AFTER THE FLOOD: DEVASTATION OF THE TRADITIONAL EARTHEN ARCHITECTURAL LANDSCAPE IN THE HADHRAMAUT VALLEY OF YEMEN; CAN MUDBRICK BUILDINGS BE MADE MORE RESISTANT TO CLIMATE CHANGE?

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Abstract: On 23-24 October 2008, the Hadhramaut province of Yemen experienced a devastating flash flood resulting from 50 cm of torrential rain in a 40-hour period in a location that normally receives 7.5 cm per year. With a loss of 5,000 earthen buildings, the 100-year flood was unusual because the rain occurred over the entire region, potentially indicative of future catastrophic events resulting from climate change.

The Hadhramaut Valley and its tributary wadis are well known for their spectacular ensembles of mudbrick tower houses, representing one of the last regions of the traditional Arabian oasis. The author, on behalf of Yemen's Social Fund for Development, UNESCO's World Heritage Centre and the Netherlands' Prince Claus Fund, visited the province to evaluate the damage in December 2008-January 2009. Most of the buildings lost were of more recent construction. By comparison, older buildings fared better, and particularly those found in the tributary valley, Wadi Do'an.

Some interesting observations will be discussed about the vulnerability of newer Hadhrami construction, which appears to have been partly due to the quality in construction. Although Yemeni mudbrick architecture is extraordinarily sophisticated, changes in methods of payment for contracting, as well as indifference to construction rules of thumb in flash flood zones, have taken their toll on the quality of new construction. Can lessons be learned from older buildings that survived? If flash floods become more frequent in the Hadhramaut Valley as a result of climate change, how can traditional mudbrick buildings be made more resistant? Can these ideas be incorporated into the new settlements that the local provincial government plans to build to replace those destroyed?

1. INTRODUCTION

On 23-24 October 2008, 40 hours of a torrential rain and resulting flash floods devastated the Hadhramaut province of Yemen. The Hadhramaut region is located in the former People's Democratic of Yemen (South Yemen), and the area that was most affected was the Wadi Hadhramaut and its tributary valleys. Part of a vast watershed system in southern Arabia consisting of valleys that are dry river beds (wadis) in between flat mesas, the area typically experiences two rainy seasons per year as a result of cyclical monsoon weather affecting the Indian Ocean during the spring and fall. These sometimes cause flash floods, although more typically, the average amount of rainfall per year is only 7.5 cm. However, what made the event of 23-24 October 2008 unusual was duration (40 hours), amount (50 cm), the fact that it

rained simultaneously throughout the main wadi and its tributary valleys, and number of buildings lost (estimates vary between 3,000 and 5,000), with entire villages wiped out. The event was considered a 100-year flood.

The Hadhramaut Valley is well known for its sophisticated mudbrick construction of tower houses. Clustered on the escarpments of the 300-meter high limestone and sandstone cliffs, this building typology developed to fulfill defensive requirements from tribal warfare in the past, the desire to keep the fertile valley floor free for cultivation, and the need to protect against occasional flash floods (Jerome et al., 1999, p. 40). The walled city of Shibam, the World Heritage Site in the region often referred to as the Manhattan of the Hadhramaut, exemplifies the typology of tower houses although not along the escarpment – it rises above the valley floor on an ancient tell (Fig. 1).

Fig. 1 – The walled city Shibam was inscribed on the World Heritage list in 1982. Although mentioned in the Bible, the town, in its present configuration with ten-story mudbrick tower houses, dates to 1533. (credits: Pamela Jerome, 2006)

Other main towns in the valley include Seyoun, the regional capital dominated by the imposing citadel-like Kathiri sultan's palace; Tarim, the spiritual center famous for its 50-meter high mudbrick minaret, palatial mansions, manuscript library, and Safa'i schools of jurisprudence; and, to a lesser degree, al-Qatn, once the inland commercial capital of the Kuwa'iti sultan. Wadi Do'an, a tributary valley, is one of the most intact examples of a traditional Arabian oasis cultural landscape.

