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Mud Bricks and the Process of Construction in the Middle Bronze Age Southern Levant

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This study investigates patterns in the process of construction during a period of urbanization early in the Middle Bronze Age of the southern Levant. Detailing the manufacture and use of sun-dried mud bricks in this period's architecture, this study presents a hypothetical reconstruction of urban building processes based on data collected and analyzed from three case-study sites: Dan, Megiddo, and Pella. A number of important considerations are discussed as part of this reconstruction, such as strategies of brick manufacture, rates of labor, and costs of construction. Straw temper used in brick manufacture is highlighted as a particularly important aspect of the construction process, since it provides a tangible connection between the agricultural system and the mud bricks that form the building blocks of urban architecture. Likewise, the chaîne opértoire *of the construction process links such varied components of urbanization as monumental architecture, rural agriculture, and people, while the analyses and reconstruction presented in this study help render such components perceptible within the archaeological record by looking at issues of specialized production and standardization.*

INTRODUCTION

Urbanism during the Middle Bronze Age in the southern Levant has been discussed in a number of general studies (e.g., Bietak 2002; Bietak ed. 2002; Broshi and Gophna 1986; Cohen 2002; Dever 1985; 1987; 1997; Falconer 1994; 2001; Fritz 1995; Gerstenblith 1983; Greenberg 2002; Herzog 1997; Ilan 1995; Kempinski 1992a; 1992b; Kenyon 1973; Kotter 1986; Maeir 2002; 2010; Magness-Gardiner 1997; Mazar 1990; Oren 1997; Wapnish and Hesse 1988; Yasur-Landau, Cline, and Pierce 2008), many of which employ predominantly descriptive approaches toward the subject of urbanization and the archaeological material. Perhaps the most notable aspect of this period is the marked shift toward monumental construction at new and reoccupied settlements, construction that is characterized particularly by new architectural innovations in fortifications, such as earthen ramparts and multi-entry gates, as well as new strategies for urban planning and settlement expansion. These features occur alongside technological innovations in other aspects of material culture (e.g., ceramics, metallurgy, textiles, stone vessels) within a highly interconnected socioeconomic system fostering specialized production, distribution, and ultimately standardization (cf. Maeir 2010; Uziel 2011).

In the present study, I attempt to conceptualize one aspect of the overall process of urbanization by investigating building methods during this period of social transformation. Some of the organizational processes that are involved in construction may be grounded in the archaeological record by examining manufactured materials used in architecture—namely, sun-dried mud bricks. Mud bricks are one of the most ubiquitous objects encountered in archaeological excavation,

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yet, as commonplace and mundane as they may seem, through their analysis, major patterns in the process of construction can be revealed. This study details practices of mud-brick construction in the Middle Bronze Age and presents a hypothetical reconstruction of this aspect of building within the milieu of urbanization based on data from three case-study sites: Dan, Megiddo, and Pella. By highlighting the crucial role of construction, and especially tracing the *chaîne opértoire* of mud-brick building practices, key organizational mechanisms within the greater process of urbanization can be interpreted, particularly how patterns within architecture may indicate socioeconomic processes otherwise difficult to perceive.

MUD-BRICK CONSTRUCTION

Mud bricks were—quite literally—the building blocks of ancient cities and remain a key archaeological material that may be used to indicate patterns in the construction process. As artifacts, mud bricks contain valuable information regarding their manufacture, and the ways in which they were used in structures reflect choices in construction. A number of general studies have discussed the use of mud bricks in the ancient Near East and provide a basis for further research (e.g., Barrois 1939; Clark and Engelbach 1930; Delougaz 1933; Emery 2009; Glueck 1940; Kemp 2000; McHenry 1984; 1996; Moorey 1994; Nims 1950; Oates 1990; Politis 1999; Reich 1992; Sauvage 1998; Schaub 2007; Spencer 1979). However, only a limited number of studies have undertaken systematic analysis of particular sets of material using scientific techniques in order to identify brick compositions, types, and/or potential sources of material (e.g., Emery and Morgenstein 2007; Love 2012; Morgenstein and Redmount 1998; Nodarou, Frederick, and Hein 2008; Rosen 1986). The following description of mud-brick construction synthesizes the current research with my own study within the specific context of the Bronze Age Levant.

The strength of a mud-brick wall greatly depends on two factors: the quality of the brick manufacture and the expertise of construction. Although mud brick has negligible tensile strength, its compressive (weight-bearing) strength is fully adequate for any ancient building (Wright 1985: 408). The durability of a mud-brick wall depends on its remaining dry throughout; to achieve this, dry bricks must be used during construction and the external faces of the wall must be treated with mud-plaster. Without such precautions, the external exposures of a wall will erode, and cleavage planes may develop as a result of moisture in the core. Also to this end, mud-brick walls in the Bronze Age Levant almost always consisted of a brick superstructure on top of a simple stone foundation, the latter providing stability and preventing erosion from running water and upward (capillary) absorption of moisture into the bricks from ground level.

Mortar is crucial to the structural integrity of a brick wall. If the composition of mortar is stronger than the brick, the brick will tend to break in the setting, but if it is weaker than the brick, then the joints constitute a weakness (Wright 1985: 409). Mortar in the Bronze Age generally consisted of a composition similar to the bricks and was almost always used along horizontal joints (between courses) and sometimes between vertical joints.[1] In order to minimize joint stress, and therefore maximize overall wall strength, bricks were arranged in bonding patterns that staggered the potentially weak joints between bricks along alternating courses, dispersing stress equally through the entire wall (Kemp 2000: 88). Brick bonding techniques in the Levant were basic and variable, usually consisting of a running bond (each course offset by half a brick length) (cf. Spencer 1979: 116). In order to anchor the extremities to the core of a wall, rectangular bricks were often incorporated along the edges, arranged as alternating headers and stretchers in different combinations. On average, the amount of mortar used in Middle Bronze Age walls contributed to ca. 13% of the total volume of the structure, which makes this aspect of construction quite significant. With regard to mortar manufacture, the material may not differ from the bricks whatsoever, being derived from the very same process. In this case, a portion of brick admixture might be reserved for mortar, which would have to be taken, still wet, to the site of building and used immediately. Alternatively, mortar material may derive from recycled occupational debris near the location of building, whereby the individuals laying bricks in a wall would most probably continually mixed fresh mortar as they moved from these easily accessible sediments.

Mud plaster is the final key component to a mud-brick wall. The mud mixture used for plaster can be the same for both bricks and mortar, yet it often con-

[1] Kemp (2000: 92) observes that, at least in Egypt, internal bricks might be laid without any mortar at all within very thick walls. However, laying bricks without mortar within the wall would result in less internal volume, creating a dip in the middle that would place extra stress on all the brick joints throughout the wall.

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sists of slightly finer sediment with fewer inclusions.[2] After the bricks are laid in a wall, and the mortar dries sufficiently, the fresh mixture of mud plaster is spread over the interior and exterior faces of the wall in successive coats. This coating on the surface of walls functions in three major respects: (1) it adheres to the bricks and mortar, which it supplements by binding the bricks together and increasing structural stability; (2) it serves as a barrier to prevent moisture (as well as plants, insects, and animals) from penetrating the wall and causing permanent degradation in the core; and (3) it provides an aesthetically pleasing, smooth surface rather than exposed bricks, which may be mottled, uneven, and irregularly bonded. The coating requires regular maintenance to prevent any damage from occurring to the wall, but as long as a mud-brick wall remains dry and protected from external damage, it might remain standing indefinitely.

The mud-brick construction process, then, comprises multiple related materials used in conjunction to produce standing architecture. Yet it is the bricks themselves that have the greatest potential value for elucidating patterns within the greater construction process. With regard to the following analysis of mud bricks, there are two primary matters to consider: their composition and dimensions. Generally speaking, one would expect mud bricks within a single site to have similar composition, because they were generally made from like materials and are likely to have been made to comparable norms. Likewise, ancient brick-makers presumably cast their bricks using sets of molds that produced similar-sized bricks in order to build walls of regular dimensions; since the same sets of molds presumably produced huge quantities of bricks, cultural horizons of settlements should demonstrate consistent dimensions with limited variability. These assumptions are tested in the brick analysis below.

Brick Composition

The raw sediment used in brick manufacture varies in quality by the amount of sand, silt, clay, organic matter, and carbonates incorporated in it (Rosen 1986: 75). Carbonates serve to harden bricks and may be obtained from ashy occupational material, whereas sand, gravels, and microartifacts (e.g., small pottery sherds, bones) serve as a sort of skeletal frame to which the fine-grained plastics cling (Rosen 1986: 75). Sand also helps to limit the amount of cracking due to both the shrinkage that occurs during initial drying as well as the expansion that results from relative amounts of moisture at other times. Excessive amounts of sand, however, may result in weak, crumbly bricks, as demonstrated by Fathy (1973: 225–26). Clay, the most essential component in sun-dried bricks, makes bricks dense, acts as a binder, and increases resistance to water erosion. Too much clay, however, is detrimental to brick composition, since it may cause them to shrink and crack in the dry heat (Rosen 1986: 76).

Tempering (or stabilizing) materials make the admixture less sticky and more workable during the actual mixing process and, most importantly, vastly improve the tensile strength of bricks.[3] Straw (ancient Egyptian *dḥꜣ*, Arabic *tibn*), and sometimes chaff, has always been the universally preferred type of temper used throughout the Near East; whenever this is not a readily available commodity, alternatives may include chopped grasses or weeds, tree bark, and potsherds (Van Beek and Van Beek 2008: 135). Hillman (1984: 127–28) appropriately distinguishes between various classes of vegetal temper according to their derivation from the process of winnowing and coarse-sieving cereals, highlighting their commonly assigned different uses: (1) “fragmented light straw” (*tibn*) is probably the type of vegetal temper most commonly used in mud bricks; (2) “medium-coarse winnowed straw” (*zerrak*) features more commonly in mud plaster or is used as fuel; and (3) “chaff,” which results from a later step during cereal processing, may be used for bricks or wall plaster. In any case, these fibers serve a number of key functions: (1) they hinder cracking upon drying by distributing tension throughout the bulk of the brick; (2) they accelerate drying by improving outward drainage of moisture to the surface of the brick; (3) they significantly reduce the bulk density of the brick, lightening its weight and reducing its thermal conductivity; and (4) most importantly, they increase the tensile strength of the brick, the lack of which is one of its inherent disadvantages (Houben and Guillaud 1994: 82). The necessity of temper may vary depending on the quality of the sediment, yet straw was almost always used in Middle Bronze bricks in the Levant (cf. Nims 1950: 25–26) and is often apparent from impressions (and phytoliths) left in bricks. Straw

[2] The temper used may also be finer chaff rather than thick straw, and of higher quantities than required in brick and mortar to prevent cracking (Wright 2005: 94).

[3] These stabilizers also bind and chemically strengthen the clay in bricks by adding humic acids (Kemp 2000: 82; Rosen 1986: 76).

