Modelling the built environment: Spatial patterns, siting techniques and layout works of non-monumental architecture in Early Bronze Age Eastern Arabia

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Modelling the built environment: Spatial patterns, siting techniques and layout works of non-monumental architecture in Early Bronze Age Eastern Arabia

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Abstract
Interest in the built environment of Early Bronze Age (EBA) Eastern Arabia is rapidly increasing with the emergence of new field data from the excavation of settlement sites. However, little is known about architectural planning and spatial patterns in the region. This article explores non-monumental architecture throughout the third millennium BCE. A series of methods (Pythagorean triples, modular grids, interception of circles) were used to assess the geometric and metric characteristics of buildings, and to stress regularities and variation in the long term. The results of these analyses suggest the application of specific techniques in layout and construction works: the intersection of circles during the Hafit occupations, and more sophisticated techniques, combining the properties of circles and triangles, during the Umm an-Nar period. The diachronic approach allowed by the temporal span of the occupations highlights a firm progression of architectural paradigms and building crafts throughout the EBA. The evidence hints at the existence of a specialised workforce since the dawn of the Bronze Age, and reveals a sharp increase of technicity and standardisation towards the end of the third millennium.

KEYWORDS
Architecture, architectural planning, building technology, Early Bronze Age Arabia, geometric analysis, organisation of workforce, spatial patterns, specialisation of work

1 | INTRODUCTION

Architectural vestiges constitute a major culturally related element and are key in defining archaeological complexes. Each and every of component of the built environment reflects a social dimension that constitutes its essence, and is a significant proxy for socio-economic and cultural dynamics (cf. Azzarà, 2012: 432–433; in press). The analysis of the architectural space is essential to comprehend how settlements integrate with the wider cultural landscape, how housing integrates settlements, how communities cope with their needs at the level of the social unit and beyond, and ultimately how populations conceive their own socio-economic organisation.

Understanding how buildings were designed in the past is a core question when approaching architecture and its development, and a question that has long been the object of archaeological research (e.g. Arnold, 1991; Emery, 2007; Forest, 1991; Kubba, 1990). By conceiving architecture as *active material culture*, the analysis of architectural materiality and design reveals its social dimension both in the final

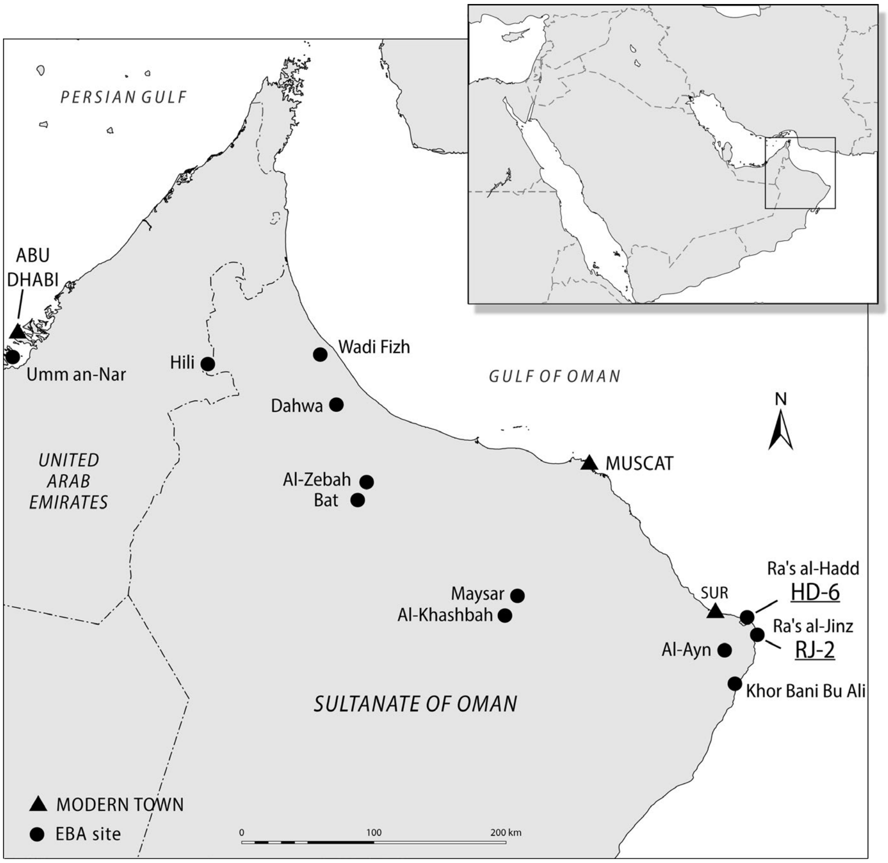


FIGURE 1 Map of Eastern Arabia, with the location of EBA sites mentioned in the text (map: V. Azzarà)

product and in its process of construction. The analysis of architectural plans can help us grasp a significant dimension of social complexity, highlighted by the diversification and specialisation of labour in the field of building crafts. Recent developments in the archaeology of Eastern Arabia have highlighted major socio-economic transformations occurring from the end of the fourth millennium BCE: permanent architecture and settlement complexes (e.g. Azzarà, 2013; Thornton et al., 2016), evidence of farming (e.g. Munoz, 2017), technological innovation and specialised labour (e.g. Weeks, 2003; Azzarà, in press). Yet, while a number of monumental graves and towers have been explored, a real shift of archaeological projects towards the exploration of "regular" occupations has taken place only in the last few years. The investigation of settlement sites and the study of the built environment—with both solid architecture and ephemeral structures as an integral part of it—is paramount, however, for grasping the local dynamics that led to diversification and specialisation of labour, economic interdependence at the regional and interregional level, and social complexification.

This article presents a geometrical study of non-funerary and non-monumental architectural vestiges from Early Bronze Age (EBA) Eastern Arabia (Figure 1), both from the Hafit (*c*. 3100–2600 BCE) and Umm an-Nar periods (*c*. 2700–2000 BCE).

Sites such as Bat (Thornton et al., 2016), al Khashbah (Schmidt & Döpper, 2017) and Ras al Hadd HD-6 (Azzarà, 2013; Azzarà & Cattani, 2018), in Oman, show the appearance of permanent architecture at the very end of the fourth millennium BCE, but only Ras al Hadd HD-6 displays domestic modular buildings; the other sites are marked by circular—or roughly circular—monumental towers, a type of structure significantly widespread during the following Umm an-Nar period (e.g. Cable & Thornton, 2013; Döpper, 2018).

Non-monumental settlement evidence and modular architectures are more widely attested during the second half of the third millennium, at sites such as Umm an-Nar (Frifelt, 1995) in the United Arab Emirates (UAE), or Wadi Fizh WAJAP-S63 (Düring & Botan, 2018), Bat (Swerida, 2018), al Zebah (Schmidt, 2018), Maysar 1 (Weisgerber, 1981), Dahwa DH1 (al-Jahwari et al., 2018) and Ras al Jinz RJ-2 (Azzarà, 2018; Cleuziou & Tosi, 2000) in Oman. Research works focusing on EBA architectures of Eastern Arabia, however, are still rare, and the study of their geometric characteristics has been seldom expounded.

This paper will focus in particular on the sites of Ras al Hadd HD-6 (Figure 2) (c. 3100–2600 BCE) and Ras al Jinz RJ-2 (Figure 3) (c. 2600/2500–2000 BCE), which have been the object of thorough excavations in the frame of the Joint Hadd Project, directed by S. Cleuziou and M. Tosi (e.g. Cleuziou & Tosi, 2000). Some contemporary sites will be also analysed. The temporal span of the occupations, covering the whole third millennium BCE, allows a diachronic approach, and highlights a firm progression throughout the EBA, marked

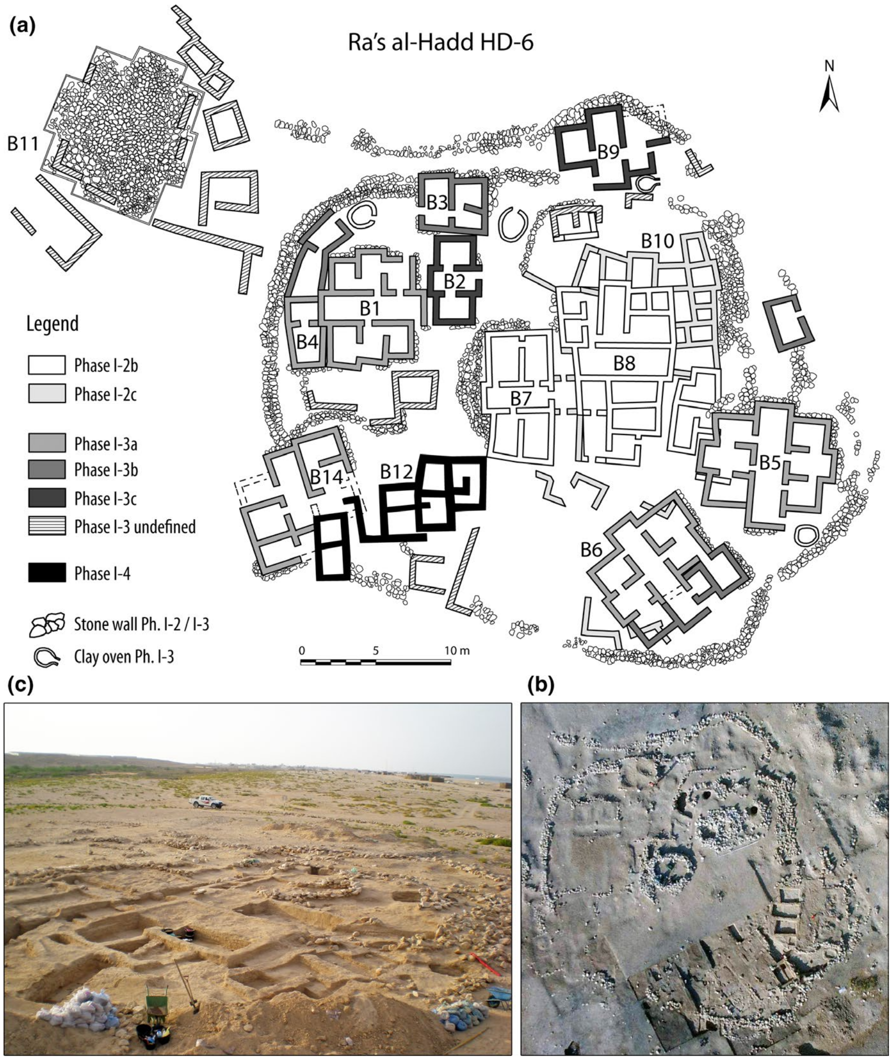


FIGURE 2 (a) Plan of the Hafit occupation at HD-6; (b) Zenithal view of the site; (c) The settlement of HD-6, view from the west (plan: V. Azzarà; photos: Joint Hadd Project) [Colour figure can be viewed at wileyonlinelibrary.com]

by increasing normalisation of buildings. Furthermore, geographically restricted distribution of the vestiges, mostly located in the easternmost area of southern al-Sharqiyah (Oman), results in a definition of architectural evidence at what could be defined as micro-regional scale—i.e. a radius of 10–50 km, combining the distances conventionally used in prehistory (e.g. Binford, 1982) and the scale of distribution of raw materials and local productions in the area (e.g. Méry, 2000: 283).

2 | THEORETICAL APPROACH AND METHODOLOGY

Pythagorean triples and, more generally, Euclidean geometry and trigonometry, are a powerful tool for researchers to highlight technical structural traits of ancient buildings; in many cases, the buildings have been conceived as a direct product of these concepts (e.g. Kubba, 1990; Ranieri, 1997). Such theoretical tools do not constitute an a priori structure of thought (e.g. Mansfield & Wildberger, 2017; Robson, 2001), and manipulating Euclidean geometry is not a prerequisite for geometric conceptualisations and/or systematisation of building design. Indeed, empirically generated intuition, based on trial and error and reproduction of ideal models, could be considered as a triggering factor for theoretical abstraction (e.g. Forest, 1991: 165). As stressed above, however, Euclidean geometry constitutes a valid tool to point out the recurrence of specific measures or modules and other building characteristics, such as the accuracy of orthogonality. Even though past societies may have conceived these patterns through a different approach, it is worth using the Euclidean approach as a means to reach a more objective explanatory understanding of building plans.

One of the methods selected for this study consists in the application of Pythagorean triples—or natural triples—i.e. positive integers representing the length of the sides (a, b) and of the hypothenuse (c) of a right-angled triangle, and satisfying the equation $c^2 = a^2 + b^2$ (see Figures 4 and 5a). The method used here is more specifically based on the approach elaborated by Ranieri (1997) through the analysis of different chrono-cultural contexts. What the author calls "the art of squaring space", is explained as a continuous and gradual evolution of building methods through a series of successive

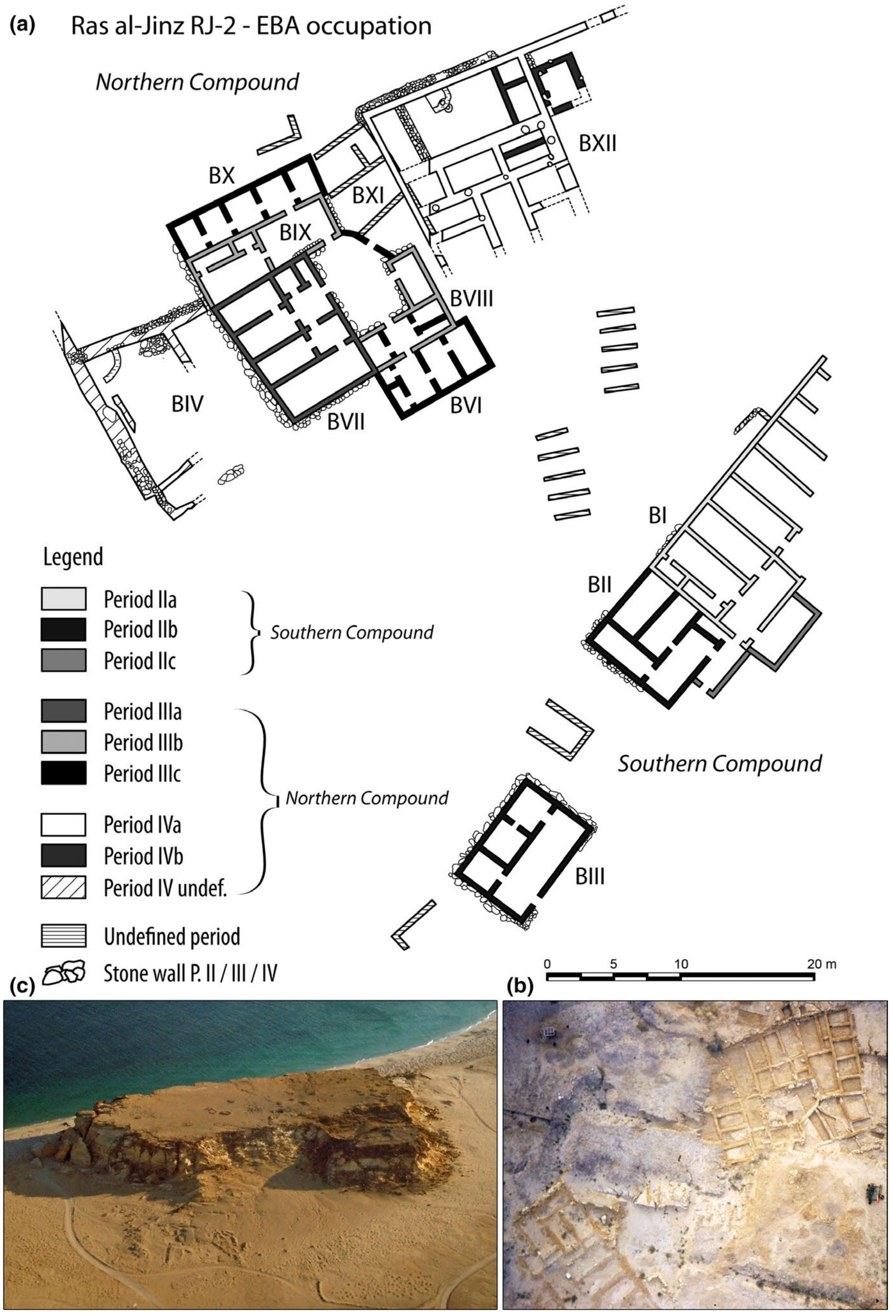


FIGURE 3 (a) Plan of the Umm an-Nar occupation at RJ-2; (b) Zenithal view of the site; (c) The settlement of RJ-2 at the foothill of a limestone terrace, view from the north-west (plan: V. Azzarà; photos: Joint Hadd Project) [Colour figure can be viewed at wileyonlinelibrary.com]

stages, implying increasing accuracy in measurements and orthogonality of the structures. Unlike other authors considering the utilisation of Pythagorean triples, Ranieri goes beyond the classic triads 3-4-5, 4-8-9 and 5-12-13, proposing a selection of natural triples that include about 20–25 ratios—the ratio being the quotient of adjacent sides a and b ($r = b/a$). The selected triads are not only related to the Pythagorean triples with perfectly square angles (*P-triads*); when considering these perfect triads, the number of triples consisting of small numbers, which can be easily remembered and orally transmitted without complex mathematical knowledge, is very limited—there are only six triples with numbers smaller than 30. Hence, Ranieri broadens this range using the notion of "quasi-precise triples" (*Q-triads*), which do not satisfy the theorem of the sum of squares, but have a ratio close to that of P-triads and produce reasonably orthogonal angles. Suitable for practical purposes, these triples are far more numerous for integers smaller than 30 (Ranieri, 1997: 214–218, fig. 5, tab. 4.6; cf. Figure 4, Table 1).