1.1 Construction technology

The vernacular construction technology consists of load-bearing mudbrick on rubble-stone foundations, finished with mud and/or lime plaster. Quartered date palms or a local hardwood (*'ilb*) serves as beams to support mud floors and roofs. Columns at

the ground floor are often lime-plastered stone, but at upper floors they are decoratively carved local hardwood or, sometimes, Malaysian hardwood.

This system of construction is perfectly suited for the local climate and geographic location. Temperatures regularly rise to 50 degrees Celsius during the summer, and nighttime temperatures in the winter can go down to 5 degrees Celsius during a cold spell. With an inadequate supply of electricity, the Hadhramaut cannot afford to provide ample power for air conditioning or heating. Hadhrami mudbrick buildings require neither, as the interior environment remains perfectly tolerable in all of the extreme variations of external temperatures.

The author has traveled to the Hadhramaut on a more-or-less annual basis since 1997 to research and document traditional mudbrick construction. Under the auspices of the American Institute for Yemeni Studies, she is currently a cultural heritage consultant for the Hadhramut region to the Social Fund for Development (SFD), a local QUANGO that includes funding of cultural heritage projects in its mandate. Over approximately a month from December 2008 through January 2009, at the behest of the SFD, UNESCO's World Heritage Centre (WHC), and the Prince Claus Fund of the Netherlands, she evaluated damage caused by the flash flood of 23-24 October 2008.

1.2 Global climate change (GCC)

In addition, the assessment was particularly relevant because in her position as an officer of ICOMOS's Scientific Council, the author's role is to lead the interdisciplinary research program on global climate change (GCC) and its effects on cultural heritage. Although acknowledged to be a 100-year flood, with GCC credited as the cause of more frequent and intense storms, it is unlikely that this event will turn out to be unique or even unusual, but potentially, a harbinger of weather patterns to be expected in the future. According to NASA satellite data between 2003-08, 2 trillion tons of land ice have melted from Greenland, Antarctica and Alaska. With the 2008 Arctic fall temperatures 4 degrees Celsius warmer (Omestad, 2008), the "Arctic amplification effect" has increased exponentially outpacing current GCC computer models, as black-water surfaces absorb more heat and accelerate Arctic melting. Warmer temperatures lead to warmer waters, which not only expand in volume but are also linked to the increase in frequency and intensity of storms.

2. CHANGES IN CONSTRUCTION METHODOLOGY

Obviously, mudbrick construction cannot be expected to withstand a massive flash flood. Yet, the author observed patterns that were consistent with the collapse of mostly newer structures, whereas older buildings remained standing. The author reviewed flood damage in the main wadi as well as in tributary valleys, including Wadi Do'an and Wadi Sa. Surprisingly, very little damage occurred in the Wadi Do'an, despite the steepness of the escarpments and narrowness of the valley. However, after seeing so many newer houses devastated by the flash flood, it begged the question, why newer houses and not older ones? In addition, why did the buildings in Wadi Do'an survive so much better than the ones in Wadi Hadhramaut? It is the author's intimate understanding of Hadhramaut's traditional construction technology that permitted a comparison based on an accumulative knowledge gathered from evaluations of structures and interviews with master masons over more than a decade.

2.1 Location

It seems that a type of collective "amnesia" has occurred about the path of floodwaters. While it is true that flash floods meander and can be unpredictable, and that typically, torrential rain is not experienced in all tributaries simultaneously as was

the case during the 23-24 October 2008 flash flood; however, there are known areas of the flood plain to be avoided, and despite this, construction occurred (Fig. 2).