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Fig. 1. Depiction of captives making bricks in 18th Dynasty Egypt (Newberry 1900: pl. 21).

would not always be readily available throughout the year, being only widely available following harvest. Therefore, in the Levant, where bricks can only be made in the dry season, the availability of straw creates a notable constraint for the construction process, particularly during major building projects.

Making sun-dried bricks requires some specialized technical knowledge, but any individual in the ancient world would have been roughly familiar with it. Brick-making consists of these basic steps (see fig. 1): (1) clearing a large, open space for the bricks to be dried; (2) finding and digging up appropriate sediment; (3) mixing the sediment with water and tempering material; (4) putting the mud into wooden molds and scraping off the excess; and (5) after a batch of bricks is made, leaving them to dry for about a week, turning them on alternating sides. Fathy (1969: 118) describes allowing the brick admixture to sit for up to 48 hours in order to allow the straw to rot or "ferment," inducing acids that make the bricks stronger and less absorbent than hastily made ones, as well as creating more homogeneity of texture throughout the bricks (cf. Politis 1999).

Where this process takes place basically depends on sediment, water, and open space. Taken together, these three constraints provide a strategic challenge for cost-efficient manufacture of bricks on a large scale. Sediments may have derived from nearby "mud-extraction pits," which are known from Mesopotamia (Old Babylonian *yarrum*), and may be identified by archaeological survey, as argued by Wilkinson (2003: 109–11). However, unlike the natural taphonomy in other regions, the high amount of alluvial aggradation in many of the low-lying areas in the southern Levant during the millennia following the Middle Bronze Age renders pits or depressions such as these undetectable using survey techniques implemented in recent decades. In relatively modern Mesopotamia, brickfields were commonly in, or adjacent to, a cultivated field beside a canal or river (Moorey 1994: 305), and since most Middle Bronze Age sites in the southern Levant were located immediately adjacent to (or incorporated) water sources (Kotter 1986), the manufacture of bricks probably occurred very near the water wherever there was enough free surface area for drying. As such, there would be plenty of water to fulfill the required proportion of about one part water to three parts sediment by volume for the brick admixture (Wright 2005: 107). An additional constraining factor is the time it takes for the bricks to dry properly (see below), and during this period of drying, a brickfield would be unable to produce more bricks until new space became available for drying. In the Levant and northern Mesopotamia, this process would have to be confined to the dry season in order to facilitate the drying of the bricks.

Brick Dimensions

The scope of this paper permits detail concerning only one of many relevant research methods for the present topic. Yet, before proceeding with the analysis of brick composition, a brief summary is in order relative to research on brick dimensions, as this has important implications for patterns of construction. Bricks provide an abundant source of material from which to infer ancient metric practices, since they were manufactured "to fit," being form-molded to particular dimensions in order to be used effectively in walls. While it is methodologically difficult to analyze the available corpus of brick dimensions from disparate excavation reports, which are often poorly contextualized or disproportionately represent the types of bricks at sites, some general patterns permit a few important preliminary observations.

Overall, it appears that bricks in the Bronze Age Levant are larger than those in Egypt and Mesopota-

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mia, suggesting a possible preference for volumetric efficiency; yet this difference may also relate to the availability of appropriate raw materials best suited for ideal brick manufacture. Whereas sediments in Egypt and Mesopotamia tend to have high amounts of clay, and must be greatly tempered by sand and straw, the various sediments throughout the Levant tend to have a more even distribution of particle sizes, making the sediments naturally better suited for brick manufacture with less alteration. The larger a brick is in any way, the greater its own mass undermines its tensile strength; therefore, basic material constraints limit the practical size of bricks manufactured on a large scale. Further constraints to brick size include an optimum weight for transporting bricks, probably with a preference for transporting multiple small ones over a single, less manageable brick, and longer drying time for large bricks.

The bricks found in the Levant occur in both the elongated rectangular form, which is a common Egyptian convention, as well as the square form common in Mesopotamia. However, upon closer examination, Levantine bricks appear to share very little in common with the dimensions of bricks in Egypt, which are smaller and longer than they are wide (cf. Hesse 1970; 1971; Kemp 2000: 84–88; Spencer 1979: 147–48). Levantine bricks have slightly more in common with Mesopotamian bricks (cf. Powell 1982; Robson 1999: 58–67), but they are thicker, and major differences clearly exist between the properties and manufacture of sun-dried versus kiln-fired bricks.

The database of mud-brick dimensions I have compiled draws mainly from numerous excavation reports and some personal observation. Altogether, the database represents more than 150 instances of brick dimensions from across the Levant, and levels of assessment include a diachronic comparison between the Early and Middle Bronze Age, as well as regional comparisons, such as between the north and south. The results indicate there was more consistency among dimensions in the Middle than the Early Bronze Age in terms of both general dimensions and proportions of mud bricks. Frequencies also suggest that in the Bronze Age, there existed roughly standard units of the "common" (ca. 50 cm) and "short" (ca. 40 cm) cubit, as well as something akin to the "foot" (ca. 33 cm) and subdivisions of "palms" (ca. 11 cm) (cf. Wright 1985: 118–20). All of these units are more frequent in the Middle than the Early Bronze Age, as are square bricks.

The fact that the Middle Bronze Age Levant had more consistent brick dimensions and proportional ratios than the Early Bronze Age Levant implies a higher degree of organization and standardization at work during our period of interest, which may be deeply rooted in the impetus and nature of urbanization. Also, since the Levant demonstrates norms differing from those of neighboring regions, it would seem unlikely that urbanization—or at least urban architectural innovation—during this period necessarily derived from exogenous sources.

CASE STUDIES

The present analysis uses samples of bricks from architecture at certain case-study sites: Pella, Megiddo, and Dan. These sites were selected as case studies because they represent contemporary and similar settlements located in different, yet comparable subregions in the southern Levant: the central Jordan Valley (Pella), northern Jordan Valley (Dan), and the Jezreel Valley (Megiddo). These sites are also suitable for direct comparison because they contain relatively recent and accessible archaeological exposures of early Middle Bronze Age strata that contain similar types of architecture (i.e., elements of fortification). The sampling strategy involved taking representative samples of characteristic bricks, as well as typical mortars and wall facing (where possible), all from clear in-situ contexts. Samples were described and processed using a number of analytical methods, including grain-size, microartifact, magnetic susceptibility, and loss on ignition. The following brief summary of the case studies attempts to contextualize the samples within each site in order to demonstrate their comparative value.

Pella

Pella (Ṭabaqat Faḥl) is situated ca. 5 km east of the Jordan River in the central Jordan Valley, and comprises the main mound and adjacent Tell Husn. Among the samples of Middle Bronze bricks that were taken from the main site, I discuss bricks from two particular areas (fig. 2) of the University of Sydney excavations (Bourke et al. 1998; 2003; Bourke, Sparks, and Schroder 2006; McLaren 2003). Area XXVIIIC lies on the southern side of the site and consists of a tower system (Tower 1) flanked by city walls. The tower, which measures 8 (east–west) × 12 m (north–south), is preserved to a height of 5 m (43 courses) in the north, with a curtain wall (Wall 9) 2.5–3.0 m wide extending 11 m to the west and another (Wall 10) of the same width extending 16 m to the east (McLaren 2003: 16–18). Samples were taken from a trench excavated

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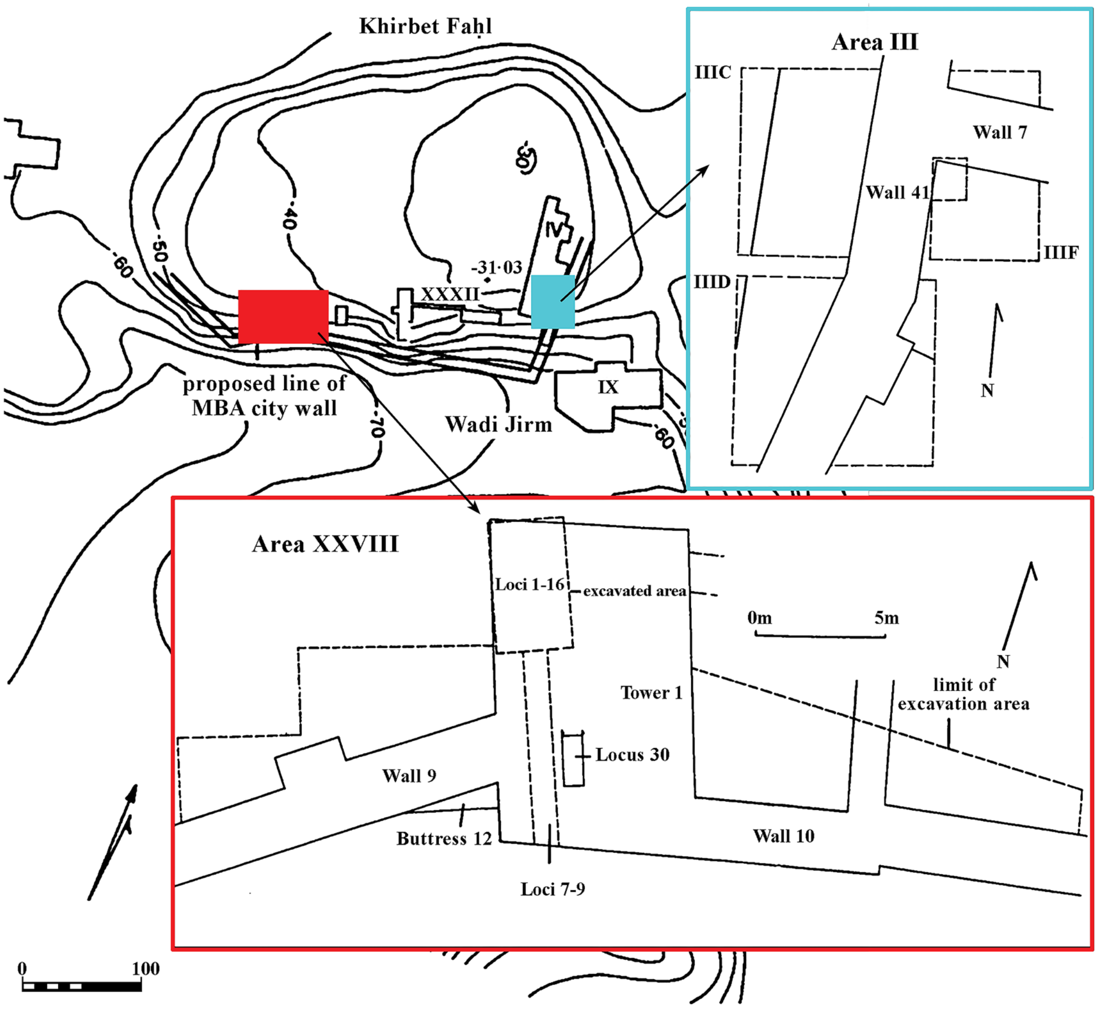

Fig. 2. Site plan of Pella highlighting the Middle Bronze fortifications in Areas III and XXVIIIC (adapted from Bourke et al. 2003: fig. 1; McLaren 2003: figs. 8a, 17). (Courtesy of the Pella Project.)

through the tower (fig. 3), the west exposure of the tower, and the north exposure of Wall 9 (fig. 4). Area III lies on the eastern side of the site and contains another segment of the city wall (Wall 41), which was 3.5 m wide, preserved to a height of 6 m (35 courses), and appears to have been constructed using series of "bands" of the same brick type. Also in Area III is a wall segment (Wall 7) perpendicular to Wall 41 that may reflect either a change in the direction of the city wall or possibly the presence of a gate (McLaren 2003: 14–15). Samples were taken from the lower and upper sections of Wall 41.

