Assessment of structural damages and development of rehabilitation procedures for the Old City of Ghadames, Libya

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Abstract

The Old City of Ghadames, a UNESCO registered world heritage site in recognition of its impressive living heritage that has been preserved in the form of a uniquely distinct architectural style and building practices, a highly organized social fabric, and an attractive landscape, has been progressively loosing its vitality and luster since the early 1970’s when its inhabitants started to leave it to a new “concrete” city with modern amenities. This departure marked the beginning of the deterioration of the city’s buildings and with it the search for ways to conserve it.

The objective of this paper was to assess the overall structural integrity of the city through an architectural and structural survey of selected buildings in different states of deterioration. Types and causes of structural damages were identified. They were due mostly to design shortcomings, rainwater and seepage, excessive or unevenly distributed loads, material and quality control defects, and environmental factors. Based on these findings, rehabilitation procedures were outlined and a systematic approach to assessment and rehabilitation was developed.

1 Introduction

The Old City of Ghadames (OCG), a desert city lying about 600 kilometers southwest of Tripoli, Libya, near the Libyan-Tunisian-Algerian borders, has played an historic role as a cultural and trade center between the Mediterranean sea and Africa [1]. It was listed as a world heritage site/city by UNESCO (1986) and the Organization of World Heritage Cities (1999) in recognition of its impressive living heritage that spans many centuries of traditions and culture that
have been preserved in the form of a uniquely distinct architectural style and building practices, a highly organized social fabric, and an attractive landscape with full respect to the socio-religious values and full consideration of the harsh desert environment. A major factor that has contributed to the city’s sustainability was the total reliance on local building materials and the development of a traditional knowledge base in adobe construction practices. A second factor was the strict adherence of residents to frequent evenly timed maintenance practices.

The OCG has been progressively losing its vitality and luster, however, since its inhabitants started to leave it in the early 1970’s in favor of a new “concrete” city with modern amenities. Their exodus marked the beginning of the decline process of the city’s buildings which was accelerated markedly by the interruption of regular maintenance operations. To counter this decline, a project was launched focusing on building the capacity to ensure the rehabilitation and sustainability of the OCG and particularly its adobe structures.

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2. Architectural features of the OCG

The oasis of Ghadames is remotely located in the midst of the barren Libyan desert. The OCG, occupying 8 hectares of the total circle-shaped oasis area of 215 hectares, lies entirely within the south-western part of the oasis thus enjoying natural protection from the hot winds and sand storms and a protective and productive green built that earned it the historic title Jewel of the Desert.

The city’s urban planning, architecture and adobe construction were perfect adaptations to social needs, religious values, resource limitations, harsh environmental conditions and remote location.

2.1 Neighborhoods

The city consists of seven neighborhoods “quarters” surrounding the eternal Ain AlFaras spring, the source of life for the city throughout its long and prosperous history. A neighborhood is comprised of a main “large” street with several “smaller” branching alleys leading to “yet smaller” passageways. Streets, alleys and passageways are curved following the almost always curved walls of the buildings.

Each neighborhood has its own properly located and sized public places in addition to the houses. Bench-like sitting places for different age groups are placed at strategic locations along the streets, alleys and passageways. The city’s neighborhoods contain a total of about 2000 buildings including houses, shops, mosques, zawias, Quranic schools, entrances and gates [2]. Houses constitute about three quarters of the city’s buildings.

The streets are covered to provide protection from heat, cold, wind, dust and rain with lighting and ventilation shafts regularly spaced along them. Effective
protection against the harsh environmental conditions is also achieved through site selection, compactness, use of highly insulating building materials and routine maintenance.

2.2 Houses

Ghadamsi houses are practically identical in their architectural design that is a perfect response to the human needs and scale and to the economic and environmental constraints. A house is typically constructed in four levels (ground, first, split third and fourth) with a total height of about 12 m.

Natural lighting of the house during the day and ventilation are secured through small windows and a large shaft in the roof projecting into a smaller one in the living room floor thus ensuring that light and air reach all floors.