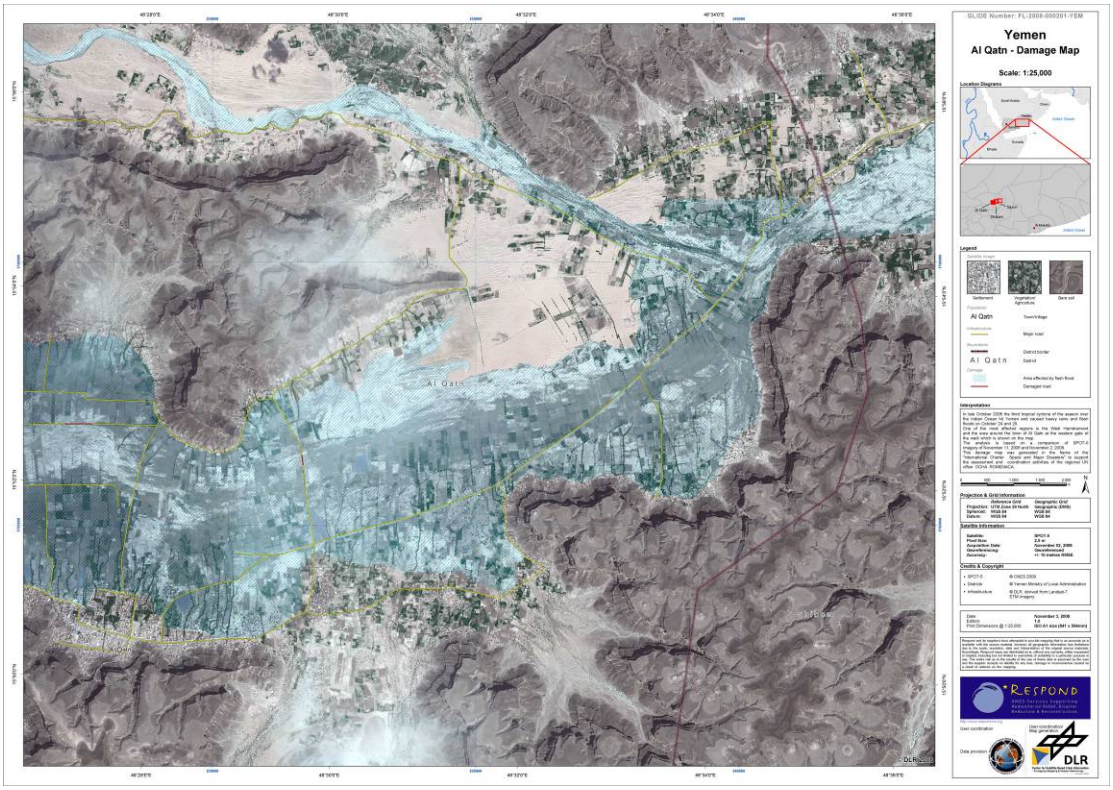

Fig. 2 – Satellite image of the Wadi Hadhramaut in the vicinity of al-Qatn, where over 700 buildings were lost. (credits: DLR, 2008)

2.2 Foundations

Many of the damaged newer houses had inadequate or no foundations. Foundations, traditionally of stone, require 2 m below grade as well as about 1 m of exposed stonework above grade (Jerome et al., 1999, p. 42). Judging from examples in Wadi Do'an, where the valley is narrower and the escarpments steeper, the above-grade height is over 1.50 meter (Fig. 3). Steep narrow streets also act as spillways during flash floods, with dry-stonework serving both to retain the hillside and to break the force of the cascading water.

In addition, Wadi Do'an's traditional use of dry rubble stone is particularly helpful as it precludes rising damp, which happens through capillarity. While this does not seem to have been the tradition in the Wadi Hadhramaut where the hydraulic mortar, *ramad*, was used in the past prior to the introduction of cement, at least *ramad* – a mixture of lime putty, ash and sand – did not introduce soluble salts into the mud superstructure. By contrast, cement contains soluble salts deleterious to mud construction. Cement mortar now commonly used in foundations, or even concrete foundations, promote the migration of soluble salts from the cement into the mudbrick superstructure with disastrous results.