Megiddo

Tel Megiddo (fig. 5) is situated along the edge of the Carmel Range at the mouth of Wadi Arah, which connects the Coastal Plain to the Jezreel Valley. Multiple excavations have been carried out on the tell over the course of the 20th century, from which the most relevant Middle Bronze finds have been: (1) the fortifications discovered in Schumacher's trenches along the side of the tell (Schumacher 1908: 23–36); (2) the Oriental Institute of the University of Chicago's Strata XIII and XII in Areas AA, BB, and CC, in which early

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Fig. 3. Locations of samples taken from Tower 1 in Area XXVIIIC at Pella, from the east. (Photograph by the author, with permission from the Pella Project.)

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Fig. 4. Locations of samples taken from Wall 9 in Area XXVIIIC at Pella, from the north. (Photograph by the author, with permission from the Pella Project.)

Middle Bronze fortifications were excavated (Loud 1948); and (3) strata encountered in Areas F, K, J, and M of the current excavations by Tel Aviv University (Finkelstein, Ussishkin, and Halpern 2000; 2006).

The highest-resolution data from Megiddo come from firsthand excavation and detailed sampling in Area K. Situated in the southeast of the site, Area K is oriented above the outer slope of the tell, with the Middle Bronze city wall running along the very edge of the area. To investigate the extent and construction of the Middle Bronze fortifications in the area, the following work has been undertaken in recent seasons: (1) a trench (the "Q 10 Trench") in the northernmost 1.5 m of Square Q 10 was excavated by sequential arbitrary steps (Situations 1–4), cutting a section through the wall; (2) the mud bricks across Square Q 10 were leveled to the same general course in order to gain a clear understanding of the horizontal arrangement of the bricks within the wall (Situation 3); and (3) the Q 10 trench was excavated for a further ca. 60 cm in order to produce a deeper section and in hopes of finding the lowest extent of the wall (Situation 4; fig. 6). Samples were taken from the four successive situations of exposure, and additional samples were taken from the southern section of the Q 10 trench (fig. 7).

In addition to the samples taken from Area K, samples were also taken from in-situ mud bricks still exposed in the University of Chicago's Area AA (fig. 8). The three types of early Middle Bronze architecture to which these bricks belong are from Stratum XIII: (1) the city gate, (2) the city wall, and (3) a domestic wall.

Dan

Tel Dan (ancient *Laish*) is located in the Hula Valley near the base of Mount Hermon and at the head of tributaries feeding the Jordan River. Excavations by Hebrew Union College (Biran 1984; 1990; 1994; Biran, Ilan, and Greenberg 1996) encountered Middle Bronze architecture at multiple points along the perimeter of the site, mostly comprised of massive earthen ramparts. The so-called Triple-Arched or Canaanite Gate was discovered in Area K on the southeast corner of the site (fig. 9). The entire gate structure measures 15.45 × 13.5 m (preserved as high as 7 m), with an opening flanked by towers on both sides and the double-chambered passage spanned by three radial arches.

Mud-brick samples were taken from multiple exposures of the gate structure (figs. 9–10): (1) the uppermost remaining portion in the north; (2) inside the core of the northern tower; (3) a later addition abutting the south of the structure; (4) inside the core of the southern tower; and (5) external facing preserved

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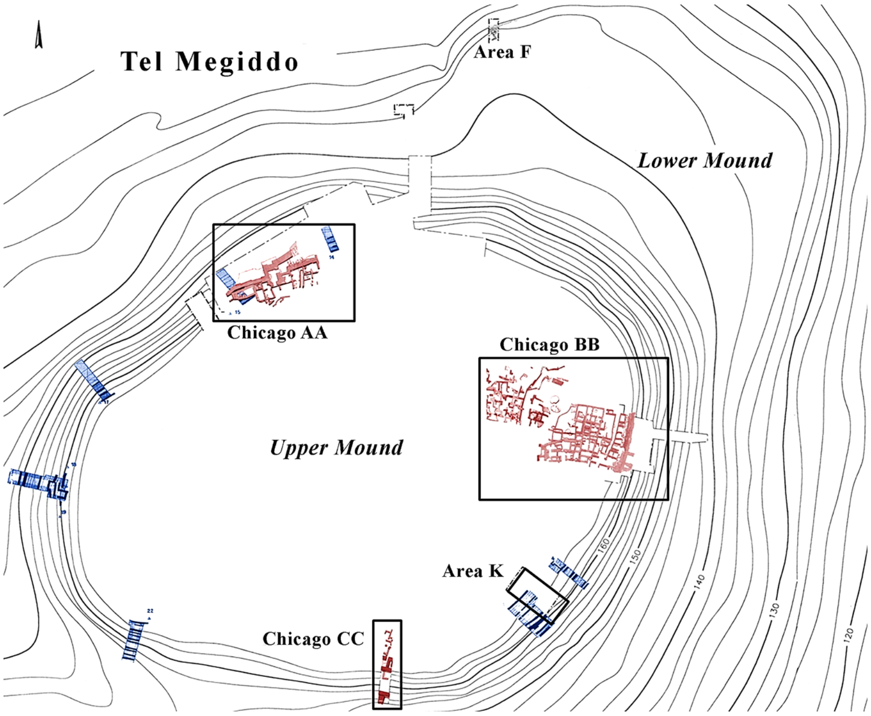

Fig. 5. Topographic map of Tel Megiddo showing areas of excavated MB I (MB IIA) remains (adapted from Loud [1948: figs. 378, 397–98, 407] from the Oriental Institute; Schumacher 1908: Taf. 2).

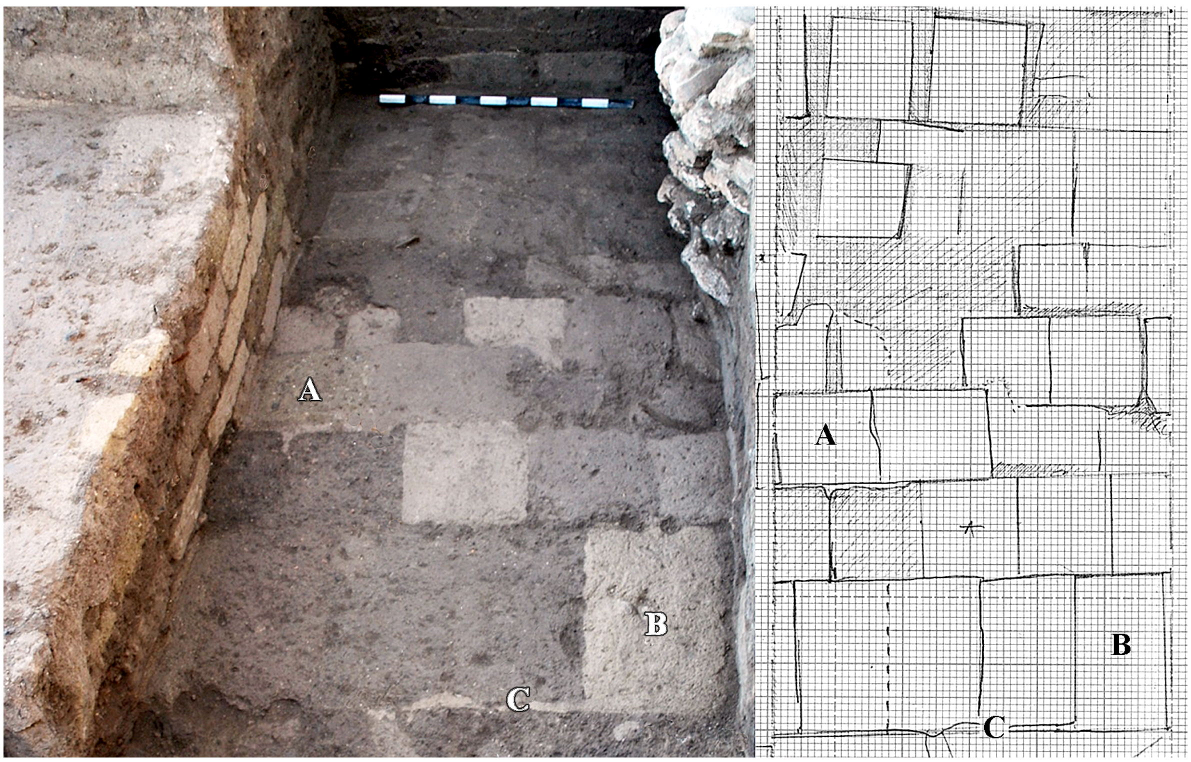

Fig. 6. Photo and plan of Situation 4 of the Q 10 trench at Megiddo, from the east, with sample locations indicated. (Courtesy of The Megiddo Expedition, Tel Aviv University.)

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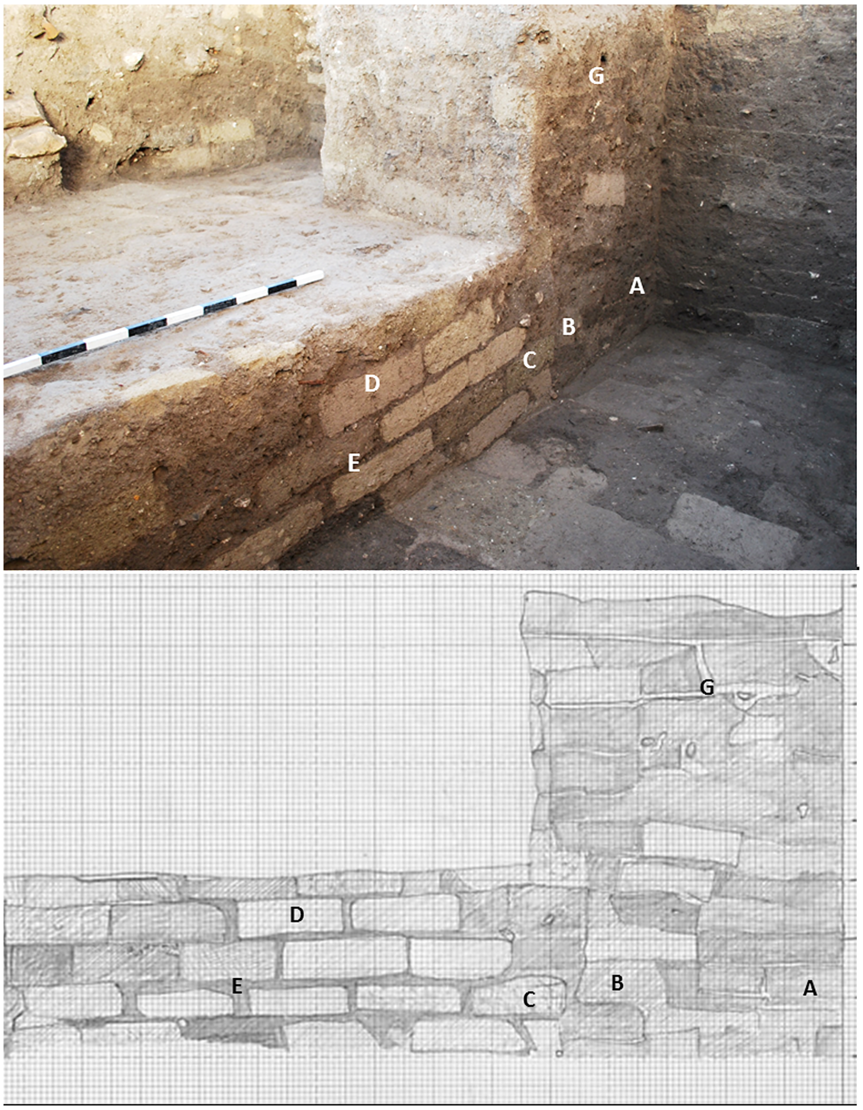

