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H. Wilkins

From Massive to Flimsy: The Declining Structural Fabric at Mohenjo-daro

This paper examines architectural change at Mohenjo-daro in light of the cycles of decline and rebirth that have been observed at Harappa (Kenoyer/Meadow 1997), and seeks to explain the particular nature of the change. It proposes a modification of the traditional view that the buildings of Mohenjo-daro fell into decline only in the Late Urban phase (Mackay 1838, 6): the 'flimsy' buildings of the later phases merely represent a late moment in a trend towards lighter construction that was ongoing from the time of the earliest excavated buildings. A continuation of this trend would have led to even lighter and more adjustable structures, offering some explanation for the proposed Post Urban move to mobile structures (Franke-Vogt 2001, 279–280).

The trend began at least as early as the start of the Mature Harappan phase (the building sequence of the earliest levels being currently unascertainable) and continued into the final occupation phases. Its existence is most clearly revealed by an examination of the thickness of the main structural walls of the buildings, which is directly related to their potential capacity to support upper storeys. The structural capacity gradually diminished over time although, concurrent with this, the internal spaces became more thermally variable over time.

The explanation for the existence of this trend can be found in what the architectural profession refer to as Adaptive Comfort Theory (ACT). ACT, based on a vast body of research, states that humans have a universal preference for being able to make thermal choices, in preference to being always thermally 'comfortable'. The massive construction of the earlier buildings at Mohenjo-daro would have been thermally 'comfortable' (i. e., they would have been cool inside compared to the heat outside), whilst the later ones would have been thermally 'uncomfortable', but the later ones would have offered greater thermal choice to the occupants.

ADAPTIVE COMFORT THEORY

Studies into human thermal 'comfort' began in 1936, but it was not until the results of the earlier studies were compiled by Humphreys in the mid-1970s (Humphreys 1975) that the theory was quantitatively applied to the study of human thermal behaviour. Since then studies into the thermal responses of human subjects under diverse conditions, in a wide range of climates and cultures, have been carried out both in the field and under laboratory conditions and a vast data set has been compiled (for meta-analyses ref. to Humphreys 1975; de Dear/Brager 1998). The theory states that there exists a universal preference amongst humans for having the ability (or perceived ability) to make thermal choices, regardless of cultural and climatic differences and in preference to being always thermally 'comfortable' (de Dear/Brager 2001). The inability to make thermal choices is thought to be the catalyst for a wide range of stress-related symptoms that go under the label of Sick Building Syndrome. The symptoms range from skin rash to dizziness and nausea and cannot be attributed to any specific disease or diagnosable cause (Raw 1992).

The fundamental findings of the studies, and of ACT, is that people are active participants in person-environment feedback loops, adjusting naturally to changing thermal conditions (Brager/de Dear 1998). If discomfort is experienced people will react in ways to alleviate the discomfort, as long as they have the ability to do so. If people do have this ability to make actual or perceived thermal choices, they will tolerate greater degrees of discomfort than if they do not. A feeling of thermal discomfort is not, therefore, to be viewed as a negative sensation, but as a positive sensory stimulus, which causes the person to interact with the thermal environment. "The change of stimulation, rather than the absolute level involved, is the more important consideration. Moreover, a

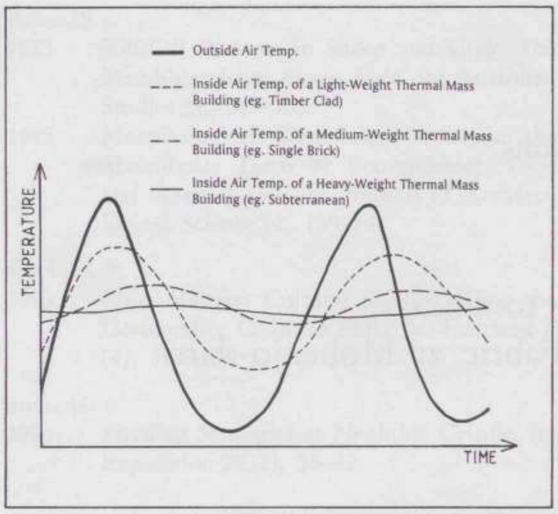

Fig. 1. Time lag (diurnal temperature fluctuation) for various types of construction.

momentary limited change of level in thermal stimulation, in either a positive or negative direction, can result in a positive effect" (Gerlach 1974, 15). That is, a thermally static environment is synonymous with minimal thermal choice and a thermally variable environment is synonymous with enhanced choice.

THERMAL CHOICE AS A SELECTIVE MECHANISM

Making a thermal choice refers to a conscious decision by a subject to effect a thermal adjustment to either their person (personal and cultural adjustments) or to their environment. Of these, only environmental thermal adjustment relates to the built environment and, with regard to the built environment, only thermal choice is rooted in human physiology (whether consciously or unconsciously). People make choices about their built environment (thermal, cultural, social, economic, ritual etc.) but, of these, it is the thermal performance of building types that will have a selective impact on the built environment: over an extended time period it will select for increased thermal choice and control. Buildings with more thermal choice and control would, in the long run, be expected to succeed over types that have less.

