# Traditional adobe building practices in the historic city of Ghadames, Libya

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# Abstract

The adobe-constructed historic city of Ghadames, Libya, a UNESCO registered world heritage site, is an outstanding example of a sustainable human settlement. The objective of this paper is to document traditional adobe building practices employed in Ghadames and, ultimately, to expose practitioners to the valuable experiences accumulated over a period of 1400 years. To achieve this objective, a survey of local knowledge on materials, preparations and building techniques was conducted. This survey was complimented with field investigations of existing structures undergoing several levels of deterioration and visual observation and monitoring of ongoing repair and reconstruction works employing traditional materials and techniques. Finally, the environmental merits of these practices and the challenges to the city's sustainability are presented.

# 1 Introduction

The adobe-constructed historic city of Ghadames (HCG), Libya, a UNESCO registered world heritage site, is an outstanding example of a sustainable human settlement thanks to its highly developed urban planning, architecture and adobe construction which were perfect adaptations to human needs, cultural and physical environments and remote location. The objective of this paper is to document traditional adobe building practices employed in Ghadames and, ultimately, to expose practitioners to the valuable experiences accumulated over a period of 1400 years. To achieve this objective, a survey of local knowledge on materials, preparations and building techniques was conducted [1]. This survey



was complimented with field investigations of existing structures undergoing different levels of deterioration and visual observation and monitoring of ongoing extensive rehabilitation works, conducted by UNOPS/UNDP for the Secretariat of Tourism, Libya, employing traditional materials and techniques. The results of this survey are used to draw conclusions regarding the sustainable use of adobe technologies in historic and newly developed urban areas.

## 2 Geo-historic context

Ghadames is located on the northern peripheries of the Sahara desert about 600 kilometers south west of Tripoli, Libya's capital and only a few kilometers from Algeria and Tunisia. The city is the gift of Ain AlFaras (AAF), the eternal artesian spring, whose warm water flowed naturally through 5 canals passing underneath or around the city to be used sequentially for drinking, ablution and irrigation. Consequently, agriculture flourished ensuring food sufficiency and providing building materials as well as an aesthetic landscape.

Because of its desert location and relatively low altitude (350 m AMSL), the city's prevalent climate is eremitic; extreme temperatures range from 55.2 °C to -6.5 °C, precipitation averages only 36 mm/year, average evapotranspiration rates exceed 2700 mm/year and relative humidity averages only 33 %. Strong sand-laden southerly winds blow about 23 days/year.

Founded by Canaanites [2], Ghadames has traditionally been the Sahara's most important city. Historic as well as archaeological findings around the city testify to the presence of the Garamantes, Phoenicians, Romans, and Byzantines around Ghadames. It was the Moslem Arabs who founded the adobe-constructed HCG over 1300 years ago to become a center of enlightenment, a pilgrimage route for the faithful from Maghreb and caravan trade between the Mediterranean and sub-Saharan Africa for many centuries and a living symbol of Islamic desert engineering and architecture. Ottoman, Italian and later French troops occupied the city successively until 1956 when it was turned back reluctantly to newly independent Libya.

## 3 Architecture and urban morphology

Environment, security and access necessitated locating the 7.5 ha. city inside the 200 ha. almost circular oasis while limitations of arable land dictated a vertical expansion resulting in an extremely high population density (> 1000 persons/ha.). The city consisted of seven quarters each having its own major street, alleys and passageways with public places including mosques, zawias, schools, public squares and private houses forming 80 % of the city's buildings.

The city is characterized by its covered streets and compact wall-to-wall structures ensuring environmental protection, privacy and economy. Ghadamsi houses are covered courtyard plan type and of practically identical architectural designs. Constructed in two main levels, the ground floor is reserved to farming ancillaries. The first floor contains the heavily decorated living room, the main room, and the socio-religious kubba. On a slightly higher "mezzanine" level are



located more sleeping rooms and storage spaces. The kitchen is located on the roof terrace to disperse smoke into the air.

# 4 Building materials and techniques

Ghadamsi buildings consist of a stone foundation, adobe walls, palm trunk/adobe mortar roofs, palm trunks lintels, gypsum/spongy stone arches, vaults and domes and stairs. A description of building materials and techniques is presented below.

