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Shape Reproducibility and architectural symmetry during the Chalcolithic period in the southern Levant

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ABSTRACT

Architecture reflects social aspects of past communities. Structure attributes such as shape, size, building material and decoration, provide valuable information beyond their immediate structural function. However, while attributes such as size can be measured and therefore objectively compared between structures, the comparison of shape between structures is based on subjective observations. In the current study we use two quantification methods for analyzing prehistoric shape-based architectural data: (1) we developed a new method, Shape Reproducibility (SR), based on objective computerized procedure for analyzing the similarity and difference between shapes of ancient buildings; and (2) we use Continuous Symmetry Measure (CSM), a method which was originally developed for analyzing flint artifacts and ceramic vessels to objectively compare between shape symmetry. Applying these methods to settlement data of the Chalcolithic period enables quantification of the level of architectural similarity within and between different sites and their comparison to architectural data of later periods, such as the Early Bronze Age II urban center at Arad. Our CSM results suggest that the symmetry of architecture does not increase through time. Our SR findings demonstrate that in the main cultural Chalcolithic entity, the Ghassulian, the architecture of different sites could not be distinguished from one site to the other. In addition, we demonstrate that the architecture of the Chalcolithic sites in the Golan Heights is homogeneous and significantly differs from other Chalcolithic sites, while Ghassulian intra-site variability is higher. In comparison with Arad, however, this variability is relatively low and limited. These results suggest that status differentiation or hierarchical social organization cannot be indicated from Ghassulian architecture.

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1. Introduction

Building is among the prime activities carried out by humans since earliest times (Bar-Yosef, 1992: 31). Architecture is a visible cultural manifestation that influences social behavior and provides the framework for social interaction and community organization (Byrd, 1994: 643; Ingold, 2000: 175–178; Wilson, 1988: 21). It is also evident that dwellings are subject to spatio-temporal changes (e.g. Flannery, 1972; Goring-Morris and Belfer-Cohen, 2008; Kempinski and Reich, 1992). Different attributes of structure such as shape, size, building material and decoration have significance beyond their immediate function. They provide invaluable information about the social aspects of past societies, as well as evidence concerning modes of adaptation to environments, changes in population size, technology and subsistence economy (e.g. Allison, 2002; Banning, 2010, Banning and Byrd, 1987; Binford, 1990; Carsten and Hugh-Jones, 1995; Flannery, 1972; Hillier and Hanson, 1984; Hodder, 1994; Lévi-Strauss, 1963; Rapoport, 1969, 1982; Wilson, 1988).

The first structures in the southern Levant were made of perishable materials leaving practically no traces, and their existence is inferred on the basis of the spatial distribution of other finds, such as in the case of the Early Epipalaeolithic site of Ohalo II (ca. 21,500–20,500 B.C.) (Bar-Yosef, 1992: 31; Goring-Morris and Belfer-Cohen, 2008: 249–250; Nadel and Werker, 1999). Later on, during Natufian cultural phase (ca. 13,000–9600 B.C.), the existence of post-holes indicates some sort of roofing, as at Ein Gev I and III (Arensburg and Bar-Yosef, 1973; Martin and Bar-Yosef, 1979). In other sites architectural remains consist of several walls made of undressed stones that probably supported wooden poles, or a few freestanding walls, oval or rounded in shape (Valla, 1988). Pre-Pottery Neolithic A (ca. 9600–8500 B.C.) architecture consists

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of oval and subcircular structures that were either freestanding or semi-subterranean (Finlayson et al., 2011a, 2011b; Kuijt and Finlayson, 2009; Kuijt and Goring-Morris, 2002: 373). These structures were made of a stone foundation with mud brick superstructure. Worth mentioning is the large Neolithic tower of Jericho. This unique tower is 8.25 m in height and 8 m in diameter made of undressed stone with a staircase built inside (Kenyon, 1957; Kenyon and Holland, 1981). During the Pre-Pottery Neolithic B period (ca. 8500–6400 B.C.) the transition from oval/rounded to rectangular structures is evident. Constructions during this period were mainly of mudbrick on stone foundations (Banning and Byrd, 1988; Bar-Yosef, 1992; Goring-Morris and Belfer-Cohen, 2003, 2008; Kuijt and Goring-Morris, 2002; Kuijt et al., 2011; Moore, 1985; Rollefson, 1997). Stone and mudbrick rectangular architecture continued well into the Pottery Neolithic (ca. 6400–4500 B.C.) and Chalcolithic (4500–3900 B.C.) periods (Ben-Shlomo and Garfinkel, 2009; Garfinkel and Ben-Shlomo, 2002; Garfinkel et al., 2009; Porath, 1987, 1992). In addition to the rectangular above ground structures, subterranean structures were uncovered in Chalcolithic sites of the northern Negev such as Abu Matar, Bir es-Safadi (Perrot, 1984), and Horvat Beter (Dothan, 1959; Rosen and Eldar, 1993). Preservation of mudbrick walls is poor and in many Chalcolithic sites preserved were only fragments of walls, in many cases without side or parallel walls. Bricks were made by hand, of local silts (Porath, 1992: 44), and after their collapse they disintegrated and could not be distinguished from the natural sediment. Along with other destructive processes, walls are under-represented in comparison to pits and other installations (Gilead, 1995: 30).

Architectural studies are usually based on the analysis of structures at different sites in order to explain the similarity or variability of the shape patterns. In many cases the researchers define a ‘typical’, frequent or ‘average’ house shape that characterizes specific cultures/periods/regions. Such as the Four Room House or the Israelite house during the Iron age (Faust and Bunimovitz, 2003), or later examples such as the Arab-Islamic House (Ron, 1998) or the Black Tent (Manderscheid, 2001). Analyses of architectural shapes are commonly based on the researcher’s skill, intuition, and subjective evaluation which result in biased and sometimes inaccurate conclusions and may lead to equivocal results. Although there are few exceptions (e.g. Dickens, 1977; Fletcher, 1977) most studies of past architectural shapes lacks formal quantitative methods. Below we introduce two methods for objective and accurate quantification for characterizing and comparing between shapes applied here to prehistoric architectural data.

Quantitative analyses of artifact shapes have been carried out for more than half a century (Clarke, 1968: 525–534), and they have increased significantly during recent years (e.g. Durham et al., 1995; Gero and Mazzullo, 1984; Gilboa et al., 2004; Grosman et al., 2011, 2008; Karasik, 2010, Karasik and Smilansky, 2008; 2011; Leese and Main, 1983; Liming et al., 1989; Saragusti et al., 2005, 1998). Such studies are also based on advance computing along with a variety of technologies such as 3D and laser scanning. These studies, however, focus mostly on pottery vessels and lithics, while architectural remains are left behind. These studies have introduced a number of important mathematical methods for quantifying shape attributes such as symmetry, roughness and deformation.

Continuous Symmetry Measure (CSM) is a versatile method which was originally developed to distinguish molecules from each other by their degree of shape chirality (dissymmetry) (Zabrodsky and Avnir, 1995). This tool was first used in archaeology for measuring the degree of symmetry of Lower Paleolithic handaxes (Saragusti et al., 1998). It has been demonstrated that symmetry of handaxes and pottery vessels increases with time (Saragusti et al., 2005, 1998). It should be noted that though there are many aspects of symmetry such as symmetry of rotation, treatable symmetry, etc., the archaeological study of symmetry is usually limited to bilateral symmetry, meaning that the shape does not change upon undergoing a reflection. Bilateral symmetry or reflection symmetry in archaeological studies is referred to simply as “symmetry”.

Symmetry appears in the form of artifacts, buildings and built environments all over the world (Wynn, 2002: 390). Many studies regard the degree and nature of symmetry as cultural attributes or as manifestations of cultural progress (e.g. Bridgeman, 2002; Lycett, 2008; Oakley, 1972; Shennan, 2006; Simao, 2002; Wynn, 1985). Others argue that symmetry is related to the evolution of human cognition (Stout and Chaminade, 2007; Toth, 1990; Wynn, 2002), or link it to functional effectiveness (Jones, 1980; Machin et al., 2007; Mitchell, 1996), to sexual display (Kohn and Mithen, 1999), or to aesthetics (Hodgson, 2011; Schick and Toth, 2001: 282). There are, however, studies that show that symmetry could result from coincidental factors such as type of raw material, resharpening (McPherron, 2000; Nowell, 2000, 2002), or post depositional processes which involve environmental disturbances that damage stone tools (Grosman et al., 2011).

