Earth Aftershock

A Housing Reconstruction Proposal Rooted in Seismic Resilience and Traditional Practice

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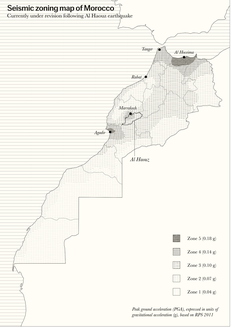
On September 8, 2023, an earthquake struck Morocco's Al Haouz province in the High Atlas Mountains, where earthen construction has long reflected adaptation to local climate and geography.
For reconstruction, concrete quickly emerged as the default material, seen as fast and regulation-compliant, yet contributing to the loss of threatened heritage. Standardized plans were widely implemented under time pressure, often misaligned with local needs. Despite these choices aimed at accelerating reconstruction, many families remain in temporary shelters, facing harsh conditions and bureaucratic delays.

In response to this situation —while acknowledging it only addresses part of the complex post-disaster reality— this project proposes an incremental, seismic-resistant housing system built primarily from site-sourced materials.
To illustrate one possible implementation, a site in Ouirgane was selected. The process begins with a seismic-resistant core in rammed earth (*pisé*), a technique suited to the local soil and enabling the reuse of earth from collapsed walls. This initial structure allows for rapid yet dignified resettlement and can be progressively extended according to evolving needs and means. Additional volumes connect through lightweight elements, offering spatial flexibility without compromising seismic safety.

By reclaiming earthen construction as a resilient and context-specific alternative, this approach reduces costs, limits environmental impact, and supports local economies by reviving traditional knowledge. It resists both institutional reconstruction frameworks and prevailing perceptions that mislabel earth as outdated or inadequate—seeking to restore trust in a material deeply rooted in place, memory, and resilience.

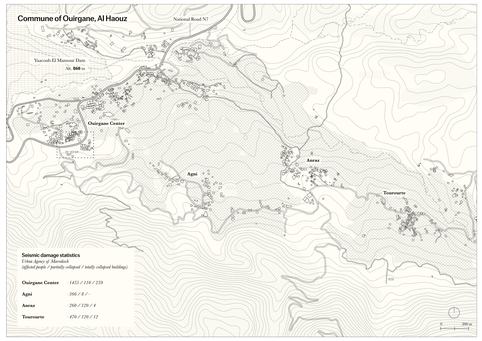
Seismic zoning map of Morocco

Currently under revision following Al Haouz earthquake



Peak ground acceleration (PGA), expressed in units of gravitational acceleration (g), based on RPS 2011

Commune of Ouirgane, Al Haouz

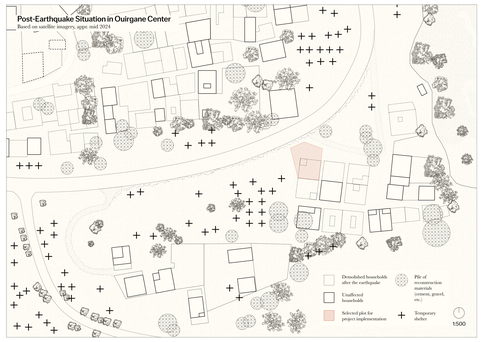


Seismic damage statistics
Urban Agency of Marrakech
reflected people / partially collapsed / totally collapsed buildings)

Ouirgane Center	*1435 / 138 / 219*
Agni	*386 / 8 / -*
Aurez	*268 / 126 / 4*
Tourourte	*678 / 126 / 12*

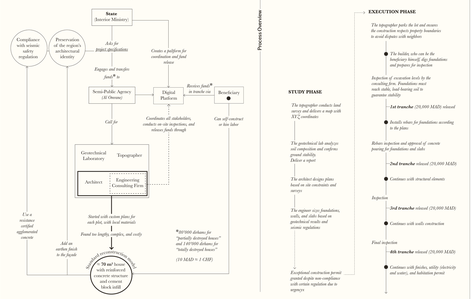
Post-Earthquake Situation in Ouirgane Center

Based on satellite imagery, sept. mid 2024



Typical State-Led Reconstruction Process

Based on a discussion with a consulting firm overseeing the reconstruction of over 1,500 houses