Adjustments to the built environment encompass a large degree of inertia compared with personal and cultural adjustments (Fletcher 1995, 43–65) and the more massive the building, the more the inherent inertia, and the less likely it is to meet the transient and individually unique thermal preferences of the occupants (Ong 1995). Not all buildings will, however, have the same range of thermal demands placed on them: a large, single-purpose building will not have to meet as wide a range of thermal preferences as a small communal dwelling. Buildings that must satisfy a wide range of thermal preferences (multi-purpose buildings) will be most strongly subject to selective forces and, consequently, their thermal performance 'type' will ultimately either encompass enhanced thermal choice, or cease to exist.

People's thermal choices are met by either moving about in the landscape or by modifying it to suit. A building occupant's thermal choices are met by either moving between spaces with different thermal properties, or by modifying a single space to suit. For example, a building of many rooms, some warmer and some cooler, some breezy and some calm, some humid and some dry, will offer wide thermal choice to a mobile occupant. Alternatively, a single room comprised of numerous thermally-adjusting components, such as numerous closable-openings with diverse orientations, operational wind-scoops and water-features, will potentially offer the same wide choice.

If, however, the building is of heavy, load-bearing construction, with a high thermal mass, and with minimal openings it will have relatively constant internal temperatures throughout a twenty-four hour period, at any position within the space. It will be thermally homogeneous (fig. 1). Alternatively, if the building is of a light construction, with a low thermal mass, it will interface more closely with the natural external environment and will have greater internal temperature variability, both within the space and over a twenty-four hour period. It will be thermally variable and will offer an associated increased thermal choice.

Maximum thermal choice in buildings is achieved by having maximum thermal choice and control. This is achieved with a heavy thermal mass punctuated by numerous, well-insulated closable-openings. This allows the interior to selectively interface with the external environment. An analysis of urban change at Mohenjo-daro shows that over time the buildings came to interface better with the external environment, offering enhanced thermal choice, but they did never achieve enhanced thermal control. The earlier, heavy buildings gradually lost both thermal choice and control, as their ability to support upper storeys diminished and the associated range of different types of thermal spaces diminished. The buildings that gradually replaced these buildings were of a smaller (Mackay 1938, 6) and lighter construction that offered more thermal variability and choice, but they were no more thermally controllable, having openings that were no larger or more numerous.

MOHENJO-DARO

Mohenjo-daro (27° 15' N/68° 15' E) is the largest of the Harappan cities, at approximately 200 ha (Kenoyer 1998, 49). The 'unoccupied' areas have not yet revealed any brick building remains, though it is likely that they encompassed buildings built of more ephemeral materials. Additionally, depending on how 'outer suburbs' and artefact scatters are interpreted, it may have extended for almost 2 kms eastward (Jansen 1987, 14–15; 1993b, 46). There is some debate over the nature of the climate at Mohenjo-daro during the late Holocene, ranging from wetter than the present and changing to drier at appox. 1800 BC (e. g. Staubwasser et al. 2003), to no difference from the present of temperatures or rainfall (e. g. Vishnu-Mittre 1974). It might, therefore, be concluded that, even if the climate had become slightly wetter towards the end of the urban period, temperatures were relatively the same as the present, with very hot summers (46 °C mean) and very cool winters (12 °C mean) (Siddiqi 1985). This data makes it possible to do the sort of thermal analysis discussed here for the buildings at Mohenjo-daro.

Early work at Mohenjo-daro was instrumental in generating the conventional view that Harappan settlements were generally master-planned, clinical, monotonous and unchanging. "The architecture, artefacts and internal organisation particularly at Mohenjo-daro in southern Pakistan came to be the standard against which all discoveries at other sites were compared" (Kenoyer/Meadow 1997, 61). Of the next two largest cities, Harappa at approximately 150 ha. (Kenoyer 1998, 49) and Dholavira, Harappa has a paucity of residential remains and Dholavira is substantially unpublished. Therefore, although excavation was halted at Mohenjo-daro in 1965, an understanding of the processes underpinning the changing built environment at Mohenjo-daro is fundamental to an understanding of Harappan urbanism generally.

Building Sequence at Mohenjo-daro

Jansen, in support of Mackay, has proposed that the Mature Harappan phase at Mohenjo-daro was initiated with the construction of mud-brick platforms, built as protection against flooding and as a means of elevating certain select buildings (Mackay 1938, 171; Jansen 1987, 15; 1993b, 43). Jansen has proposed that the site was abandoned to facilitate the construction of the "founding platforms" on which the proposed large scale urban planning was based (Jansen 1993b, 47). The Mature Harappan settlement then purportedly appeared fully-formed within the space of approximately 80 years, c. 2400 BC, along with the seals, script, burnt-brick technology, circular wells, drains and bathing platforms that constitute the Mature Harappan assemblage (Jansen 1987, 15–16; 1991, 78). Irrespective of this, however, the earliest excavated buildings represent the earliest 'mappable' moment in the architectural growth of the settlement and the earliest point in the ongoing trend towards lighter and more adjustable buildings.