#### 4.1 Building materials, sources and uses

Adobe is the basic material of construction in Ghadames along with stones, gypsum, lime, and palm tree products; all of these materials are available in ample supplies locally along with traditional construction skills. Quarries of stones and soils are common property with unlimited access to all residents.

#### 4.1.1 Stone

Two types of stone are commonly used, namely, hard limestone and akarshu, a coral stone which resembles sponge in its void filled structure. Two types of akarshu are used; a light and strong type used for domes, vaults and arches and a denser but weaker type used in constructing farm foundations. Stones are found around the oasis while akarshu is found below ground surface inside it.

#### 4.1.2 Soils

Five types of soil are used in Ghadamsi construction. Agricultural topsoil, found naturally in the oasis, is differentiated into three sub-types according to level of usage and hence size and degree of compaction. They are: 1) fine, compacted soil which has been overused and heavily fertilized, 2) less used and compacted soil, and 3) natural undisturbed soil. White soil, found abundantly below ground surface, is known for its relatively high compressive strength. Agricultural and white soils are mixed to make brick and mortar. Black soil is found in the oasis at depths over 0.5 m; however, it is usually replaced by farmers by better soil and may be found in the form of heaps scattered within the oasis. Red soil, found in quarries southwest of the city, is used mainly for plastering of external walls; a practice that started only about 60 years ago. Greenish clayey soil, found directly southwest of the city, is used for making pots, house ovens, and lime preparation ovens. Soils quality is judged qualitatively by its high water retention.

#### 4.1.3 Gypsum

Found in many locations around the city and in different degrees of hardness and purity, gypsum is used for constructing arches, beams, vaults and beams, for plastering internal sides of walls, as top layer of roof terraces staircases and parapets, and for repair of wall cracks. It is also used for internal and external decorative works including stepped finials on parapet corners.

#### 4.1.4 "Melous"

Melous grey rocks are found north west and southwest of the city. They are used as a whitewash material.



#### 4.1.5 Palm trunks, frond stems and leaves

Palm trees are very important for sustaining construction as they supply palm trunks, palm frond stems and leaves. Palm trunks are used as beams in roofs, lentils and arches and in making doors. Trunk characteristics depend on the source palm type; Tammoudi palm trunks are preferred in long span roofs as they bend gradually giving sufficient warning for replacement while Tesseween trunks, being decisively stronger, are preferred for heavy concentrated loads. The strong but easily breakable Medghiwa trunks are suitable only for short spans. Palm frond stems are used as load distribution mats on top of beams while leaves are used as filler to prevent slab material from flowing downwards onto floors.

#### 4.2 Preparation of building materials

Building materials are prepared according to traditional methods tested, refined and perfected over the centuries. Preparation procedures are described below.

#### 4.2.1 Mortar "binder mix"

Mortar is used to make and bind adobe bricks, to bind palm trunk beams on walls, to make sitting benches and roof slabs. It is made using white and black soils in a ratio of 1:2 mixed in water and allowed to soak "ferment" for periods of one week to over a year with water added intermittently. The soak period is shorter for mortars used as binder and for recycled materials. Well soaked and mixed mortars have better workability as sufficient time is allowed for homogenization and stabilization of constituents.

#### 4.2.2 Adobe

Adobe bricks are made from well mixed mortars using 1 or 2-brick wooden moulds. Three "standard" sizes are made based on loads and weight as bricks are lifted manually. Brick width and depth are fixed at 30 and 7 cm, respectively, while lengths of 70, 50-60, and 40-50 cm are used in ground, first and roof terrace levels, respectively (Fig. 1). The largest area is topped with extra mortar forming a "hump" believed to improve strength. Bricks are left to dry for 3-5 days in summer and 7-10 days in winter. To ensure uniform dryness, bricks are turned sideways after 2-4 days and cleaned from attached natural soil.

Compressive strength of adobe increases with higher fractions of white soil then declines with the appearance of larger cracks. Higher fractions also imply higher adobe costs; hence the addition of black soil and the use of less white soil fraction in farm walls.

Mix/mortar quality is inspected visually for consistency. Adobe bricks are tested for strength "breaking" by dropping them on edges from chest height (1.5 m).