The application of quasi-precise triads evokes the question of the accuracy and the acceptable margin of error within a given society or group when operating these procedures. Such a margin is obviously difficult to define, even more so when lacking written sources. However, as regards vernacular architecture, it seems likely that the notion of accuracy could have a relative value, especially in contexts where Euclidean principles were not formalised or deliberately used. Certainly, the

TABLE 1 List of the natural triples (expressed as natural numbers) attested at HD-6 and RJ-2 (adapted from Ranieri 1997, table 4.6); in bold the triples more frequently attested. **a**, **b** and **c** represent the three sides of a right triangle; **r** indicate the ratio between **b** and **a**; **γ** represents the angle formed by **a** and **b**; **α** represents the difference between the right angle (90°) and **γ**. The triples are listed from the smallest to the largest ratio **r**. See also Figure 4a

HD-6 and RJ-2 – Natural triples (T)								
Site	**Symbol**	**a**	**b**	**c**	**r (b/a)**	**γ (AĈB) [DEG]**	**α (90- γ) [DEG]**	**Phase**
HD-6	Q	5	5	7	1.0000	88.8540	1.1459	I-2/I-3
	V	20	21	29	1.0500	90.0000	0.0000	I-2/I-3
	VA	15	16	22	1.0667	90.3581	0.3581	I-3
	S	8	9	12	1.1250	89.6021	0.3979	I-2/I-3
	3/W	**20**	**25**	**32**	**1.2500**	**89.9427**	**0.0573**	**I-2/I-3**
	D	**3**	**4**	**5**	**1.3333**	**90.0000**	**0.0000**	**I-2/I-3**
	LD	**16**	**23**	**28**	**1.4375**	**89.9222**	**0.0778**	**I-2/I-3**
	L	**10**	**15**	**18**	**1.5000**	**89.8090**	**0.1910**	**I-2/I-3**
	LVC	**14**	**23**	**27**	**1.6429**	**90.3559**	**0.3559**	**I-2/I-3**
	2/SB	**11**	**19**	**22**	**1.7273**	**90.2741**	**0.2741**	**I-2/I-3**
	MA	4	7	8	1.7500	88.9768	1.0231	I-2/I-3
	M	8	15	17	1.8750	90.0000	0.0000	I-2
	MC	12	23	26	1.9167	90.3114	0.3114	I-2/I-3
	2Q	4	8	9	2.0000	90.8953	0.8952	I-3
	2QA	13	27	30	2.0769	90.1632	0.1632	I-2/I-3
	2VC1	5	11	12	2.2000	88.9582	1.0417	I-2/I-3
	2D	6	16	17	2.6667	89.1047	0.8952	I-2/I-3
	G	12	35	37	2.9167	90.0000	0.0000	I-2/I-3
	$\sqrt{10}$	6	19	20	3.1667	90.7539	0.7539	I-2
	3D	16	63	65	3.9375	90.0000	0.0000	I-3
RJ-2	**Q**	**7**	**7**	**10**	**1.0000**	**91.1694**	**1.1694**	**II, III**
	V	20	21	29	1.0500	90.0000	0.0000	II, III
	VA	15	16	22	1.0667	90.3581	0.3581	IV
	S	**8**	**9**	**12**	**1.1250**	**89.6021**	**0.3979**	**II, III, IV**
	D	3	4	5	1.3333	90.0000	0.0000	II, III, IV
	LD	**16**	**23**	**28**	**1.4375**	**89.9222**	**0.0778**	**II, III**
	L	10	15	18	1.5000	89.8090	0.1910	III
	π/2	7	11	13	1.5714	89.6279	3.3721	IV
	2/SB	11	19	22	1.7273	90.2741	0.2741	IV
	MA	4	7	8	1.7500	88.9768	1.0231	II, III
	MC	12	23	26	1.9167	90.3114	0.3114	IV
	2Q	**4**	**8**	**9**	**2.0000**	**90.8953**	**0.8952**	**II, III, IV**
	WA	**10**	**23**	**25**	**2.3000**	**89.5018**	**0.4982**	**II, III**
	W	**5**	**12**	**13**	**2.4000**	**90.0000**	**0.0000**	**II, III**
	2D	**6**	**16**	**17**	**2.6667**	**89.1047**	**0.8952**	**II, III**
	G	12	35	37	2.9167	90.0000	0.0000	III
	3Q	6	18	19	3.0000	90.2653	0.2653	II
	2LVC	7	23	24	3.2857	89.6441	0.3559	III
	GA	7	24	25	3.4286	90.0000	0.0000	II, III

acceptable degree of precision is not univocally related to technical needs. As already stressed, architecture reflects in the first place a social dimension. It can respond to an ideal canon, which must be considered as a social product on its own, "conceived and articulated by individuals and societies with particular preconceptions, motivations,

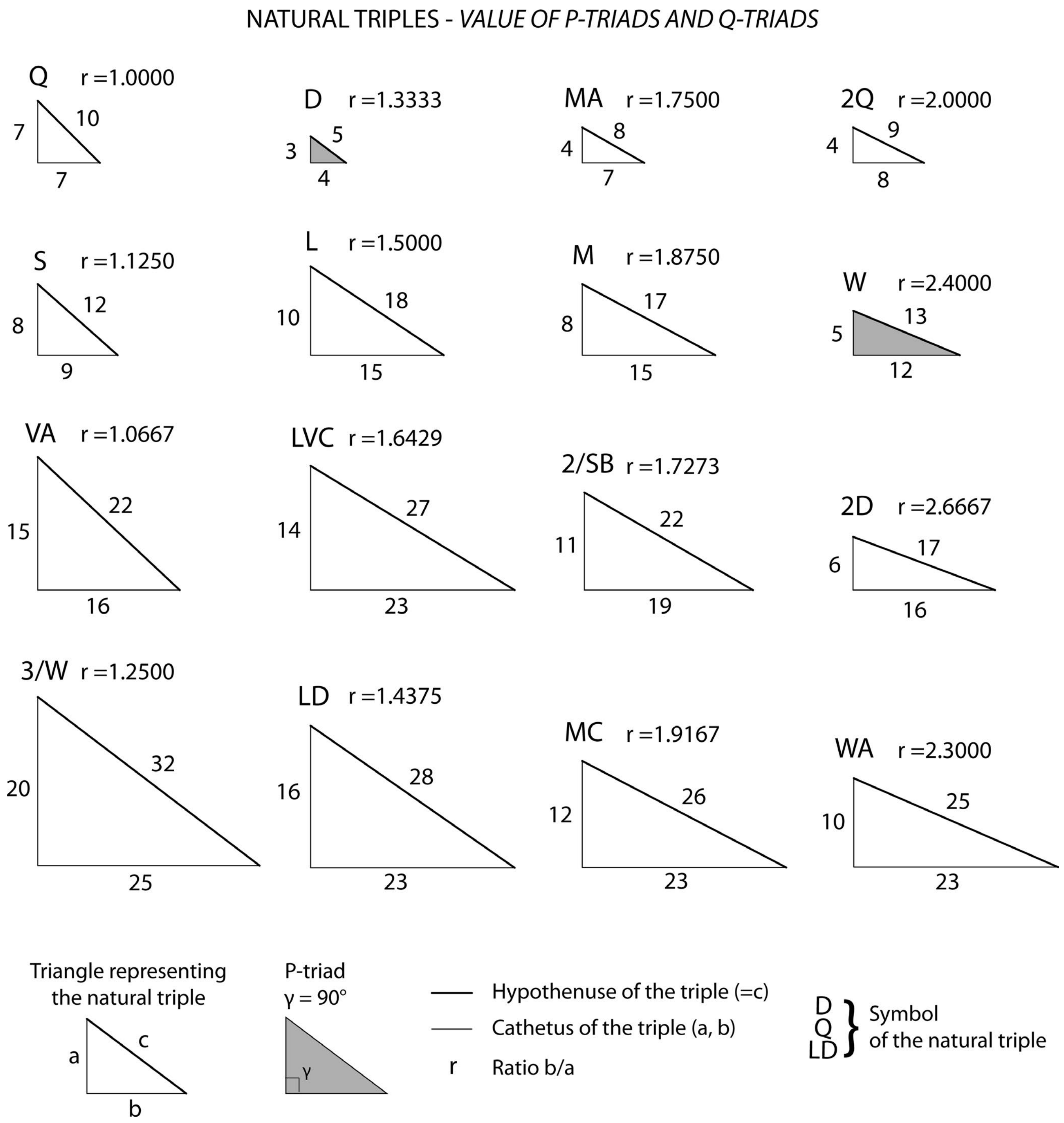


FIGURE 4 Graphic representation of the natural triples mainly attested at HD-6 and RJ-2, showing the lengths of the P-triads and Q-triads and the ratio b/a

and modes of communication"—in the words of Robson (2001: 170) for describing geometry and mathematics. As such, this canon must reflect the social needs of the community, which do not always respond to modern western conceptualisations, including the notion of exactitude. Construction procedures do not necessarily result in consistent and exact layouts, especially when lacking a ritualised dimension. When attempting to study vernacular architecture, the notion of accuracy—including layout, measurements, orthogonality—must be framed by this concept.

Firmly grounded in this conceptual framework, and based on the geometric approach described above, this study presents in detail the architectural evidence uncovered at HD-6 and RJ-2. The sequence of construction is well known at both sites (cf. Figs. 2 and 3), and in both cases the buildings were analysed based on the first discernible phase of construction, which reflects the original planning and layout works.

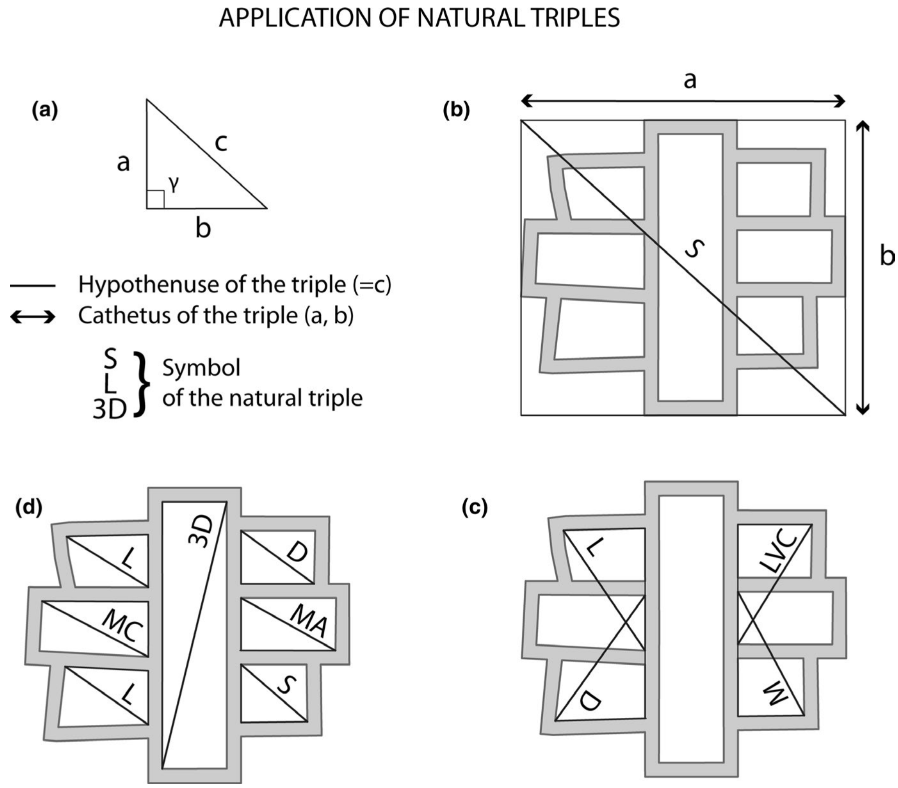


FIGURE 5 Examples of the application of natural triples for the analysis of building layout. (a) Representation of a right triangle, where γ is a 90° angle, a and b are the adjacent sides (catheti) and c is the hypotenuse; (b) Triple applied to circumscribed parallelogram; (c) Triples applied to the lateral wings; (d) Triples applied to the rooms (plans: V. Azzarà)

For instance, Building 6 of HD-6 was analysed in the form known for Phase I-3a, without the additional rooms to the south, and Building I of RJ-2 was analysed based on the plan of Period IIa, once again without the rooms added during further occupations.

Each building was first analysed as a unit inscribed in a rectangular parallelogram, which can be subdivided, in its turn, into two triangles (Figure 5b). The structures were then analysed considering different components of the architecture, such as the wings (Figure 5c) or the rooms (Figure 5d); the labels of the triples described in this study correspond to those assigned in the typology elaborated by Ranieri (1997).

Following this analysis, which helped highlighting existing regularities, the data set was explored through two other methods (modular grids, intersecting circles, see below), to put forward building methods that could have been more likely used by the dwellers of the earliest structures, as they are more "empirical" and require less refined mathematical conceptualisations.

3 | EARLY FORMS OF ARCHITECTURE IN EASTERN ARABIA: THE SITE OF RAS AL-HADD HD-6

The most ancient of the sites considered for this study is Ras al Hadd HD-6 (c. 3100–2600 BCE, Hafit period), where large-scale excavations have exposed four main phases, marked by a variation of building materials, and each one presenting several sub-phases (Figure 2) (Azzarà, 2013: 12–16; 2015: 113–180; Azzarà & Cattani, 2018: 146–147). The first occupation of the area was related to short-lived structures, followed by three phases of permanent buildings in adobe. Each of these phases displays a specific type of mudbricks (Azzarà, 2013: 17–18). Phase I-2 presents structures made of mudbricks with high sandy content, measuring 58 × 38 × 5 cm. Structures of Phase I-3, which occupy almost entirely the excavated area, and mark the maximal expansion of the settlement, are characterised by mudbricks much richer in silt and clay, measuring 50 × 40 × 6 cm. The last occupation, Phase I-4, so far little explored, presents mudbricks with consistent proportions of gravel, measuring 55 × 36 × 6 cm. Characterisation analyses of 14 samples of building materials—currently expanded in the frame of a dedicated research project—confirm that paste composition of mudbricks is fairly homogeneous throughout each phase, consistently with a standardised production, and suggest that the differences in mudbrick fabrics, with different proportions of fine and coarse fractions through time, were a result of mixing and tempering (Azzarà 2013; forthcoming). This deliberate choice in the production process, resulting in more plastic materials and aimed most likely at improving structural strength, hints at increasing workers' level of technicity.