The earliest excavated buildings were of massive brick construction, with relatively small openings

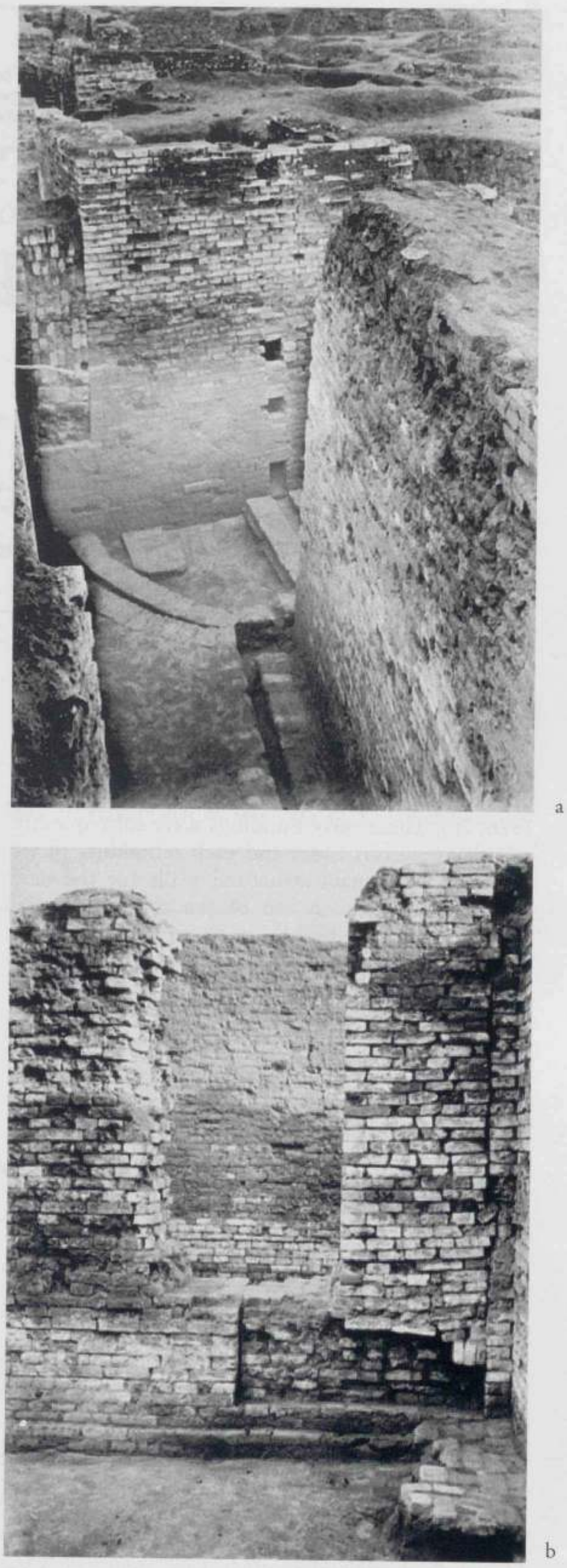

Fig. 2. a. Walls with batter: all Periods, DK-G (South), Loop Lane and Section 12, Room 2 (Jansen 1997, G2R03031). – b. Walls with setback: Intermediate II Period, DK-G (South), Section 1, Room 28. (Jansen 1997, G2R03138).

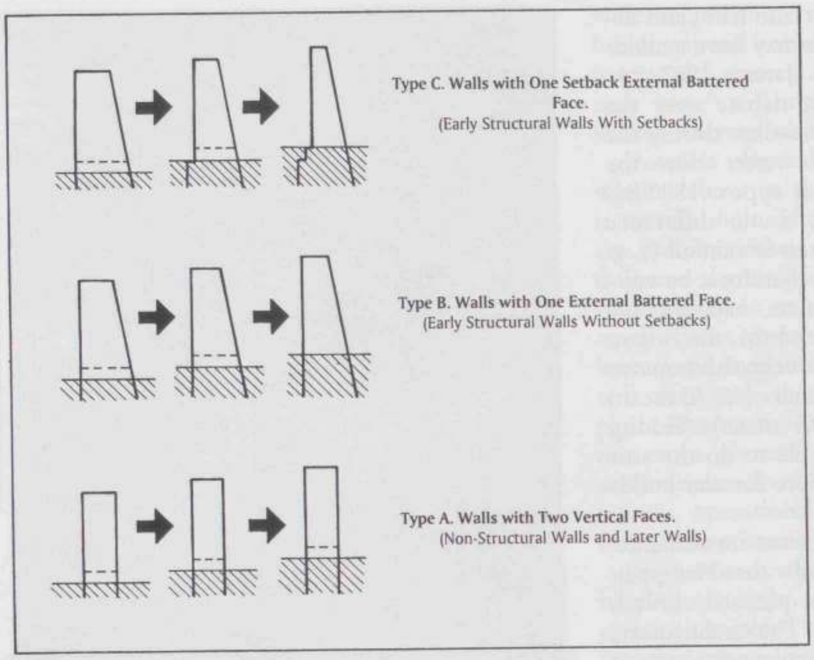

Fig. 3. Types of sequential wall construction, Mohenjo-daro.