#### 4.2.3 "Burned" gypsum

Burned gypsum is made in special 1.5-3 m cylindrical ovens "koor" dug into the ground to a depth of 1.5-2.5 m. A 10-15 cm layer of small size "fall out" gypsum mat is placed at the bottom and a perimeter wall is built using larger (20-30 cm) gypsum rocks to contain the firewood (palm trunks, fronds, tree branches). The



oven is filled with graded firewood (driest most combustible at the bottom). Larger gypsum pieces (40-60 cm) are placed directly on the firewood topped with smaller pieces, and so on forming an inverted cone. This arrangement allows larger voids at the bottom for better air/heat distribution. To ensure proper air control, bottom layer pieces are flat-shaped with minimum size openings. The cone is constructed with four symmetrically located side openings "vents" and a larger central one to provide exit for smoke. One to 3 long bisected palm fronds are placed vertically into each vent to fire the oven.

The oven is fired on a windless day just before sunrise to allow maximum observation time during the first day of burning. Once fired, gypsum is allowed to burn while "stray" smoke is stopped by filling the areas with fresh raw gypsum to ensure uniform burning and, hence, product quality. The subsidence of the cone is observed on the end of the first day or start of second day; a notable subsidence implies proper "burning". The process is completed when smoke disappears and moisture shows on the cone surface (2-7 days). An opening is made into the cone surface to check for fire and a small quantity of the product is collected. The absence of flames and white or grey appearance of gypsum are signs that the operation was successful.

Burnt gypsum is transferred for grinding manually using thick sticks, and sieved. Product quality is tested by making a paste, forming it into a ball and throwing this ball against a wall. If the ball heats up, dries quickly and sticks to the wall, good quality is assured.



Figure 1: Adobe bricks.



Figure 2: Foundation/wall construction.

#### 4.2.4 Melous "white gypsum"

Melous is prepared by women. Quarried melous is bought and carried to the kitchen where it is stored. A few small pieces are placed in the bread or food ovens where it is burnt while cooking. Burnt melous is white and disintegrates easily upon throwing on the floor; it is ground in a pestle, sieved and made into a paste for storage. Ten to 30 days later, the paste is ready for use.



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#### 4.2.5 Palm trunk beams

Beams are made from "live" palm trees only, preferably aged ones which are downed at the ground level for maximum length and skinned to make the outside smooth. The trunk is then cut to the desired lengths and bisected into two halves or four quarters depending on the trunk size, left to dry in the shade for a period of 0.5 to 2 years with the fibre exposed to the sun, properly finished to a flat inside and smoothly curved outside. Finally, beams are brushed with a preservative syrup of gypsum, peppers, salt and dates and left to soak/dry for 2 days. Beam quality is tested by inspecting the color and density of the fibres and sounding; whitish dense beams that make a vibrating sound are good.

#### 4.2.6 Palm fronds and leaves

Green palm fronds stems are cut, dried in the shade, and defoiled; each 15-20 branches are bundled and placed into a specially dug ditch just below ground surface, covered with soil and soaked with water for 5-7 days. Soaked branches, being more flexible and easier to handle, are cleaned and trimmed at the ends at almost equal lengths. Dried leaves are used untreated.

#### 4.3 Building techniques

Building operations are conducted collectively by masons and workers of extended families, neighbours, friends and fellow community members thus saving labour costs, strengthening social bonds, ensuring employment of best skills and optimum use of materials. Building operations are interrupted during the fall season as it is commonly believed that adobe and mortar "ferment" decaying easily afterwards. They are strictly manual and thus labour intensive.

#### 4.3.1 Foundations

Foundations are bearing wall type, made of hard limestone, 80-100 cm wide, and 100-150 cm deep depending on the soil type. Excavations are made to highly bearing white, black soil, or rock formation depths. Stones are placed in a compact form with voids filled with smaller sizes but without binder to prevent capillary water rise damages to adobe. Rising to a height of 50-100 cm above the ground level, they are levelled with a layer of adobe mortar (Fig. 2).