Fig. 3 – Dry rubble-stone foundations in the Wadi Do'an can be over 1.50 m in height, and in this case, closer to 1.80 m. Pictured here is a tower house in the notable village of Budha located in the right branch of the Wadi Do'an. (credits: Pamela Jerome, 2008)

2.3 Use of concrete foundations and concrete construction

Many of the damaged mud buildings were adjacent to concrete construction (Fig. 4). The concrete construction acted as barricades, and so the floodwaters found a new path. The turbulence created by concrete in the path of floodwaters and its rebounding effect pushed the flood towards more vulnerable buildings.

Fig. 4 – Recent incursions of concrete construction into traditional villages caused damage to surrounding mudbrick structures during the flood through turbulence and rebound effect. This example is in al-Jihad to the east of Tarim. (credits: Pamela Jerome, 2008)

2.4 Quality of mud

Experienced Hadhrami master masons say that the best quality soil (*zibl*) is excavated from a depth of one meter. The topsoil is considered poor in quality because it contains salts from agricultural fertilizers. In Wadi Do'an, master masons collect the mud (*tin*) from around the date palms after the floods (Jerome et al., 1999, p. 41). With the building boom of the last 10 to 15 years, is care still taken to collect soil for mudbricks of the proper quality?

2.5 Quality and quantity of straw

Chopped straw (*tibl*) is a necessary ingredient of mudbricks. It acts as fibrous reinforcement and controls shrinkage cracks as the mudbricks dry (Hughes, 1983, p. 178-79, 186). In Wadi Do'an, dung may also be added as a binder. Local straw is considered to be of superior quality and more expensive than straw imported from elsewhere in the Middle East. What is the quality of the straw being used? Is the correct quantity being used?

2.6 Water-to-mud ratio

Water is also an important ingredient, but how much water is too much? For instance, too much water weakens cement, and cement-to-water ratios are closely controlled for this reason. There appears to be a similar situation with clay, the "cementing" component of soil. Reviewing past documentation from a commercial mudbrick yard in Seyoun, the mud mix is the consistency of pea soup (Fig. 5). The result is mudbricks that are brittle and break with little exertion from the hand. By comparison, in Wadi Do'an, the mud mix is stiffer and the bricks thicker and stronger (Fig. 6).

Fig. 5 – The quality of mudbricks is affected by the amount of water and straw, as well as the type of soil. In this commercial yard in Seyoun, brittle mudbricks result from a pea-soup consistency mud mix. (credits: Pamela Jerome, 1997)

Fig. 6 – In Khoreibah, deep within Wadi Do'an, the mix for mudbricks is stiffer resulting in better quality. (credits: Pamela Jerome, 1997)

2.7 Mudbrick construction

Experienced master masons indicate that mud mortar joints should be thinner than the mudbricks, but in newer Hadhrami construction, the joints are frequently the same width as the mudbricks themselves (Jerome et al., 1999, p. 42). This does not

seem to be the case in the Wadi Do'an. In addition, the mud mortar mix itself must be of a certain quality, well mixed and reinforced with wild grass (*sahadhar*). And the mudbricks are supposed to be stacked in a running bond, with headers or soldiers connecting the width of the wall and strengthening its construction. Now walls are built a single mudbrick wide and there is nothing connecting the inboard and outboard elevations of the walls.

Finally, mudbrick construction in the Hadhramaut is only meant to be carried out during the winter months, when the weather is cool enough to not cause shrinkage cracks. Additionally, no more than one story should be built per year, giving buildings the time to settle prior to being loaded with an additional floor (Jerome et al., 1999, p. 42). Is this still the case with new construction?