Fig. 7. Photo and plan of the south section of the Q 10 trench at Megiddo, with sample locations indicated. (Courtesy of The Megiddo Expedition, Tel Aviv University.)

just inside the archway. In addition to the gate itself, samples were taken from an earlier Middle Bronze wall that was situated outside the gate and became incorporated within the subsequent earthen rampart.

Results

A comparison of the dimensions of bricks from the case studies shows a few noticeable differences among the three sites. The brick dimensions at Pella are consistently ca. 38 × 38 × 10.5 cm, with very little deviation. The square bricks at Megiddo lie within a generally consistent range of 35 × 35 × 11 cm but with a greater standard deviation than those at Pella. There is also a higher frequency of rectangular bricks, which were typically used as headers/stretchers along the face of the wall. The bricks at Dan tend to be ca. 40 cm in length and 13 cm in height but seem to vary considerably in a range from square and nearly square to rectangular stretchers ca. 53 × 40 cm. The consistency of brick dimensions at Pella suggests more standardization than at Megiddo or Dan, with a possible explanation being that brick-makers—no matter how many—used standard-sized brick molds.

The walls at each site contain a variety of brick colors and compositions. Visual distinctions discern-

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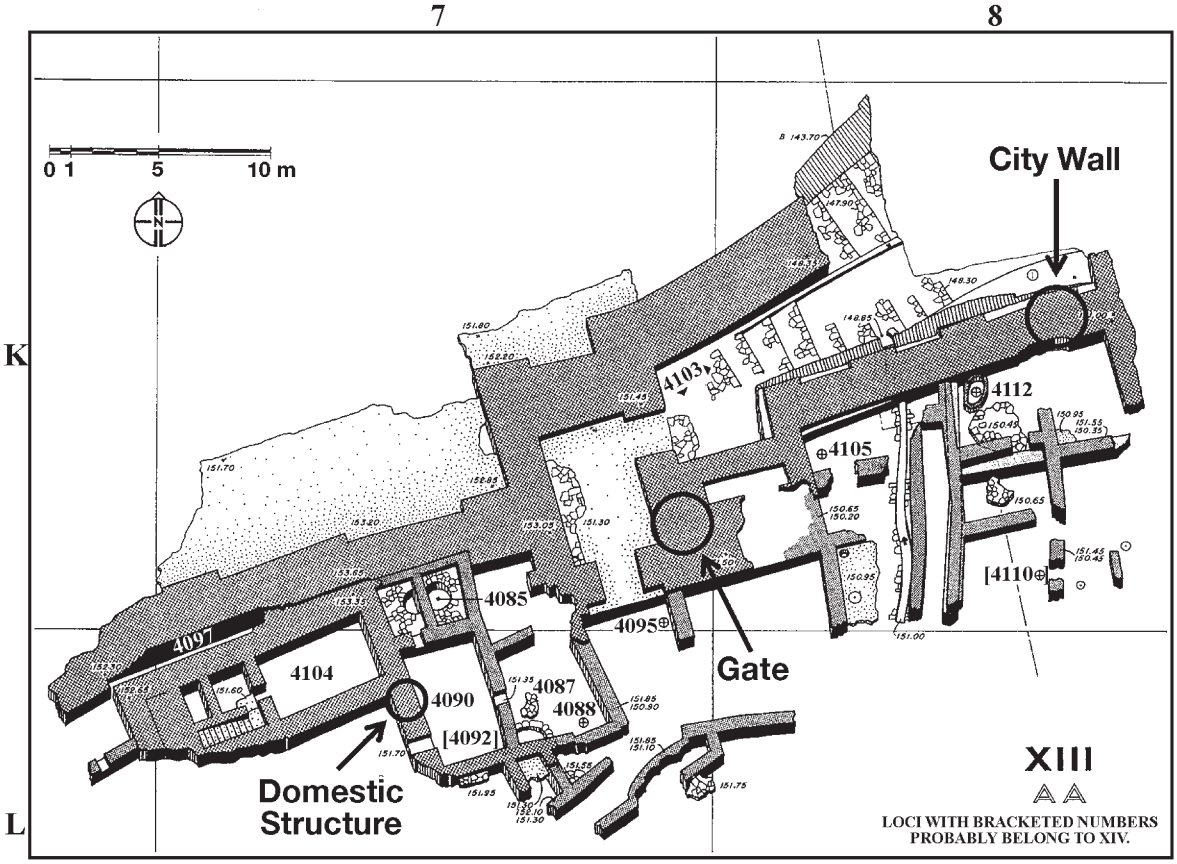

Fig. 8. Sample locations indicated with circles in Chicago Area AA Stratum XIII (adapted from Loud [1948: fig. 378] from the Oriental Institute).

ible by the naked eye fall into categories of light or dark, different hues of color, and soft or hard composition. Using further laboratory analysis, it became possible to discern brick "types" at each case-study site, based on patterns of composition (figs. 11–13). For convenience, each brick type has been subgrouped and classified according to a color, which derives from correlations between the patterns in composition and dry Munsell colors of the samples (table 1).

Pella's bricks come in four different types: (1) Light A (pale brown; 10YR 7/3–8/2), (2) Light B (pink; 7.5YR 7/2–7/3), (3) Light C (yellowish brown; 2.5Y 6/3–7/3), and (4) Dark (brown; 10YR 4/4–6/4). Overall, the grain-size composition of bricks indicates a great degree of consistency (fig. 11). Dark bricks have higher magnetic susceptibility, anthropogenic microartifacts, and sand, but less silt than their lighter counterparts. The mortars at Pella are Dark-colored, sharing the same compositional characteristics as Dark bricks and also tending to have little clay. In at least one wall (Wall 41), there are different bands of bricks of a few courses each. Although the colors of these bands are different, the composition and dimensions of the bricks are essentially identical, as is their mortar, and therefore they are functionally identical in terms of their structural properties.

Megiddo's bricks come in five different types: (1) Light A (pale yellow; 2.5Y 7/3–7/4), (2) Light B (light gray/yellowish brown; 2.5Y 6/3–7/2), (3) Light C (light gray; 10YR 7/2), (4) Light D (very pale brown; 10YR 7/3–8/2), and (5) Dark (brown/gray; 10YR 5/2–6/3). As at Pella, Dark bricks at Megiddo have high magnetic susceptibility and anthropogenic microartifacts, and all samples of mortar are Dark-colored and share the same compositional characteristics as Dark bricks. Unlike at Pella, there seems to be no pattern in the variability of the composition of bricks even among the same courses of the same wall

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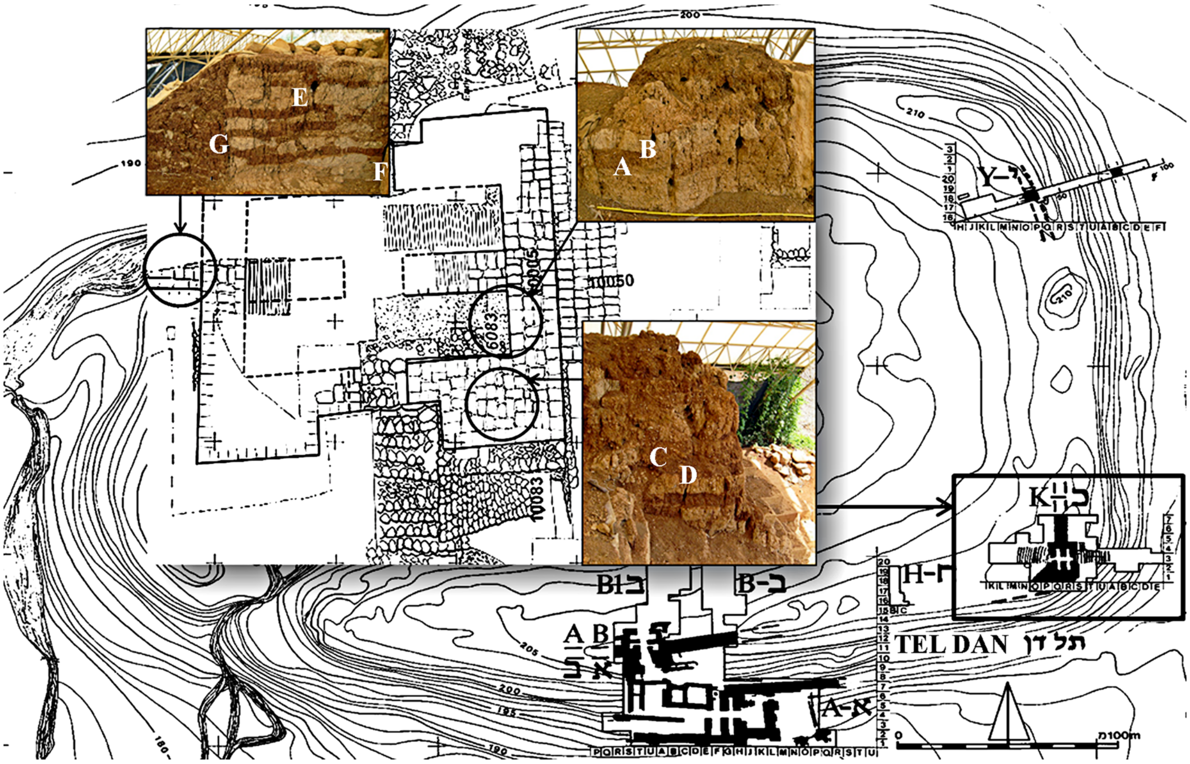

Fig. 9. Plan of Dan with sample locations in Area K indicated (adapted from Biran, Ilan, and Greenberg 1996: plans 1, 10). (Courtesy of David Ilan, Tel Dan Expedition.)

in Area K (fig. 12). Rather than bands or segments of uniform bricks in the walls at Megiddo, there is a general patchwork of many different colors with variable composition within the same courses of walls.