Along with mudbrick paste and module, other technical characteristics show a variation through time. Foundation systems, in particular, evolve from the strip footing typical of Phase I-2, to the platforms made of clay or stones and clay of Phase I-3, showing once again a technical advancement, probably aimed at reducing the impact of the dune settlements (Azzarà, 2013: 19–20). As a whole, the evidence does not indicate that the structures would need a much higher degree of restoration due to unskilled work during Phase I-2, but these traits are clearly related to an improvement of technical know-how (Azzarà, 2013: 22–24; in press).

The buildings documented at HD-6, although reproducing similar functions (see below; Azzarà, in press), show different layouts. During Phase I-3, while each structure consists of an individual architectural unit, it is possible to recognise clusters of connected dwellings, non-adjacent but yet gradually organised around an external courtyard with shared large ovens, as exemplified well by Buildings 1, 4 and 3 (built in this order). These clusters were most likely related to affiliated households, or affiliated groups within one household; the smaller buildings represented extensions of the main "core" units, occupied, for example, by elders, by concubines, by siblings—a precise definition of the household is of course not possible based on the current evidence (Azzarà 2015: 581–585; in press). Regardless of the specific relationships between buildings and groups, this gradual extension from the main buildings can explain the differences in layout principles.

Despite such differences, the structures hint at the existence of an ideal tripartite configuration, at least during Phases I-2 and I-3 (see Figures 2 and 5). Only three buildings do not show a tripartite arrangement; all the other structures present a wider central space, which constitute the main access to the dwelling and give access to the lateral rooms, located on both sides along its longitudinal axis. This is also true for Building 8, with its lateral wings on both sides of the largest hall. The complex plan of this building might suggest that the structure was originally composed of two different dwellings, modified over time; interlocking walls in the corners where one might expect later additions, however, do not support this hypothesis.

3.1 | Orientation

Before focusing on the geometric characteristics of buildings, it is worth considering the orientation of the structures. As the walls of each building are not all iso-oriented, we can define the orientation of the structures based on the orientation of the central hall, which is also the largest and main space (see Figures 7–9). The main spaces are preferentially aligned on the east–west or north–south axis, and in some cases their axis matches precisely one of the cardinal axes, suggesting a non-random alignment pattern.

The rising sun would be a plausible sighting point. The role played by the sun within local cultures has already been evoked in relation to funerary structures, from the Neolithic onwards (e.g. Salvatori, 2007: 41), and the EBA tombs in the nearby necropolis of HD-10 are also oriented towards the east (Salvatori, 2001: fig. 2, 4–5). However, the existence of two preferential orientations (east–west and north–south), does not evoke rigid orientation requirements—as, for example, a sighting performed towards the rising sun during a specific moment of the soli-lunar cycle, implying a calendrical perception. This is also supported by the fact that the orientation of some buildings diverges or slightly diverges from the cardinal axes.

Several factors may of course play a role in the orientation of the buildings and produce the observed variations, such as the topography of the area and the available space (as in the cases of Building 4, Building 9 or Building 14, see below), the displacement of landmarks with time—if landmarks where used instead of an astronomic reference—the needs and preferences of the occupants concerning prevailing winds, thermal factors, etc. This subject is indeed wide, and cannot be thoroughly developed in the frame of this paper.

The consistency of preferential orientations suggests, nevertheless, that the first step in the building process was the orientation of a line used as a reference during the layout works. Despite the limited dimensions of the buildings and of the rooms, creating parallel alignments on a specific direction and on a length of 6–9 m—the length of the main spaces, whose walls are always parallel—would not be feasible without a systematic method to trace them; in other words, the distances could not just been paced out from one extremity to the other one. Most likely, the main space was outlined first, while the partition walls and the external walls were traced afterwards.

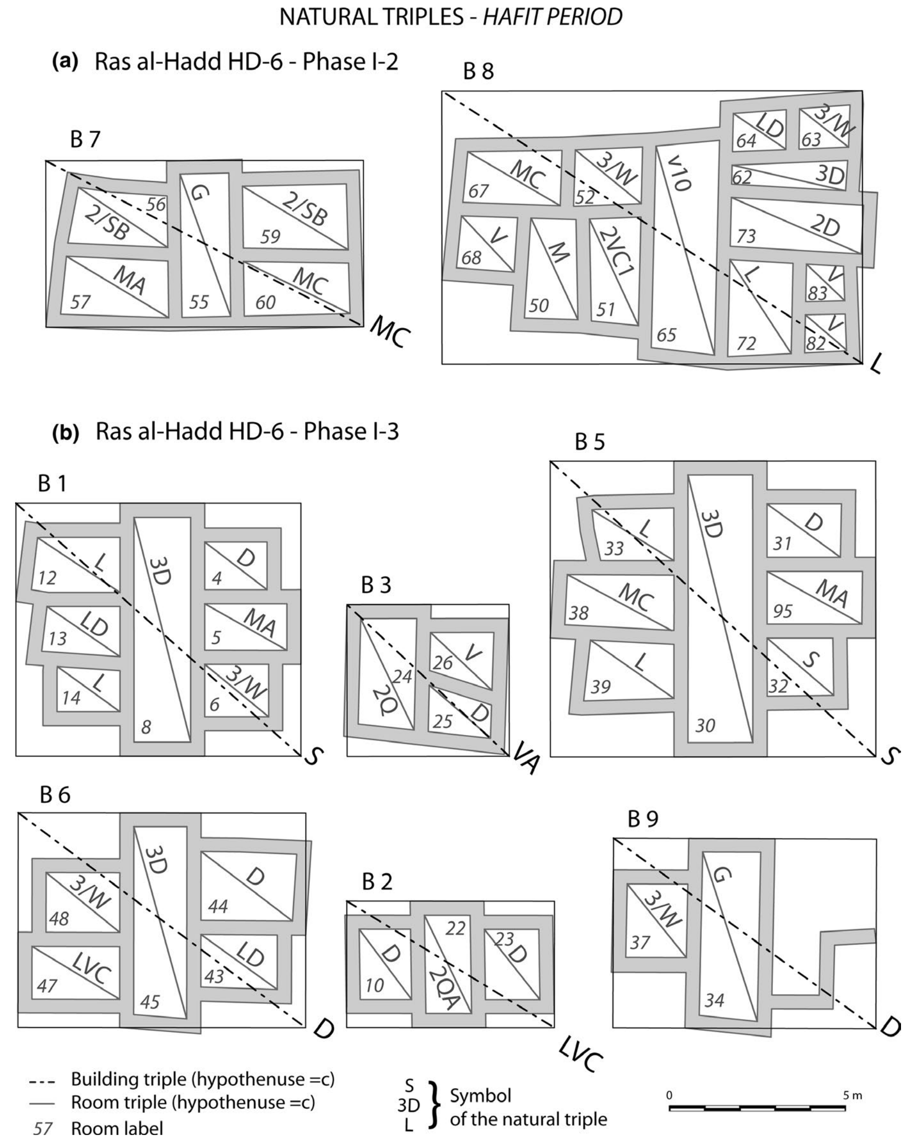
3.2 | Finding regularities: the application of natural triples

The structures of HD-6, with the central room exceeding the edge of the abutting spaces, do not reproduce a regular geometric figure. Nevertheless, plan analysis points to a series of geometric recurrences, which can be formalised through the application of Pythagorean triples, and allow some general considerations concerning the layout of the buildings.

During Phase I-2, Building 7 is both symmetric and regularly planned, with the rooms on both sides of the central space showing similar proportions in couples. Normalisation is less apparent in Building 8, which does not display specific modules on both sides of the main space (Room 65) (Figure 6a).

During Phase I-3, dwellers show greater concern for symmetry and regularity of the plan. The ratio R between the proportions of the central space (R') and the smaller adjacent rooms (r') is rather constant, even though the absolute dimensions can vary (Table 2). The rooms composing the lateral

FIGURE 6 Application of natural triples to the structures of HD-6, the example of building plans and rooms (plans: V. Azzarà)



wings reproduce equivalent proportions as well—comparing the different buildings—as the triples have very similar ratios or, in some cases, identical ratios. (Figure 6b; to compare the ratios of the triples, see Figure 4 and Table 1). Most buildings display a large central room characterised by elongated proportions (3/D or G triples) (Figure 6b).

Another significant difference concerns the orthogonality of the structures (Table 3). During Phase I-2, the corners formed by the masonries are often far from the right angle (90°), as shown by the high variance of the angles. The following phase is marked by an evolution in the accuracy of orthogonal walls. Structures where non-orthogonality is clearly noticeable are more exceptional, and they seem to depend on external conditions, which would not have allowed a different planning; a fair example is given by Building 4, whose extension during Phase I-3b was somehow forced by the presence of adjacent structures. In general, however, the dwellers countered these issues when possible, as attested, for instance, by the construction of Building 5: in this case, pre-existing buildings were terraced, preparing the surface for the new dwelling (cf. Azzarà, 2013: 20, fig. 9). In these accurately planned structures, most of the angles are close to 90°, so that the orthogonal variation is not substantial (Table 3; cf. also the value of γ' in Table 4).

3.3 | Some observations on measurements and measuring tools

The regularities detected through Pythagorean triples offer interesting clues on the system of measurement used by the constructors. The triples can be identified mainly as quasi-precise, Ranieri sensu, while precise triads are rare; moreover, the match of these proportions with the proportions of the real dimensions of buildings is not always exact—and this evidence further argues against the Pythagorean approach as the tool actually used by the builders. However, a series of triples show an exact or close correspondence with

HD-6 – Natural triples (T) – Value of R								
			T' (m)		r'	γ' [DEG]	T	R
Building	**Room**	(a'	b'	c')	(b'/a')	(A'Ĉ'B')	Symbol	(R'/r')
Building 1 (R'=3,9683)	**12**	1.58	2.36	2.83	1.4914	89.7143	**L**	2.66
	13	1.43	2.09	2.53	1.4553	89.9915	**LD**	2.73
	14	1.18	1.79	2.21	1.5239	93.7178	**L**	2.60
	4	1.36	1.78	2.24	1.3040	90.0382	**D**	3.04
	5	1.32	2.35	2.70	1.7721	90.1752	**MA**	2.24
	6	1.50	1.83	2.37	1.2168	89.9884	**3/W**	3.26
	8	1.62	6.43	6.63	**3.9683**	89.9817	**3D**	1.00
Building 5 (R'=4,1375)	**33**	1.51	2.34	2.75	1.5538	88.5006	**L**	2.66
	38	1.58	3.04	3.44	1.9238	90.3390	**MC**	2.15
	39	1.55	2.39	2.91	1.5442	92.9317	**L**	2.68
	31	1.53	2.09	2.59	1.3717	90.0353	**D**	3.02
	95	1.51	2.71	3.10	1.7937	90.0441	**MA**	2.31
	32	1.67	1.90	2.51	1.1420	89.2788	**S**	3.62
	30	1.85	7.66	7.88	**4.1375**	89.9558	**3D**	1.00

TABLE 2 Natural triples characterising the tripartite Buildings 1 and 5 at HD-6. **a'**, **b'** and **c'** represent the real value of the triples, expressed in meters; **r'** indicates the ratio between the catheti **a'/b'**; **R'** indicates the ratio **a'/b'** of the central space; **γ'** represents the angle formed by **a'** and **b'**; **R** represents the ratio between **R'** and **r'**. The value of **R** is similar for rooms having the same position within the tripartite plan

TABLE 3 Variability of the real angles **γ'** at HD-6 and RJ-2. The mean value of **γ'** is closer to the 90° angle during Phase I-3 of HD-6 compared to Phase I-2, and at RJ-2 compared to HD-6. The variance and standard deviation also indicate higher precision of the right angles through time

HD-6 and RJ-2 – Variability of γ' (A'Ĉ'B')				
Site	**Phase**	**Mean γ'**	**Variance**	**Standard deviation**
HD-6	**Ph. I-2**	89.3672	13.8007	3.7149
	Ph. I-3	90.2565	1.4268	1.1945
	Ph. I-2 + I-3	89.9418	5.8417	2.4170
RJ-2	**P. II**	90.0582	0.5338	0.7306
	P. III	89.9684	1.5419	1.2417
	P. IV	89.9855	0.0017	0.0415
	P. II + III + IV	89.9995	1.0120	1.0060

the proportions of absolute values, and the latter form right angles, or nearly right angles, with a variation of ±0.03 with respect to the reference angle. Within this group, some triples have a ratio *r*′ (*b*′/*a*′) with a divergence smaller than 0.03 from the theoretical reference triple (*r*). In this case, the ratio τ between the values of real triples (*T*′) and theoretical triples (*T*) ($\tau = T'/T$) help us evaluate the system that might have been used for building layout (Table 4).

Considering only the triples with a divergence of 0.01 and a ratio *r*′ very close to the theoretical ratio *r*, the value of τ has specific ranges, namely of 0.30 ± 1, 0.45 ± 1, 0.60 ± 1 and 0.90 ± 1. Most likely, construction workers used a relatively standardised system of measurements, with one or more units of lengths (modules such as 30 cm, 45 cm, etc.).