3 Building materials and techniques

A typical Ghadamsi building consists of a rock foundation, adobe walls, palm trunk supported lintels, gypsum arches, gypsum lined floors, roofs made from palm-trunks, branches and leaves topped with a layer of adobe mortar (Figure 1). Houses and other buildings are connected “wall-to-wall” in bee-hive structures for insulation, maximum space utilization and mechanical support. Spaces are intertwined in such a way that units of one house may lie above or below those of other houses, streets, alleys or passageways. This way, the city acts as one monolithic structure with one very large roof giving it exceptional abilities to withstand wind forces, dust, radiation, heat, cold and sound. A description of the materials and construction techniques used in these elements is given below.

3.1 Foundations

Foundations are bearing wall type. They are constructed from hard limestone in widths of 0.8-1 m and depths below ground level of 1-1.5 m. These rocks are intentionally placed without a binder to prevent damage and collapse of adobe walls above caused by capillary rise of water.

3.2 Walls and parapets

Walls are built from limestone to heights of 0.5-2 m above ground topped with adobe blocks bound by a 10-cm thick layer of (adobe mix) mortar. Adobe mortar and blocks are made from a mix of white and black soils soaked in water and left to “ferment” for 3-7 days or longer during cold seasons.

Adobe blocks are laid in courses of six layers which are left to dry before topping with another course. Walls usually follow foundations in curvatures resulting from manual and visual laying practices. Walls may also be curved vertically which presents serious structural problems.

Block sizes decrease from the ground floor upwards with decreasing loads. A typical size is 50x30x7 cm. The block has a flat bottom but a roughened humped top.
Parapet walls on top of buildings are made of thinner blocks laid longitudinally on their thinner side to occupy maximum surface area.

3.3 Floors and roofs

Ground, middle and top floors of buildings are made from compacted adobe mortar covered with a thin layer of gypsum plaster. Roofs are made from palm trunk sections treated against biological decay and used as beams. The edges of these beams are placed directly fresh mortar on adobe walls, and covered with a mat of closely tied palm branches which are covered, in turn, by palm leaves. These beams are placed along the short span of the structure with the branches placed diagonal to the beams. A 30-70-cm thick layer of mortar is placed on top of the palm-branch/leave mat Finally, a thin layer of gypsum plaster is placed on top of the mortar fill. Where the spans are short such as in stairs, roofs are made from gypsum/light rock filled arches. Domes of mosques and zawias are also made of gypsum.

3.4 Plastering

Gypsum is used for plastering walls, floors and roofs because of its effective resistance to weathering. “Gray” gypsum is used for plastering internal walls, floors, roofs and parapet walls and for making arches and external windows frames while “white” gypsum is used as a white wash.

Fine black or red soils are used for plastering external building and passageways walls leading to city quarters mainly for protective and decorative purposes.

Plastered and sometimes un-plastered wall surfaces are coated with a single thin layer of lime-wash to render them white; a preferred color of buildings and a good reflector of sun rays.

3.5 Lintels

Lintels are made of 3 palm trunk beams. To prevent movement, these trunks are tied with a strong rope.

3.6 Stairs and arches

Stairs usually consist of steps made of adobe mortar resting on palm fronds laid at proper slope or on low arches made from small light “spongy” rocks immersed in gray gypsum. They are covered with a thin layer of gypsum

4 Assessment of structural damages

Structurally damaged buildings could be seen all over the OCG. The challenging size and complexity of the problem made it necessary to develop a practical approach to assessment that would: a) include the minimum number of buildings, 2) be completed in a very short period of time, and 3) yield enough information
to form a base for a rational rehabilitation plan geared towards conservation of the maximum number of damaged buildings.