and with a battered outer face of an average 4° 4' from the vertical (Mackay 1938, 164, 171) (fig. 2 a). This is a structurally efficient method for building tall buildings, as the greatest lateral strength is provided by the least amount of material (Cowan 1976, 76). These early buildings were subsequently rebuilt numerous times and each rebuilding phase positioned the main structural walls for the new buildings directly on top of the main structural walls of the older buildings, so as to use them as ready-made footings (Mackay 1938, 163). However, this had unforeseen, long-term consequences, when combined with the practice of battering the outer face of the walls. The massive walls became progressively thinner over time, because the battering reduced the available structural width on which to build the later walls (fig. 3).

There does not appear to have been much in the way of compensation for the diminishing wall thicknesses, such as cantilevering the later walls out past the line of the earlier walls. The situation was, in fact, exacerbated by the occasional setting back of the inner face of the exterior walls from the inner face of the footing, producing a ledge (Mackay 1938, Pl. XV) (fig. 2 b; 4–6). This produced an ever decreasing structural wall thickness and an associated decreasing structural capacity to support upper storeys as a factor of the diminishing wall thickness and the increasing room span.

This is best seen in the DK-G (South) area, which encompasses some of the deepest (and oldest) excavated sections (Jansen 1993a, 55). Mackay's section-plans (Mackay 1938, Pl. XV–XX) can be used to 'map' changes in wall thickness over time because, in buildings that are contiguously joined at any one point in time, there will be a "determinable horizontal and vertical growth on the basis of corresponding masonry joints" (Jansen 1993a, 128) and because they show a high degree of conformity in the grid position, size and room numbering (Jansen 1993a, 57), and, presumably, in wall thicknesses (to within a margin of error appropriate to the study of long-term changes). The case studies shown here (Sections 1, 1A, 4, and 10) show a continuously diminishing wall thickness (figs. 4–6, for a representative sample, and fig. 7 a). The later levels are overwhelmingly represented by walls of insufficient thickness to reliably have been able to support an upper storey, this being approximately 550 mm for this type of construction[1]. This estimate is based on comparative examples, the closest being the early colonial buildings of New South Wales (Cowan 1998, 12–14).

The diminishing thickness of the walls, with an associated diminishing thermal mass, would have produced interior spaces with increasing diurnal temperature variability (fig. 1), especially as the decreasing structural capacity would have resulted in a decreasing likelihood of there having been an upper storey. That is, over time the range of discrete spaces and thermal environments gradually decreased, but the diurnal variability within the spaces gradually increased.

Concurrent with this, new buildings were built, against and around the earlier buildings. These were also of lighter and thinner construction than the earliest buildings with, again, a reduced capacity to support an upper storey, but an increased

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[1] G. Gibbons, pers. comm. 2001. G. Gibbons is a structural-engineer and specialist in early brickwork and mortar.