A system of measurement implies also measuring tools, and most likely tools that were easily handled and available, such as ropes or systems of ropes. Measuring reeds would be a possible alternative; their manipulation, however, is less straightforward and suitable ligneous species are rare in the region, while ropes were certainly produced or used on site, as attested by several calcified remains (Azzarà, 2015: 437–438). The utilisation of ropes could result in less precise measurements, due in particular to hygrometric conditions modifying their length, but the impact of hygrometry can be limited by sealing the surface with fatty materials (cf. Arnold, 1991: 252). Fat of the mandibular region of dolphins was exploited at HD-6, and it is possible that it was used as waterproofing material (Mosseri-Marlio, 2000: 95). Moreover, although archaeologists mainly consider ropes as alignment tools rather than measuring tools, measuring ropes are attested by medieval sources (Stalley, 1999: 118) and they could have been used in previous periods, as suggested, inter alia, by Arnold (1991: 252), Emery (2007: 251) and Ranieri (1997: 217). Indeed, seeking a rigorous tracing of the buildings would probably be an anachronistic concept (e.g. Forest, 1991: 165), and the notion of perpendicularity itself was not necessarily strict (Robson, 2001: note 18). It is worth noting, however, that the lack of rigorous tracing cannot be assimilated with a complete lack of tracing. Although the small

TABLE 4 Value of the ratio **τ** between the lengths of real triples (**T'**) and the associated theoretical triple (**T**) at HD-6 and RJ-2. **a'**, **b'**, **c'** and **a**, **b**, **c** represent respectively the value of real and theoretical triples; **r'** and **r** indicate the ratio of the catheti; **γ'** and **γ** represent the angle formed by the catheti; **ΔR** represents the difference between the theoretical ratio **r** and the real ratio **r'**; **Δγ** represents the difference between the theoretical angle **γ** and the real angle **γ'**. The table shows values of **τ** in the ranges of 0.30 ± 3, 0.45 ± 3 and their multuples

HD-6 and RJ-2 – Natural triples (T) – Ratio real triples/theoretical triples (units of measurement) τ															
		T' (m)			r'	γ' [DEG]	T		T		r	γ [DEG]	ΔR	Δγ	τ
Site	Building	(a'	b'	c')	(b'/a')	(A'Ĉ'B')	Symbol	(a	b	c)	(b/a)	(AĈB)	(r-r')	(γ-γ')	(T'/T)
HD-6	**B5**	3.04	3.53	4.67	1.1590	90.3590	**SC**	11	13	17	1.1818	89.7997	0.0228	0.5593	**0.28**
	B3	4.35	4.63	6.35	1.0658	89.9558	**VA**	15	16	22	1.0667	90.3581	0.0008	0.4023	**0.29**
	B1	4.65	6.51	8.00	1.4012	89.9812	**LD**	16	23	28	1.4375	89.9222	0.0363	0.0591	**0.29**
	B6	2.11	3.62	4.19	1.7193	91.6444	**GA/2**	7	12	14	1.7143	91.0232	0.0050	0.6212	**0.30**
	B2	2.11	3.62	4.21	1.7147	90.9214	**GA/2**	7	12	14	1.7143	91.0232	0.0004	0.1018	**0.30**
	B2	2.11	3.61	4.21	1.7140	90.9574	**GA/2**	7	12	14	1.7143	91.0232	0.0003	0.0658	**0.30**
	B6	2.90	5.73	6.42	1.9719	89.9745	**2Q**	9	18	20	2.0000	89.1158	0.0281	0.8588	**0.32**
	B9	4.22	4.87	6.39	1.1537	89.0471	**SA**	13	15	20	1.1538	90.8815	0.0002	1.8344	**0.32**
	B2	2.92	5.93	6.62	2.0287	89.9558	**2Q**	9	18	20	2.0000	89.1158	0.0287	0.8400	**0.32**
	B9	3.96	7.51	8.49	1.8974	90.0000	**MC**	12	23	26	1.9167	90.3114	0.0193	0.3114	**0.33**
	B7	2.16	4.86	5.30	2.2536	89.5015	**2VC1**	5	11	12	2.2000	88.9582	0.0536	0.5433	**0.44**
	B5	2.66	8.47	8.87	3.1821	90.0025	**3Q**	6	19	20	3.0000	90.7539	0.1821	0.7514	**0.45**
	B5	2.66	8.47	8.87	3.1817	89.9921	**3Q**	6	19	20	3.0000	90.7539	0.1817	0.7618	**0.45**
	B4	1.36	1.78	2.24	1.3040	90.0382	**D**	3	4	5	1.3333	90.0000	0.0293	0.0382	**0.45**
	B1	1.83	3.24	3.71	1.7698	89.9643	**MA**	4	7	8	1.7500	88.9768	0.0198	0.9875	**0.46**
	B5	2.73	3.57	4.49	1.3109	89.3328	**D**	3	4	5	1.3333	90.0000	0.0224	0.6672	**0.90**
	B1	7.24	8.14	10.89	1.1250	89.9558	**S**	8	9	12	1.1250	89.6021	0.0000	0.3537	**0.90**
	B5	5.44	7.41	9.20	1.3639	90.0411	**D**	3	4	5	1.3333	90.0000	0.0306	0.0411	**1.81**
	B9	5.42	7.51	9.27	1.3848	90.0000	**D**	3	4	5	1.3333	90.0000	0.0515	0.0000	**1.81**
	B6	6.14	8.38	10.39	1.3649	89.9558	**D**	3	4	5	1.3333	90.0000	0.0316	0.0442	**2.09**
RJ-2	**BI**	6.60	6.60	9.33	1.0001	90.0058	**Q**	7	7	10	1.0000	91.1694	0.0001	1.1636	**0.93**
	BI	2.67	6.23	6.78	2.3334	89.9961	**WA**	10	23	25	2.3000	89.5018	0.0334	0.4944	**0.27**
	BIII	6.30	6.30	8.91	1.0000	89.9999	**Q**	7	7	10	1.0000	91.1694	0.0171	1.1695	**0.90**
	BIII	2.59	6.06	6.59	2.3335	90.0032	**WA**	10	23	25	2.3000	89.5018	0.0257	0.5014	**0.26**
	BVII	6.93	6.93	9.80	1.0000	89.9991	**Q**	7	7	10	1.0000	91.1694	0.0000	1.1702	**0.99**
	BVII	2.96	6.93	7.54	2.3421	90.0852	**WA**	10	23	25	2.3000	89.5018	0.0421	0.5834	**0.30**
	BVIII	6.93	6.93	9.80	1.0000	89.9985	**Q**	7	7	10	1.0000	91.1694	0.0000	1.1709	**0.99**
	BII	7.20	8.10	10.84	1.1250	89.9988	**S**	8	9	12	1.1250	89.5018	0.0000	0.4970	**0.90**
	BXII	13.05	13.85	19.03	1.0613	90.0011	**VA**	15	16	22	1.0667	90.3581	0.0053	0.3570	**0.87**

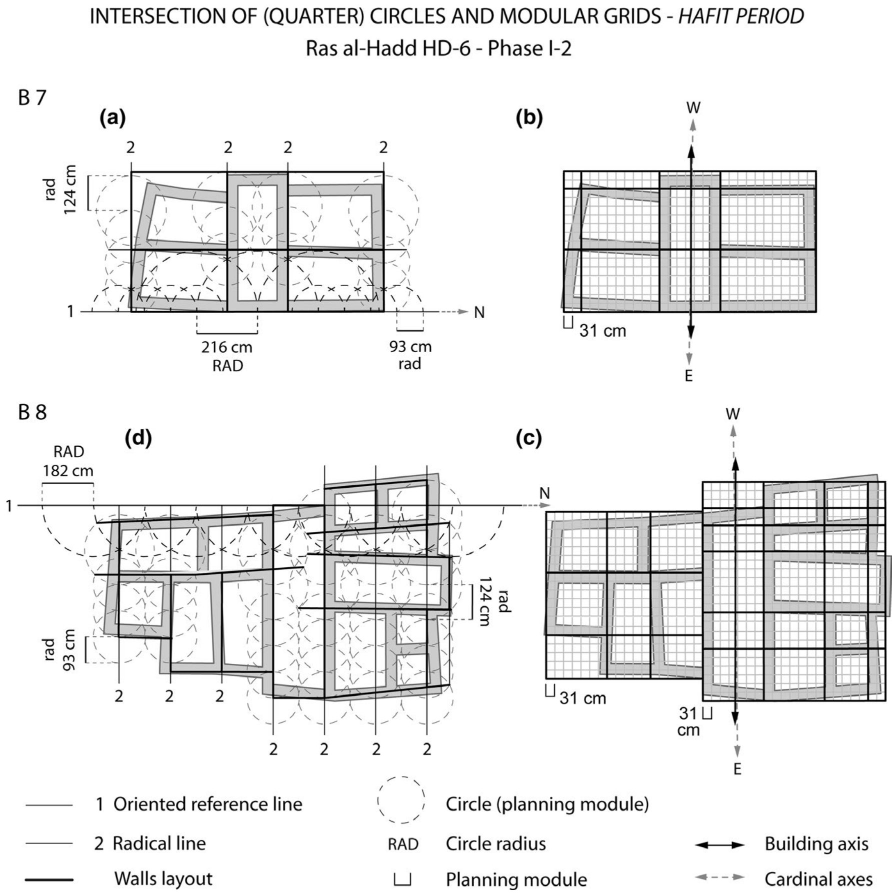


FIGURE 7 Application of intersections of (quarter) circles (a, d) and modular grids (b, c) to the buildings of Phase I-2 at HD-6. The structures are based on consistent units of lengths (planning modules) coinciding with a foot of ≈30 cm and multiples of this number. The figure also shows the orientation of buildings and reference lines compared to the cardinal axes (plans: V. Azzarà)

size of rooms could have been paced out, building plans and measurements show numerous regularities; moreover, and more importantly perhaps, it would have been difficult to establish by eye the parallelism of the long walls of the main spaces and the ≈90° corners, even in smaller rooms.

3.4 | The application of modular grids

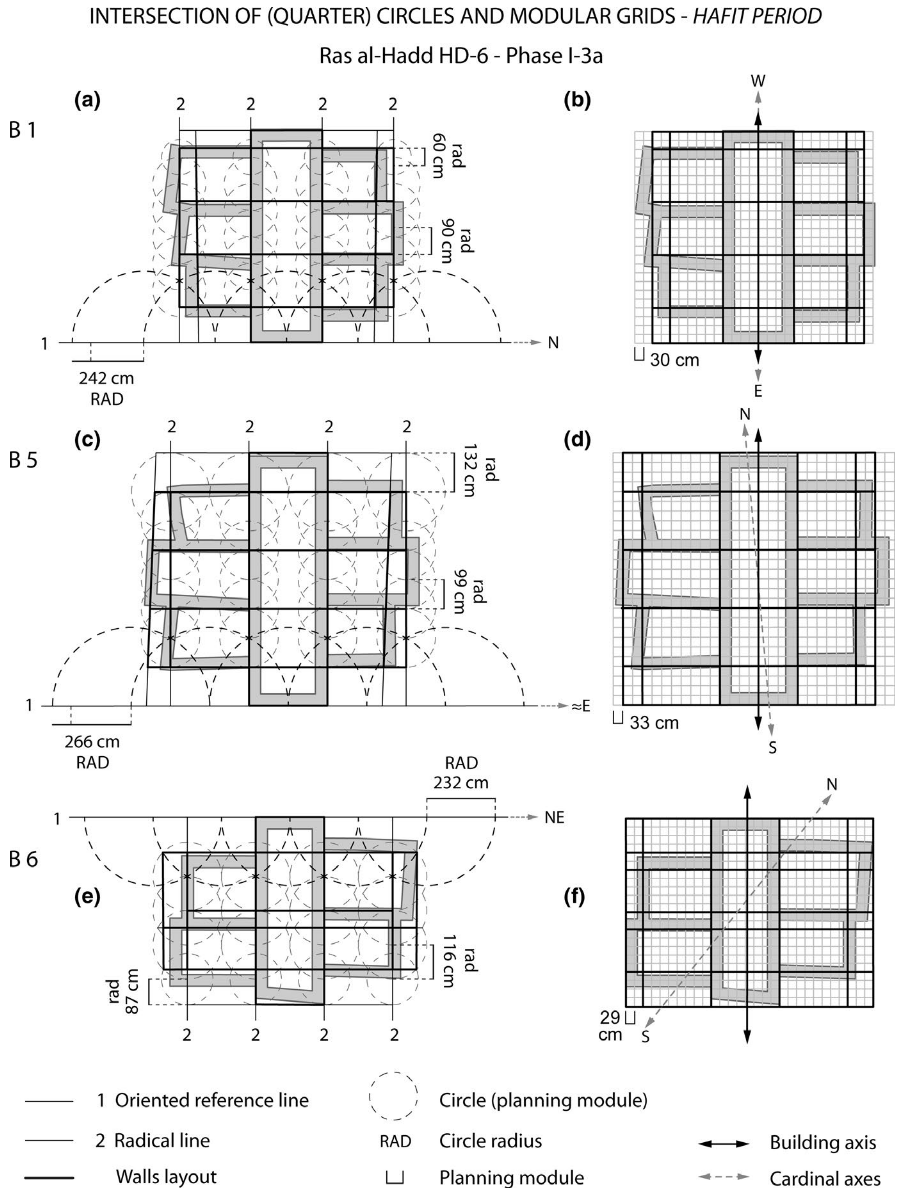
As suggested by geometric characteristics, building layout was very likely traced before the construction of the structures began; this hypothesis is corroborated by the layout of the foundation platforms (e.g., Building 11 in Figure 2), which are not just quadrangular with straight sides, and rather follow exactly the development of overlying masonries (Azzarà, 2013: 20). Overall, the regularities detected through Pythagorean triples do not imply the constructors' will of creating specific Euclidean figures, but reveal the need for design conformity; based on these regularities, we can attempt to identify the methods used in the field to trace building layout.

Several authors assessing the methods for tracing structural layout in archaeological contexts have considered the application of modular grids, which would have facilitated the operations in the field and allowed the application of standardised procedures (e.g. Emery, 2007; Forest, 1991). Unlike more conceptually complex systems, the utilisation of regular grids in contexts such as HD-6 seems perfectly plausible and might explain the regularities of the structures.

To explore this hypothesis, different modules were applied to the buildings, based on the units of lengths detected through natural triples and their multiples (30 cm, 45 cm; see above), as well as base modules corresponding to the length of the bricks (58, 50 and 55 cm; see above). The modules of 45 cm and the modules larger than 210 cm only occasionally correspond to the plan; conversely, the modules of 30 cm and its small multiples (90 cm, 180 cm) are compatible with the layout of most buildings. Seeking better accuracy, the modules were tested based on the value of τ obtained through the triples (see above and Table 4), with values from 29 to 33 cm (Figures 7b–c, 8b/d/f, 9b/d/f).

The smallest modules (≈30 cm) show an almost perfect correspondence with the perimeter of the main room. The width of such spaces is based on height modules of ≈30 cm, except for Building 2, whose main space measures seven modules; the length of the spaces mostly consists of multiples of 3 (12, 21, 24 modules). These modules roughly match the partition walls of the wings. A ≈90 base module also corresponds fairly well to the plans, with a few exceptions. Such small modules, however, have some inconvenience. A grid based on these modules implies a large number of units; Building 1 for

FIGURE 8 Application of intersections of (quarter) circles (a, c, e) and modular grids (b, d, f) to the buildings of Phase I-3a at HD-6. The structures are based on consistent units of lengths (planning modules) coinciding with a foot of ≈30 cm and multiples of this number. The figure also shows the orientation of buildings and reference lines compared to the cardinal axes (plans: V. Azzarà)



example would be based on 648 modules of 30 cm or 72 modules of 90 cm, while it would need only 20 modules of 180 cm. A large number of modules potentially implies larger error, and a significant surplus of work; a grid based on a ≈180 module, on the other hand, would require less work and reduce potential errors, but would result in less accurate tracing.

Overall, although the utilisation of a modular grid is a plausible hypothesis, this can either allow accurate alignments (small modules) or simple operations (large modules). Hence, it is worth exploring different tracing techniques.

3.5 | The application of circles intersection

A possible alternative technique must comply with the characteristics defined so far: based on a modular approach, with a base unit of 30 cm, producing a limited number of reference lines—required to align the walls—and defining right angles.

If we rule out the modular grids, such technique could consist in the intersection of quarter circles, which also allows setting up a series of reference points and reference lines for the construction of masonries. This type of technique has been suggested for the layout works of the Khufu and Khafre's pyramids (Goyon, 1969), but it is based on a simple principle: when two circles intercept in two distinct points, the segment joining them (radical line) is perpendicular to the line of centres.