Reconstruction Timeline

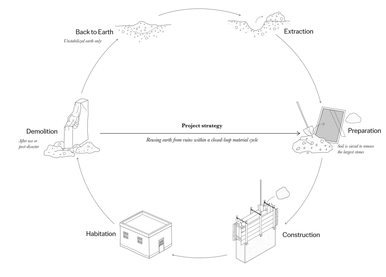
In five months: from marked ground to rising concrete blocks, paced by administrative approvals and fragmented funding

Plot in Ouirgane, October 14, 2024

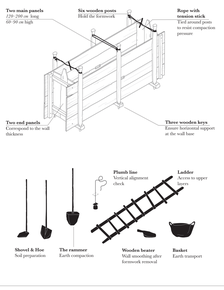
Same plot, March 23, 2025

(Re)building with Rammed Earth

Material cycle and reconstruction strategy



Rammed Earth Traditional Formwork and Tools



Construction Process

A minimum of three workers is generally required to carry out the process effectively

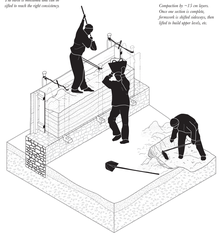
Soil preparation
One person loosens and mixes the earth with a hoe and a shovel.
The earth is moistened and can be sifted to seek the right consistency.

→

Transport and filling
One person fills and carries the basket of earth to the formwork to be poured in.

→

Compaction
The mason (master mason) compacts the earth with the rammer. This task is notably physically demanding.
Compaction lies ~1.5 cm layers. Once one section is complete, formwork is shifted sideways, then refilled in initial upper levels, etc.



Seismic Guidelines for Load-Bearing Earthen Walls

Based on *Gernot Minke (2000), UNESCO earthquake guidelines (2010)* and *RPCT Morocco (2011)*

Walls

- Load-bearing walls thickness $\mathbf{t} \geq 40$ cm
- Wall length between two successive orthogonal walls $\mathbf{L} \leq 10\,\mathbf{t}$
- Slenderness ratio $\mathbf{h} \leq 8\,\mathbf{t}$
- Use buttresses **(e)** or pillars **(d)** when the allowed wall length is exceeded
  - It is recommended that the section below the window be built as a light, flexible structure **(f)**

Structure

- Must act as a **box-like system**, meaning all walls are tied together by continuous vertical and horizontal reinforcements from foundation to roof
- Vertical reinforcements every $3 \times \mathbf{t}$
- A continuous **ring beam (a)** is required at the roof level
- **Plinth (c)** ≥ 30 cm to prevent capillary rise and protect earthen walls
- Foundations must distribute structural loads evenly into stable ground

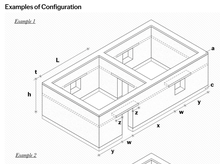
Openings

- Opening width $\mathbf{w} \leq 120$ cm
  - Distance between openings $\mathbf{x} \geq 120$ cm
  - Distance between an outside corner and an opening $\mathbf{y} \geq 120$ cm
- Lintel anchoring $\mathbf{z} \geq 50$ cm
  - The sum of the widths of openings in a wall should not exceed 1/3 of the total wall length in seismic zone A
  - Openings should be small, centred and symmetrical
  - Doors should open outward
- It is recommended to use the lintel as a ring beam **(a)** on which the roof structure rests *(see n. 2)*

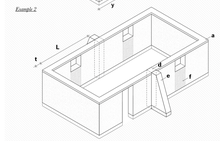
• *essential*
• *recommended*

Examples of Configuration

Example 1

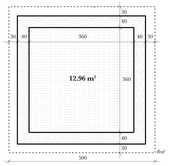


Example 2

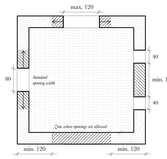


Core Module Plan

Dimensions



Opening configuration



Design constraints based on local context and Moroccan seismic regulation for earthen construction (RPCT, 2011)

Wall thickness: 40 cm
Min. required for a load-bearing seismic resistant earthen wall

Wall length: 360 cm (inner face)
Respects the RPCT limit: 10× wall thickness

Beam span: ≤ 500 cm
Limit based on local availability and affordability

Openings:
Must be limited in size and position to preserve the structural role of each wall