Indeed, symmetrical attribute signaling safer, more effective, and more predictable artifacts or buildings than asymmetrical ones (Liu and Kersten, 2003; van der Helm, 2002; Vetter et al., 1994; Wagemans, 1995). However, unlike earlier periods, when manufacturing of Acheulean handaxes was associated with different hominins, and with butchering effectiveness, during later periods the intentional concern for symmetry seems to be detached from the evolution of cognitive, adaptive or functional factors. Thus, it is reasonable to study architectural symmetrically of later periods – the Chalcolithic and Early Bronze Age periods in our case – which are much too short for evolutionary change, as a manifestation of culture change and variability (Bridgeman, 2002: 403, Hodgson, 2011: 38). Symmetry is a key element in architecture which signals balance, since pressure on a structure or building is distributed equally if there is symmetry. In the study of symmetry of prehistoric flint tools, such as Acheulean handaxes for example, the difference between early, less symmetrical artifacts and later, more symmetrical artifacts, is well established and regarded as an indication of more elaborated production techniques and increased skill (Saragusti et al., 2005, 1998; Wynn, 1985). Studies have shown that manufacturing technique involve social dynamics, and the technical knowledge is directly related to social knowledge (e.g. Dobres, 2010; Dobres and Hoffman, 1994, 1999; Schiffer and Skibo, 1987; Torrence, 1989; van der Leeuw, 1993; Wright, 1993). This is necessarily mediated by culture (Dobres, 2010: 106). In addition a progress in technology is driven by cultural accumulation of knowledge (Bridgeman, 2002; Ingold, 1990, e.g. Schiffer and Skibo, 1987). In studying the symmetry of prehistoric architecture we, therefore, expect that difference between less symmetrical structures and more symmetrical structure might reveal aspects concerning the technology and skills which characterize the societies and their cultural contexts.

Beside the degree of symmetry, studies have shown that the shape itself of a house is determined by social or economic factors (Allison, 2002; Carsten and Hugh-Jones, 1995; Donley, 1982; Hillier and Hanson, 1984; Ingold, 1995, 2000; Kent, 1990b; King, 1980; Lau, 2010; Rapoport, 1969, 1982; Wilson, 1988). Nevertheless, there are others who argue that the main factors are environmental or physical. These factors include: climate (e.g. Correa, 1982; Fitch and Branch, 1960; Givoni, 1969; Herzog, 1980; Mauss and Beauchat, 1979; Sozen and Gedik, 2007); topography or land scarcity (e.g. Alexander, 1964; Sopher, 1964); technology and building materials (e.g. Aalen, 1966; Agorsah, 1985; Laksmi, 2006; Rumana, 2007).

A good archaeological example for the examination of house shape and its possible implication on past societies' social and economic organization can be found in the transition from circular huts to rectangular houses. Flannery (1972) argued that this transition reflects population growth and intensification of production during Pre-Pottery Neolithic times, and the development of privatized storage, which is more effective in rectangular houses (Flannery, 1972: 38–46, 2002: 418–422). Following Wills (1992: 169), who suggests that reduced sharing, more restricted land tenure, and growing privatization of storage greatly increased the economic options of early farmers, Flannery now stresses that archaeologists should expect to find "a lot more variation in house size, house shape, storage facilities…and other features." (Flannery, 2002: 423). On the other hand Saidel (1993) argues that the change from round to rectilinear dwellings indicates social change which results from the "combined effect of anticipated mobility, agriculture and small craft production resulted in an increased mode of production and a change in social organization." (Saidel, 1993: 96). Hunter-Anderson (1977) study sought a functional interpretation to round and rectilinear houses. Accordingly, within round dwellings few of the activities were shared by the group or recognized as a person's identity, meaning there was low level of social or task-role differentiation within such society. While, within rectilinear building the architectural differentiation of internal space have helped coping with the spatial and social problems inherent when multiple contemporary activities needed to be carried out within a single building. The segmentation of internal space and the making of rooms prevented interference and disturbances between contemporary activities (Hunter-Anderson, 1977: 305).

Here, by using CSM, we examine change in symmetry through time. We ask whether symmetry increases in later periods, whether similar levels of symmetry can quantified in different sites of the same cultural entity, in trying to evaluate whether architecture building and planning techniques have been the product of accumulated knowledge over time. By using SR our aim is to examine the variability of architectural shapes within and between settlements in order to illuminate, social, cultural and economic aspects of late prehistoric communities in the southern Levant. More specifically we attempt to determine the socio-economic correlates of the dwellings forms, whether they can be traced in different sites or cultures, and of the degree shape variation within a single cultural entity.

2. Architecture of the Chalcolithic period in the southern Levant

Several cultural entities existed in the southern Levant during the Chalcolithic period, of which the Ghassulian culture (ca. 4500–3900 B.C.) was the most prominent (Gilead, 2011; Lovell, 2001; Rowan and Golden, 2009). The Ghassulian culture features assemblages broadly similar to those found at the upper levels of Teleilat Ghassul, the Ghassulian type-site (North, 1961). This culture extends from the Northern Negev and the Dead Sea basin, to the Shephela, the coastal plain, and the Jordan valley and the Galilee. Other Chalcolithic cultural entities are the Besorian, the Timnian and the Golanian (Epstein, 1998; Gilead, 2011; Rosen, 2011). Since the Timnian architecture is poor and it is geographically limited to the arid zones of the Southern and Central Negev, the Aravah, southern Jordan and Eastern and Southern Sinai (Rosen, 2011), it is not included in our analysis. Also excluded is the Besorian since it predates the Ghassulian (Gilead, 2007) and its architectural remains are meager. The Golanian sites are located in the Golan Heights, and are contemporary with the Ghassulian, but feature a remarkably different and locally manufactured ceramic assemblage (Epstein, 1998). The following analysis will concentrate on Ghassulian (Teleilat Ghassul, Shiqmim, Abu Hamid) and Golanian (Rasam Harbush) architecture (Fig. 1), because they provide relatively well defined architectural remains, that have been frequently studied during recent decades.

The Chalcolithic architectural unit is usually composed of a single room, located on the narrow side of a rectangular or trapezoidal walled courtyard (e.g., Teleilat Ghassul, Fasa'el, Meser, Golan sites). These rooms are rectilinear in shape and often termed "broad-room" or "broad house" (e.g. Gilead, 1988:416, Porath, 1992:41; Rowan and Golden, 2009: 29) indicating that the entrance to these structures was located in one of the long walls. Installations such as hearths and silos are usually located in front of these structures, sometimes enclosed by courtyard walls. The small structures were probably used for sleeping and storage while other daily activities were carried out in the courtyards or adjacent to the dwelling unit. Although structures are variable, neither size differentiation nor size hierarchies are apparent (Gilead, 1988: 417–418). Structures in a site may be organized in different ways (Banning, 2010). In the Chalcolithic, there are sites where the architectural units are clustered, such as in Teleilat Ghassul and Shiqmim. In other sites, such as Gilat (Levy, 2006) or Grar (Gilead, 1995), the units are less clustered. In the Golan sites the structures are arranged in lines, or as labeled by Epstein "house chains"(1998: 6–8).

One of the great challenges of Chalcolithic period research has been to interpret the architectural remains in terms of social and economic organization. Levy (1986a), for one, suggests that "the layout of Shiqmim, for example, may indicate the presence of a single decision maker…" and that "…a similar pattern can be observed at Teleilat Ghassul in the Jordan Valley." (Levy, 1986b: 11). Thus, the "Chalcolithic settlements…are characterized by planned villages" (Levy, 1995: 229), that indicate "…the presence of a central authority" (Levy, 1986a: 88) and "the emergence of a new social organization, the first 'chiefdoms' in Palestine" (Levy, 1995: 238). In addition he suggests that Shiqmim's architecture "preview many of the architectural features that are fully developed at the northern Negev urban site at Arad in the following Early Bronze Age." (Levy and Alon, 1985: 78). Gilead (1988), on the other hand, suggests that "…structures and settlement…were unplanned and there is no clearly observed structural hierarchy" (Gilead, 1988: 418). Epstein (1998: 7), on the basis of her excavations in the Golan, writes that "…none of the [mostly structural] evidence can be interpreted as indicating status differentiation" and that their standardized dwellings indicate that "the community was egalitarian". She also suggests that "the Golan structures resemble those of Teleilat Ghassul" (Epstein, 1977: 58). Porath also notes the similarity between the Chalcolithic domestic architecture at different sites, and states that "their basic plan was similar" (1992: 40). Bourke (2001), based on a close examination of Mallon's Tulayl 1 settlement plan, argues that "there is considerable variation in the size, shape and elaboration of construction in individual dwellings…" (Bourke, 2001: 120) and that the proposition that it may "reflect the development of elite residential complexes…is not unreasonable." (Bourke, 2002: 22). Banning (2010) use space syntax analysis on late Neolithic–Chalcolithic settlements to find "variation in the built environment over this period" which he suggests indicate "political and economic inequalities beyond those determined by gender, age, talent, or ability"… "a degree of socio-economic ranking" (Banning, 2010: 79). Thus there is little agreement on the meaning of structural patterning in this period, at least partially because there is no objective means of analysis and comparison.