Two individuals can easily operate in the field using a rope fixed on two sticks; starting from the reference line, one can maintain a stick on a point of this line, while the other draws a circle on the ground using the other stick (Figure 10a). Once the first circle has been drawn, a second circle of equivalent radius, centred on the same reference line, can be

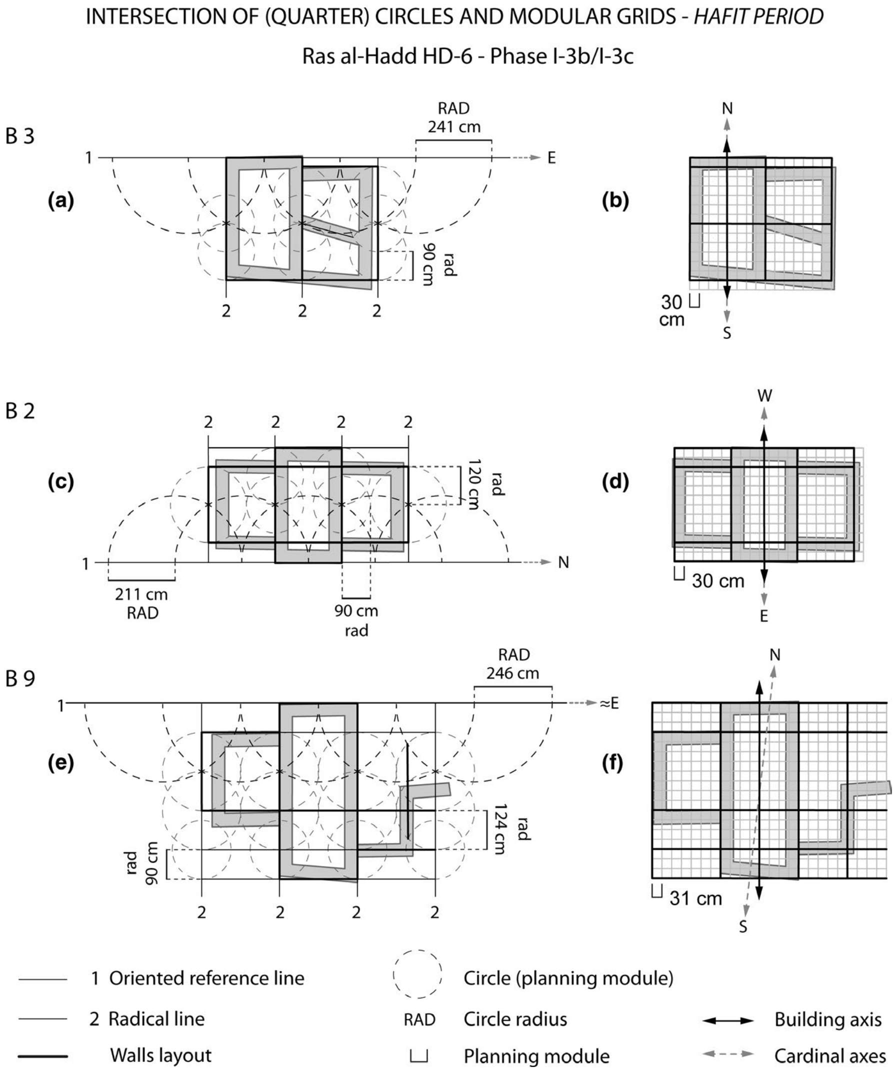


FIGURE 9 Application of intersections of (quarter) circles (a, c, e) and modular grids (b, d, f) to the buildings of Phase I-3b/I-3c at HD-6. The structures are based on consistent units of lengths (planning modules) coinciding with a foot of ≈30 cm and multiples of this number. The figure also shows the orientation of buildings and reference lines compared to the cardinal axes (plans: V. Azzarà)

outlined at a distance equalling the radius itself. The double intersection of the circles allows a segment to be traced perpendicular to the first line. The intersections of these circles with the reference line can also constitute the centres of new circles, which can be used in their turn to trace additional radical lines. The latter, finally, can be used to outline another series of circles, each centred on the intersection of the previous one with the segment itself (Figure 10b). Using ropes of a given length would produce circles that can be considered as modules of the given dimension. The points traced with this method can be connected to create a grid, whose precision depends on the length of the ropes, and operators' accuracy during the field works. Such system combines the utilisation of relatively small units with a limited number of modules (repetition of the unit), with obvious advantages compared to the modular grids (Figure 10c). Of course, tracing the entire circles is not necessary, and only quarter circles would be drawn on the ground.

The grids obtained through the intersection of quarter circles show a fair correspondence with the alignments of the walls of the archaeological structures, as actually detected in the field. The accuracy is even higher when considering that multiple intersections for one single circle might explain the rough orientation of some of the walls, probably traced starting from the "wrong" intersection (Figure 10d).

The modules tested for HD-6 were obtained by giving the first circle a radius corresponding to the width of the main space, which is always a multiple (generally by 8) of the smallest unit obtained through triads and modular grids, i.e. ≈30 (Table 5, Figures 7a/d, 8a/c/e, 9a/c/e); all the tripartite structures can be outlined using five circles of constant radius. The circles intersecting the perpendicular lines also have a radius corresponding to a multiple of the smallest unit; with a few exceptions, such lines are obtained using two different modules, which correspond respectively to three and four times the unit. It is worth highlighting the reiteration of these dimensions, which is unquestionable and corresponds to the measures identified through modular grids and natural triples.

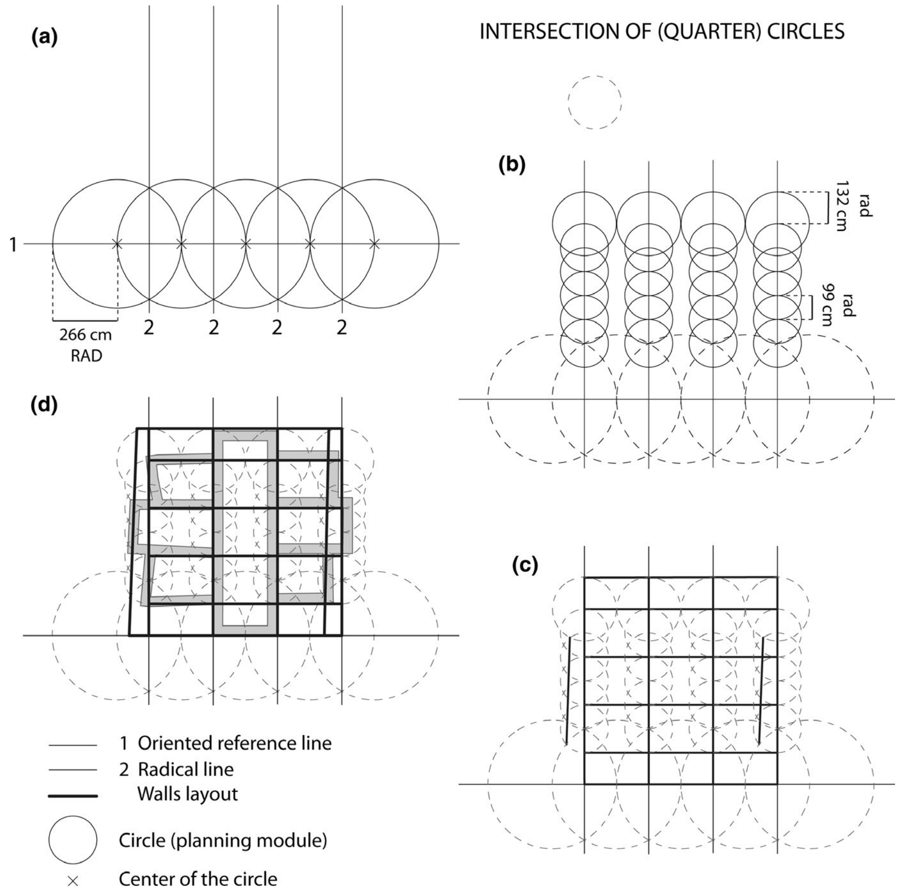


FIGURE 10 Examples of layout tracing through the intersection of (quarter) circles at HD-6. (a) First circles traced starting from the reference line (1), and radical lines (2), traced starting from circle intersection; (b) Circles traced on the radical lines, centred on the intersection between previous circles and radical lines; (c) Grid based on circle intersections; (d) Walls layout based on the grid (plans. V. Azzarà)

TABLE 5 Value of the radius of circles potentially used as measuring modules at HD-6. **RAD** indicates the radius corresponding to two quadruple or two triple feet (see Figures 6–8 and 9a); **rad** indicates the radius corresponding to a double, a triple or a quadruple foot (see Figures 6–8 and 9b)

HD-6 – Modules of Circle Intersection			
Phase	**Building**	**RAD (cm)**	**rad (cm)**
I-2b	**B7**	216	93–124
	B8	182	93–124
I-3a	**B1**	242	90–60
	B5	266	99–132
	B6	232	87–116
I-3b	**B3**	241	90
I-3c	**B2**	211	90–120
	B9	246	93–124

3.6 | Layout works during the Hafit period: an architecture “from the inside to the outside”

Given the characteristics of building plans, it is clear that dwellers applied some sort of standardised procedure for the layout works at HD-6. On a theoretical plan, modular grids and intersection of quarter circles could both be considered as plausible techniques; while entailing fairly standardised field operations, both methods allow outlining different layouts based on a unitary conception. However, circles intersection would be the most likely for a number of reasons: (i) the coincidence of models and actual wall layout using a limited number of modules; (ii) straightforward operations; (iii) less significant degree of error, compared to modular grids, because a grid necessitates a much larger number of modules to obtain the same degree of accuracy. Moreover, this method also explains the rough orientation of some of the walls and provides an *empirical specific correspondence* to the actual plans of the buildings.

The likely utilisation of this method is further backed by another observation. Tracing buildings could imply two different procedures. One would start by outlining first a quadrangular figure, subdivided afterwards through internal alignments, proceeding from the outside of the building layout towards the inside (e.g. Forest, 1991; Kubba, 1990). As an alternative, the layout could be traced in the opposite way, from the inside to the outside. This seems to be the case for the buildings of HD-6, as suggested by the preferential orientations of the main spaces and the precise parallelism of their walls, as opposed to the less regular alignments of partition walls and external walls of the buildings, both within each structure and comparing different structures (Table 6) (see

HD-6 and RJ-2 –Building traditions					
Period	**Site**	**Building**	**Phase**	**Date**	**Building tradition**
Hafit	**HD-6**	**B7**	**Ph. I-2**	*c*.2900–2800	**Inside-out**
		B8			
		B1	**Ph. I-3**	*c*.2800–2600	
		B5			
		B6			
		B3			
		B2			
		B9			
Umm an-Nar	**RJ-2**	**BI**	**P. II**	*c*.2500–2300	**Outside-in**
		BII			
		BII			
		BVII	**P. III**	*c*.2300–2100	
		BVIII			
		BIX			
		BVI			
		BX			
		BXII	**P. IV**	*c*. 2100–2000	

TABLE 6 Table synthesising the divergence of building traditions between the Hafit and the Umm an-Nar periods. The earliest buildings (Hafit period) were built starting from the main internal space, and then adding the lateral rooms (*inside-out*). The Umm an-Nar structures were built starting from the perimeter, while the partition walls were traced afterwards (*outside-in*)

above). Besides, we can notice a significant coincidence between the grids based on small modules and the perimeter of the main rooms of the buildings.

If, as proposed above, the first operation in the field was the orientation of a reference line, then such line would first be used to trace the main space of the building, while the perimetral and partition walls would be traced afterwards. In this case, modular grids would not be the most appropriate method to trace the layout, as they would be more logically applied from one of the external sides towards the opposite side. The intersection of circles, on the other hand, would be compatible with the coincidence of both orientation and grids with the walls of the main central space.

4 | EVOLUTION OF ARCHITECTURE DURING THE EBA: THE SITE OF RAS AL JINZ RJ-2 AND REGIONAL COMPARISONS

Located about 10 km south of HD-6, in the bay of Ras al Jinz, the site of RJ-2 constitutes one of the key sites for the study of Eastern Arabian populations during the Early Bronze Age. The excavations carried out during the 1980s and 1990s, which resumed from 2007 to 2011, have detected four main occupations, defined by structural-stratigraphic remains (Azzarà & De Rorre, 2018; Cleuziou & Tosi, 2000) (Figure 3). The earliest evidence, represented by the remains of a few ephemeral structures, is dated to the fourth millennium BCE (Cleuziou & Tosi, 2000: 28). Following abandonment of the area during the early third millennium BCE, the vestiges attest a three-phase reoccupation of the site throughout the second half of the third millennium BCE (Umm an-Nar period, c.2600/2500–2000 BCE). The first of these occupations, Period II (c.2600/2500–2300 BCE), displays two separate dwelling complexes, known as *Southern Compound*, developing on three stratigraphic-structural phases. Period III (c.2300–2100 BCE) is marked by the construction of a cluster known as *Northern Compound*, consisting of five different buildings progressively built around a common courtyard, on a timespan of at least three stratigraphic-structural phases. The last occupation, Period IV, corresponding to the Final UAN period (c.2100–2000 BCE), consists of two structures made of rammed earth and abutting the *Northern Compound*, developing on two phases (Azzarà & De Rorre, 2018).

According to Cleuziou and Tosi (2000: 29), Period II and III present a series of mudbrick structures, characterised by large, flat modules (40/42 × 34/38 × 6/8 cm), laid as stretchers, and alternated with layers of butted sandy clay, about 20 cm thick. Recent observations made in the field, in the frame of a sampling campaign of earthen building materials for petrographic and geochemical analyses, suggest that building techniques used during these periods might have been more varied. From the beginning of Period IV the walls are made of rammed earth, associated with mortared stonework (Azzarà & De Rorre, 2018).

As for siting techniques and layout works, the plans of the architectures show a clear variation in the passage between Period III and IV and, conversely, consistency of techniques between Periods II and III (see above) (Azzarà, 2015: 309–316; Azzarà & De Rorre, 2018: 20–22). During both these periods, the buildings, although displaying different layouts, can all be inscribed in a rectangular figure of consistent proportions; at least one of the sides is occupied by a single large room, bordered by smaller spaces. During Period IV, the buildings, which occupy a much larger surface, present different proportions, and are organised around three sides of a wide internal courtyard, integrated to the structures since the construction.

In the same micro-regional context, comparisons for Period IV can be found at the sites of Khor Bani Bu Ali SWY-3 and Al-Ayn ALA-2, excavated under the field direction respectively of S. Méry and O. Blin (Figure 1). The settlement of SWY-3 displays the remains of an approximately squarish building made of stone and clay, marked by an internal partition dividing the dwelling into two rooms (cf. Figure 12g) (Méry & Marquis, 1998: 218–219, fig. 2–3). The site of ALA-2 has delivered the remains of two successive buildings. The most recent appears as a quadrangular structure lacking any type of internal partition, built of dry stuck stones, representing perhaps the base of a mudbrick structure (cf. Figure 12f); these vestiges obliterated an earlier building with slightly different orientation, similar to the former (Blin 2012: 487–488, fig. 13a–b).

4.1 | Orientation

The buildings are not iso-oriented, but every complex of structures presents a uniform or fairly uniform orientation. In addition, despite the slight difference among the main axes of the different compounds, the position of the settlement within the bay of Ras al-Jinz suggests that the complexes had likely been oriented following equivalent standards, dictated, most likely, by specific factors related to the quality of life within the buildings—ventilation and lighting in particular.

Considering the greater level of regularity and the larger size of buildings compared to HD-6, we can assume that also at RJ-2 the construction was preceded by the placement of a reference line. If such a line was parallel to the axes of the structures (roughly oriented on the north-east/south-west axis), the sighting point would have likely been a terrestrial landmark, rather than the rising sun. However, the tombs located on top of the terraces indicate that the east–west direction was still the preferential axis for grave orientation (Munoz et al., 2012: 455). The reference line of a building should not necessarily correspond to the axes of the structures. Such reference could correspond to the bisector or the trisector of the angles of the structures; the external walls of the structures could have been raised at 45° with respect to a bisecting line, or at 30° and 60° with respect to a trisecting line (cf. Figure 14).

Both the bisectors and the trisectors reasonably match the east–west axis, showing a difference of a few degrees; hence, the application of this method seems plausible, and we can presume that the layout works were not performed at a specific moment of the soli-lunar cycle, which would explain the slight variations of building orientations. Since every complex presents a core to which other buildings were added with time, the first structure would mainly serve as reference for the abutting dwellings.