Roof heverhang: 30 cm
Minimum required for moderate annual rainfall

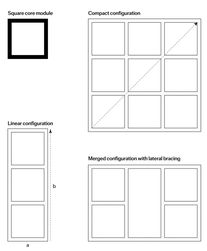
Wall height: 240 cm (clear height without plinth and ring beam)
Requires reinforcement (slenderness ratio = 6)

Storeys: One only
As required for seismic zones 3 and 4

Plan shape:
Should remain compact and symmetrical

Spatial Plan Configuration from Core Module

Seismic-safe layouts must remain compact, symmetrical, and limited in length
More complex forms require a seismic joint



Limited to 3 units without seismic joint **(b & c: 5m)**

Merging two modules creates a larger space, lateral modules provide structural bracing

Extension Strategies

Three main ways to extend while ensuring seismic safety

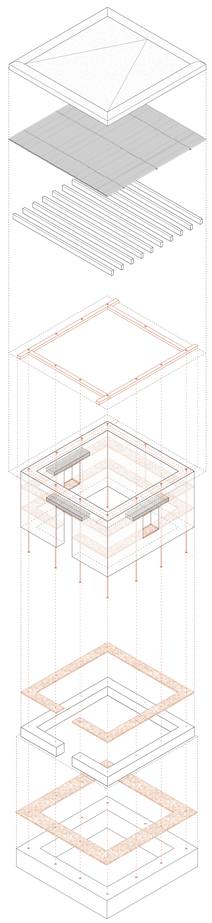
A. Structural junction
The new volume connects to the core unit using shared load-bearing elements

B. Separation joint
A flexible joint absorbs movements between volumes

C. Total independence
The new volume is structurally independent and physically detached

Structural Components of the Core Module

Seismic-resistant structure based on compact geometry and internal reinforcements



Earthen Roof Layer
- Compacted earth layer laid over the roof structure
- Provides thermal mass and insulation
- Shaped with a 1–2% slope for drainage

Reeds Ceiling
- Traditional woven reed mat tied onto perpendicular support reeds
- Transfers loads to the beams and supports the earthen roof
- Often left visible as a traditional ceiling finish

Roof Beams
- Main structural elements of the roof, resting on and connecting with the ring beam
- Sized and spaced according to local timber availability
- May include perpendicular secondary beams to improve lateral stability and diaphragm action

Ring Beam
- Continuous timber band at the top of all load-bearing walls
- Ties walls together and anchors vertical reinforcements, ensuring box-like behavior under seismic loads
- Supports the roof structure
- Should be securely connected to walls to prevent separation during seismic events

Lintels
- Must span the full wall thickness and extend well beyond both sides of the opening
- Can be made of multiple joined timber elements

Rammed Earth Walls
- Main load-bearing element (40 cm thick)
- Built in successive lifts with generally soil
- Reinforced with tensile elements to improve strength and cohesion

Vertical Reinforcement
- Inserted at wall corners, beside openings, and at regular intervals along walls
- Continuous from foundation to ring beam, anchored at both ends *(n. 9)*
- Tied to horizontal elements (e.g. wire, synthetic cord)
- Tied to horizontal reinforcements to form a 3D grid
- Reduce vertical cracking and out-of-plane failure, and improve tensile strength

Horizontal Reinforcement
- Placed at each lift or at key levels (e.g. top of plinth, above/below openings)
- Made of tensile materials (e.g. geogrid, timber)
- Tie lifts together, improve strength, reduce sliding and delamination

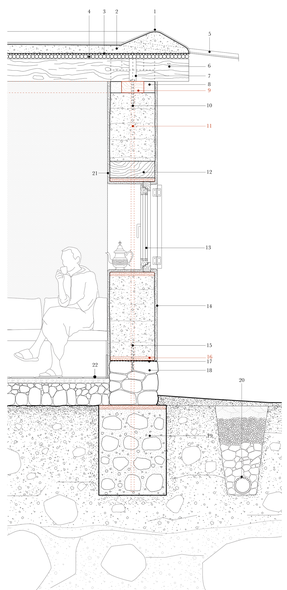
Plinth
- Act as a capillary barrier protecting earthen walls, raised at least 30 cm above ground level
- Material must be resistant and insensitive to water

Strip Foundation
- Ensure good load distribution into the soil
- Must rest on stable, homogeneous soil (>80 cm deep)

