving multiple stakeholders. Instead, we explored an approach where "handmade and digital tools interact" (7), bridging the gap between industrial manufacturing and craftsmanship.

3. Mixed Reality in Design and Construction in a Digital Participatory Setup

3.1. Virtual Design Process

As mentioned, the wall in this experiment was designed using parametric software (Rhinoceros/ Grasshopper) and an Augmented Reality plugin (Fologram), which provided a real-time construction guide streamed to the Meta Quest 3 mixed reality headset on-site. This parametric workflow not only generated the wall's design but also guided users in placing each brick during construction. The real-time adaptability of the model was integrated from the beginning of the design phase in November, ensuring a dynamic and responsive design process.

Employing computational design tools, particularly Grasshopper's algorithmic capabilities, the project generates a fluid, curvilinear wall that seamlessly integrates two opposing seating areas. This digital approach facilitates geometric exploration, allowing the architecture to embody the organic flow in-between the different past(s) in search of a contemporary response. "Computational design has increasingly been recognized for its ability to synthesize complex spatial and cultural narratives, enabling architects to explore non-linear forms that respond to both contextual and social dynamics" (8). Additionally, computational tools support exploration and experimentation in designs. The playful nature of the immersive setup engaged architecturally untrained participants be part of the planning process.

In this project, we explored the possibilities of a cooperative and immersive planning process, emphasizing social participation as a fundamental aspect of design. Changing the perception of materials through immersive technologies emerged as a key methodology, integrating conceptual, computational, and material explorations into a cohesive, evolving narrative. This participatory approach aligns with contemporary architectural discourse, which underscores the importance of user engagement in design to foster a sense of belonging and collective authorship (9). By incorporating iterative experimentation and material research, the project reinforces the idea of flux – an adaptable design process that allows for design

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transformation up to and even during the building phase, reflecting the transitional nature of BARZAKH.

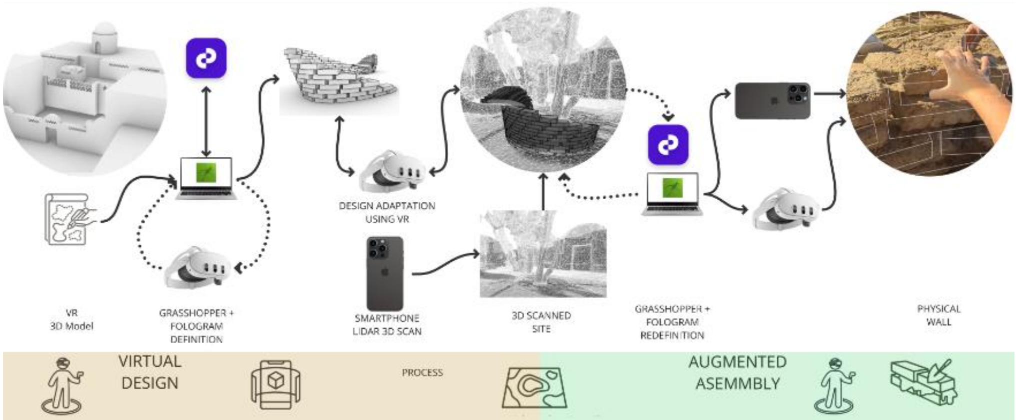

Figure 4. Digital Setup for Virtual Design and Augmented Building Process

3.2. Augmented Building Process (Mixed Media Digital Design Fabrication)

The use of AR technology requires precise placement of the model in the real environment (Figure 5), which often consists of uneven surfaces, irregular terrain, and surrounding architectural and other elements (trees, furniture, people etc.). To ensure accuracy, Fologram relies on defining three or more markers in the digital workspace and placing them in the physical environment to align the 1:1 model correctly. However, maintaining continuously visiblity of these marker can be challenging in the real-world applications.

In our design-build experiment, we prepared a 3D Rhino model using Google Earth data to analyse and understand site conditions and to position the digital design proposal in the digital model (VR) and in the real world (AR) context. Initially, we tested a tracking method by placing four markers on architectural elements (e.g., door frame) to establish a reliable tracking system. However, this approach proved unreliable due to the tracking drift – Quest 3 headset moved farther from the markers, tracking accuracy deteriorated, leading to misalignment. Additionally, the architectural reference points were too distant from the construction site, preventing a consistent visual connection during the building process. The earthen materiality of these (reference) elements results in inaccuracies due to their natural unevenness. A second approach involved placing three markers in a straight line on flat ground. However, this method also resulted in imprecise tracking, as the unevenness of the terrain affected the model's positioning. In addition, the earthen materiality of these elements naturally results in a slight unevenness of the surfaces.