The characterization of patterns of settlement layouts, and conclusions concerning their implications, should be treated with reserve mainly due to the fact that most settlement layouts are fragmentary and come only from a small section of the site. This is

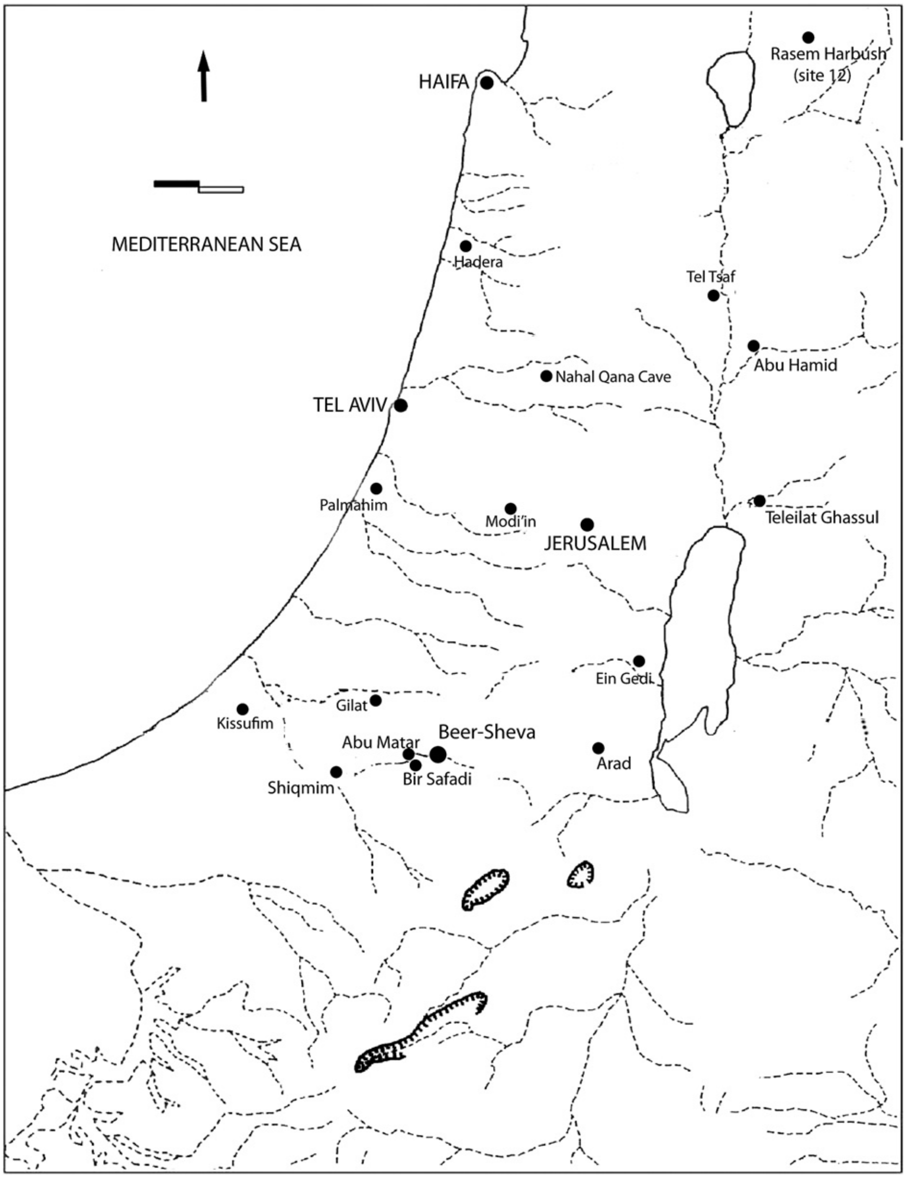

Fig. 1. Map of the southern Levant showing the locations of the studied sites and other Chalcolithic sites.

due mainly to the poor preservation of mudbrick. The probability that smaller and ephemeral sites are underrepresented while large sites may be exceptional rather than typical cannot be excluded. Even when a larger part of sites had been excavated and the architecture is relatively well-preserved (e.g. Teleilat Ghassul – Tulayel 1 and 3 which were excavated between 1929 and 1938), stratigraphic uncertainties and errors are common, and we cannot be sure that all the building attributed to a phase or stratum were contemporary (Banning, 2010: 53–54).

Nevertheless, structures at Teleilat Ghassul are according to Epstein, on the one hand, similar to those of the Golan sites, and thus reflect a society that is undifferentiated in terms of status. According to Levy, on the other hand, Teleilat Ghassul is similar to Shiqmim, and both represent a chiefdom society. Finally, according to Bourke, Teleilat Ghassul demonstrates significant variability which implies a hierarchical society, although not a chiefdom. Here, we present a detailed analysis of the architectural remains which provides additional important information that may illuminate further some of these social and cultural issues.

3. Methodology

The methods used here comprise four elements: (i) data acquisition and digitization of architectural ground-plans from site reports; (ii) application of the Continuous Symmetry Measure method (CSM) to evaluate structures symmetry; (iii) application of Shape Reproducibility (SR) for quantifying the similarly between structure shapes; and (iv) evaluating the results in terms of Chalcolithic period social organization. We use Matlab and Geographic Information System (GIS) platform for these analyses (for previous GIS based analysis on Chalcolithic period dataset see: Fletcher, 2008; Fletcher and Winter, 2008; Fletcher et al., 2008; Pierce, 2006; Winter-Livneh et al., 2010, 2012).

3.1. Dataset

The analysis presented here is based on a sample of 99 structural units, retrieved from four Chalcolithic sites (Teleilat Ghassul, Abu Hamid, Shiqmim, and Rasam Harbush) and one Early Bronze Age site (Arad) which is used here as a comparative dataset (Fig. 1; Table 1). Teleilat Ghassul (Fig. 2a) is located in the southern Jordan Valley, some three kilometers north-east to the Dead Sea and consists of several differentiated hillocks (Tulayl) which cover an area of approximately 25 ha. Each hillock contains a cluster of dwellings which includes a small structured unit located on the narrow side of a walled courtyard. Excavations started in the late 1920s (Mallon et al., 1934), and it has been intensively researched since (see Bourke, 2001: 107–111, 2002: 2–5; Lovell, 2001).

Abu Hamid (Fig. 2b) is located in the central Jordan Valley, 0.5 km east of the Jordan River. The excavations of the site started in 1986 by Dollfus and Kafafi (Dollfus and Kafafi, 1986; Lovell et al., 2007: 51) and three main levels of occupation were unearthed. Phase II is a subject of dispute between Garfinkel (1999: 158) who defines it as Ghassulian, and Lovell *et al.* (Lovell et al., 2007: 63, 74) who suggest it is pre-Ghassulian. Thus, we limit our analysis to the remains of phase III, the undisputed Ghassulian phase at Abu Hamid. The settlement includes rectangular houses, often unicellular, built either completely in mud bricks or in some cases on a stone foundation. The dwellings are separated from each other by large spaces, sometimes delimited by long, stone walls (Lovell et al., 2007: 57).

The northern Negev site of Shiqmim (Fig. 2c), about 18 km south-west of Beer-Sheva, is one of the largest Chalcolithic sites in the area. Seven seasons of excavations directed by Levy and Alon during 1979–1993 uncovered a Chalcolithic village with subterranean structures and a nearby cemetery. The settlement consists of above ground rectangular dwellings structures as well as underground structures in the northern part of the site. The above structures can be divided into two main sizes: small (ca. 2.5 × 5.5 m) and large (5.5 × 10 m). They are built of mud bricks with stone foundation, associated with rectangular courtyards. Small finds within these structures indicate the domestic nature of food preparation and consumption and other activities. Some of the buildings are associated with copper working (Levy, 1987; Levy and Alon, 1982, 1985).

Rasam Harbush, in the Golan Heights, is the largest of a number of Golanian sites (Fig. 2d). The site was excavated by Epstein (1977, 1998) and it consists of rectangular dwellings, built of local stone, attached to rectangular courtyards. The site dwellings are positioned one next to the other from east to west forming together several parallel lines of dwellings which are referred by Epstein as ‘house chains’ (1998: 6–8).

The Early Bronze Age town of Arad (ca. 3000–2650 B.C.) is located in the northern Negev, about 30 km east of Beer-Sheva (Fig. 3). Arad is a large fortified urban settlement that consists of residential units separated by streets and alleys. Dwellings are of many sizes, the smallest ca. 50 sq m and the largest 150 sq m. There are also public structures in Arad, including a water system and a temple complex (Amiran and Ilan, 1996; Ben-Tor, 1973; Herzog, 1980).

The areas covered by the plans do not represent the extension of the entire sites but rather the parts subjected to our analyses. Repeated excavations at Teleilat Ghassul have been largely confined to the hillock known as Tulayl 1 of which some 3,500 m^2 with rich artifactual assemblages and mudbrick architecture were unearthed. In Tulayl 3, two phases of occupation with architectural remains were excavated (Koeppel et al., 1940: Plan I and II). The PBI excavations are of considerable importance and they are a cornerstone in the research of Chalcolithic architecture. However, we excluded Tulayl 3 from our analysis since the stratigraphy of each architectural phase is very problematic, and later expeditions found it difficult to define the stratigraphic horizons clearly (Bourke, 2002: 2–3, 2007). In addition, we excluded architectural elements that are too fragmentary. Only structures that more than 80% of their contours were preserved are included in the dataset.