2.8 Quality of mud plaster

Mud plaster (*mahadha*) is the first line of defense for mudbricks, which are the load-bearing structure. Mud plaster acts as a sacrificial coating; when the mudbricks begin to show, it is time to re-plaster. Experienced mud masons say that mud plaster should be mixed with finely chopped straw and allowed to rest for three days prior to use. Now, mud plaster is mixed with less straw and applied after a half hour. In addition, the fresh mud plaster is troweled on in a thick layer, as opposed to three layers (scratch coat, brown coat, finish coat). As a result, it washes off with the first rain instead of lasting ten years.

2.9 Method of bidding construction projects

In the past, construction crews were paid by the day. Now, they are paid by the project. This results in rushed and poor quality construction.

3.0 CONCLUSION

It is the author's opinion that training led by experienced master masons should be organized to raise the quality of construction in the Wadi Hadhramaut. In addition, payment for construction needs to return to day wages as opposed to lump sum bids.

Camel shrub (*sesabana*), an invasive species that is pervasive in the Wadi, has taken over the flood channels. In the past, these were cleaned annually – camels were used to do this. Now the flood channels have been allowed to silt up and to become overgrown with vegetation, so there is nowhere for the flood to go; therefore, the floodwaters carve a new path. This tradition needs to be reinstated.

Throughout the Wadi Hadhramaut and its tributaries, there is a traditional system of flood management. The 100-year flood seriously damaged this system. It is estimated that $150 million is required to repair the entire catchment system. The World Bank is currently considering this issue.

Obviously, avoiding the flood plain for new construction is a priority, but returning to traditional know-how will also help. The fact that new construction is built without proper foundations, using lesser quality bricks, and with poorly braced walls can be rectified through better quality control and information dissemination to prospective homeowners. Traditional Hadhrami town planning also takes into consideration flood paths and manages floodwaters. These lessons can easily be incorporated into the new settlements that the provincial government intends to build in order to house those who lost their homes.

Unfortunately, when the author met with the Vice Governor's engineers who are designing the new towns, this was not the case. The town plans show regular blocks near the escarpments without any regard to flood patterns. Each family is scheduled

to receive a plot of land that measures 25 x 25 or 1,200 square meters. From drawings, the plots are walled-in compounds with a single-story 200-square-meter house of mudbrick on stone foundations. Houses on steep slopes will be provided with concrete foundations. The houses, although constructed of traditional mudbrick, are designed with square windows set high off the floor. None of the layouts of the several house types as currently designed include storage areas or a room for livestock.

Walled compounds are typical of western-style Saudi suburban construction. Yemeni villages tend to be tightly constructed with tall houses on small plots of land. This provides much needed shade in the streets, and also cultivates social interaction. Walled compounds enclosing large lots are both costly and isolate society. Typical Hadhrami houses have windows that are rectangular and are set just above the finished floor surface. This is because very little furnishings are used – instead carpets, cushions and pillows are the furniture and every room can potentially serve more than one function (Jerome et al., 1999, p. 43). Small square windows high above the rectangular windows are common. These allow light in the rooms, as shutters and curtains tend to be drawn so that the women of the house can go about freely without being seen. Since the villages that were wiped out are agricultural in nature, the need for a storeroom and a room for livestock are paramount.

If concrete foundations are going to be used, then the concrete needs to be isolated from the mud foundation fill and the mudbrick superstructure. This can be accomplished by application of a bitumen coating or installation of a plastic sheet. These foundations could also be lime plastered for aesthetics, thus concealing the fact that they are concrete.

However, it is the author's opinion that a central authority should be established to coordinate the reconstruction efforts. Civil engineers experienced with flood risk, urban planners and architects familiar with local lifestyles and traditional construction need to be employed to design the replacement towns. An international meeting of such experts could open a dialogue with Yemeni administrators and technical professionals to put forth a vision that is appropriate to the Hadhramaut. Without careful evaluation of the local vernacular, the potential of the new towns having a negative impact on the cultural landscape is enormous.

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