4.2 | Finding regularities: the application of natural triples

The architecture of RJ-2 presents a relatively regular layout. The plans are not entirely uniform or perfectly symmetric, but the buildings conform to quadrangular geometric figures, at least in their original layout, which is sometimes modified through time. The masonries mostly form right or very close to right angles, excepted a few design errors. Altogether, the structures display more significant regularities and smaller variability compared to the dwellings of HD-6. Geometric properties of these buildings hint at deliberate reproduction of geometric abstractions or indicate, at least, that layout techniques resulted in regular figures.

The buildings of Periods II and III display the reiteration of specific modules, with persistent proportions and associations of proportions between distinct structural sections. This is especially evident on the dwellings that we could define as "compound cores", such as Buildings I and VII, abutted by later structures, or Building III, all marked by LD triples—or by the sum of a Q and a WA triple (Figures 11a–b, 12a–b, 13a–b, Table 1) (Azzarà, 2018: 109, fig. 13). The rooms also show reiterated modules, expressed by a small group of natural triples, and sometimes a structure can display one prevalent module (cf. Figures 11a–bI, 11b–bVI, VII).

As for Period IV, the plans of Building IV and Building XII, although partially known, reveal the utilisation of different modules, compared to previous periods, for both the perimeter and the internal partitions (Figures 11c and 12e); comparable proportions characterise the structures uncovered at SWY-3 and ALA-2 (cf. Figures 12f–g) (Azzarà, 2018: 109, fig. 14). Based on the material culture, the occupation of SWY-3 is coeval to Period IV at RJ-2, i.e. the very end of the third millennium (Méry & Marquis, 1998).

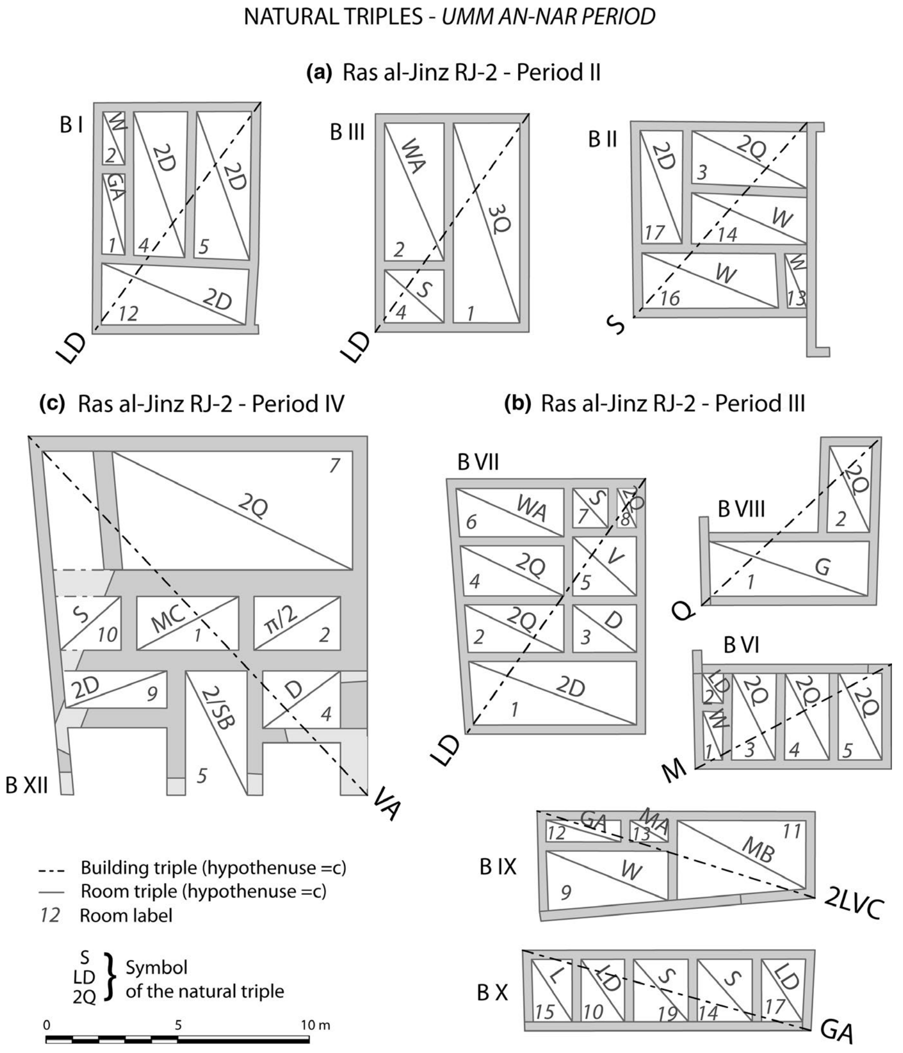


FIGURE 11 Application of natural triples to the structures of RJ-2, the example of building plans and rooms (plans: V. Azzarà)

The chronological frame of the Umm an-Nar occupation at ALA-2 is less accurate (Blin, 2012), but structural evidence might justify an attribution to the last centuries of the third millennium BCE.

4.3 | The application of modular grids

Geometric properties of buildings at RJ-2 show the existence of recurrent measures and proportions. Compared to HD-6, the high occurrence of specific associations of modules and their smaller variability suggests that geometric features were deliberately outlined, or at least that a series of geometric properties were known by the construction workers. While it is possible that a small series of Pythagorean triples were used to trace building layouts, alternative methods must be considered as well.

A series of modular grids of different base units were applied to the buildings, based on the units of lengths detected through natural triples and their multiples (30 cm, 45 cm, etc., Figure 12, Table 4). As a general assessment, building plans overlap with a grid of ≈90 cm base unit, which could be identified as a triple foot.

The consistency in the reiteration of modules is noteworthy. Buildings I, III and VII, corresponding to an LD triple, display identical proportions, with the short and the long sides measuring seven and ten modules respectively; Building VII displays height modules on its northern side, but this is related to the non-orthogonality of the western side. These buildings can also be seen as the merger of two different components, the main one of which corresponds to a Q triple with a side length of seven modules (Figure 12a–b). Building VIII, corresponding to Q triple as well, has identical sides, measuring seven modules (Figure 12b). As for Period IV, the plan overlaps a grid of 16 and 15 modules, which coincides with the triple VA (Figure 12e); although it must be stressed once again that the plan of Building XII is incomplete, the same proportions characterise the structures of SWY-3 and ALA-2, of which at least the former is coeval with Building XII (Figure 12f–g).

The internal partitions of buildings show consistent proportions as well (Figures 12a–c, e). During Periods

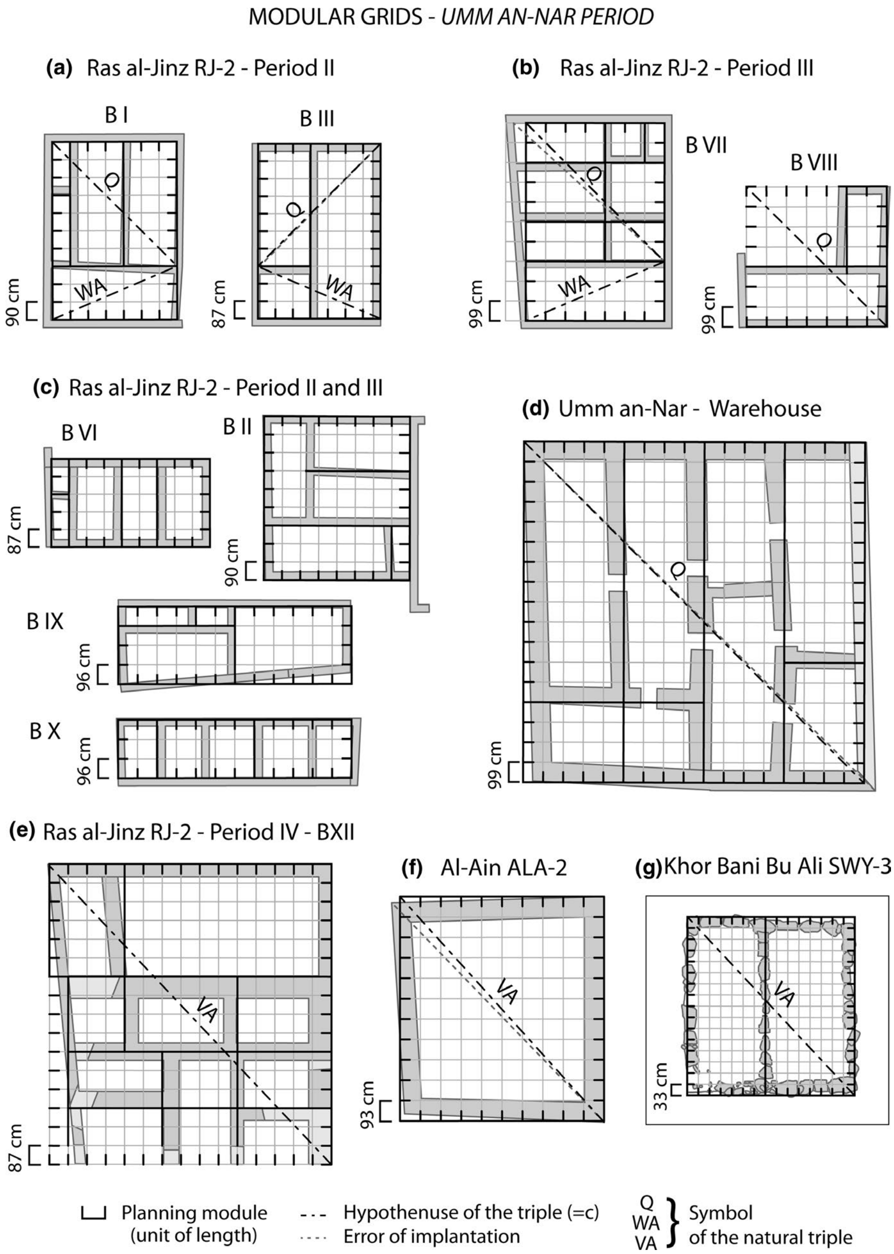


FIGURE 12 Application of modular grid to buildings of the Umm an-Nar period. All the structures are based on consistent units of lengths (planning modules) coinciding with a triple foot of ≈90 cm or a foot of ≈30 cm. The grid also corresponds to specific natural triples; the ratios of the triples [Q, WA] is consistent through Period I and II of RJ-2 (a, b) and has a comparison at Umm an-Nar (d); Period IV (e) shows a variation [VA], with parallels at the sites of ALA-2 (f) and SWY-3 (g) (plans: V. Azzarà)

II and III, the sides of the largest rooms mostly measure three and seven modules; smaller spaces have a width of two or three modules, and a length of five or six units, while the smallest rooms measure three modules in length and one to three modules in width. During Period IV, the proportions of rooms shift towards shorter rectangles.

Similar to Pythagorean triples, modular grids hint at the existence of a standardised layout system; moreover, in most cases, the number of units identified by applying the grids corresponds exactly to number of units defined through the natural triples; for instance, the triple Q 7-7-10 is matched by a grid of 7 (≈90) – 7 (≈90) – 10 (≈90), where ≈90 is a unit corresponding to the triple foot (≈90 cm).

4.4 | The application of circles intersection and the properties of triangles

As for HD-6, the intersection of quarter circles might have been used at RJ-2 to trace building layouts. The characteristics of the structures suggest that the properties of triangles might be exploited as well. The buildings that I have defined as "compound cores" consistently reflect a space composition of three triads (cf. Ranieri, 1997: 225, fig. 6.3); they correspond to an LD triple (16-23-28), composed in turn of a Q triple (7-7-10) and a WA triple (10-23-25) (Figures 13a–b, cf. Fig. 13c); an additional WA triple and an MA triple (4-7-8) can be added to the composition. Tracing smaller figures (such as Q and WA instead of LD triples) would imply the

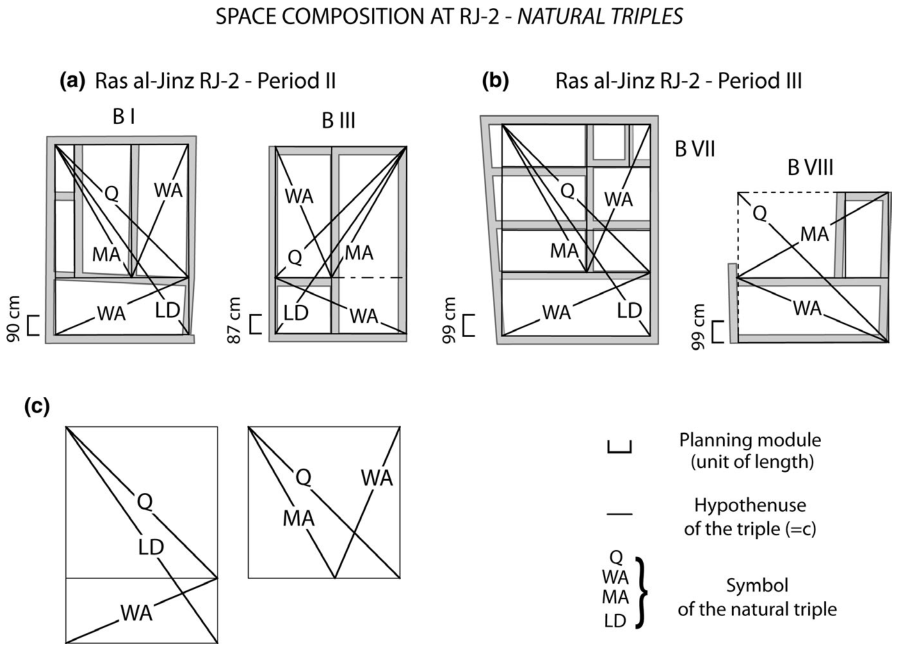


FIGURE 13 (a–b) Space composition of the "core buildings" (abutted by later structures) Building I, Building III, Building VII at RJ-2. These buildings consistently display a space composition associating the main triple LD to smaller triples Q and WA. The triple Q can be segmented in its turn into MA and WA triples; this segmentation also characterises Building VIII; (c) schematic representation of the composition (plans: V. Azzarà)

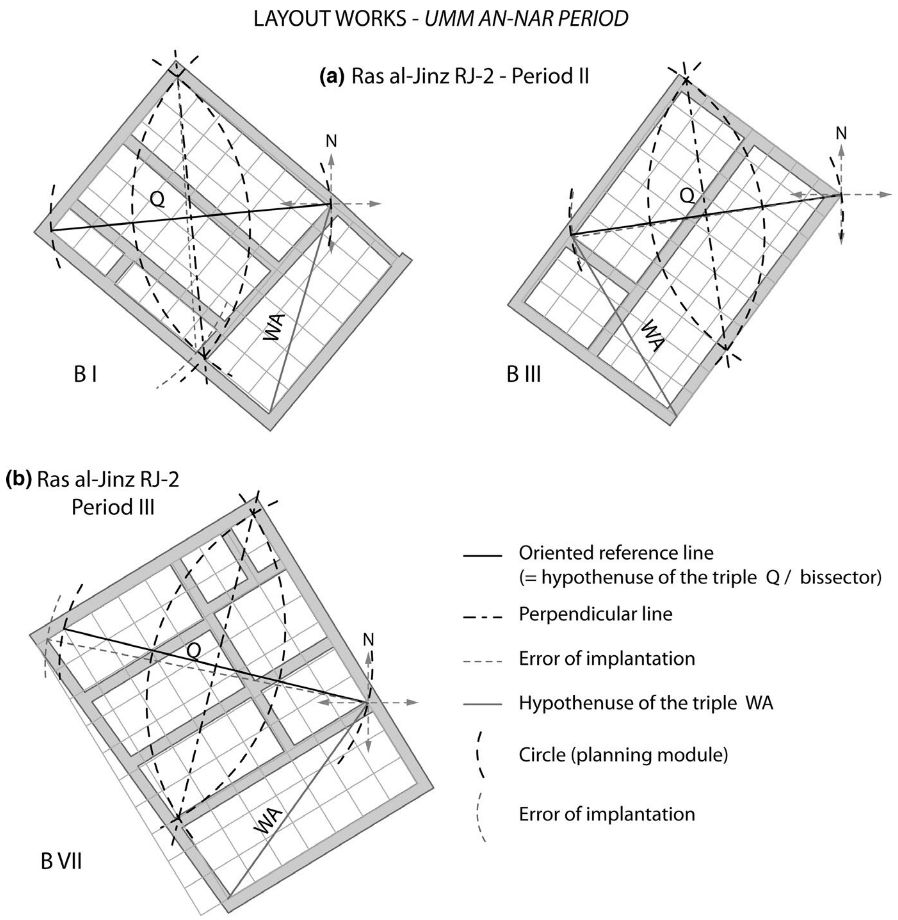


FIGURE 14 Examples of layout tracing through the intersection of circles or using the properties of equilateral triangles, with the oriented reference line corresponding to a bisector of the building and to the hypotenuse of a Q triple (plans: V. Azzarà)

utilisation of smaller length/width values, resulting in higher precision and more straightforward operations; thus, we may assume that the final plan of the structures would be obtained by juxtaposing two smaller figures, which could easily be cross-checked through the additional triples.