The digitization process is based on the manually drawn ground-plans published by the excavators. Each ground-plan was scanned (Fig. 5a.i) and transformed into a GIS platform as layers for further modifications. The procedure consists of defining the layout of each illustrated unit (i.e. room). This was done by identifying the corners of the structure with each shape’s points (vertices) (Fig. 5a.ii), and initiating straight line segments between them that form a closed polygonal surface, an accurate presentation of the architectural shape (Fig. 5a.iii). To enable comparisons between the shapes and to avoid size effects, we normalized the original structures sizes into the same equivalent absolute size (Fig. 5b). This was done by dividing each edge length by the square root of the shape’s area.

3.2. *Continuous Symmetry Measure (CSM)*

CSM was first introduced to archaeological research by Saragusti et al. (1998) and is described in detail by Zabrodsky and Avnir (1995). In our study we use this method to measure the distance between locations of points in the original architectural shape and their locations as designated by the nearest mirror-symmetrical shape (bilateral symmetry). These points are the boundary points or vertices that provide and design the shapes’ general boundary line. The number of points is determined according to the nature of the architectural shape providing a small number of vertices which represent the cornerstone locations. Next, we find the reflection line that will cause the minimal move of points to create the nearest mirror symmetrical shape. The line is determined from the averaged sum of each pair of coordinate points. According to this reflection line, each subset of points is duplicated. Redrawing the outlines according to these points, results in a polygon of a mirror-symmetrical shape (Fig. 4). This “folding–unfolding” method (explained in detail by Zabrodsky and Avnir [1995]; and see also Saragusti et al., 1998: Appendix 1) is repeated for each set of two points. The polygon of the mirror-symmetrical shape closest to the original shape is chosen for comparison with the original shape. Symmetry measurement (Saragusti et al., 1998: 819) is defined in Equation (1):

$$S(G) = \sum_{i}^{n} \left\| P_i - \hat{P_i} \right\| \tag{1}$$

Where P_i is the location of the n vertices of the original shape configuration, and $\hat{P_i}$ are the corresponding points in the symmetric configuration. Note that the size is normalized in order

Table 1
The dataset table includes four Chalcolithic sites and one Early Bronze Age II site.

Site	Excavated area size (m^2)	Number of structures	Culture	Date	Period	Reference
Teleilat Ghassul (Tulayl 1)	3500	21	Ghassulian	4500–3900 B.C.	Chalcolithic	Mallon et al., 1934: Fig. 12
Shiqmim	4500	15	Ghassulian	4500–3900 B.C.	Chalcolithic	Levy, 1987: Fig. 6.2
Abu Hamid (phase III)	1350	7	Ghassulian	4500–3900 B.C.	Chalcolithic	Lovell et al., 2007: Fig. 2
Rasam Harbush (Golan site 12)	4500	18	Golanian	4500–3900 B.C.	Chalcolithic	Epstein, 1998: Plan 1a
Arad (strata II-I)	5500	38	Early Bronze II	3000–2650 B.C.	Early Bronze II	Amiran and Ilan, 1996: Plate 70

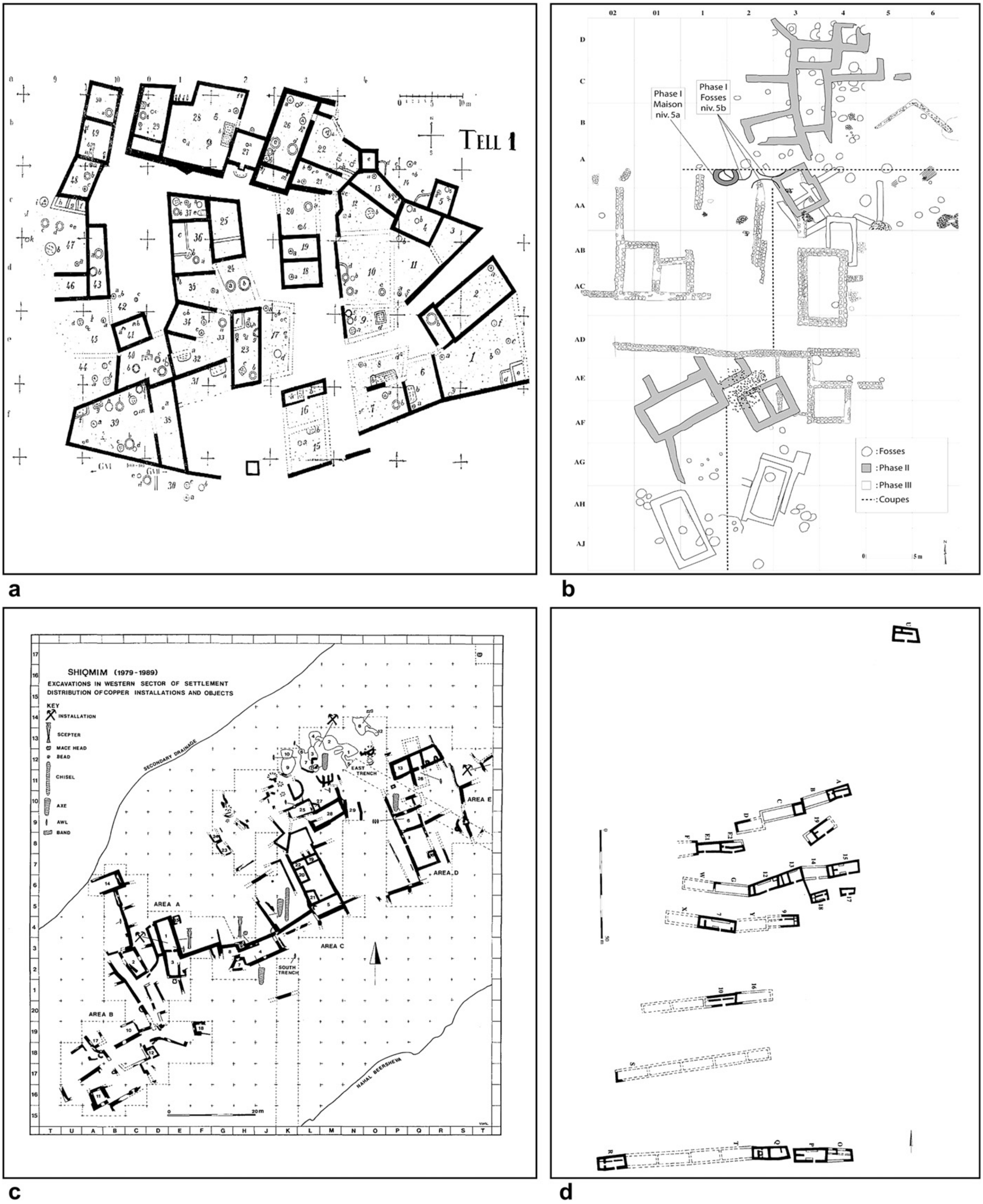

Fig. 2. Sites ground-plans: (a) Teleilat Ghassul (after Mallon et al., 1934: Fig. 12); (b) Abu Hamid (after Lovell et al., 2007: Fig. 2); (c) Shiqmim (after Levy, 1987: Fig. 6.2); (d) Rasam Harbush (Epstein, 1998: Plan 1a).

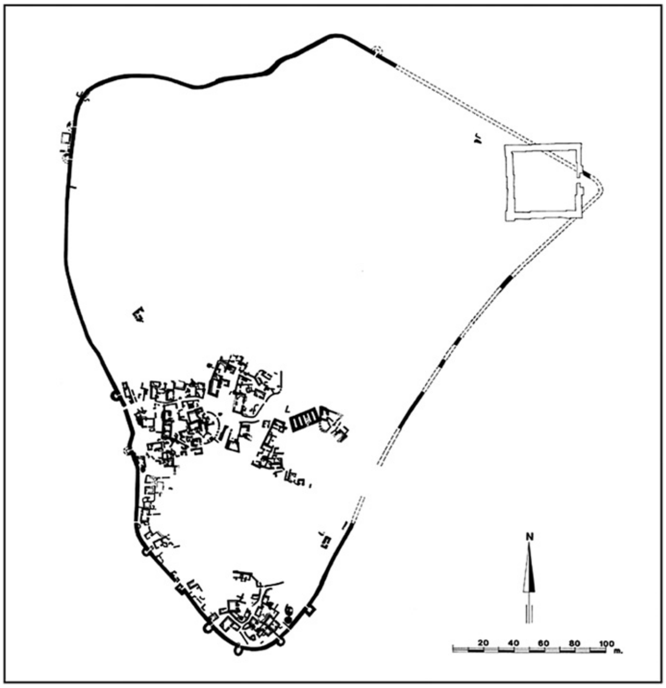

Fig. 3. Arad ground plan (Amiran and Ilan, 1996: Plate 70).