#### 4.3.2 Walls

Walls are made of adobe bricks with orientation varying with the floor level in a way that ensures good load distribution and stability (Fig. 2). Outer ground level walls are built using two adjacent layers of interlocked bricks; outer walls of first level and roof terrace are built with the longer side perpendicular to the wall direction while bricks of inside walls are placed with the longer side in the direction of the walls. The top layer of parapet walls is made with bricks laid on their depth-length area with the corners made into stepped triangular finials and bound using gypsum to ensure strength. One of the interior "common" roof terrace walls is reserved as a community "public footpath" for use by women and children during daytime in line with adult gender separation traditions; hence, it



is made with bricks in maximum width orientation and topped with grinder stones to ensure stability/safety and resist intensive use and erosion.

Rows of brick are topped by a 5-10 cm thick mortar layer, constructed in 6-8 row courses, and left to dry; the courses of higher levels have less rows (5 and 3-4 in first and terrace levels, respectively). A local rule of thumb is that the mortar thickness should equal brick thickness. Adobe bricks are placed with a horizontal spacing of 3-5 cm. Outer walls are constructed first following the construction of the cesspit whose floor is generally made of stone. Mortar is made into soft balls which are placed on dry mix for traction and thrown to the mason.

Walls are lined visually; therefore, they are bent horizontally and vertically. Following common wisdom, external walls are sloped gently inwards to "ensure long term stability as un-braced high rise walls will tend to fall to the outside if they are perfectly vertical". To ensure lateral support, retaining walls are extended along outside walls (Fig. 3). Walls are connected by commonly shared bricks within a given building, but different buildings walls or those built at different times are usually not interconnected showing clear separation (Fig. 4).

Farm walls are built similar to building walls, but with less emphasis on material quality and control. White soil fractions are reduced and foundation stones are of less quality. Foundations are higher than maximum "flooding" water level to protect adobe walls. Bricks are oriented in the long direction. A top decorative layer is made with bricks in standing or slightly sloping position.



Figure 3: Retaining walls.



Figure 4: Wall separation, capping and finials.

#### 4.3.3 Arches, vaults and domes

Arches are used extensively in Ghadamsi buildings. They form a distinguishing feature of the city's architecture because of their unique shape and purely decorative (non load bearing) function (Fig. 5). Loads are supported by palm trunks above.

Columns supporting the arch are built first using gypsum bounded stone followed by making the arch form using adobe bricks topped with mortar giving the desired shape on which decorations are drawn along with craftsmen names,



handprints and execution dates. A thin fine sand layer is sprayed next to ease separation upon completion of arch construction.

Gypsum is prepared by pouring small quantities into water and mixing manually. The "semi-fluid" mix is poured immediately on the "form" to a depth of 2-3 cm. A second layer of gypsum/gypsum aggregate is placed next topped with 10-20 cm size light akarshou stones and binding gypsum. An excellent bond is formed as gypsum flows into the voids. The process is continued to the proper height. Dryness of arch is tested by removing of the top "form bricks" and observing gypsum solidification. As gypsum dries quickly thanks to its heat of hydration, arch forms are removed as soon as construction is completed. Vaults - used to support staircases – and domes of mosques and zawias are built similarly. Stairs are topped with a 3-5 cm layer of gypsum for durability.



Figure 5: Unique Ghadamsi arches.



Figure 6: Roof construction.

#### 4.3.4 Lentils

Lentils are built using 2-3 palm trunk beams tied centrally with a rope for ease of handling, structural support and early warning of failure when it ruptures. They are placed on flat stones to distribute loads and bound using adobe mortar.

#### 4.3.5 Floors and roof slabs

Floors are made using a 10-20 cm adobe mortar layer which is sprayed to saturation with water, levelled and covered with a 4-6 cm layer of gypsum aggregate topped wit fine gypsum. Roof slabs are made of palm trunks covered with a mat of palm frond stems to distribute the load of an adobe mortar layer on top of it. Trunks are laid in the shorter span (width) direction with their edges placed directly on top of the wall or on a flat stone; occasionally, edges are flattened to balance trunk and provide larger contact area and, hence, better load distribution. Lengths vary from 2 to over 6 m including contact distances of 20-40 cm on each side. Beams are spaced 50-70 cm from each other requiring a mat of 70 branches.