The hypotenuse of the Q triple always corresponds to the bisector of a building corner, roughly oriented on the east–west axis, and this bisector possibly coincided with the original reference line. From the latter, a right angle could be traced based on the properties of equilateral triangles and on the principle that for every point of a given circumference, the angle intercepted by the diameter is a right angle. More precisely, a 45° angle would have been traced on each side of the reference line (1) by (i) using the intersection of circles to create a perpendicular to the reference line (2), and (ii) starting from the intersection of these lines, tracing segments of identical length on one side of the reference line and on two sides of the perpendicular (Figure 14).

The three points obtained with this method could be used to outline a right angle having as a bisector the reference line, and the two other sides of the quadrangle could have been obtained through the same technique. This specific case corresponds exactly to a quadrangle having as a diagonal the hypotenuse of a Q triple. The same result could be obtained by tracing a circle of a given diameter starting from a point on the reference line (1′); the intersection between the circle and the line itself would give two points of the quadrangle, which in their turn would be the centres of new circles (2′); the intersections of these circles would give the remaining points of the quadrangle. It is worth noting that such layout techniques could have been used at the site of Umm an-Nar as well, where the Warehouse shows similar proportions, with a Q triple corresponding to 17-17-24 (Figure 12d) (Azzarà, 2018: 109, fig. 13).

Following the construction of the first right angles, the segments corresponding to the walls could be prolonged through Pythagorean triples (WA triple, in this case), or more easily by extending them on a given length, corresponding to three modules of ≈90 cm.

4.5 | Layout works during the Umm an-Nar period: an architecture “from the outside to the inside”

The consistency of proportions and modules detected at RJ-2 suggests the existence of a standardised layout system, implying some degree of knowledge of triangles properties and the intersection of circles. This is further emphasised by the fact that both techniques could be used producing an identical result, unlike what would happen at HD-6.

As noted above, the structures of HD-6 evoke building processes implying as a first step the outlining of the central space, with external rooms traced afterwards. Conversely, the buildings uncovered at RJ-2 were most likely traced starting from the external masonries, while partition walls would have followed (Table 6). Hence, such buildings were conceived “from the outside towards the inside”, a trait that some scholars consider as a mark of “true architecture” (cf. Forest, 1991: 170–171; Kubba, 1990: 46). Applying to RJ-2 the concept of architecture stricto sensu would perhaps be anachronistic, but the vestiges clearly hint at the deliberate utilisation of standardised modules.

5 | MODELLING THE BUILT ENVIRONMENT: CONTINUITY AND VARIATION

The analysis of the structures detected at HD-6, RJ-2, and a few contemporary sites, show a clear normalisation of building models and building techniques through time, starting from the layout works. The analyses also show a certain degree of continuity, concerning namely the system of measurement, identical within different spatial patterns.

All the systems used in the frame of this study to analyse spatial patterns (i.e., Pythagorean triples, modular grids and intersection of circles) point at the recurrence of real measures of ≈30 cm and its multiples, in particular ≈90 cm and ≈120 cm; thus, we can identify a base unit of ≈30 cm, which could be defined as a foot. Modules corresponding to three or four base units (≈90 cm and ≈120 cm) are consistent within all the buildings, and throughout the whole period analysed here; we can assume that they constituted predefined modules, identified as a triple foot and quadruple foot. These values have a close parallel in the modules characterising Mesopotamian architectures of the LC5 period; for these structures, Emery (2007: 282–285, tab. 6–7) suggests the utilisation of a triple and a quadruple foot, and identifies a base unit foot measuring 26–31 cm, with an average value of 29 cm, and the highest concentration of values between 29 and 31 cm.

Of course, such modules display some variability in terms of real measures, both at HD-6 and at RJ-2; in the same way, buildings from both periods can present design errors. This might depend on a number of reasons. First, it would be anachronistic to expect the utilisation of extremely accurate tools, and such accuracy would not be necessary in the first place. As ropes were probably one of the main tools used during the layout works, we must consider the deformation produced by hygrometric conditions, however small, and the impact of human error; besides, the notion of “accuracy” itself might have had a relative value. Finally, the bias related to vestige preservation should not be underestimated.

Reading metric data in this type of vestiges requires a certain degree of flexibility, within which a variance of 3–4 cm (or more, for bigger modules) would be acceptable. Reference values and a system of measurement did indeed exist, and the construction works were carried out following these parameters. No technical or cultural need, however, would demand the unconditional respect of these parameters, especially considering the probable lack of a ritualised dimension. Besides, the lack of written sources discourages us from seeking precision beyond one centimetre, especially considering that variability in measures has been attested in other cultural contexts, such as Mesopotamia, even in the presence of written codifications (e.g. Emery, 2007: 282–285, tab. 6–7).

As for the variation, the transformation of building layout through the occupations is significant, especially marked by the passage between Phases I-2 and I-3 of HD-6, by the passage from the Hafit (HD-6) to the Umm an-Nar period (RJ-2), and by the passage between Periods III and IV of RJ-2. At HD-6, the huddled agglomerations of Phase I-2, where buildings abutted each other without an apparent patterning, were replaced by the more symmetric and compact structures of Phase I-3, whose planning is also consistent. A series of buildings present a tripartite configuration, which might hint at cultural influence from nearby regions (see Figure 2; cf. Azzarà, 2013: 22–23, fig. 11). The possible origin of such a tripartite model might be related with the tradition of tripartite buildings typical of Mesopotamian architecture; this hypothesis is somewhat corroborated by similar systems of measurement (see above). Carter (2013: 584) points out the striking similarity with Ubaid structures; the latter, however, are chronologically too distant from the occupation of HD-6, and the similarity can only be formal (cf. Azzarà, 2013: 22–23, note 8). The tripartite pattern still characterises the architectures from LC5 to EDI–II periods (e.g. Emery, 2007), roughly coeval to HD-6. An exhaustive comparison exceeds the scope of this paper, but we can point out a series of substantial divergences. Along with the absence of T-shaped structures—i.e. structures with a long room at one end—the buildings at HD-6 display an irregular perimeter and a much smaller size; their internal partitions are also much smaller, and the side rooms have a different orientation; finally, the circulation system is quite distinct and, unlike Mesopotamian examples, the central hall is directly connected to the outer space (cf. Azzarà, 2013: 22–23, fig. 11). If the rather small size of the rooms was probably dictated by the characteristics of available roof beams—as ligneous species in the region are not suitable to produce long, straight beams (cf. Azzarà, 2018: 106)—the system of circulation and visibility of space indicate significantly different cultural needs (Azzarà, 2015: 297–300). Some form of cultural transfer must be taken into account (see below), but, as remarked by Aurenche (1981: 49–51), the main characteristic of this type of architecture is not the tripartite form itself, but the ideal symmetry that underpin its planning. The tripartite model is one of the most obvious arrangements if the aim is building a symmetric structure with a larger space.

As for RJ-2, the variation of spatial layout is quite substantial as well (see Figure 3; cf. Azzarà & De Rorre, 2018: 21–22, fig. 10). During Period II, the structures were built along the same axis, and connected by internal passageways at the end of the occupation. Period III is marked by the construction of a complex progressively organised around a shared courtyard. Period IV develops from this configuration, with buildings organised since the construction along three sides of an internal courtyard, each one comparable in surface to the whole compound of Period III. Although the analysis of plans indicates a variation of layout system in the passage from Period III to Period IV, these transformations of spatial layout most likely reflect a reorganisation of a cultural nature, concerning namely the relationships within and outside the social unit, and its size (Azzarà & De Rorre, 2018: 22–24; Azzarà, in press).

In the long term, the passage from the Hafit to the Umm an-Nar period corresponds in the first place to a shift in the architectural paradigm, which no longer complies with the need for a symmetric representation. The repetition of the models evokes nonetheless the conceptualisation of the built environment as the representation of a model also during the Umm an-Nar period. Beyond the cultural needs of the dwellers, we can stress a clear normalisation of building and siting techniques, and the construction of larger and more regular structures. One of the most evident transformations concerns the perimeter of the constructions. The buildings of HD-6 are not perfectly inscribed in a regular geometric figure. The similar articulated plans of Mesopotamian architectures have been interpreted as a means to provide shadow and shade (e.g. Crawford, 2015: 26). It has also been suggested that the articulations could reinforce structural solidity to allow the construction of a second storey (Margueron, 1989: 64–65, fig. 14). While this is unlikely for HD-6, the passage from an irregular perimeter (HD-6) to a regular figure (RJ-2) could indeed have technical reasons and indicate increased technical capacities.

We can see an analogous progression in the circular monuments widespread in the region, as shown, for instance, by the towers of Hili 8. Here, the later structures reveal more skilled work, compared to the earliest construction; for the latter, Cleuziou (1989: 63–64; 2002: 197) points out irregular thickness of the walls and significant flaws in verticality, and remarks that building techniques evoke dry-stacked stone rather than adobe structures, showing that masons were still unfamiliar with this type of building when first approaching a new form of construction. Unsurprisingly, the progression concerns funerary architecture as well, as monumental graves of the Umm an-Nar period also reveal significant advancements (e.g. Munoz, 2015).

6 | CONCLUSIONS

The analysis of buildings uncovered in a series of sites in Eastern Arabia allows an assessment of spatial patterns and layout systems in the region, and of their evolution throughout the third millennium BCE.

Whereas the first buildings attested during the Hafit period—and namely during Phase I-2 of HD-6—show a certain degree of imperfection, nothing suggests that the structures needed constant restoration and remodelling due to unskilled workmanship, and technical know-how cannot be considered as primitive (cf. Azzarà, 2013). The buildings hint at the utilisation of standardised procedures that, while undergoing unquestionable progression through time, do not show radical transformation. The structures uncovered at HD-6 seem to picture an "ideal" architectural canon from the beginning. This paradigm, acknowledged by the whole community, was associated to specific building procedures known by construction workers, although not strictly applied.

The current data set, however, does not show a continuity and evolution of techniques well rooted in preceding traditions, as is the case in Mesopotamia (e.g. Aurenche, 1981; Azzarà, 2013). This evidence evokes a Lamarckian model of evolution; in other words, the acquisition and development of know-how in the field of building crafts occur within a few generations. This obviously hints more at cultural transfer than at the experimentation ab imis of building techniques, as could be suggested by the appearance of tripartite patterns and of mudbrick architecture, as well as by the system of measurement, paralleling Uruk-type architecture (see above). Still, allochthones models and technical processes had been clearly adapted to the local socio-cultural needs, with the creation of local architectural paradigms and procedures (see also Azzarà, 2013). This savoir-faire increases through the generations, and results, at the Umm an-Nar period, in the generation of more standardised models, showing a clear perception of geometric properties, regardless of the actual formalisation of geometric principles. The filiation of Umm an-Nar standards from Hafit models is not patent, as it is, for instance, in pottery production (e.g. Méry, 2000: 79–123), and Umm an-Nar modular architecture lacks the characteristics of symmetricity, which is the main trait of Hafit archetypes. Following further investigation, Phase I-4 of HD-6, still little known, might offer interesting clues, as it shows some degree of continuity with Umm an-Nar material culture (Azzarà, 2015: 433, 609). Such continuity is attested by the utilisation of analogous systems of measurement throughout the EBA.

More work is certainly needed to fully understand the passage between the Hafit and the Umm an-Nar periods, and architectural studies should constitute an integral part of the archaeological research in this regard. A broader understanding of this transition can actually stem from an integrated analysis of what Rapoport (1990: 13–15) defines as the *fixed-features elements* (the buildings), the *semi-fixed feature elements* (i.e. the material remains related to the utilisation of space and the domestic or craft activities) and, through these, the *non-fixed-feature-elements* (the social actors and their behaviours) (Azzarà, 2012: 437; in press). In this respect, the example of HD-6 and RJ-2 is enlightening, as it shows the gradual transformation of the relationships among the individuals and an evolution in the way they organise their activities.

At the Hafit period, the architectural units of HD-6 reiterate a similar set of activities, and their spatial organisation is quite consistent within the various dwellings, with rooms in analogous position reproducing comparable functions (for specific details on the archaeological record and the interpretation of space use, see Azzarà, in press). However, during Phase I-3, the southern buildings display a room univocally related to craft activities throughout the different occupations of the dwelling. These workshops, relatively segregated within the buildings, show the traces of specialised manufactures, such as the production of hard-stones beads, and were probably related to specific categories of individuals. The record suggests that, while every household would produce soft-stone and shell ornaments, only a few specific households truly specialised in the production of jewellery, with quantities exceeding the consumption at the household or even at the village level, and including the manufacture of hard-stones. Still, these workshops were integrated to the domestic space, and the site does not present function-specific buildings. Most likely, every building identifies a single household (Azzarà, 2015: 581–595; in press).

RJ-2, on the other hand, displays function-specific buildings, and, more generally, the function-related segmentation of space is more evident, with higher degree of segregation between domestic and manufacturing activities (Azzarà, 2015: 595–602; 2018: 109–111, 118; in press). Buildings having different functions were associated with a single household, which probably consisted of a higher number of individuals, and perhaps more than one nuclear family. Starting from the end of Period II, the site also yields function-specific areas located outside the buildings, such as a workshop for bronze melting and casting (see De Rorre, 2012). From about the same period, the entire site of RJ-3, about 300 m away, was most likely a craft-related area connected to the settlement of RJ-2 (Azzarà & De Rorre, 2019; De Rorre et al., in press).

The nature of these variations helps tackle socio-economic transformations and diversification. The increasing segmentation of space in manufacturing activities and the growing standardisation of procedures, in particular, hint at gradual reorganisation of the workforce and increased know-how in a series of cottage industries, at both the intra-site and inter-site level, and, for the late occupations, even the appearance of separated workshop areas (for the dynamics of socio-economic complexification, see also Rouse & Weeks, 2011).

We cannot define gender or age categories, as the archaeological association of artefacts and individuals within the

EBA collective burials is virtually impossible. Yet, the analysis of settlement evidence and, more generally, of the archaeological record related to craft activities at the regional level, stresses the existence of socio-economic categories, i.e. individuals connected to specific activities (metalworkers, stone and shell craftspeople, potters, etc.) (Azzarà, in press).

Parallel technical developments characterise the domain of construction, certainly as far as funerary architecture is concerned (e.g., Gagnaison et al., 2004; Munoz, 2015), but also in "regular" settlement architecture. Similar to other craft domains, the characteristics of buildings and building materials suggest the existence of specialised workforce, not only at the Umm an-Nar period, but also during previous Hafit occupations.