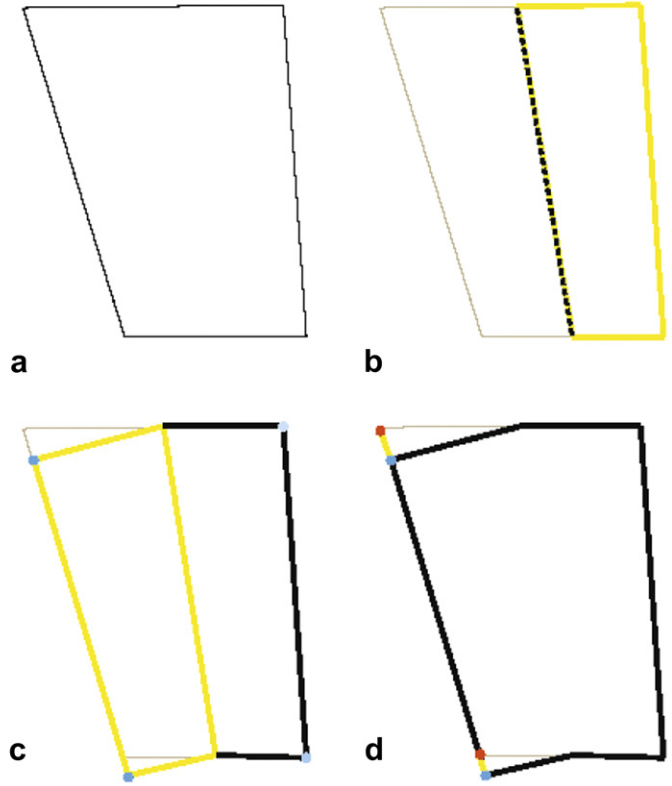

Fig. 4. Continuous Symmetry Measure – "folding–unfolding" of the shapes: (a) The original outline of the shape. (b) Through the center of each pair of points a reflection line (dashed) is positioned and the shape is divided accordingly (yellow). (c) The mirror-symmetrical shape (yellow) produced by redrawing the outline according to the shape's points (blue) and the reflection line. (d) Measuring the distance (yellow) between the original shape vertex coordinates (red) and the mirror-symmetrical shape's vertex coordinates (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

to avoid size difference influencing our results. The resulting $S(G)$ value equals zero if the shape has the desired absolute symmetry, i.e., represents the highest symmetrical quality. The symmetry value, $S(G)$, increases as the shape departs from its nearest symmetric configuration, i.e., is more asymmetrical or indicates a low symmetrical quality.

3.3. *Shape Reproducibility (SR)*

To illuminate aspects such as continuity, repetition or reproducibility, and standardization of building activity, we developed the Shape Reducibility measure (SR) which measures the similarity of architectural shapes within and between different sites. SR measures how much each structure's shape is similar to another shape. The result for each architectural shape is always relative to the shape (structure) it is compared to. A simple way to explain the idea of SR is to describe it as a process in which the original ground-plans of two different structures are normalized and placed one above the other. Then, by rotating one of them, we seek to find the optimal orientation which will provide the largest overlapping area resulting in the smallest residual area. Thus, we can measure these residuals and compare them to residuals of other structures measured in the same technique. The smaller the residual is, the similar the structures are. The important aspect of SR is the ability to measure exactly how much a given shape is similar to another shape rather than describing it in subjective terms. Below we describe each step of the SR methodological process (Fig. 5).

3.3.1. *Normalized area*

The first stage of the process is to normalize the area of all shapes to an equal arbitrary one (Fig. 5b). This stage is critical because it allows direct comparison of structure's shapes with different areas size.

3.3.2. *Central point*

Next, we calculate the central point for each shape. This allows us to position each pair of structures one on top of the other according to their shape centers. This is done while the original orientations of the structures are left unchanged (Fig. 5c).

3.3.3. *Rotation matrix*

Next, one of the shapes is rotated by 5° at a time and the residual area between the two shapes is calculated for all possible orientation from 0° to 360° (Fig. 5d). The turning of the shape by an angle about a fixed point is defined after Arfken (1985: 195) by the rotation matrix in Equation (2):

$$R_\theta = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \tag{2}$$

Where R is the matrix that rotates around a given vector coordinates system by a counter clockwise angle of $-\theta$ relative to a fixed set of axes. When the orientation in which the residual area between the two shapes is the smallest, it is selected to represent the SR value. We repeated this process for all possible pairs of structures units ($n = 99$).

3.3.4. *Similarity matrix*

After collecting SR values for all possible pairs of structures, data were arranged into a similarity matrix (i.e., table) and the values of structures from the same site were clustered together. Similarity matrix is illustrated in Fig. 5e where 0 or blue indicate maximum similarity and 1 or red indicate minimum similarity. This arrangement simplifies the calculation of three different measurements that were used: (i) intra-site similarity – the mean of the similarity indices at the site identity diagonal; (ii) inter-site similarity – the means of the similarity indices that lay outside the site identity diagonal; and (iii) intra-site deviation – to measure whether the intra-site level for each site is lower than the inter-site levels the mean of the intra-site similarity index the intra-site mean of this site was subtracted from its corresponding inter-site mean values. In addition, we classify the structure shapes of the Chalcolithic period in order to locate the most typical or prototype architectural shape among them. This is achieved by calculating the mean of each column of the similarity matrix, which equals the mean similarity of each individual structure with the rest of the structures included in the study. Next, we sort structures by their mean from the one which provided the lowest SR mean value (the most typical structure) to the one which provided the highest SR mean value (the least typical structure). In summary, this new method provides a quantitative and automatic approach that enables this present study, and future research, to objectively and systematically evaluate the similarity of prehistoric architectural shapes within and between sites.

4. Results

CSM mean values of all the studied sites indicate a significant difference between Teleilat Ghassul and the Ghassulian sites of Shiqmim and Abu Hamid (student *t*-test $p < 0.03$) (Fig. 6). Namely, the higher value of CSM of Teleilat Ghassul indicates greater levels of asymmetry than in the other two Ghassulian sites. Similar CSM values have been found between the Golanian site Rasam Harbush and the Ghassulian sites of Shiqmim and Abu Hamid (student *t*-test $p > 0.05$), which indicate similar symmetrical levels to the architecture of sites of different cultural entities. In addition, the results indicate a significant difference between Chalcolithic symmetry values and that of Early Bronze Age Arad (student *t*-test $p < 0.001$), suggesting that the degree of asymmetry in Arad is significantly higher than that of the Chalcolithic sites.

Our intra-site analysis indicate a significant difference between the Ghassulian sites (Teleilat Ghassul, Shiqmim, Abu Hamid) and the Golanian site Rasam Harbush (student *t*-test $p < 0.01$) (Fig. 7). This suggests that the homogeneity of architectural shapes at the Golanian site of Rasam Harbush is significantly higher than that of the Ghassulian sites. Additional significant difference was found between Arad and all Chalcolithic sites (student *t*-test $p < 0.00005$). Even after excluding Rasam Harbush, a significant difference between Arad and the Ghassulian sites was found (student *t*-test $p < 0.003$). This suggests that Ghassulian sites are more homogenous architecturally compared to that of the Early Bronze Age.

Next, we explore the architectural uniqueness of the sites by normalizing their intra-site SR value (discussed above) and comparing it with their inter-site SR values (as described in Fig. 5d). In Fig. 8 the SR mean value of each site is converted to zero (a dashed orange line), while the mean values of its inter-site