1:50

Wall Section Detail

Material choices guided by structural safety, economy, and local availability



1. Roof finish
Thin lime-based coating over earthen roof for water resistance and surface durability

2. Earthen roof layer
Compacted earth and straw, shaped with a drainage slope

3. Waterproof membrane
Polyethylene sheet placed below the earthen roof

4. Reeds ceiling
Tightly bundled reeds forming a rigid, breathable ceiling Can be woven into decorative patterns (traditional mats)

5. Water spout
Fired clay element projecting rainwater away from wall base

6. Roof beams
10×10×300 cm poplar or eucalyptus beams, spaced at 50 cm

7. Beam anchorage
Metal fixings securing roof beams to the ring beam to ensure structural continuity

8. Adobe infill
Adobe bricks filling voids between rammed earth and timber structure

9. Ring beam
Continuous 10×10 cm timber beam, connected to vertical reinforcements

10. Top anchorage
Embedded anchors (wood, rope, or rebar) embedded at wall top and tailed to ring beam
Ties roof beams to ring beam to ensure structural continuity and resist uplift

11. Vertical reinforcement
Rope, cane, or wood inserted during ramming
Anchored in foundation and ring beam

12. Lintel
Wooden lintel above openings, extending ≥ 50 cm laterally

13. Window opening
Wooden frame fixed to a timber element embedded laterally in the rammed earth wall
Positioned to free up the interior depth as a functional sill

14. Exterior plaster
Applied in three layers
- *Bonding layer: thin earth –sand slurry for adhesion*
- *Body layer: 1–2 cm of earth, sand, and chopped straw*
- *Finish layer: earth or earth–lime mix for water resistance and breathability*

15. Base anchorage
Embedded ties (cane, wood, or rebar) linking wall to plinth
Prevents sliding and ensures structural continuity at base

16. Horizontal reinforcement
Synthetic geogrid embedded in lime mortar

17. Capillary barrier
Asphalt sheet placed above the plinth
Blocks capillary rise into earthen wall

18. Plinth
Stone masonry bonded with lime mortar, min. 30 cm high
No plaster on exterior face to allow evaporation

19. Foundation
Cyclopean lime concrete with stones (≥ 5–25 cm)
Width = 1.5× wall thickness, resting on stable soil

20. Drainage system
Perforated pipe wrapped in stone, gravel, and sand filter
Conveyed by sloped topsoil to discret runoff

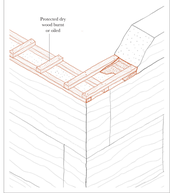
21.Interior plaster
Same breathable mix as exterior, in thinner coats (~2 cm)
In wet areas (kitchen and bathrooms), a polished lime finish (tadelakt) is used for water resistance

22. Interior floor
Packed earth laid on a compacted earthen over a hardcore layer of gravel and stones
Ensures stability, drainage and thermal inertia

1:10

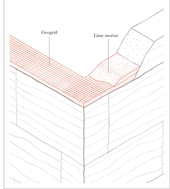
Wooden Horizontal Reinforcement

Wooden planks or round timbers, placed horizontally within the wall

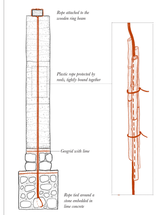


Geogrid Horizontal Reinforcement

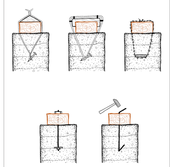
Placed in the horizontal joint and embedded in lime mortar.



Observed Reinforcements on Site

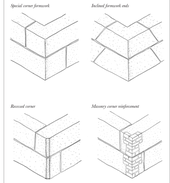


Types of Ring Beam Anchorage



Drawing: Based on the Moroccan Seismic Regulations for Earthen Construction (RPCT, 2011) and G. Minke, Building with Earth (2000).