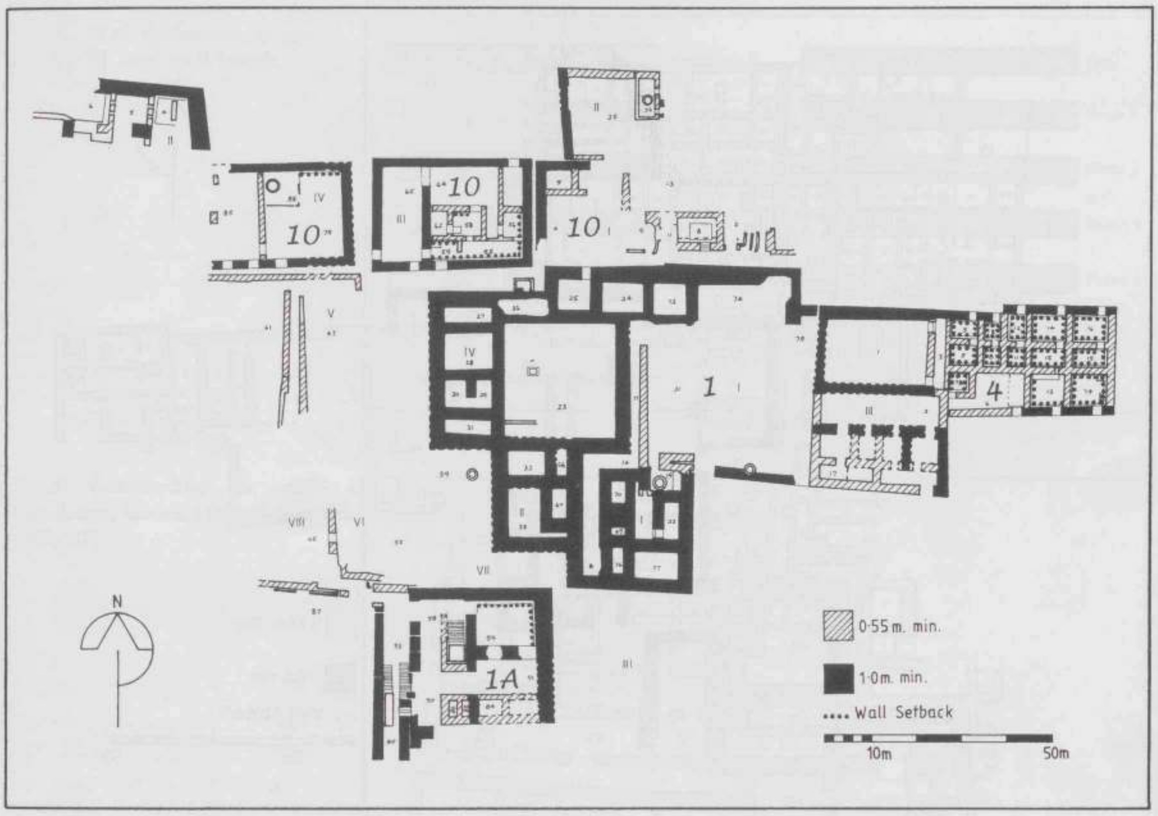


Fig. 4. Plan DK-G (South) area, Sections 1, 1A, 4 & 10, Intermediate III Period (after Mackay 1938, pl. XV). Wall thickness and wall setbacks.

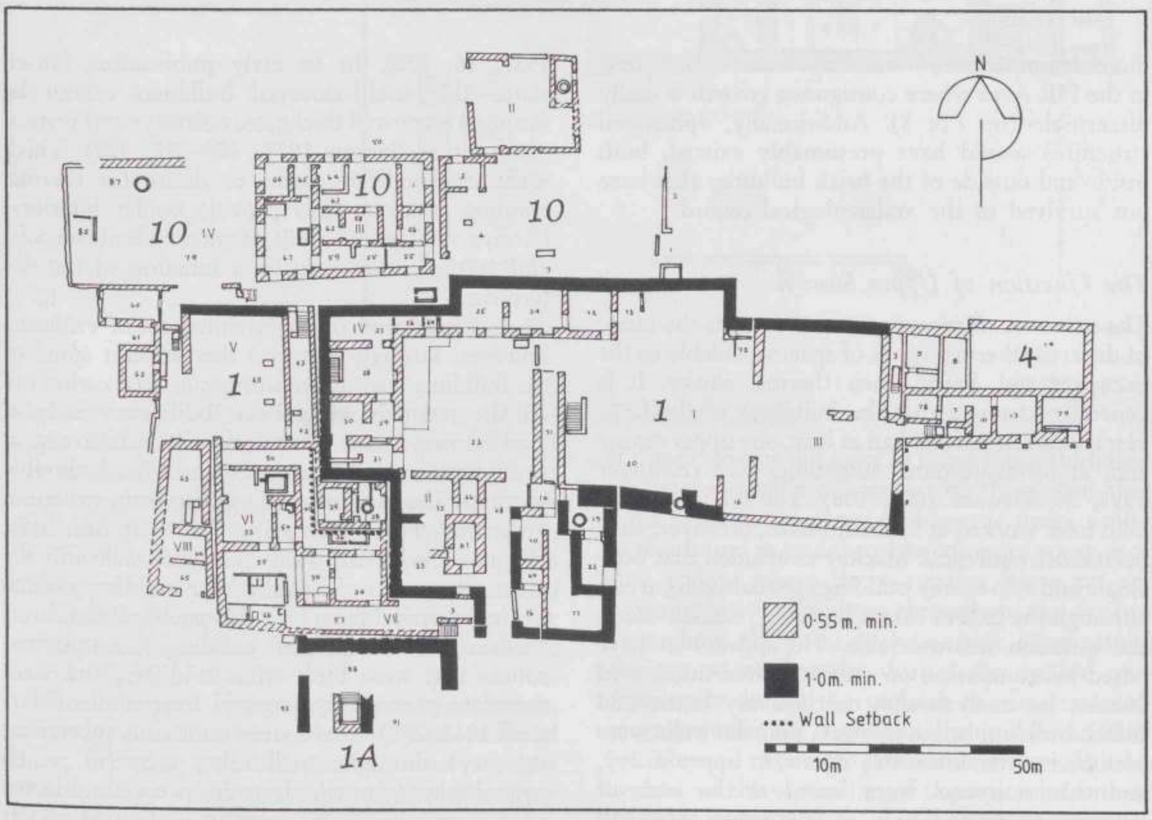


Fig. 5. Plan DK-G (South) area, Sections 1, 1A, 4 & 10, Intermediate I Period (after Mackay 1938, pl. XVIII). Wall thickness and wall setbacks.