To overcome these challenges, we explored a novel approach using a smartphone equipped with a LIDAR sensor and Polycam scanning app to 3D-scan the environment. The scanning procedure took approximately 10 to 15 minutes, producing a low- to medium-density 3D model (Figure 6), which we then imported into Rhino. This method helped verify the Rhino model dimensions, improving accuracy and mapping the uneven ground surface for better marker placement.

Figure 5. Augmented Building Process
Photos: screenshots from screen recording Quest 3 during workshop

In the final step, the process of markers allocation was reversed for improved alignment with the real environment. This inversion allows to reduce the errors and align the position of the markers with the real ground conditions. First, the markers were placed on site using a red tape measure, separated by fixed distances from existing architectural and natural elements. The environment was then scanned again, and the resulting model was imported to Rhino, where the position of the three markers was digitized.

Figure 6. Design development within the landscape and build project BARZAKH
Illustration Scanned Environment with Design, Photo: Hussein Elsarnagawy

This redefined workflow achieved a high degree of accuracy, aligning the digital and real environments at the same time, improving precision not only for this project but also for future AR-based construction projects. Using the AR headset, we validated this accuracy by aligning the textured model matched the real-world elements in both positioning and scale. However, the resulting 3D model requires additional time for editing and refinement before it could be used to produce digital drawings or images. For future experiments, we recommend placing markers along the boundary of the model or an imaginary boundary around it to help reduce drift and maintain the visual connectivity with the markers.

4. Material and Structural Design

4.1. Material History

Earthen architecture practice has been present in the region of the Nile valley for over 6 millennia (10), with mudbricks being predominant. It is assumed that the origin of brick architecture in Egypt dates back to the late Predynastic Period, where bricks had been used for main settlements at Naqada according to Spencer (11). The brick structures of the mastabas of Saqqara and Naqada dating back to the First Dynasty are amongst the earliest mudbrick structures found in Egypt (11).

Mudbrick construction has been used in vernacular architecture practices in the local context of Luxor West Bank (Ancient Thebes) for millenniums, with the Ramesseum's (13th Century BC) storage facility walls being a prominent preserved example of the region (11, 12) and as resumed in Hassan Fathy's New Gourna Project (1)(Appendix V), (13). Hassan Fathy, inspired by the Nubian vernacular architecture of upper Egypt (Aswan), integrated the Nubian earth architecture in his practice from the early 1940s onwards (13). One of the typical dimensions used by him in his New Gourna project was an adobe brick produced in a mold of 24 cm x 12 cm x 8 cm, resulting in bricks measuring 23 cm x 12 cm x 7 cm (1)). The ratio of length to width of approximately 2:1 has been found to be traditionally used in Egyptian brick architecture, dating back to the Early Dynastic Period (11, 14). While the dimensions varied through the eras with the tendency to use smaller dimensions for small houses and larger ones for public structures, dimensions around 24 cm length and 12 cm width could be identified as a norm size used in the Early Dynastic Period (11,14). The presence of this ratio can exemplarily be observed very close to the site of the BARZAKH project, around 2 km from New Gourna, in the walls of the ruins of the Ramesseum's storage facility walls (11, 12).

4.2. Production and properties of the mudbrick in the project

The mudbricks used for the project were produced by local earth from the West Bank mixed with straw fibres according to the traditional production process, manufactured by hand in formworks and air-dried. They showed variations in all dimensions. Typical imperfections based on the handmade nature of mudbricks. The chosen adobe brick dimensions had an approximate length of 22-24 cm and a width of 11-12 cm, with the height ranging from around 5-6.5 cm. Laboratory testing was conducted for water content and densities in the laboratory in the GUC Laboratories. The mudbricks had an average water content of 4.3 % resulting in an average space load (due to self-weight) of 131 kN/m^3 at an average dry density of 1281 kg/m^3 and average wet density of 1336 kg/m^3.

4.3. Structural aspects

The digitally designed brick structure can structurally be described as a fluid, curvilinear wall. Its double curvature provides potential for structural benefits, as it can contribute to a geometrical stabilization of the adobe wall. Curvilinear structure references can also be observed in close proximity to the BARZAKH project, at the archaeological excavation site next to Old Gourna (Figure 9). The parametric wall design's intention was not primarily to optimize structural stability; thus, some secondary curvature areas also challenge the wall stability through playing with eccentricities out of plane, in which case the stabilization effect of the curvature becomes relevant.