Wall Continuity and Corner Reinforcement



Drawing: adapted from CRAterre, Construire en terre, 3rd edition (2000)

Cyclopean Lime Concrete Process

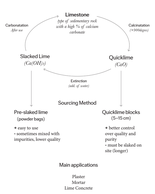
1. Excavation & first layer of lime concrete
   Lime concrete: 1 lime : 3 sand : 6 crushed red bricks

2. Add stones (≥ 25 cm)
   Leave 2–3 cm gaps between stones

3. Compact
   Repeat steps 2 & 3 until reaching the top level

4. Final level
   Keep surface humid for 3–4 days to enable carbonation

Lime Cycle and Main Uses

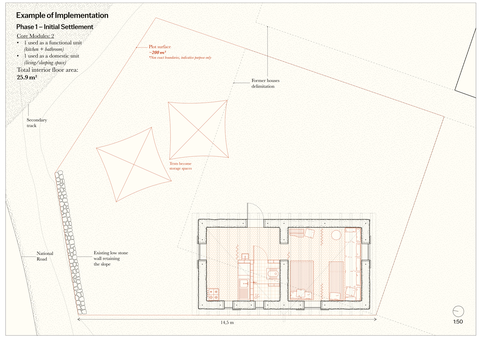


Example of Implementation

Phase 1 – Initial Settlement

Core Modules: 2
- 1 used as a functional unit *(kitchen + bathroom)*
- 1 used as a domestic unit *(living/sleeping space)*

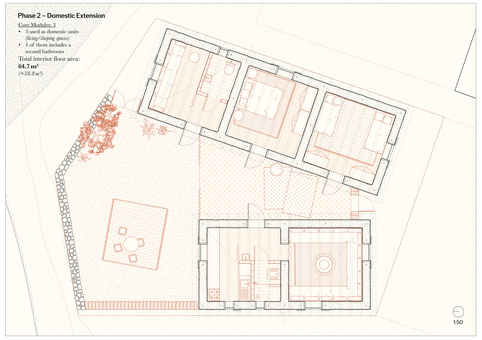
Total interior floor area:
25.9 m²



Phase 2 – Domestic Extension

Core Modules: 3
- 3 used as domestic units *(living/sleeping space)*
- 1 of them includes a second bathroom

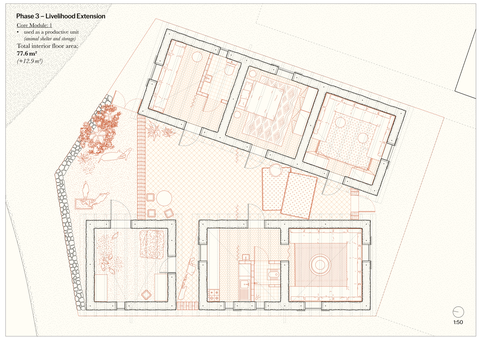
Total interior floor area:
64,7 m²
(+38,8 m²)



Phase 3 – Livelihood Extension

Core Module: 1
- used as a productive unit *(annual shelter and storage)*

Total interior floor area:
77,6 m²
(+12,9 m²)

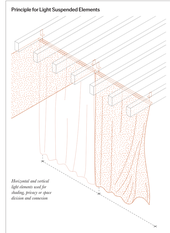


Exterior Perspective

West Façade

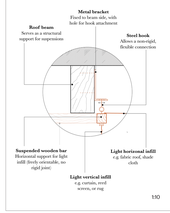
Interior Perspective

Principle for Light Suspended Elements

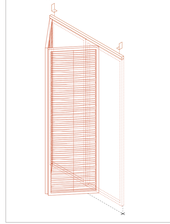


Horizontal and vertical elements provide light shading, privacy or space division and enclosure

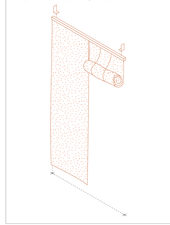
Suspension Detail



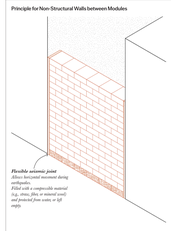
Example : Sliding Reed Door



Example : Rolled pannel (woven, rug, fabric)

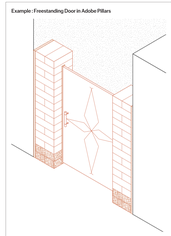
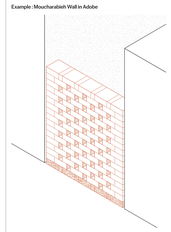


Principle for Non-Structural Walls between Modules



Flexible seismic joint
Allows movement between modules during earthquakes.
Filled with a compressible material (e.g., straw, fibre, or mineral wool) and protected from water, or left empty.

Example : Freestanding Door in Adobe Pillars



Example : Moucharabieh Wall in Adobe