Of course, introducing the concept of a specialised workforce requires further defining. For both periods, and for each of the categories evoked above, we can exclude full specialisation of work, full-time specialised craftspeople, and rigid social hierarchisation. Rather, we can assume they only worked part-time as craftspeople, and were engaged most of the time in activities more strictly related to subsistence and production of food supplies (Azzarà, 2015: 590–591, 598–600). Some of these categories probably overlapped with each other, and they certainly were non-attached specialists, independent from any form of elite sponsorship or control (cf. Costin, 1991). However, we can imagine the presence of "master-craftspeople", individuals who had broader and more precise know-how in some specific activities, and probably worked with apprentices (see also Brun et al., 2006). In the building domain, the master-masons could be helped by a less skilled workforce and, especially during older periods, by other community members (cf. CORPUS, 2012: 4). We can speculate further on the division of labour, assuming that the specialists would be responsible for marking off the layout on the ground, or producing the mudbricks (as two different but possibly superimposable categories), while actually laying mudbricks or stones would require less specialisation, and carrying materials and tools no specialisation at all (cf. also Ranieri, 1997: 219).

The degree of specialisation of these individuals would have increased with time, resulting probably towards the end of the third millennium in a clearer diversification of tasks, as would have happened in the domain of funerary construction (e.g. Munoz, 2015). For the Umm an-Nar period, we can even imagine that a limited number of individuals would have moved when needed from one settlement to the other, at the local or at the micro-regional level, to ensure the construction or the restoration of buildings (Azzarà, 2015: 567, 605); building design of structures dated to the Final UAN occupation in Southern Sharqiyah (SWY-3, ALA-2, RJ-2) suggests consistent layout procedures, and might indicate movement at a micro-regional radius of c.50 km (see above), although obviously this could just indicate shared traditions. Of course, this remains purely hypothetical, and it would not hint at a proper system of itinerant craftspeople or a masons' guild, implying full-time highly specialised work. Rather, this type of organisation would exist in the frame of non-attached, locally organised craftsmanship, and could indeed play an active role in strengthening the system of tribal alliances distinctive of Eastern Arabian populations.

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REFERENCES

Arnold, D. (1991). *Building in Egypt: Pharaonic stone masonry*. Oxford: Oxford University Press.

Aurenche, O. (1981). L'Architecture mésopotamienne du 7e au 4e millénaire. *Paléorient*, *7/2*, 43–55.

Azzarà, V. M. (2012). Household and domestic architecture: the "sociogram" of a social system. In J. Giraud, G. Gernez, & V. De Casteja (Eds.), *Aux marges de l'archéologie: Hommage à Serge Cleuziou* (Collection Travaux de la Maison René-Ginouvés 16) (pp. 431–442). Paris: De Boccard.

Azzarà, V. M. (2013). Architecture and building techniques at the Early Bronze Age site of HD-6, Ra's al-Hadd, Sultanate of Oman. *Proceedings of the Seminar for Arabian Studies*, *43*, 11–26.

Azzarà, V. M. (2015). *L'architecture domestique et l'organisation de la maisonnée dans la péninsule d'Oman à l'âge du Bronze ancien (IIIe millénaire av. N.E.)*. PhD thesis, Université Paris 1 Panthéon-Sorbonne, Paris.

Azzarà, V. M. (2018). Exploring cultural, social and economic complexification: settlement life through the Umm an-Nar period at Ras al-Jinz RJ-2. In S. Döpper (Ed.), *Beyond tombs and towers—Domestic architecture of the Umm an-Nar period in Eastern Arabia* (Series Arabia Orientalis 4) (pp. 97–120). Wiesbaden: Harrassowitz.

Azzarà, V. M. (in press). The rise of socio-economic complexity in non-urban societies: functional organisation and social meaning of space in Early Bronze Age Eastern Arabia. *Proceedings of the XVIII UISPP Congress, Paris, 4–9 June 2018*.

Azzarà, V. M. (forthcoming). Technical evolution of adobe building materials and specialisation of labour at Ra's al-Hadd HD-6 (Oman). In L. Jallot & A. Peinetti (Eds.) *New perspectives on ancient earthen architecture: Detection of structures and characterisation of building techniques*. Oxford: Archeopress.

Azzarà, V. M. & Cattani, M. (2018). The Hafit settlement of HD-6 at Ra's al-Hadd. In S. Cleuziou & M. Tosi (Eds.), *In the shadow of the ancestors: The prehistoric foundations of the early Arabian civilization in Oman*, 2nd expanded ed. (pp. 146–150). Muscat: Ministry of Heritage and Culture.

Azzarà, V. M., & De Rorre, A. P. (2018). Socio-cultural innovations of the Final Umm an-Nar period in the Oman Peninsula: new insights from Ras al-Jinz RJ-2. *Arabian Archaeology and Epigraphy*, *29*, 10–26. https://doi.org/10.1111/aae.12095

Azzarà, V. M., & De Rorre, A. P. (2019). The first excavation season at the Early Bronze Age settlement of Ra's al-Jinz RJ-3. *Journal of Oman Studies*, *20*, 25–47.

Binford, L. (1982). The archaeology of place. *Journal of Anthropological Archaeology*, *1*, 5–31.

Blin, O. (2012). Prospection et fouilles au pied du Djebel Salim Khamis (Ja'alan, Sultanat d'Oman): occupations et habitat du IIIe millénaire av. J.C. In J. Giraud & G. Gernez (Eds.), *Aux marges de l'archéologie. Hommage à Serge Cleuziou* (Travaux de la Maison René Ginouvès 16) (pp. 483–490). Paris: De Boccard.

Brun, P., Averbouh, A., Karlin, C., Méry, M., & De Miroschedji, P. (2006). Les liens entre complexité des sociétés traditionnelles et niveau de spécialisation artisanale: bilan et perspectives. *Techniques et culture*, *46–47*, 325–347.

Cable, C. M., & Thornton, C. P. (2013). Monumentality and the third-millennium "towers" of the Oman peninsula. In S. Abraham, P. Gullapalli, T. P. Raczek, & U. Z. Rizvi (Eds.), *Connections and complexity: New approaches to the archaeology of South Asia* (pp. 375–399). New York: Routledge.

Carter, R. (2013). The Sumerians and the Gulf. In H. E. W. Crawford (Ed.), *The Sumerian world* (pp. 579–599). London: Routledge.

Cleuziou, S. (1989). Excavations at Hili 8: a preliminary report on the 4th to 7th campaigns. *Archaeology in the UAE*, *5*, 61–87.

Cleuziou, S. (2002). The Early Bronze Age of the Oman peninsula from chronology to the dialectics of tribe and state formation. In S. Cleuziou, M. Tosi, & J. Zarins (Eds.), *Essays of the late prehistory of the Arabian Peninsula* (Serie Orientale Roma XCIII) (pp. 191–236). Rome: IsIAO.

Cleuziou, S., & Tosi, M. (2000). Ras al-Jinz and the prehistoric coastal cultures of the Ja'alan. *Journal of Oman Studies*, *11*, 19–73.

CORPUS (2012), Euromed Heritage. A7 Mud brick walls. Traditional Mediterranean Architecture. Retrieved from http://www.meda-corpus.net/eng/gates/PDF/F2/A07_MAR.PDF

Costin, C. L. (1991). Craft specialization: Issues in defining, documenting, and explaining the organization of production. In M. B. Schiffer (Ed.), *Archaeological method and theory* (pp. 1–56). Tucson, AZ: University of Arizona Press.

Crawford, H. E. W. (2015). *Ur: The city of the Moon God* (Archaeological Histories Series), London: Bloomsbury Academic.

De Rorre, A. P. (2012). Un atelier de bronzier du IIIe millénaire au Sultanat d'Oman. In J. Giraud, G. Gernez, & V. De Casteja (Eds.), *Aux marges de l'archéologie: Hommage à Serge Cleuziou* (Collection Travaux de la Maison René-Ginouvés 16) (pp. 475–482). Paris: De Boccard.

De Rorre, A. P., Berger, J.-F., Delfino, M., Kenoyer, J. M., Maini, E., & Azzarà, V. M. (in press). The Ras al-Jinz reloaded: Resuming excavations at the edge of Arabia. *Proceedings of the Seminar for Arabian Studies*, *53*.

Döpper, S. (2018). Towers and ditches in third millennium BC Eastern Arabia, a view from Building II at Bat, Sultanate of Oman. *Paléorient*, *44*, 121–133.

Düring, B. S., & Botan, S. A. (2018). The Early Bronze Age settlements of the Sohar Hinterlands: Scratching the surface. In S. Döpper (Ed.), *Beyond tombs and towers—Domestic architecture of the Umm an-Nar period in Eastern Arabia* (Series Arabia Orientalis 4) (pp. 17–27). Wiesbaden: Harrassowitz.

Emery, A. (2007). *Concevoir et bâtir dans la Mésopotamie protohistorique. L'utilisation de schémas architecturaux au IVe millénaire av. J.-C*. PhD thesis, Université Paris 1 Panthéon-Sorbonne, Paris.

Forest, J.-D. (1991). Le système de mesures de longueur obeidien, sa mise en œuvre, sa signification. *Paléorient*, *17*, 161–172. https://doi.org/10.3406/paleo.1991.5094

Frifelt, K. (1995). *The Island of Umm an-Nar, Vol. 2. The third millennium settlement*. Aarhus: Jutland Archaeological Society Publications XXVI/2.

Gagnaison, C., Barrier, P., Méry, S., & al Tikriti, W. Y., (2004). Extractions de calcaires éocènes à l'âge du Bronze et architecture funéraire à Hili (Emirat d'Abou Dhabi). *Revue d'Archéométrie*, *28*, 97–108. https://doi.org/10.3406/arsci.2004.1065

Goyon, G. (1969). Quelques observations effectuées autour de la pyramide de Khéops. *BIFAO*, *67*, 71–86.

al-Jahwari, N. S., Douglas, K., al-Belushi, M., & Williams, K. D. (2018). Umm an-Nar settlement at Dahwa (DH1), Oman: Preliminary results of the archaeological investigation, 2014–2016. In S. Döpper (Ed.), *Beyond tombs and towers—Domestic architecture of the Umm an-Nar period in Eastern Arabia* (Series Arabia Orientalis 4) (pp. 29–49). Wiesbaden: Harrassowitz.

Kubba, S. (1990). The Ubaid period: Evidence of architectural planning and the use of a standard unit of measurement, the 'Ubaid-Cubit' in Mesopotamia. *Paléorient*, *16*, 44–45.

Mansfield, D. F., & Wildberger, N. J. (2017). Plimpton 322 is Babylonian exact sexagesimal trigonometry. *Historia Mathematica*, *44*, 395–419. https://doi.org/10.1016/j.hm.2017.08.001

Margueron, J. C. (1989). Architecture et société à l'époque d'Obeid. In E. F. Henrickson, & I. Thuesen (Eds.), *Upon this foundation—The Ubaid reconsidered. Proceedings from the Ubaid Symposium, Elsimore, 30 May–1 June 1988* (CNI Publications 10) (pp. 43–78). Copenhagen: Museum Tusculanum Press.

Méry, S. (2000). *Les céramiques d'Oman et l'Asie Moyenne. Une archéologie des échanges à l'âge du Bronze*. Paris: Édition du CNRS.

Méry, S., & Marquis, P. (1998). First campaign of excavation at Khor Bani Bu Ali SWY-3, Sultanate of Oman. *Proceedings of the Seminar for Arabian Studies*, *28*, 215–228.

Mosseri-Marlio, C. (2000). Sea turtle and dolphin remains from Ras al-Hadd, Oman. In M. Mashkour, A. M. Choyke, H. Buitenhuis, & F. Poplin (Eds.), *Proceedings of the 4th International Symposium on the Archaeozoology of Southern Asia and adjacent areas* (pp. 94–103). Groningen: ARC.

Munoz, O. (2015). La "fabrique des ancêtres". Complexification sociale et sépultures collectives dans la péninsule d'Oman à l'âge du Bronze ancien. In G. Delaplace & F. Valentin (Eds.), *Le funéraire. Mémoire, protocoles, monuments* (Colloques de la Maison René-Ginouvès 11) (pp. 255–265). Paris: De Boccard.

Munoz, O. (2017). Transition to agriculture in South-Eastern Arabia: Insights from oral conditions. *American Journal of Physical Anthropology*, *164*, 702–719. https://doi.org/10.1002/ajpa.23307

Munoz, O., Ghazal, R. O., & Guy, H. (2012). Use of ossuary pits during the Umm an-Nar period: New insights on the complexity of burial practices from the site of Ras al-Jinz (RJ-1), Oman. In J. Giraud, G. Gernez, & V. De Casteja (Eds.), *Aux marges de l'archéologie. Hommage à Serge Cleuziou* (Travaux de la Maison René Ginouvès 16) (pp. 451–467). Paris: De Boccard.

Ranieri, M. (1997). Triads of integers: how space was squared in ancient times. *Rivista di Topografia Antica*, *VII*, 209–244.

Rapoport, A. (1990). Systems of activities and systems of settings. In S. Kent (Ed.), *Domestic architecture and the use of space, an interdisciplinary cross-cultural study* (pp. 159–176). Cambridge: Cambridge University Press.

Robson, E. (2001). Neither Sherlock Holmes nor Babylon: A reassessment of Plimpton 322. *Historia Mathematica*, *28*, 167–206.

Rouse, L. M., & Weeks, L. (2011). Specialization and social inequality in Bronze Age SE Arabia: Analyzing the development of production strategies and economic networks using agent-based modelling. *Journal of Archaeological Science*, *38*, 1583–1590. https://doi.org/10.1016/j.jas.2011.02.023

Salvatori, S. (2001). Excavations at the funerary structures HD 10–3.1, 4.1, 4.2 and 2.1 at Ras al-Hadd (Sultanate of Oman). *Rivista di archeologia*, *XXV*, 67–83.

Salvatori, S. (2007). The Prehistoric Graveyard of Ras al-Hamra 5, Muscat, Sultanate of Oman. *Journal of Oman Studies*, *14*, 1–353.

Schmidt, C. (2018). The Umm an-Nar settlement of al-Zebah. In S. Döpper (Ed.), *Beyond tombs and towers—Domestic architecture of the Umm an-Nar period in Eastern Arabia* (Series Arabia Orientalis 4) (pp. 71–86). Wiesbaden: Harrassowitz.

Schmidt, C., & Döpper, S. (2017). The development of complexity at 3rd millennium BC al-Khashbah, Sultanate of Oman: Results of the first two seasons 2015 and 2016. *Proceedings of the Seminar for Arabian Studies*, *47*, 215–226.

Stalley, R. (1999). *Early medieval architecture*. Oxford: Oxford University Press.

Swerida, J. (2018). Bat and the Umm an-Nar settlement tradition. In S. Döpper (Ed.), *Beyond tombs and towers—Domestic architecture of the Umm an-Nar period in Eastern Arabia* (Series Arabia Orientalis 4) (pp. 51–69). Wiesbaden: Harrassowitz.

Thornton, C. P., Cable, C. M., & Possehl, G. L. (2016). *The Bronze Age towers at Bat, Sultanate of Oman. Research by the Bat Archaeological Project 2007–12* (University Museum Monographs 143). Philadelphia, PA: University of Pennsylvania Press.

Weeks, L. (2003). *Early metallurgy of the Persian Gulf. Technology, Trade and the Bronze Age World*. Boston: Brill Academic Publisher.

Weisgerber, G. (1981). Mehr als Kupfer in Oman–Ergebnisse der Expedition 1981. *Der Anschnitt*, *33*, 174–263.

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