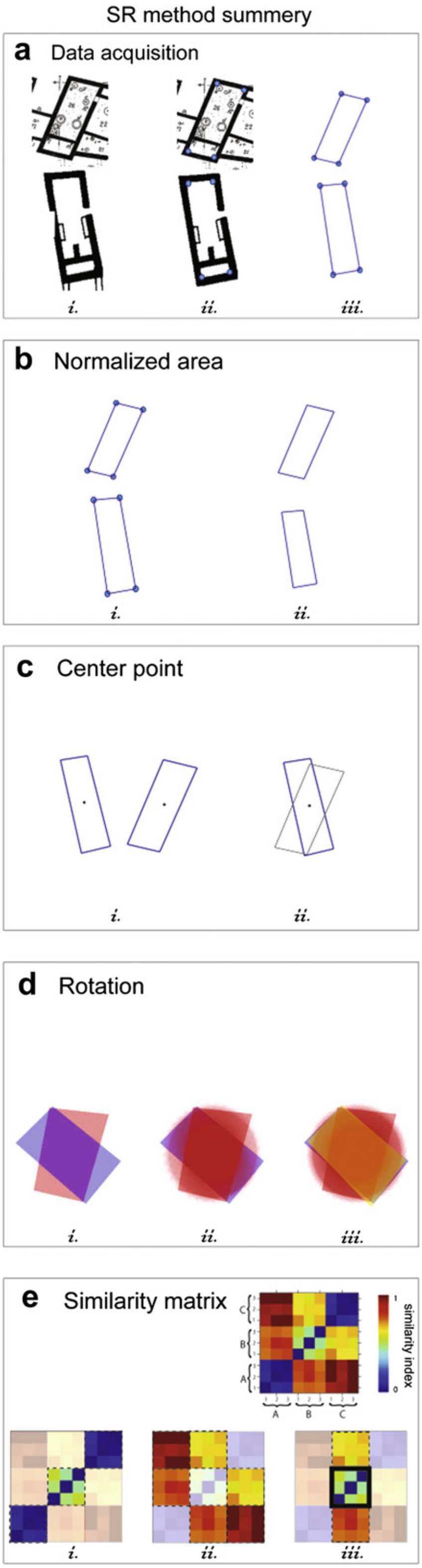

Fig. 5. Shape Reproducibility method summery: (a) Data acquisition process (Teleilat Ghassul on top Rasam Harbush on bottom): (i) scanned illustration of the original published architecture (ii) vertexes (blue) represent the structure shape's corners (iii) closed polygonal surface of the architecture shape based initiating straight line segments between the vertexes; (b) Normalizing of the areas: (i) the structure's shapes polygons in their original size (ii) the polygonal surface after normalizing its size; (c) Center point: (i) calculating the center point for each polygon (ii) placing each pair of structures one on top of the other according to their center points. (d) Rotation process: (i) a pair of structures one (blue) on top of the other (red) according to their center (ii) rotating one of the shapes (red) 5° at a time until completing a full turn (iii) finding the structure orientation (yellow) which provides the smallest remnant areas (=SR value) comparing to all possible orientation. (e) Similarity matrix: the illustration shows the similarity index between all structures at three different sites (A–C). Notice that the values at the diagonal are zero (maximum similarity or similarity between a structure and itself) and that the squares along the diagonal of the similarity within same-site structure are lower than the similarity found in other areas of the matrix, which are between different sites. (i) Calculation of intra-site similarity, based on the mean of the similarity indices at the site identity diagonal; (ii) inter-site similarity, based on the mean of the squares outside the site identity diagonal, and can be used to compare the similarity among multiple sites; (iii) to test whether intra-site similarity is lower than inter-site similarity, the intra-site similarity mean (at the figure mark for site 'B') is subtracted from the corresponding column (the second column at the illustration). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

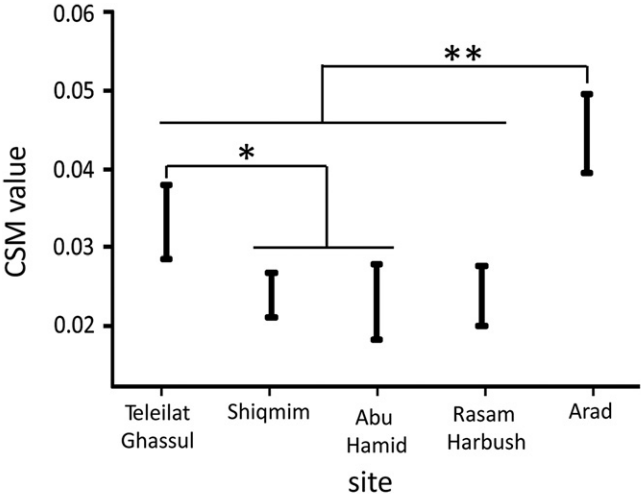

Fig. 6. Continuous Symmetry Measure results: shown are the mean ± s.e.m. of the CSM value of each site (* is for $p < 0.03$, and ** is for $p < 0.001$).

similarity to the remaining sites vary between 0.15 and −0.05 (below or above the site's mean value). Accordingly, sites which are located above the zero line indicate dissimilarity to the specific site while sites located below the zero line indicate similarity to the site. These results display a similar pattern of both higher and lower inter-site SR means for all Ghassulian site. These results indicate that the architectural shapes within these sites cannot be distinguished from one another. But comparing them to Rasam Harbush or Arad indicates they could be distinguished from them.

Rasam Harbush on the other hand displays a different pattern since it consists only of higher inter-site normalized mean values. This indicates that it is different from the other sites, suggesting the architecture here is unique. Comparing Arad with the SR mean values of the Ghassulian sites demonstrates a pattern that is not distinguishable from these sites, excluding Rasam Harbush. That is, if we were to mix the architecture shapes of each Ghassulian site with those of Arad it is highly unlikely that we could distinguish between them, but if we were to mix the Rasam Harbush architectural shapes with those of Arad we could, in high probability, distinguish them.

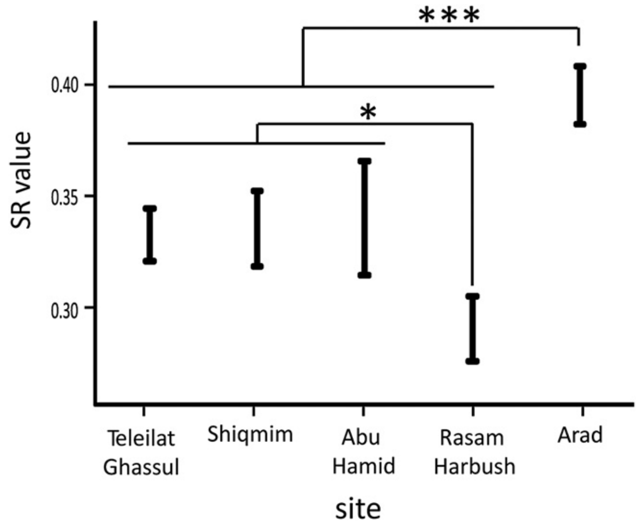

Fig. 7. Shape Reproducibility intra-site results: shown are the mean ± s.e.m. of the SR values within each of the sites (* is for $p < 0.03$ and *** is for $p < 0.00005$).

Fig. 9 illustrates the similarities between the Chalcolithic sites by calculating the mean similarity indices between each pair of sites. The smaller the SR value is, the more it resembles the paired site. These results demonstrate exactly how much the Ghassulian sites Shiqmim, Teleilat Ghassul and Abu Hamid are similar to one another and differ from Rasam Harbush and Arad.

In Fig. 10 the Chalcolithic period architectural shapes are displayed and classified in decreasing order according to their level of similarity with all the rest of the Chalcolithic period structures within our database. The data sample ($n = 61$) includes four Chalcolithic sites. According to this analysis the most typical dwelling shape is found at Teleilat Ghassul: structure 23 depicted in Fig. 12 of Mallon et al. (1934), with a width:length ratio of 1:2.2 (Fig. 10: top left corner). The least typical structure shape, a very narrow rectangle, on the other hand, is found in Rasam Harbush (Epstein 1998: plan 1a, structure 7) with a ratio of 1:4.5 (Fig. 10: rightmost on bottom row).

5. Discussion

We have presented here a new method, Shape Reproducibility, to examine and identify intra- and inter-site similarities of structures on the basis of prehistoric architectural ground-plans. We found that Ghassulian communities built relatively similar structures which could not be distinguished from one site to another. The Golanian community shaped their structures differently, thus producing unique structure shapes which are significantly different from those of the Ghassulian. In addition, we found that the intra-site variability of the architectural shapes of the Ghassulian culture is significantly higher than the intra-site variability level of Golanian culture. However, in comparison with Early Bronze Age Arad, Ghassulian intra-site variability is significantly lower, demonstrating that Chalcolithic architecture is more homogenous than that of the Early Bronze Age. Furthermore, we found that the degree of symmetry in Chalcolithic architecture is higher than in the architecture of the Early Bronze Age.

The CSM results indicate that the symmetry of structures correlates negatively with time (Fig. 6). It seems that the change from Chalcolithic to Early Bronze Age did not necessarily lead to more symmetrical structures. This may be interpreted in different ways. First, the low levels of symmetrical quality observed in Teleilat Ghassul and Arad are not indicative of architectural incompetence or limitations, but that there was probably no particular technological or physical need for higher symmetry when building these structures. Another possibility is that building materials and local environmental variables have influenced the architectural symmetry. The possibility that corralling played a role in a number of the sites (Epstein, 1998: 16–17) cannot be excluded. However, it seems that this role was limited since the remains of human habitations predominate the archaeological record. CSM analysis of architectural remains could be perhaps more effective when applied to longer chronological time spans or to larger geographical areas in order to detect increase in the symmetry. In previous studies, the symmetry of flint artifacts such as Acheulean handaxes, a tool type that was produced during hundreds of thousands of years was examined. It is possible that several hundreds of years are a too short time period to identify a gradual change or increase in the symmetry of prehistoric architecture.