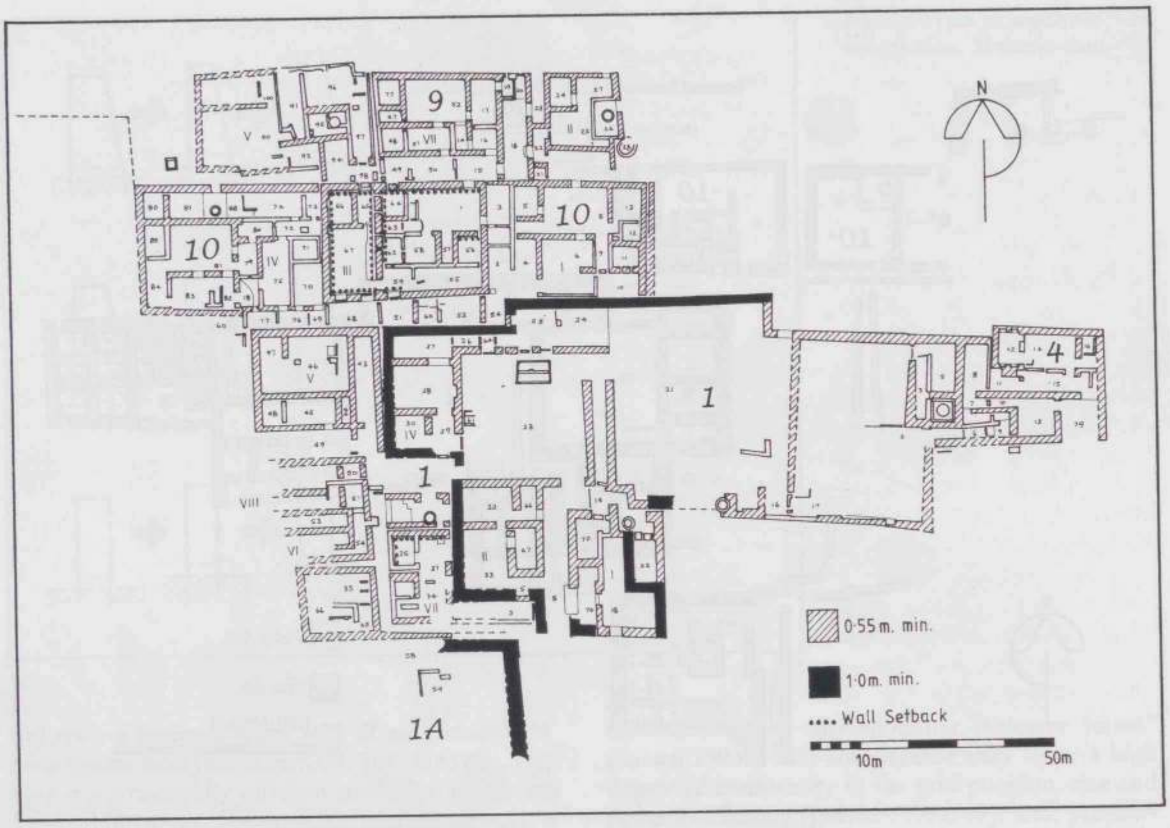


Fig. 6. Plan DK-G (South) area, Sections 1, 1A, 4 & 10, Late I & II Periods (after Mackay 1938, pl. XX). Wall thickness and wall setbacks.

diurnal temperature variability. This is best seen in the HR Area where contiguous growth is easily discernible (fig. 7 b; 8). Additionally, ephemeral structures would have presumably existed, both inside and outside of the brick buildings that have not survived in the archaeological record.

The Question of Upper Storeys

The existence of an upper storey extends the range of different thermal types of spaces available to the occupant and, hence, their thermal choice. It is generally assumed that the buildings of the large Harappan settlements had at least one upper storey and, at Mohenjo-daro, sometimes two (Kenoyer 1998, 58; Possehl 2002, 108). The archaeologists who have worked at Mohenjo-daro, however, have been more equivocal. Mackay concluded that both single and two storey buildings probably occurred, although the lack of extant building remains makes the question unanswerable. He appears to have based his conclusion on only a limited number of factors: his analysis that nearly every house and public building had a stairway, that the walls were of sufficient thickness to support an upper storey, and that stairways were found at the ends of passages connected only to the street (Marshall 1931, 16. 276). In an early publication, Jansen stated that multi-storeyed buildings cannot be assumed from wall thickness, stairways and vertical pipes alone (Jansen 1977, 406–407. 420). Thick walls may indicate status or desire for thermal comfort (thicker walls provide cooler interiors) (Konya 1980, 41–43. 112), stairs may lead to roofs, and vertical pipes may be a function of the site terracing.