The foundation of the wall structure was ensured by one base brick layer lowered into a preliminarily dug base lining in the ground, ensuring a stable placement. The wall was then

Figure 7. Wall construction process with mud mortar and mudbrick sample 1.3 in the laboratory in Cairo. Photos: Hussein Elsarnagawy (left), Nouran Mohamed (right)

constructed one brick lining at a time, using mortar both in the horizontal and vertical joints. The wet brick wall construction was advantageous for several reasons. The mud mortar creates a composite structure, increasing the wall's stability against local tilting and buckling. Furthermore, the mud mortar was employed to address any significant discrepancies from the designed virtual model during the construction process.

5. Seamless workflow and participation

Building on the previous sculptural and experimental explorations with mudbricks (DIGITAL IMPERFECTION) and natural stone bricks (IMMERSIVE imPERFECTION), BARZAKH aimed to move beyond the purely experimental sculpture. It foregrounded the often-overlooked potential of collaborative and participatory processes in construction.

Finding a suitable site was crucial – not only for realistic building experienced but also for engaging an environment rich in human interaction, with both trained and untrained participants – people from the neighborhood. The opportunity to conceptualize and realize BARZAKH in front of a renovated Hassan Fathy Project added meaningful context and motivation, extending the project's architectural and conceptual relevance. Where a purely experimental approach might suggest a simplified and controlled building environment BARZAKH embraced complexity. The chosen site, with uneven terrain and existing trees, demanded that the curvelinear walls nestle into place. Rather than pursue robotic precision, the project build on the inherent imperfection of mudbrick construction – an aesthetic that was reinforced through the augmented, human-centred process. This process carried out by a diverse group of participants (Figure 8), celebrated imperfection not as a flaw, but as a core quality of this sustainable material (Figure 7, 9).

Unlike "a craft-specific augmented reality system" (15) Barzakh created an open and partly nearly chaotic immersive process. But exactly this echoed local practices, and dynamics in the area of New Gourna, while introducing a novel interplay between digital and physical realities. The mixed-reality setup enabled participants to test and refine the structure in real time, but also revealed time-consuming limitations. These challenges, while substantial, pointed the way toward future refinement in setup and coordination.

Although the methodology is not yet economically scalable, its participatory dimension remains vital. It promotes collaboration over separation between designers and users – aligning with Hassan Fathy's core belief in direct participation: "when projects are executed directly by those who will later occupy them" (7). The mistranslation "Construire avec le people" (1) into and "Architecture or the Poor" still reasonates when reflecting on Fathy's New Gourna model village.

Figure 8. Participants (top) and brick layering process (bottom)
Photos: Hussein Elsarnagawy (left), Christian Schmitt (bottom right)

In contrast, BARZAKH advocates for shared workflows in which traditional knowledge is not replaced or romanticized but embedded into digital construction logic. This participatory approach ensures locals communities – contribute meaningfully to a re-evolving material culture. It creates a feedback loop between virtual experimentation (VR) and physical application. The dynamic interaction between craftmanship and digital tools enables a new kind of low-tech construction, one that integrates advanced design thinking. In this context IMMERSIVE imPERFECTION a conceptual strength – a defining feature or possibility rooted in material authenticity rather than smooth precision. Traditional design processes, with their dependency on high detailed printed plans, often clash with the bottom-up, in-situ strategies BARZAKH explores. Using ubiquitous tools such as smartphones offers a more accessible alternative, especially for non-experts. The project becomes a practical investigation into how traditional craftmanship can be meaningfully integrated into digital construction frameworks – particualry within participatory and materially responsible design.

6. Earth as a contemporary building material

BARZAKH affirms the relevance of mudbricks not as a relic of the past but as a dynamic, future-oriented building material – responsive to today's ecological and social imperatives. By combining them by mixed reality, it repositions mudbrick as a medium of both innovation and sustainability.

The dialogue between precision and imperfection, digital workflows and manual labour, does not dilute but rather enhance then authenticity of earthen architecture. This approach breaks with the perception of clay, earth or here mudbrick aa primitive or purely vernacular and reframes it as a flexible, scalable, and most important a forward-looking material. While challenges around workflows refinement and economic viability remains, BARZAKH lays groundwork for inclusive, immersive architecture – one that merges material awareness, aesthetics, tactility, sustainability, people, and technology.

BARZAKH is a statement. Technology is becoming ubiquitous and accessible – but earth always was.

Figure 9. Built result of BARZAKH and curvilinear references in the archaeological excavations next to Old Gourna, Photos: Hussein Elsarnagawy (left), Farida Salama (right)

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