Dan's bricks come in three different types: (1) Light (light brown; 10YR 6/3, 7.5YR 6/4), (2) Medium (strong brown; 7.5YR 5/6), and (3) Dark (red; 5YR 4/6). One main compositional difference is the higher amount of clay in darker versus in lighter bricks (fig. 13).[4] Unlike at Megiddo and Pella, Dark bricks at Dan have low magnetic susceptibility, anthropogenic microartifacts, and sand. The mortar that was used is essentially the same composition as the bricks themselves, and its use appears to be quite variable—in some places, Light mortar is set with Dark bricks, or vice versa, and in other places Dark mortar is used with Dark bricks. Most importantly, there is much less mortar used (regularly) in the gate structure than we see at Megiddo and Pella, and there is no discernible difference in the level of magnetic susceptibility between bricks and mortar at Dan, as there clearly is at the other sites.

Discussion

A few important patterns emerge from these comparisons. The number of brick types at a site and their distribution probably indicate different batches of brick manufacture. Discrepancies among batches of bricks evidently relate to different raw materials and/or proportions of those materials in the admixture for each batch. On the one hand, it is possible that different brick types could be produced by the same brick-maker, or brick-making group, simply representing slight variations in raw materials, proportions, or mixing time/thoroughness among different production batches. On the other hand, such variations may reflect multiple groups of brick-makers, each having its own "recipe" derived from particular materials and mixed according to particular proportions and practice. Therefore, two possible interpretations for the source of different brick types are: (1) each type represents a different batch, or single episode, of manufacture that may always vary to some degree based

[4] A study done by the Getty Conservation Institute (2000: 80–87, 105–6) indicates only two types of bricks in the Dan gate, light and dark, which were low and high in clay content, respectively.

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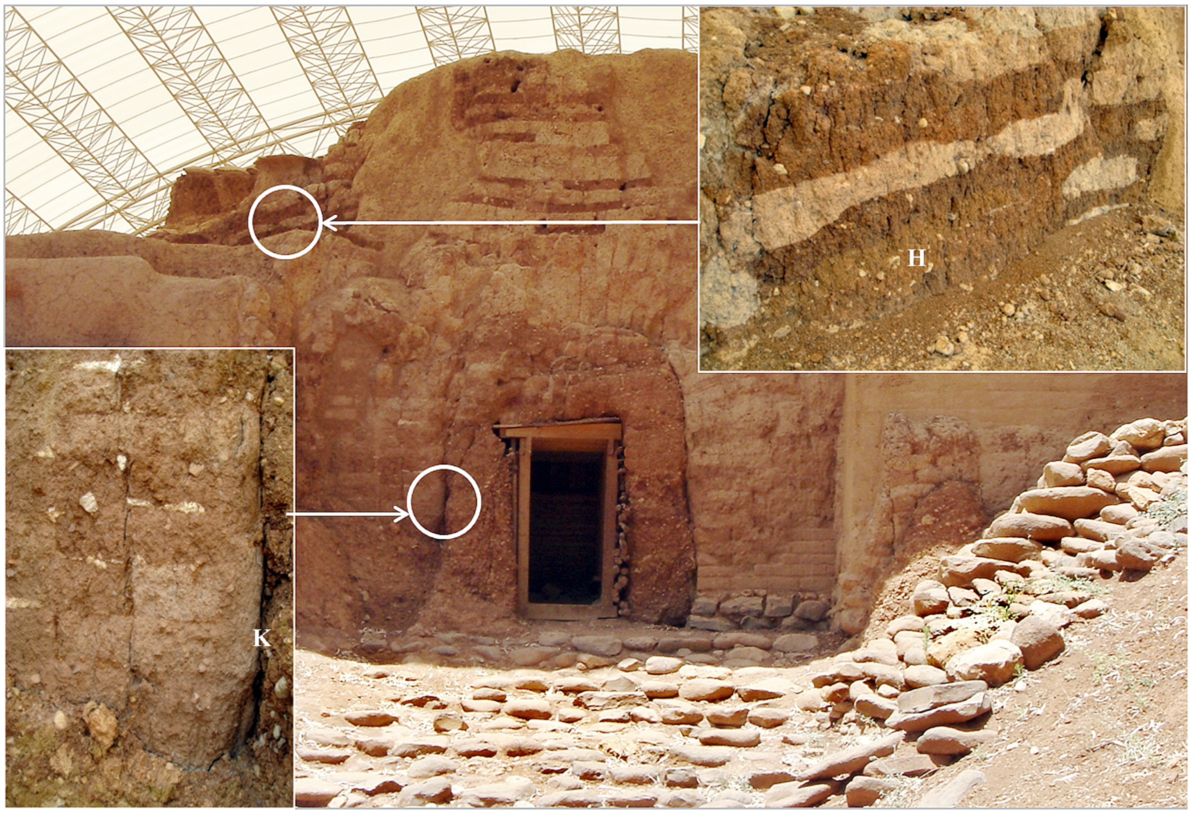

Fig. 10. Eastern exposure of the gate at Dan, with sample locations indicated. (Photograph by the author, with permission of David Ilan, Tel Dan Expedition.)

on discrepancies in ingredients, proportions, or mixing time/thoroughness; or (2) each type represents a manufacture recipe preferred by a brick-maker, and the number of brick types reflects the number of different brick-makers. Of course, these interpretations are not exclusive of one another, and they most likely occurred together.

The bricks at Pella are very uniform, in general, and also segregated by type rather than mixed at random, indicating that segments of walls may have been built with sets of bricks from the same batches. It is important to note that a number of bricks of the same batch (if not all) were used at one time in the same place, rather than being divided and distributed to multiple points around the site. This observation possibly suggests that only one segment of architecture was being constructed at a time, and/or groups of brick-makers were dedicated to specific loci of construction (e.g., a particular portion of the city wall, gate, tower). In contrast with Pella, the bricks at Megiddo and Dan exhibit much more variability within even the same courses of walls. Megiddo demonstrates the most brick types, yet two of the types seem to occur only in the wall in Area K, suggesting that not all brick types were universally available everywhere on-site at any given time during the construction of the fortifications.

There appears to be no structural benefit gained by the distribution of these different types of brick throughout a wall, since different brick compositions will expand and contract at unequal rates, relative to humidity and temperature. Thus, it would be preferable to lay homogeneous bricks within the same courses of walls (as at Pella) in order to prevent deterioration and disaggregation of bricks within the structure; the deterioration of the gate at Dan is a prime example of combining bricks of dissimilar composition.[5] For Megiddo and Dan, it seems likely that the bricks of multiple brick-makers were incorporated at a single time in the process of building. Since the homogeneity

[5] As observed by the Getty Conservation Institute (2000: 32, 87), the lighter mud bricks tended to be used as exterior facing bricks in the construction of the walls, with the dark bricks composing the core. Since these types of bricks were found to have considerably different compositions, including their plasticity index and swelling capacity, rapid changes in temperature and humidity probably caused serious deterioration to the structure, especially the facades.

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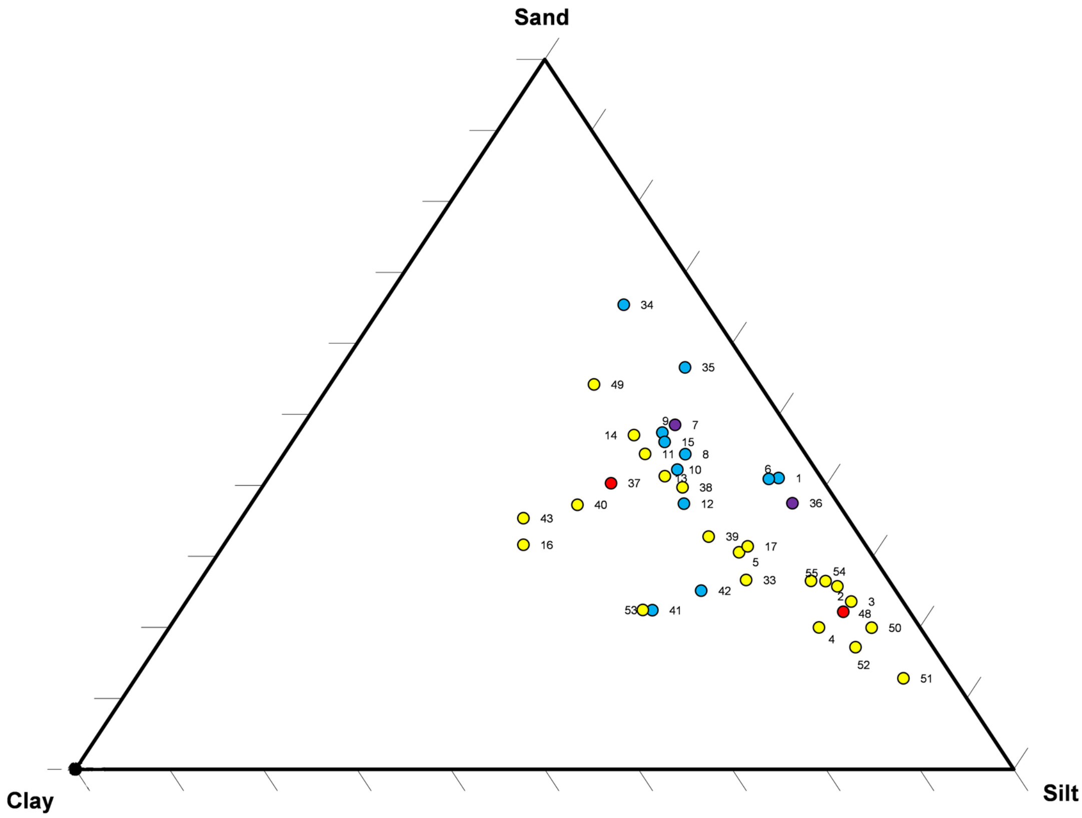

Fig. 11. Ternary graph of bricks at Pella, with brick types distinguished by color (yellow = Light A; red = Light B; purple = Light C; and blue = Dark).

of bricks appears to have been of low priority, a possible scenario for these sites is that walls were built rapidly with whatever variety of bricks were available at a given time. In such a case, many independent groups of brick-makers may have produced an overall high quantity of bricks that were comprised of many batches and brick types. Furthermore, the variability of brick type distribution within the walls at Megiddo and Dan may have resulted from an ad hoc use of all available bricks by the builders. These patterns also appear when correlating the dimensions of bricks at each site: those at Pella are very standardized, whereas there appears to be more variation at Megiddo and Dan. The differences between Pella, on one hand, and Megiddo and Dan, on the other, are probably a matter of the organization of production—that is, the specialized mud-brick production at Pella may be characterized as more attached than at the other two sites, which appear to be more independent (e.g., Costin 1991).