A compilation of an extended set of evidence, however, strongly suggests that at least some of the buildings had upper storeys, at least earlier on. All the extant buildings were built extensively of load-bearing burnt brickwork, which is strong in compression, and had substantial and durable footings. The earliest buildings had main structural walls that were battered on their exterior faces, compared with the non-structural walls or the main structural walls of the later buildings, which had two vertical faces (e. g. House III, DK-G area, Section 10). Numerous buildings incorporated rooms that were built without doors, and were therefore presumably accessed from above (Marshall 1931, 274). There were numerous substantial stairways throughout the site, some of which connected only to the street and were not a factor of site-terracing (e. g. stairway leading south off

Fig. 7. Wall thicknesses as percentage of total wall length.

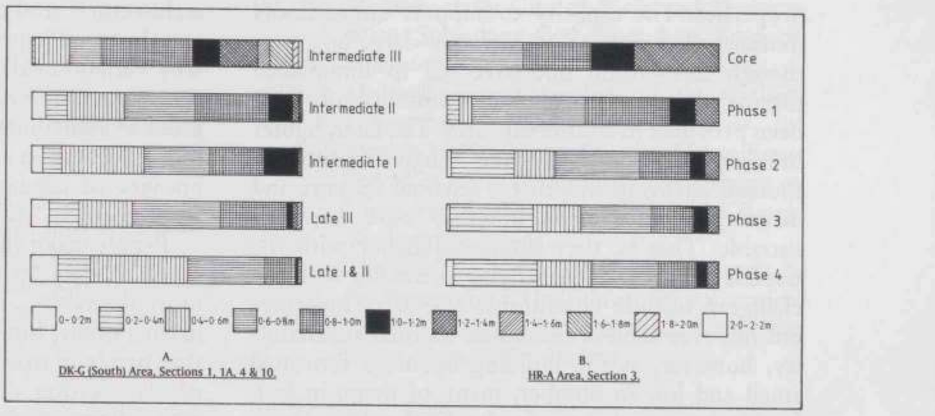
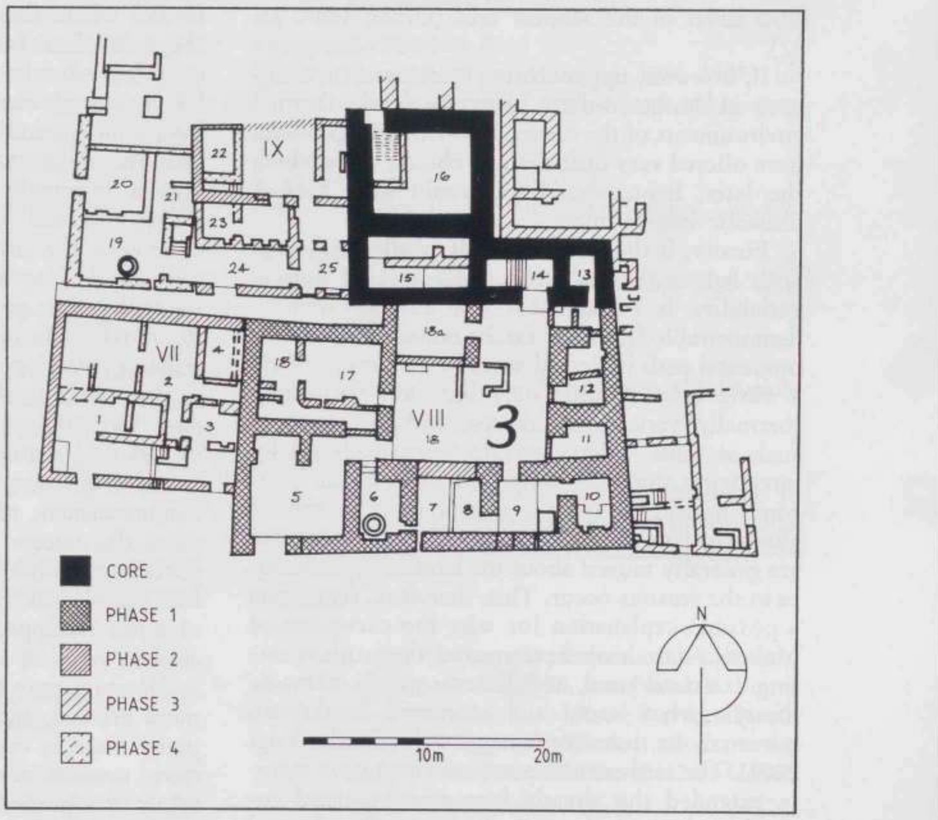


Fig. 8. Construction sequence: HR-A area, Section 3 (after Jansen 1984, 47).