Our SR results demonstrate that the intra-site similarity of the Golanian site of Rasam Harbush is higher than that of the Ghassulian sites (Fig. 7). This finding is in line with previous studies suggesting a high homogeneity level and architectural standardization of the Golanian architecture (Epstein, 1977, 1998). Furthermore, we demonstrate that Golanian architecture consists of unique rectangular proportions which differ from those at the

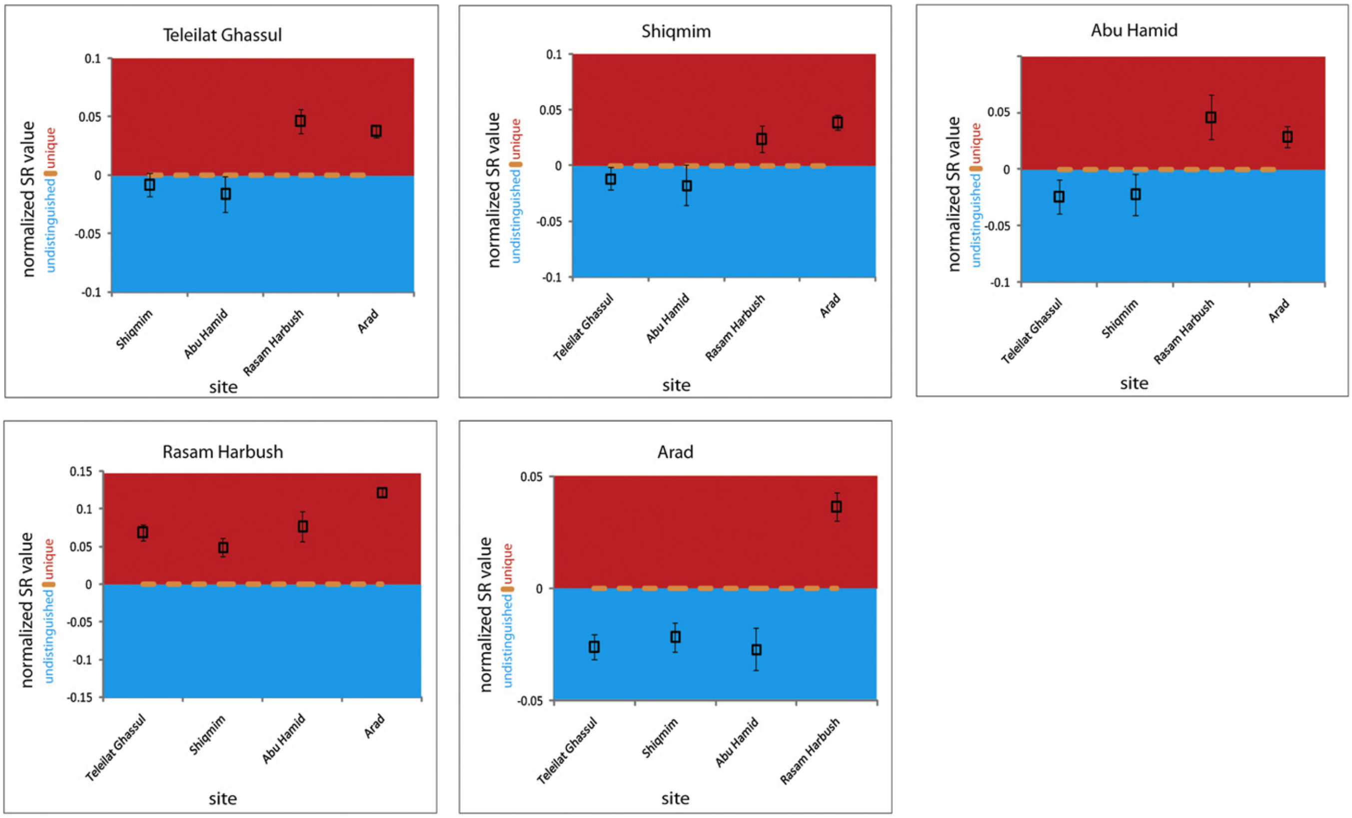

Fig. 8. Shape Reproducibility inter-site results: shown are the normalized mean ± s.e.m. SR values of the intra-site similarity of each site (=0, and marked with dashed orange line) in comparison with its inter-site normalized mean ± s.e.m. SR values. Inter-site mean that is lower than 0 indicate similarity to the site (undistinguished), while a higher than 0 result indicate difference (unique). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

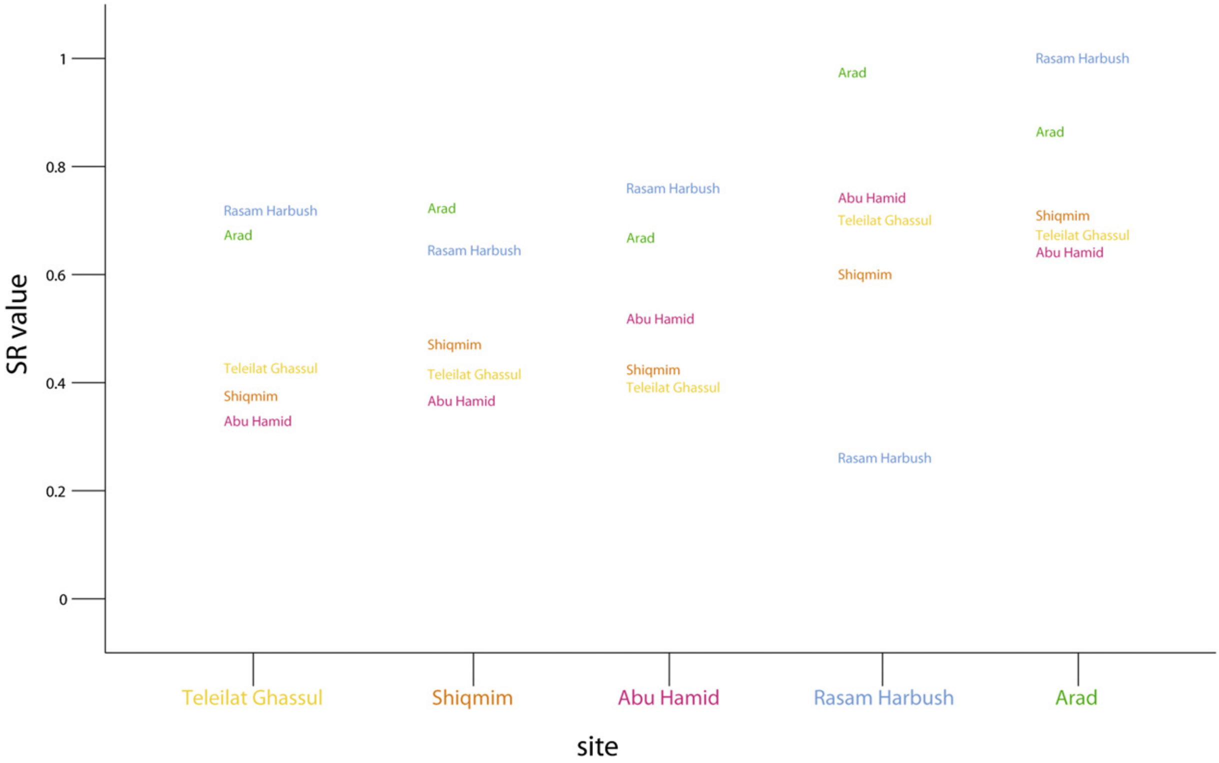

Fig. 9. Shape Reproducibility inter-site results: shown are the normalized mean SR values of each site. The lower the SR value is the more the site resemble to the comparative site.