Based on the analyses undertaken, the raw sediment used at all of the sites could have derived from any of the naturally occurring sediments in the proximity of each site. Based on cost efficiency, the most likely sediments would be those nearest the springs adjacent to (or incorporated within) the sites, where there also would have been ample water for the manufacture of the bricks. Since ancient builders were probably inclined to conserve cost (i.e., labor) by utilizing the nearest possible resources, sourcing and production would have been as close as possible in order to eliminate the need for excess transportation. Along similar lines, the mortar at both Megiddo and Pella appears to derive from occupational deposits, suggesting that it was sourced and manufactured directly on-site. This observation is based on the fact that all the samples of mortar from both sites consistently have higher magnetic susceptibility (derived from pyrotechnic activities) and higher quantities of anthropogenic inclu-

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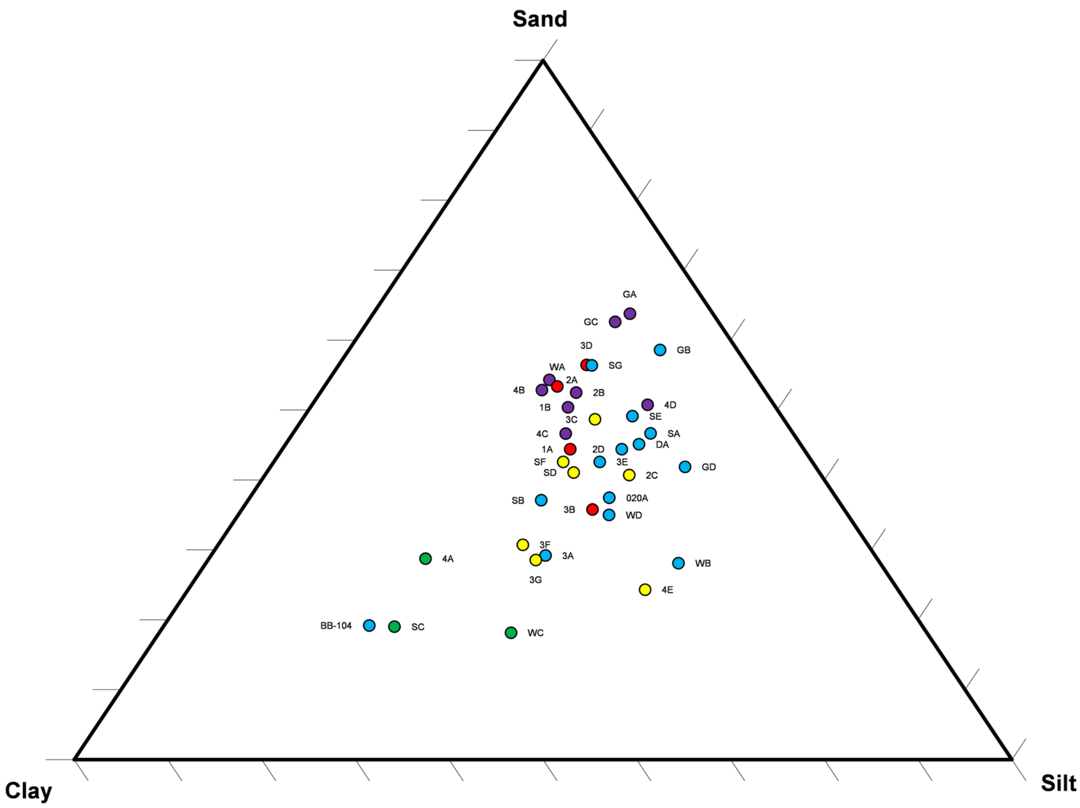

Fig. 12. Ternary graph of bricks at Megiddo, with brick types distinguished by color (purple = Light A; green = Light B; yellow = Light C; red = Light D; and blue = Dark).

sions as compared with the bricks. As Rosen (1986: 84) observes, organic and carbonate residues derived from the breakdown of ash and charcoal from occupation debris can serve as an effective binding agent, especially in lieu of high clay content. The practice of making mortar from recycled occupation material was apparently not implemented at Dan, suggesting the possibility that Megiddo and Pella realized a particular technological innovation that Dan did not, possibly relating to different spheres of sociocultural interaction, with distinct sets of technical conventions.

THE COST OF CONSTRUCTION

In order to take the overall patterns of mud-brick practices a step further toward conceptualizing the greater process of construction, we may attempt to quantify the cost of constructing particular architecture at a given site in terms of (1) the rates of labor and (2) the volume of architecture. By adopting the approach of "architectural energetics" (Abrams 1994; Abrams and Bolland 1999), we may quantify the cost of construction in terms of energy and express it as units of labor. The following rates of labor are quantified in terms of "person-days," which is the amount of work one might expect from an individual during a full workday and according to the dimensions of bricks and type of mortar most frequent at Megiddo and Pella, as guidelines.[6]

[6] Although the length of a workday may be suggested as between five to eight hours, depending on the physical intensity of the work (Abrams 1994: 43; Erasmus 1965), defining a precise workday is less important than approximating the product of the labor, especially in terms of bricks manufactured, transported, and laid.

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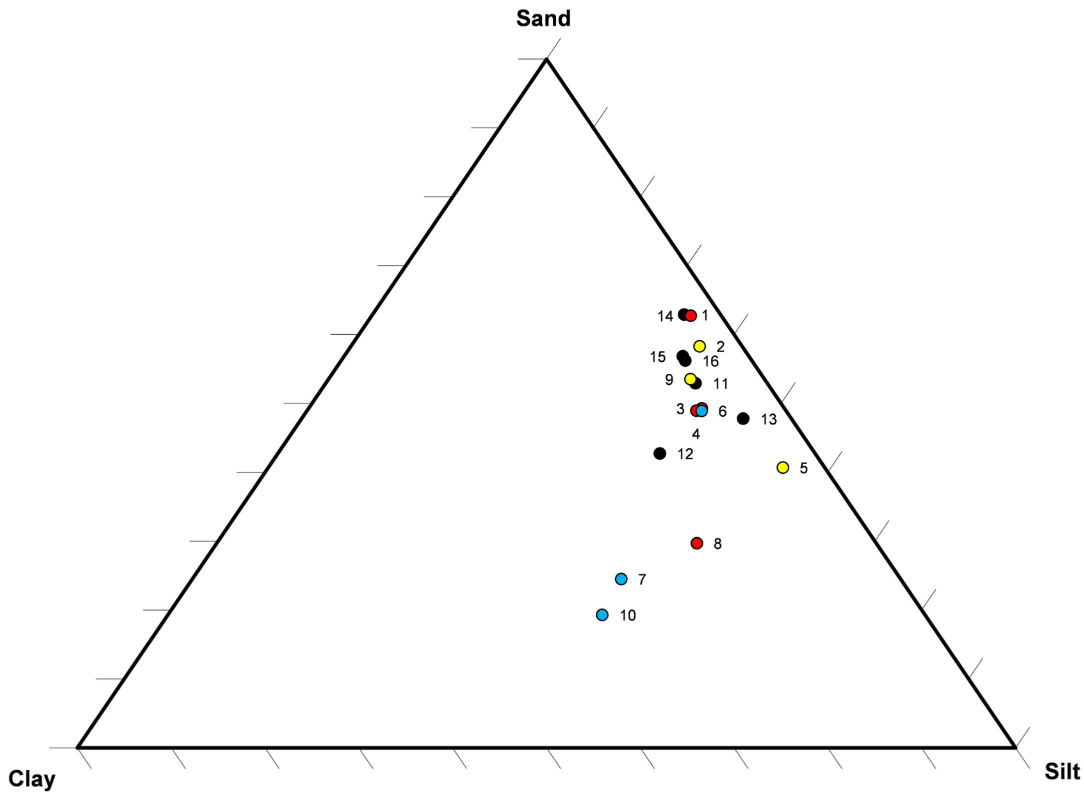

Fig. 13. Ternary graph of bricks at Dan, with brick types distinguished by color (yellow = Light; red = Medium; blue = Dark [black = samples from rampart in Area K]).

Rates of Labor

Situating this study of bricks within the overall process of construction may help identify greater patterns of labor organization and centralization of resources. Building on previous work, such as Burke's (2008: 141–58) study, as well as ethnographic research, experimental archaeology, contemporary Mesopotamian texts, and the patterns derived from the brick analysis, I have ascertained rates of labor for the following specific tasks involved with mud-brick construction (shown in table 2): (1) excavation of sediment, (2) brick manufacture, (3) transportation of bricks, (4) mortar manufacture, and (5) bricklaying.[7] A summary explanation for each of these rates of labor is summarized below.

Excavation. As noted above, the sediment used for mud-brick manufacture would have come from the nearest available source within proximity to both the site and the source of water where the bricks would be manufactured and dried.[8] Erasmus's (1965: 285) experimental research in Mesoamerica concluded that one man could excavate 2.6 m^3 of earth in a five-hour day using wooden tools (cf. Ashbee and Cornwall 1961). Old Babylonian texts demonstrate a practice of calculating labor in person-days based on volume and units of commodities (e.g., bricks); indeed, public

[7] Due to the oversimplicity of these rates of labor, and ignoring less labor-consuming aspects of construction (e.g., plastering walls, roofing, stone foundations), the rates represent minimum estimates for the overall processes.

[8] In the case of earthworks, the majority of the sediment used would most likely have come from the excavation of a fosse at the base of the rampart (Prausnitz 1975: 208).

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TABLE 1. Brick Types by Site and Their Characteristics

Site	*Brick Type*	*Color*	*MagSus*	*OM*	*Micro*	*Sand*	*Silt*	*Clay*
Pella	Light A	Pale brown	L	M	M	L	M/H	M
Pella	Light B	Pink	L	L	L	M/H	L	H
Pella	Light C	Yellowish brown	L	H	M	M	M	L
Pella	Dark	Brown	H	M	H	M/H	M/L	M/L
Megiddo	Light A	Pale yellow	L	L	L	H	L	L
Megiddo	Light B	Light gray/yellowish brown	L	H	M	L	L	H
Megiddo	Light C	Light gray	M	M/H	M	M	M	M
Megiddo	Light D	Very pale brown	L	L	L	H	M/L	M
Megiddo	Dark	Brown/gray	H	M/H	H	M/L	H	M/L
Dan	Light	Light brown	H	L	H	M/H	M	L
Dan	Medium	Strong brown	L	M/H	M	M	M	L
Dan	Dark	Red	M	H	M/L	L	M	H

Note: MagSus = magnetic susceptibility, OM = organic material, Micro = microartifacts, L = low content, M = medium content, H = high content.

TABLE 2. Estimated Rates of Labor

Person-Days	*(per) Particular Task*
1	3 m^3 of sediment excavated
6	1,000 bricks manufactured (mixed and molded)
35	1,000 bricks transported (after being dried)
2	2.24 m^3 of mortar manufactured per 1,000 bricks
2	1,000 bricks (and mortar) laid

labor projects, such as irrigation canals, occurred as "story problems" in mathematical texts (Walters 1970: 119, 148). Mesopotamian texts provide the figure of 10 *gín* (ca. 3 m^3) as the median quantity of earth that an individual laborer was expected to dig in one day of canal excavation (Goetze 1962: 15). Since canal excavation in Mesopotamia bears a considerable similarity to the excavation of sediment in the Levant, the rate of 3 m^3 seems like a very reliable figure (Burke 2008: 144–45). Of course, there are further variables that would greatly affect any rate of excavation—namely, the weight and density of material, and the tools used to excavate it. However, until additional data are available, the rate of 3 m^3 may be assumed as the most reliable figure for the purpose of this study.