4.1 Approach

To develop an efficient assessment process, background information was collected through: a) review of technical literature available on the OCG, b) visiting and visual inspection of damaged buildings, and c) interviews with local experts on construction practices. Based on this “preliminary survey”, the following conclusions were made:

1. There was practically no quantitative data on the state of the OCG buildings;
2. Building architectural designs ranged from simple to sophisticated. They were very functional with perfect respect to human scale and needs.
3. The designs of houses were very similar and well known to young and old residents alike making it easy to reconstruct any house if destroyed;
4. Public buildings’ designs were unique and well known only to a few “older” residents thus requiring immediate survey lest they are lost upon collapsing;
5. Lack of routine maintenance and severe environmental conditions have caused extensive damages to many OCG buildings ranging from minor to very serious necessitating immediate intervention;
6. Construction materials and skills needed to effect rehabilitation were available locally ensuring the sustainability of the rehabilitation works;
7. As deterioration rates increase rapidly with time, collapsing buildings must be surveyed and rehabilitated urgently before completely collapsed buildings or those sustaining minor damages; collapsing buildings simply can’t wait!
8. Rapid assessment should necessarily be limited to a small number of representative damaged buildings that have special (cultural, tourist, etc.) significance and whose details are likely to be lost upon collapsing. Public buildings were thus identified along with some houses having unique features or uses.

4.2 Architectural and structural survey

A limited number of buildings was thus selected based on the constraints and conclusions above. A comprehensive architectural and structural survey was developed generating sufficient data and information for documenting the existing state of a building and, subsequently, its assessment. Detailed descriptions of the architectural and structural states of the individual elements (foundation, walls, etc.) of a building were identified, types, causes and treatment of damages were defined and quantities of materials needed for rehabilitation were estimated. The data were analyzed further to categorize buildings according to damages and rehabilitation works needed.

4.3 Causes of damages and rehabilitation procedures

Based on the results of survey analysis, the most common damages encountered, their probable causes and rehabilitation procedures were determined as follows:
1. Design related damage; examples of which include building on soft soils, insufficient use of reinforcement, lack of connections between different elements especially walls, excessive loading, inadequate roof sloping. 

*Design of buildings should thus be reevaluated based on full knowledge of the engineering properties of building materials and structural analysis principles through new research and development programs.*

2. Water related damages caused mainly by runoff from roofs, seepage of ground water from Ain AlFaras, water conveyance canals, and piped water introduced in limited areas of the city. Rainwater accelerates weathering of parapet walls, roof and wall materials directly by dissolving them and indirectly by entering through cracks along with wind blown dust causing expansion and separation thus leading to further damages. Seepage, on the other hand, causes foundation settlement which leads to wall separation. Moreover, if water rises to the walls, it can cause serious damage to buildings leading to total collapse (Figure 2). Ironically, water, the eternal source of life in the city, has become a major threat to its sustainability!

*Selection of waterproof roof materials and proper sloping with proper drainage are thus necessary to avert runoff problems. Lowering of the water table and complete waterproofing of buildings must be provided to avoid separation and collapsing problems. Where the problem is limited, separating walls should be connected properly.*

3. Damages caused by excessive or unevenly distributed loads including deformations, cracks and failures of structural elements. Cracks and separation of walls and arches (Figs. 3, 4), and deformations, cracks, and breakage of beams (Fig. 5) are common examples. Beam edges with minimum contact area are usually set directly on mortar crowning of wall thus causing high shear concentration cracks (Fig. 6). Moreover, as there is generally no positive connection between beam and wall, the beam will pull out from the wall upon any outward pressure on the wall. Natural settlement of walls and foundations is another cause of cracks and separation in walls.

*These problems can be overcome by reducing loads on structural elements. Foundations should be constructed properly. Spans between palm sections beams should be reduced along with the thickness of the cover to the minimum required along with provision of connections between beams and walls; provision of tensile reinforcement to walls by palm sections placed horizontally at regular distances; more even load distribution from beams to walls through larger contact area (another beam laid along wall top); walls should be connected preferably using palm sections; palm trunk sections may be used as beams to support loads on damaged arches or walls with openings; damaged and separated walls may be connected by shear connectors (palm trunk sections).*