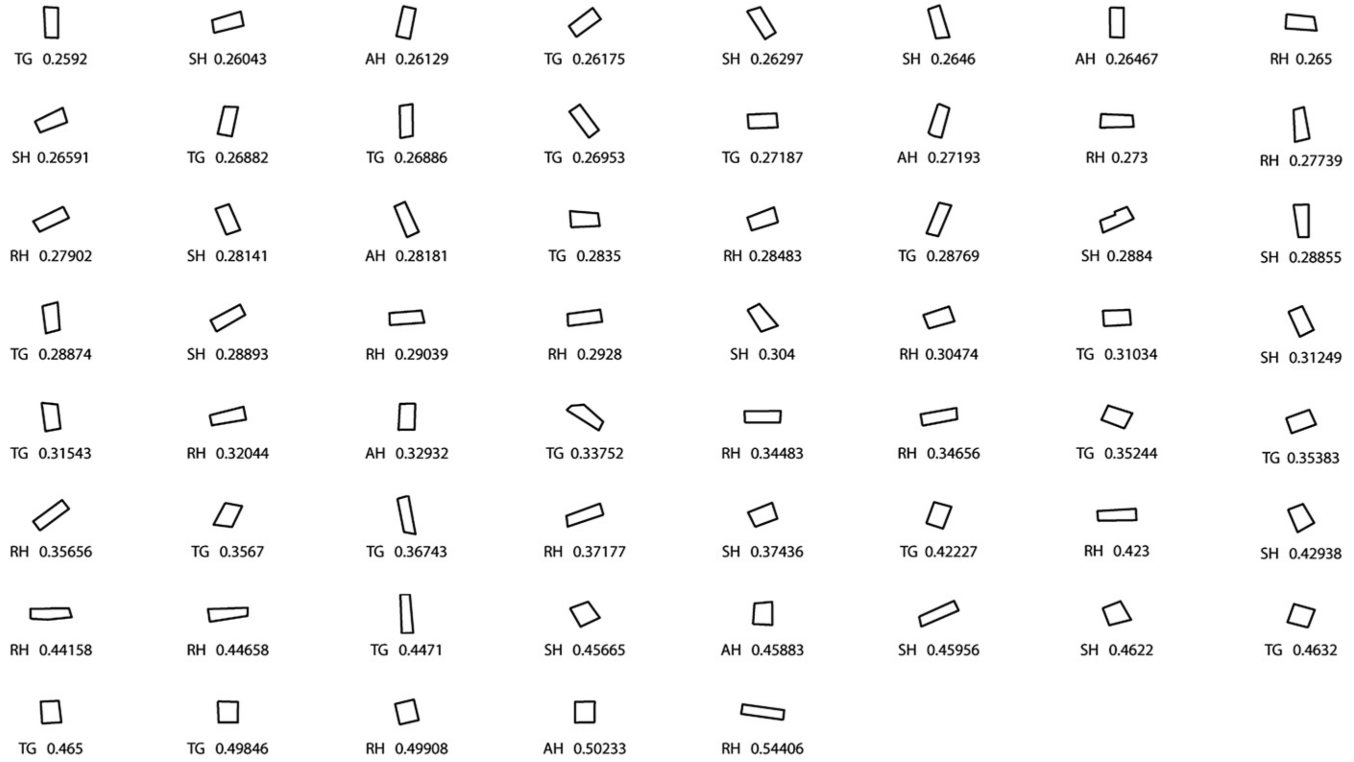

Fig. 10. Classification of the Chalcolithic period structures units according to the similarity of each structure with the rest of the structures. The shapes are organized in a decreasing order starting at the top left with the most typical structure (low SR mean) ending at the bottom right with the least typical structure (high SR mean). The dataset includes structures from Teleilat Ghassul (TG), Shiqmim (SH), Abu Hamid (AH), and Rasam Harbush (RH) ($n = 61$).

other sites (Figs. 8 and 9). Although this was recognized previously and supports the claim that the Golanian differs from the Ghassulian (Epstein, 1998: 334, Gilead, 2011: 15–16), it contradicts the statements that Rasam Harbush dwellings are similar to those found in Teleilat Ghassul (Epstein, 1977; Porath, 1992). Even though Teleilat Ghassul displays a relatively high level of intra-site variability, the SR results indicate that Rasam Harbush architecture is significantly different (student *t*-test $p < 0.03$). The architectural uniqueness of Rasam Harbush might reflect its distinctive and different cultural and socio-economic character.

The Ghassulian sites demonstrate a certain degree of architectural intra-site variation. In addition, inter-site comparisons indicate that Ghassulian architecture, and its intra-site variability levels, are similar in the three sites we studied (Figs. 8 and 9). This intra-site variability level, however, is significantly lower in comparison with the Early Bronze Age site of Arad. These results contradict previous assumptions that Ghassulian architecture consist of considerable variation in shape (Bourke, 2001, 2002; Levy, 1986a, 1995; Levy and Alon, 1985). Nonetheless, the relatively low degree of variability in shapes during the Chalcolithic period implies a similarity that should be explained. One possibility is that this level of similarity could be the outcome of physical or environmental factors such as topography or building material. This, however, is unlikely since the studied settlements here are located within different environments which consist of different topographical conditions and different available local materials. Moreover, based on anthropological studies, although the physical environment could exerts great constraints over the builders and the options they had, it appears that these environmental factors are secondary to the socio-economic ones (Allison, 2002; Ingold, 1995, 2000; King, 1980; Rapoport, 1982). Accordingly, house form is considered a "…direct expression of changing values, images, perception and the ways of life…" (Rapoport, 1969: 12), and is "governed by a society's ideas, its forms of economic and social organization, its distribution of resources and authority, its activities and the beliefs and values which prevail at any one period of time." (King, 1980: 1). The explanation of the similarity level should be, therefore, sought within the social and economic aspects of Chalcolithic communities.

One of the primary interests of the current research in the study of Chalcolithic period is in the organization level of the society. There are researchers who view the archaeological evidence as reflecting social hierarchy (Gal et al., 2011; Golden, 2009; Levy, 1986a, 1995). Bourke (2002) suggests that Chalcolithic site structure reflects variability which can imply the existence of residential elite. Levy (1986a: 88) suggests that Chalcolithic architectural variability implies central authority and a single decision maker. Based on Service (1962) and Fried (1967) anthropological models, he argues that Chalcolithic architecture signifies the appearance of "hereditary chiefdom society" (Levy, 1995: 235). However, the results of our study do not support the idea of hierarchically stratified communities.

Our results indicate that in the case of Early Bronze Age Arad the level of intra-site variability is high and may signify a stratified society. This variability results from the different types of structures, including residential structures and public structures, such as the probable temple complex. Architectural variability of Arad is significantly higher than that of the Ghassulian sites and might suggests that the level of organization in the latter is less complex than currently suggested. There is no significant difference between structure forms which can represent habitations of community members of a distinct social status. In addition, Epstein (1998: 7) suggests that the very standardized Golanian architecture indicate that the structures were built by an egalitarian community.

According to our findings this assertion cannot be excluded. The Golanian site of Rasam Harbush lacks any visible presentation of social differentiation, neither in the architecture nor in other aspects of the material culture. It even suggests that the local community was less differentiated socially than were the other Ghassulian communities.

Architectural variability may imply an increase in socio-economic options (e.g. Flannery, 1972, 2002; Kent, 1990a, 1990b; Rapoport, 1969, 1982; Wilk and Rathje, 1982). Previous studies have emphasized that the Ghassulian subsistence economy witnessed an intensification of agricultural production, greater investment in craft production (in ceramics, flint artifacts, basalt working, and ivory carving) and technological innovations, notably metallurgy (e.g. Gilead, 1988; Golden, 2009; Levy, 1986a; Rowan and Golden, 2009). Moreover, Ghassulian economy is also linked to an increase in storage (Bourke, 2002; Golden, 2009; Levy, 2003), that may have been combined with the appearance of semi-subterranean features (Gilead, 1988), and a land tenure system (Winter-Livneh et al., 2012). These features may suggest a connection between the economic structure of Ghassulian society and the levels of intra-site variability, levels which are significantly higher than the level of the Golanian site of Rasam Harbush and significantly lower than the level found in Early Bronze Age Arad.

6. Conclusions

Ghassulian architecture exhibits a certain degree of variability, high in relation to that of Rasam Harbush and low in relation to that of Early Bronze Age Arad. The available evidence suggests that social hierarchy is not apparent architecturally in Ghassulian society. Nonetheless the relatively higher level of architectural differentiation within Ghassulian settlement than the Golanian settlement might reflect socio-economic intensification. In addition, Ghassulian architectural shapes cannot be distinguished from one site to the other, while those of the Golanian site Rasam Harbush are unique and therefore distinguishable from all the other sites we examined. This may support the contention that the Golanian is a cultural entity which differs from the Ghassulian. We suggest that the differences between Ghassulian and Golanian architecture probably results from the different nature of the social and economic characteristics of each of these two cultural entities.

The SR method helps in distinguishing different architectural patterns that probably reflect socio-economic features of the past communities we studied. The Golan site of Rasam Harbush is characterized by an intra-site structural homogeneity. The shape of structures here was deliberately or undeliberately restricted to basically one shape and the resulted is a particular settlement type. Thus, Rasam Harbush lacks any indication of socio-economic differentiation. Partial heterogeneity was revealed in Ghassulian sites such as Shiqmim and Teleitat Ghassul and suggests a certain level of differentiation between the dwellings within each of the settlements. This low-level heterogeneity may signify variability in a number of socio-economic aspects, such as intensity of production, craft specialization and technological innovation, different activities or different production intensities resulted in structures with for example, different storage requirements, and thus of different shapes. A relatively high level of heterogeneity was observed among the structures at Arad. This suggests a significant visible dissimilarity which is a result of structures having different function. Public structures (such as the temple complex) and dwellings were designed differently to express socio-economic distinction.

Changes in symmetry levels of prehistoric architecture over time do not support the idea that accumulation of knowledge over time results always in technological progress. On the one hand, it is plausible that the symmetry of prehistoric structures fails to reflect social changes. On the other hand, it may, at least in some cases, indicate that architectural techniques and traditions are diverse and do not develop unilineatly.

To conclude, Building activity patterns in prehistory are part of an expressive and complex system of social and economical meaning. Future studies should reveal further micro and macro scale social aspects of the builders and dwellers in the southern Levant prehistory. In addition studies should address related important issues such as how the house forms within different settlements are organized spatially. Moreover, there is a need to objectively measure and compare the similarity not only between individual structures, but also between ways clusters of structures are spatially distributed within each settlement. Future studies should also aim at finding whether different building material may have influenced the symmetrical properties of architecture. Answering these questions can help us to better understand past social and economic realities.

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