Brick-making. Twentieth-century observations of traditional brick-making in the Near East suggest that almost as many as 3,000 mud bricks could be made by a single experienced brick-maker and an assistant in one day (Delougaz 1933: 6–7; Wright 1985: 352; cf. Kemp 2000: 83; McHenry 1984: 67; Norton 1997: 42). However, such observations seem to indicate only the molding of the bricks and do not fully account for excavating sediment, mixing the components, or turning/stacking the bricks during drying. Furthermore, considering the smaller size of modern bricks—only about one-third (or less) of those used in the Bronze Age—such figures considerably overestimate brick numbers. Fathy (1969: 252) provides the figure of 3,000 bricks measuring 23 × 11 × 7 cm being molded in a working day by a four-person team; however, this figure does not reflect acquisition or mixing of materials. A figure of 1,000 bricks per full-time brick-*molder* per day is a more accurate rate for making large Bronze Age bricks (cf. Burke 2008: 145–46), yet this would also require the labor support of five individuals excavating and mixing enough sediment to supply the equivalent volume of ca. 15 m^3 of admixture per day. Therefore, the most efficient energetic cost of manufacturing 1,000 bricks by a brick-making team would actually equate to six person-days, ignoring the negligible amount of labor spent on turning and moving bricks during drying (cf. Heimpel 2009: 224; Houben and Guillaud 1994: 212; Keefe 2005: 64; McHenry 1984: 67; Robson 1999: 75–76; Van Beek and Van Beek 2008: 151). Also, when referring to a *brick-maker*, in terms of the patterns observed from

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the case studies, we should actually think in terms of a group of individuals—a brick-making team—whose cooperative work produces the same bricks.

Brick-drying. An often underemphasized constraint on the rate of brick manufacture is the amount of time needed for drying. It is of utmost importance that bricks dry thoroughly in order to prevent structural weakness in walls. Different estimates suggest drying times of bricks to be anywhere from merely a few days (cf. McHenry 1984: 63) to weeks (Van Beek and Van Beek 2008: 153). For Bronze Age bricks, drying probably took roughly a week at an even rate during the warm dry season in the Levant, with bricks first being dried flat (as they were cast) for three days, turned over for two days, and then stood on alternating ends for an additional two to three days before they could be stacked loosely for use (Nims 1950: 27; Wright 1985: 352). Taking the standard dimensions of bricks from Pella (38 × 38 × 10.5 cm) as a guide, with each brick measuring 0.14 m^2 in surface area (lying flat), and assuming 1,000 bricks were produced in one day, then over 200 m^2 of open surface (a square of 14.5 × 14.5 m) would be needed for the first five days of drying.[9] After these initial days, the bricks would be laid on alternating ends for a few additional days, taking up only ca. 80 m^2 (a square of 9 × 9 m), and eventually loosely stacked. Continuously manufacturing bricks at the rate of 1,000/day in the same area would require a fairly flat surface area of nearly 1,300 m^2 (a square of 36 × 36 m). If 1,000 bricks per day were produced from mid-May through mid-October (ca. 150 days), the total product would number 150,000 each year at a cost of 900 person-days. If the scale of production at a single water source were seven times greater (e.g., 7,000 bricks/day), then an area up to 1 ha would be required for drying. Yet, this seasonal output (1,050,000 bricks) would also require 42 full-time laborers, for a total cost of 6,300 person-days.

Transportation. Since the majority of sediment used as raw material did not require transportation, either for earthworks or mud-brick manufacture, the main commodity needing transportation would have been dry mud bricks. Estimating the weight of dry bricks presents a problem, since they consist of a mixture of sediment and temper. The weight of sediment varies depending on its grain-size composition, density, and level of moisture, yet the dry weight of 1 m^3 of the type of sediment used at our case-study sites would have been at least 1,500 kg (Julien 2010: 325; Finkelstein 1992: 208; cf. 1 ft^3 of solid chalk weighing ca. 50.8 kg: Ashbee and Cornwall 1961: 131). If mud bricks contained only sediment, the weight of each brick would then be at least 22.5 kg; however, the addition of temper not only would have strengthened the bricks but also lowered their bulk density, making them considerably lighter for transport. Van Beek and Van Beek (2008: 260–61) indicate the average density for bricks from Tell Jemmeh (Bronze Age through Hellenistic) at 1.16 oz/in^3 (2.01 g/cm^3), suggesting that the Pella bricks would weigh 30.48 kg. However, according to Old Babylonian sources dealing with construction, the weight of "Type-5" bricks (after Powell 1982), measuring 25.0 × 25.0 × 8.3 cm, was ca. 7.5 kg (Heimpel 2009: 191; cf. Robson 1999: 62–63), which is a density of 1.44 g/cm^3. Following this contemporary example as a guideline, a typical (square, "short cubit") brick from our case-study sites would weigh ca. 22 kg.

Estimating the rate of labor at which bricks could be transported relies on determining the most effective loads an individual can manage over particular distances. Based on Cotterell and Kamminga's (1990: 194) rates for the transportation of loads, the following provides a suitable model for the rate of transport by an adult male: carrying a 60 kg load and returning unloaded for a daily distance of 11 km, at a daily rate of 660 kg/km. At sites such as Megiddo and Pella, where the brick-manufacture sites were probably proximate to the springs adjacent to the tells, the average distance that loads of bricks would have to be transported would be around 800 m, and less at Dan. At the rate of 660 kg/km, if an individual carried three bricks at a time, ca. 66 kg, over a total of 11 km, they would be able to carry up to 13 loads in one day, or 39 bricks. In Old Babylonian mathematical texts, the *nazbalum*, or "carriage," is the well-attested product of bricks that may be carried over a certain distance by an individual laborer. In the case of (sun-dried) bricks, the carriage is 64,800 (in metric terms) for Type-5 bricks (after Heimpel 2009: 191; cf. Robson 1999: 62–63). Therefore, over a distance of 800 m, 81 such bricks—or 607.5 kg—could be carried per person-day, translating to roughly 28 of our bricks. Therefore, transporting 1,000 bricks would cost 35 person-days.[10]

[9] This space allows for 15 cm between bricks to enable turning, walking, and handling the molds. However, since a series of bricks may be cast using one large mold, the spaces on some sides of the bricks could be as narrow as 1–2 cm.

[10] Although there is no evidence for the use of animals to transport bricks, if donkeys were used, then the rate of 9 bricks/load (ca.

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Mortar. With regard to mortar manufacture, as noted above, the sediment from which mortar was made at Megiddo and Pella was probably recycled directly from tell deposits near the location of building. The purpose for this source location would likely have been proximity to the place where the mortar would be used immediately, since it needed to remain moderately wet for plasticity. The individuals laying bricks in a wall most probably continually mixed fresh mortar as they moved from the easily accessible sediments, since it would have been difficult to transport fresh, wet mortar from elsewhere. Mortar could be manufactured on-site, unlike bricks, because (1) the lower volume required less water and chaff, both of which would have to be transported on-site; (2) there was no need for drying space; and (3) the mortar needed to be wet rather than dry. Therefore, since only a small portion of the materials for the admixture had to be transported, the cost of manufacturing mortar was less than that for bricks. The situation at Dan appears to be quite different, since the mortars consist of the same material as the bricks themselves and therefore probably derive from the same manufacturing process, meaning that part of the wet brick admixture was transported to the construction site for use as mortar. Although the difference in cost between the mortar manufacture and transport at Dan versus that at Megiddo and Pella is negligible, it was probably ideal for builders to be able to use fresh mortar as needed when laying bricks; perhaps this is why there was much less mortar used at Dan than at the other sites.

At Megiddo and Pella, the amount of mortar in walls averaged ca. 1 cm on every side of a brick (personal observation). Using the standard brick size at Pella, for every 0.0152 m^3 brick in a wall, there would have been 0.0023 m^3 of mortar, accounting for over 13% of the total volume of a wall (cf. Burke 2008: 146). For every 1,000 bricks (15.2 m^3), 2.24 m^3 of mortar would be required, which could easily be excavated and mixed in one day by one individual, with another transporting water and straw, equaling a cost of two person-days. Finally, bricklaying per 1,000 bricks was probably done by a team of two individuals, possibly with assistance from the mortar-mixer.

Temper. Another important consideration for the cost of brick manufacture is the vast quantity of straw or chaff required. Although, at present, it is not possible to estimate the rates of labor involved in the acquisition and handling of temper, it remains a crucial commodity for the manufacture of bricks. An often-cited example of the amount of temper used in bricks comes from Oates (1990: 389–90), who provides a rough estimate that 100 bricks (of unspecified size) would require ca. 60 kg of chaff, the product of ca. 0.125 ha of barley. Based on these figures, Oates suggests that 1,000 bricks would require the by-product of around 1 ha of agricultural land, as a conservative estimate. Although this estimate provides a helpful beginning point, the amount of chaff suggested is probably excessive, whereas the estimated yield of chaff per hectare is far too low. Other figures for brick manufacture suggest that straw should account for 2.5% of the weight of the mud mixture (Keefe 2005: 58) or a volumetric guideline of three parts sediment to one part straw (Politis 1999), the more the better.

Emery (2011: 2) notes that in Egypt chopped straw was added to the earth mixture in a ratio of roughly one part straw to five parts earth. Furthermore, Emery observes that straw in modern Egypt is sold by the *hamla* or *himl*, a measure of 555 pounds, which is theoretically what a donkey can haul in its baskets (e.g., Fathy 1969: 198–99), and in ancient Egypt, the donkey load for straw was a known measurement expressed as *ꜥꜣt*. In Fathy's construction of the village of New Gourna in Egypt, he followed traditional brick-making techniques, employing a ratio of 45 lbs (20.4 kg) of straw to 1 m^3 of nearby soil and 0.33 m^3 sand, which was mixed with water and left to soak and ferment for 48 hours (1969: 118, 252). Taking the middle ground between Oates and Fathy, we may assume the conservative figure of 40 kg of straw per 1 m^3 of sediment for the manufacture of Bronze Age bricks in the Levant. The bulk density of straw may range between 24 and 111 kg/m^3 (Lam et al. 2008: 356), depending on moisture and other factors, yet a typical density for chopped straw may be 70 kg/m^3 (Food and Agricultural Organization of the United Nations 2004: 25). Therefore, in terms of volume, the ratio of straw to sediment in the manufacture of bricks may have been close to 1:2.