4. Material and quality control related damages including: a) erosion, separation and eventual collapse of structural elements. Large difference in engineering properties of construction materials leads to marked differences in mechanical strength, erosion resistance, and expansion rates. These difference are accentuated by non-uniformity in the techniques and treatments employed during preparations and applications. Separation of mortar, gypsum plaster and lime wash from walls and roofs due to
heterogeneity of materials bound among other factors (Fig. 7). This separation accelerates rates of erosion and gives way to rain water, wind, and sand to be trapped between gypsum sheet and the wall thus increasing further the erosion rates. This phenomenon is most evident in parapet walls that are exposed to the most severe environmental factors (wind, sand, rain, temperature variations, etc.). In fact, it is these walls that suffer most damage and collapse in practically all buildings of the old city. The roughened humping tops of adobe blocks make it difficult to cover them evenly with mortar giving way to uneven covers or to loss of cover when semi-fluid mortar mixes are applied causing slumping of mortar or incomplete bedding of bricks. Erosion and reduced strength in walls may also be accelerated by the non-uniformity of the sizes and materials of adobe and the uneven application of mortar to walls. Separation of lime wash from gypsum plaster reflects poor adhesion, poor preparation and application of lime wash mix. Clearly, proper selection and upgrading of materials and good quality control should be emphasized during the construction and rehabilitation of buildings to alleviate such problems;

5. Environmentally induced damages (erosion) due to large temperature gradients (−6.5 to 55 °C [3]), heat, light, water, wind, sand, etc. usually cause and/or accentuate existing structural damages (Fig. 8). Biological decay of palm section beams reduces significantly the beam size and strength (Fig. 9) and leads to failures as explained above. Good knowledge of the local environmental conditions should be used as a base for materials selection, handling and preparation, execution and rehabilitation.

4.4 Classification of buildings according to level of damages

Based on the diagnosis above and the survey results, buildings were classified according to their structural state into the following categories:

1. Completely damaged buildings (mostly those damaged during World War II air raid), those collapsing or on the verge of collapse because of serious irreparable structural damages to elements (serious seepage problems) exhibiting hazardous to workers, visitors and residents frequenting the city. Such buildings should be demolished and reconstructed completely with architectural details collected from the field and from local experts;

2. Partially damaged buildings containing elements undergoing severe erosion of parapets and wall tops or having serious structural cracks. These elements should be replaced or strengthened and repaired;

3. Buildings suffering minor damages (erosion and/or minor structural cracks) should be repaired;

4. Structurally sound buildings suffering non-structural cracks or no damages requiring only routine maintenance.

5 Conclusions and recommendations

The OCG is a fairly well-designed and executed desert city. However, lack of routine maintenance and severe environmental conditions have caused extensive
damages to many OCG buildings. To optimize rehabilitation works effectiveness, an assessment of the overall state of damaged buildings was conducted on a necessarily small number of pre-selected buildings yielding sufficient indications of the nature and size of the damages as well as rehabilitation procedures. Based on the results of this assessment, the following conclusions and recommendations were made:

1. Building architectural designs were very functional with perfect respect to human scale and needs. House designs were very similar while public buildings’ designs were unique;
2. Execution levels varied widely ranging from very good to very poor. Similarly, the level of deterioration varied from minor to very serious necessitating immediate intervention.
3. Structural damages were due mostly to design shortcomings, rainwater and seepage, excessive or unevenly distributed loads, material and quality control defects, and environmental factors. Rehabilitation and sustainability of the city must, therefore, focus on addressing these causes.
4. Continued use of local materials and methods of construction is a prerequisite to ensuring the city’s sustainability with emphasis on: a) improving and upgrading them to overcome inherent shortcomings and b) transfer of traditional know-how from older to younger generations;
5. A comprehensive survey of all buildings should be conducted to document the existing state of the whole OCG and provide a database for its rehabilitation.; the sooner this survey is completed the better to capture the exact state of buildings especially those that are on the verge of collapse;
6. Whenever it is possible with assured durability, rehabilitation should be preferred to reconstruction as it is usually less costly and time saving.

Acknowledgement

This work was supported completely by Project LIB: 00/01: Rehabilitation of the Old City of Ghadames executed by UNOPS/UNDP for the benefit of the High Authority for Tourism and Antiquities of Libya. The authors wish to express their indebtedness to these institutions for this generous support.

References

Figure 1: Materials and components of a Ghadamsi house
Figure 2: Water caused damages

Figure 3: Separation of walls
Figure 4: Crack in arch

Figure 5: Crack of palm trunk beams
Figure 6: Shear concentration cracks

Figure 7: Separation of plaster
Figure 8: Erosion caused damages

Figure 9: Decay of palm trunk beams