Central Street, DK-G (South) area, Late III Period). Many of the extant beam holes are of substantial dimensions, greater than would have been necessary to support only a roof structure (Marshall 1931, 277; e. g. Room 49, House V, Section 2, HR-B area). There are several examples of vertical clay pipes built into the walls and of a size that suggests that they were used for ablution purposes only (e. g. Room 16, House III, Section 2, HR-A area).

Finally, upper storeys may have been known at Harappa, as is suggested by a clay tablet found there, depicting a full-height, shuttered window directly above another, similar window (Kenoyer 1998, 58).

Thermal Choice

If upper storeys did exist in those earlier buildings that were capable of supporting them then their form suggests a pattern of domestic usage similar to that found in traditional buildings of south-west Asia today, where the occupants move up and down inside the buildings throughout the day and throughout the year, as the outside temperatures change: warm upstairs during the winter, cool downstairs during the summer daytime and cool rooftop during the summer night time (Stead 1980, 36). Thermal choice would thus have been available because of the separation of the upstairs from the downstairs, each floor having different thermal properties. The capacity to support upper floors diminished over time at Mohenjo-daro, however, though this would not have led to diminished thermal choice. Thermal choice would simply have been provided in a different form. The later, lighter buildings did not offer the range of different thermal environments that a separate upstairs and downstairs can provide, but they were thermally variable. That is, they interfaced better with the outside environment, changing thermally with the changing outside conditions. The later buildings did not ever achieve maximum thermal adjustability, however, as the building openings remained small and few in number, many of them, in fact, having been sealed-up in the final urban phase. This is most clearly seen in the openings onto E-W-5 street in the Moneer area (Urban 1987, 25. 32).

If, however, upper storeys were never in existence at Mohenjo-daro, then the static thermal environments of the earlier, heavy buildings would have offered very little thermal choice, upon which the later, lighter buildings would have been a dramatic improvement.

Finally, if the trend towards smaller buildings with lighter thermal mass and increased diurnal variability is extrapolated out beyond what is demonstrable from the extant remains, the developmental path indicated would be represented by a move towards ultimately light and ultimately thermally variable structures, mobile structures such as tents. Tents provide thermal choice by interfacing almost directly with the outside environment and having the potential to be moved about the landscape. The tents of nomadic cultures are generally moved about the landscape as changes in the seasons occur. This, therefore, represents a possible explanation for why the occupants of Mohenjo-daro may have moved their urban setting to a more rural, mobile setting and a nomadic lifestyle when social and economic breakdown occurred, as has been suggested (Franke-Vogt 2001). The settlements' occupants may have merely extended the already long-existing trend towards enhanced thermal choice to the thermal choice offered by less densely packed rural settlements, or mobile buildings and a nomadic lifestyle.

CONCLUSION

Mohenjo-daro's buildings became gradually and progressively less climatically appropriate, but they did became more thermally variable. The explanation for this phenomenon is to be found in the vast quantity of work that has been done in architectural studies on Adaptive Comfort Theory and theory is important because, whilst "we know why variation exists in house form: human intentionality and inventiveness ... intent is a proximate cause of something, not the ultimate cause, and we find it lacking as an adequate explanation for why lineages of artefacts, including houses, take the form they do" (O'Brien/Lyman 2000, 85).

People make choices (cultural, ritual, economic, thermal), they "select the best, the most useful, the most desirable . . . Splendid adaptations to man's desires occur, but they evolve over spans of time that preclude man's ever knowing what the fruits of his selection will be" (Rindos 1984, 4). People make choices about their built environment, which are then translated into built form, but they cannot foresee where those momentary choices will lead them or their built environment. "Large-scale, cumulative results are the end products of countless small-scale changes that took place over a very long time period" (O'Brien/Lyman 2000, 100). Had the architecture at Mohenjo-daro developed into a maximally adjustable architectural type (heavy thermal mass with numerous closable openings), the urban pattern may have taken a different developmental path than the one towards lighter building envelopes. It did not, however, and the trend set in motion by the early conservative building practices persisted.

Two main implications arise from this conclusion. First, the possible post-Harappan transition to mobile structures has a potentially very early causal origin, beginning at least as early as the commencement of the Mature Harappan phase, when the practice of building walls with battered outer faces within the thickness of earlier walls was first established. Secondly, the conventional view of a late Harappan architectural break-down, succeeding years of static, regularly-planned massive architecture, may have been actually less dramatic, more gradual, and occurring over a longer time period than is currently thought. The Harappan move towards nomadic structures was as much a result of a particular construction type and conservative building practices, both established six hundred years before, as it was the result of economic and social breakdown. The trend towards lighter buildings, offering greater thermal choice compared with the thermal homogeneity of the earlier buildings, uncharacteristically greased the wheels of a social shift to a mobile lifestyle, in contrast to the normal behaviour of buildings which is to impede social change due to their inherent inertia: there is less inertia inherent in flimsy construction than there is in massive construction (Fletcher 1995, 18–42).

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