200 kg) for 19 loads over a total of 15 km would equal 171 bricks per day (cf. Cotterell and Kamminga 1990: 194). Thus, the use of donkeys could potentially reduce the person-days significantly, and 1,000 bricks could be transported by six donkeys (operated by perhaps six individuals) in one day. Similarly, carts and sledges were very probably used during this period, yet data regarding the use of such devices during the period are indirect and scant. Therefore, awaiting further research in this regard, I exclude figures for animal transportation (e.g., Littauer and Crouwel 1979), including the use of load-bearing devices, from the suggested reconstruction, and focus solely on the most basic unit of transport—namely. the human laborer.

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TABLE 3. Cost of Construction, in Person-Days, for the City Wall at Pella

Brick Manufacture	*Brick Transport*	*Mortar Manufacture*	*Bricklaying*	*Total*
7,230	28,920	2,410	2,410	40,998

The next question regards how much straw is yielded by cereal crops, indicating how much agricultural land must have been exploited for brick manufacture. In an experimental study on crop growing and irrigation in Jordan, Mithen et al. (2008) provide figures for the amount of straw yielded from common barley and durum wheat based on various percentages of optimal irrigation. The average amount of straw yielded without irrigation was about 4 Mg ha^{-1} (tons per hectare), and an 80% optimal irrigation level yielded about 8 Mg ha^{-1} (Mithen et al. 2008: 17). Although we have no clear information on the harvest indices (the grain yield as a percentage of the total plant weight or biomass of the crop) of cereal crops during this period, based on a number of studies on archaeological grains, Araus, Slafer, and Romagosa (1999: 348) indicate they would have been around 25%. These same authors (1999: 350) suggest that grain yields in the eastern Mediterranean, Mesopotamia, and Egypt during the mid-to-late third millennium B.C.E. could have ranged from 1 to 4 Mg ha^{-1}. Assuming these figures, and implementing a harvest index of 25%, an estimated amount of non-grain biomass—essentially straw and chaff—yielded per hectare of wheat or barley might average about 7.5 Mg. Not all of this harvest by-product would be available for brick-making, since the different types of straw and chaff were also needed for other purposes: weaving, thatching, animal fodder, fuel, ceramic temper, etc.

Since the quantity of bricks required for just the city walls at our case-study sites could number well over one million, the amount of straw used in the brick manufacture would have required the full by-product of roughly 1 km^2 of agricultural land over the course of construction at a single site. The exploitation of this commodity demonstrates a high level of central control, as individuals (e.g., subsistence farmers) would have to be coerced to relinquish straw and chaff they could use for other purposes. From this example, we can see mechanisms of centralization, even in a form as simple as possible straw taxation, and we can also see how the process of construction ties directly into the system of agriculture. Furthermore, since the quantity of temper was a main constraint on the rate of mud-brick production, the more land that could be centrally controlled and managed, the faster a city could be built.

Architectural Energetics

In applying the rates of labor (table 2) to construction, we must estimate the volume of specific architectural structures in order to quantify the energetic output of the project. Estimating the volumes of city walls is difficult, since it is unusual for any architecture to be preserved to its full height, and their dimensions and features tend to vary around the site. Since the walls excavated at Pella were preserved as high as 6 m, and the gate at Dan was preserved as high as 7 m, then a working estimate may be 7 m.[11] Taking Pella as an example, the ca. 3 m wide city wall may have been ca. 1,000 m long and encompassing ca. 8 ha. Therefore, the volume of the wall would have been 21,000 m^3, 1,204,986 bricks (of the standard volume at Pella, 15,162 cm^3), and ca. 2,730 m^3 of mortar. The total cost of constructing this wall would have been tens of thousands of person-days (see table 3).

The size of the labor force and the amount of straw required to build this architecture would depend on the amount of time the planned project would take and vice versa. Construction projects in the Levant most likely took place during the dry summer months (ca. 150 days), which is the only time when bricks could be manufactured on a large scale, due to (1) the availability of straw from spring harvests; (2) the dry heat essential for bricks to dry thoroughly and quickly; and (3) a lull between intensive labor for cereal crops, maximizing the available workforce. According to our estimated figures, the net amount of agricultural land required to produce enough straw for the walls at Pella would have been ca. 112 ha. It is probably unrealistic to assume that all of the by-product of an urban center's agricultural hinterland could be fully utilized for construction purposes, because straw and chaff were required for many other purposes besides the manufacture of bricks. Therefore, two possible options exist for interpreting the size of the agricultural hinterland

[11] Contra Burke (2008: 60, 151), who suggests an average of 10 m.

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TABLE 4. Hypothetical Time-Scales for the Construction of the City Wall at Pella

Seasons	*Bricks/Day*	*Laborers*	*Agricultural Land Required (Net ha)*	*Conjectured Agricultural Land Utilized (Gross ha)*
1	8,033	273	112.0	335
3	2,678	91	37.3	112
5	1,800	55	22.4	67

based on the demands for temper. On one hand, the agricultural land might have been larger than the figure above in order to be both self-sustaining and able to provide all the temper required for urban construction. On the other hand, the demand for agricultural by-product could be minimized by constructing over a number of seasons. I prefer this second interpretation, because it is most likely that large-scale construction projects occurred over multiple seasons due to a number of additional constraints, such as labor and raw materials (see table 4).

This reconstruction accounts only for the simplified fortification wall of a portion of Middle Bronze Pella, excluding such details as earthworks, gates, and towers. Considering other types of public and domestic architecture, not to mention adjacent Tell Husn, these conservative figures could more than triple if reckoned for the entire settlement. Consequently, if we were to rescale the model accordingly, the amount of land area utilized by an urban entity like Pella early in the Middle Bronze Age may have been as much as 3 to 4 km^2. Likewise, the scale of urbanization's impact on the square kilometers of "rural" hinterland around a site becomes clear, thus rendering the urban-rural dichotomy to be an untenable approach toward understanding urbanism. The "urban" entity could not be physically constructed, constituted, or subsequently sustained without the resources (labor and commodities) derived from the "rural" hinterland. Thus, even from the limited perspective of mud-brick construction, it becomes clear that the system of urbanism extended far beyond the walls of an urban settlement and was fundamentally integrated with the agricultural system.

DISCUSSION

Expanding the discussion to a regional perspective, if the case-study sites are representative of urban construction throughout the southern Levant, then it would seem that there were site-specific variations of common mud-brick building practices. On one hand, minor variations in building practices among sites suggest considerable autonomy, particularly with regard to strategies for brick manufacture and the management of labor. On the other hand, the overall similarities suggest a fairly high level of interaction among sites, through which common urban planning, building strategies, and innovations (e.g., earthen ramparts, multi-entry gates, standard units of measurement) must have been shared. Likewise, the architectural similarities demonstrated among sites, and the particular patterns that exist within each site, should be considered in terms of the role of standardization during nascent urbanization in the Middle Bronze Age.

Different degrees of standardization may be observed in (1) the higher frequencies of specific dimensions of Middle Bronze bricks as compared with Early Bronze predecessors; (2) consistency of brick composition and/or dimensions within sites; (3) widths of walls and other dimensions of architecture within sites; and (4) the regularity of these observations at different locations around a site. In the construction process, a high degree of standardization might suggest centralized management of technological issues with building material (e.g., compatibility, interoperability, repeatability, quality) and organization of labor and production. Using our example of mud bricks, different brick-makers would likely have different mental templates for what constitutes an ideal mud brick, resulting in as many idiosyncrasies within a site as there are various groups of brick-makers. In order to achieve the most homogeneity and compatibility across a site, full-time attached "workshops" would be capable of mass-producing bricks with relatively few idiosyncrasies. Under such intense production, specialization and routinization likely played important roles in standardized output, since large quantities of bricks were produced over a short amount of time by the same individuals, who retained mental templates of the composition and dimensions of bricks (cf. Costin 1991; Costin and Hagstrum 1995: 619–20; Eerkens and Bettinger 2001: 500). Deviations from standard norms, distinct patterns of standardization, or overall low degrees of standardization might indicate different "workshops," representing various social entities, in

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turn suggesting various degrees of production intensity or types of organization at play in construction. These issues of standardization, specialization, and the organization of production may be important points of inquiry for discussions regarding Middle Bronze Age urbanization, and merit further research and comparison with other aspects of standardization apparent in the material culture from the period, particularly ceramics (e.g., Maeir 2010: 109).

CONCLUSION

This study has investigated numerous aspects of mud-brick manufacture and use in order to conceptualize a major component of urban construction early in the Middle Bronze Age. The focus of the case studies and reconstruction has been on fortification walls, since they constitute a significant volume of urban architecture and the overall public construction process during this period. By reconstructing the process of building fortification walls and assessing the cost of doing so, we may interpret patterns within the *chaîne opértoire* of mud-brick construction practices, which may be applied to the vast majority of all standing architecture during this and other periods. The usefulness of this particular study is the high resolution offered for understanding patterns in mud-brick building practices based on the case studies. These data contribute toward an archaeologically grounded reconstruction of the process of urban construction which may tentatively be applied to other sites within the region during this period of sociocultural transformation, understood as urbanization. Working backward from the mud bricks ubiquitous in the archaeological record, we may elucidate the agency involved in the process of construction and provide a window into the social complexity producing them.

Connecting the manufacture and use of mud bricks with the cost of construction ultimately comes down to people and resources. Beyond being the physical manifestation of urbanization, construction most probably played a crucial role in the greater socioeconomic processes during this time. Construction appears to have helped facilitate, or at least actualize, key organizational mechanisms that were constituent of urbanization as a whole, such as the mobilization and management of labor and resources. An important phenomenon observed from the process of brick manufacture is the dependence of construction projects on the agricultural segment of society, as exemplified by the vast procurements of temper for bricks and demand for labor. Based on the requirements of temper and for the construction of the physical urban entity, it would seem that every individual within the catchment of a site was probably involved in the process of construction to some degree. Personal investment may have been as little as providing a levee of straw, or as much as being a laborer during portions of the year. The connection between urban monumental architecture, rural agriculture, and actual people may be at least partly perceived through the present investigation of mud-brick architecture, and I suggest this dynamic interdependence is of paramount importance for the success and sustainability of urbanization and the subsequent system of urbanism, which thrived during the Middle Bronze Age.

The method of assessing the cost of construction through architectural energetics should prove useful for other types of architecture besides mud-brick fortification walls, the value of which depends on data relating to building materials, building practices, and rates of labor, which may be greatly aided by future experimental archaeology and material analyses. Furthermore, investigating other forms of architecture, as well as other types of building materials, such as stone and timber, may contribute to the value of this approach. Of great relevance to the present study are the massive earthen ramparts so prevalent during the Middle Bronze Age, which should be reassessed at sites where such features have been sufficiently investigated. All of these factors should be investigated together in order to increase our knowledge of the process of construction and its implications for understanding urbanization. Even the preliminary results from the brick analysis of our case studies suggest that patterns may be interpreted from architecture regarding ancient practices of labor and production, which may have important implications for understanding social, political, and economic organization in ancient society, especially during periods of developing social complexity.

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Wake Forest University
Wellesley College
Wesley Theological Seminary
Willamette University
Yale Divinity School

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