Peripheral trunks are placed first and levelled horizontally using a straight palm branch. Walls of different floors are loaded in different directions to



equalize loading between walls. In the rare cases where a wall is loaded from two directions, trunks from different sides are laid such that their flat sides are facing each other. Roofs bearing light loads are built with beams placed on their curved side "face up".

A medium layer of decoratively rhombic shaped palm frond stems is placed on top of the beams in socially significant spaces; a larger mat of stems tied closely together with a strong rope in the center is placed on top of the decorative stems or directly on the trunks and oriented normal to the beam direction (Fig. 6).

The mat is topped with dried palm leaves and covered with a small layer of fluid mortar; more "drier" mortar is placed next ranging in thickness from 15-20 cm in lower level floors to 20-50 cm in roof to ensure insulation. This slab is compacted heavily and left to dry for 2-3 days before being levelled. A 3-5 cm layer of gypsum aggregate/fine gypsum is poured for durability (and drainage in case of roof terraces).

#### 4.3.6 Plastering and whitewashing

Internal walls are plastered using a 3-5 cm layer of fine gypsum which, upon drying, is whitewashed using "meilous". Walls of significant buildings such as mosques, street sections, squares, frames of doors and windows are plastered externally with gypsum and whitewashed as are caps of parapet walls and passageways. External walls are usually left in their natural state. However, they may be plastered to enhance appearance using red soil or to reduce erosion using adobe mortar. Plastering takes place after spraying of walls with water to dissolve fines accumulated in adobe interstices (left intentionally wide) and, hence, improve locking. As was the case with arches, gypsum mortar "paste" is made in small quantities and used immediately.

Buildings are whitewashed regularly on religious and social occasions; roof terraces are whitewashed just prior to summer so they can be used by family members at night. Whitewashing is performed using stored "meilous" paste mixed with water. The colloidal solution is brushed on the wall using a woollen cloth; the process is repeated 3 times to ensure uniformity and brightness. Occasionally, table salt is added "to improve adhesion".

#### 4.3.7 Rainwater drainage

Scarcity of rainfall made the use of adobe possible with significant impacts on construction and maintenance costs. Rainwater is drained using 50-100 cm long sloped spouts made of carved trunks or burnt clay pipes; the latter is preferred as particles don't settle in it causing clogging. These spouts are extended sufficiently to drain away from walls and into adjacent farms, street shafts, or into a collection pot emptied into nearby.

#### 4.3.8 Doors

Two types of doors are used; external "access" doors at the ground and the roof terrace levels are made of 5-7 flattened palm trunk planks nailed together with 2 palm granite branches. Other "internal" doors are made of 2-3 layers of colourfully decorated industrial wood.



## 5 Environmental considerations

Building activities in Ghadames rely heavily on local raw materials and skills, renewable energy and materials as well as collective work; hence their economic and environmental sustainability. Solar energy is used for drying. Wood, including wasted residuals from the oasis, is used to burn gypsum and whitewash. Adobe is recycled repeatedly to make new bricks or mortar.

Moreover, the design and selection of these building materials are made with special stress on thermal efficiency. The adobe-gypsum walls have a thermal resistance that is comfortably higher than required for arid zones while the adobe or whitewash surfaces have good light reflecting properties reflecting most of the incoming radiation energies. Wall thicknesses are such that a time lag of 12-15 hours is realized ensuring perfect dampening of high day temperatures [3,4].

Aware of the weaknesses of building materials, buildings are maintained annually, whenever a social occasion takes place in the building and as needed.

## 6 Future prospects

Inadaptable to modern amenities, the HCG was deserted 25-35 years ago in favour of a the new "concrete" Ghadames built within a grand national housing scheme to improve Libyan's standard of living. Interruption of routine maintenance operations has led to progressive deterioration of adobe structures. Despite concerted national efforts to conserve it [5], the continued maintenance of a depopulated city is a formidable task. Upgrading traditional materials and techniques can reduce maintenance costs significantly but time is needed to reach measurable results. Adaptive reuse can catalyze owners to rehabilitate private houses; the bulk of the city. Other venues need to be explored, while the rehabilitation efforts are enforced to rejuvenate this outstanding example of "sustainable" vernacular architecture.

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