Understanding the Dead. Preliminary Results of Data Analysis and 3D-Visualization at the Shahr-i Sokhta Graveyard

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Abstract

The Graveyard of Shahr-i Sokhta in Sistān, Iran, is one of the largest in the ancient Near East, with up to 40,000 undisturbed, mostly individual burials. An average of seven finds per burial (up to 50 in some cases), mainly ceramics, have been recovered. Since 1972, over 1,000 graves have been excavated and descriptions have been published in many cases. The central feature of this research is the use of multivariate/statistical analysis to identify the Graveyard's groupings and interpret the results. Various types of ceramics with a range of decorative motifs, such as Pear-Shaped Beakers and Truncated-Conical Bowls, as well as imported Emir Grey and Namazga Ware, are of primary interest regarding the period 3200-1800 BC. The finds themselves and their relative position, the skeletal position, and the distance between the burials are understood as vectors of information

in a multi-dimensional space. These calculated groupings can be interpreted chronologically, chronologically and sociologically. The approach to burials reflects a living society and the circulation of individuals in an interregional sphere. To deal with such immense data sets from a number of campaigns, proper digitisation and mapping of the excavated quadrants are essential. Programs such as CAD, GIS or CAPCA offer the possibility of visualising the results with an additional focus on 3D SfM Modelling.

1. Geography, geology, research history and project framework

The Graveyard of Shahr-i Sokhta,[1] the 'Burnt City', is immense. According to conservative estimates, it houses at least 20,000 and possibly more than 40,000 burials,[2] surpassing by far sites such as Gonur Tepe or Shahdad[3] in the Indo-Iranian Borderlands. It has an area of approximately 30 ha[4] and is situated to the southwest of the main settlement area (Fig. 1), from which it is separated by a small dry lake, evidenced by sedimentary deposits. Shahr-i Sokhta is located in Sistān, which got its name from the Scythians, in the easternmost part of Iran in one of the deepest points of the western Helmand Basin. Here lies the inland delta of the Helmand River, rising in the Hindu Kush, which once formed a large lake (Lake Hāmūn), with today's sparse remains to the north. In Old Persian, the area was probably called *z-r-k* (i.e. Zranka), while in Ancient Greek it was Drangiana, meaning 'sea land'.[5]

Aeolian processes can be identified, alternating with sometimes very humid situations in the Neogene and Quaternary.[6] The surface has thus been affected by both wind erosion[7] and water erosion,[8] seen in the desert area on the edges of the

1. Shahr-i Sokhta is occasionally shortened to SIS in the text.
2. Piperno - Salvatori (2007: 9) estimate 20,000 burials, Sajjadi (2003: 21) 25,000-40,000, and Bonora *et al*. (2000: 495) the most pessimistic with 18,000.
3. Gonur Tepe is believed to have over 3,000 burials (Sarianidi 2007), while Shahdad has 382 excavated graves and possibly several thousand (Hakemi 1997 and Götzelt 2002: 455).
4. On the extent of the Graveyard, see Sajjadi 2003: 23, fig. 2; Piperno - Salvatori 2007: 9.
5. Schmitt 1996: 534-537.
6. Jux - Kempf 1983: 45ff.
7. Sistan is estimated to have 120 days per year of wind from the north.
8. Erosion channels due to the infrequent but intense rains.

remaining buttes.[9] These are remnants of the erosion caused by the Hirmand's tributaries to the former lake shore, on which the site of Shahr-i Sokhta lies. Today they reach heights of over 30 m above the surrounding terrain.

Geologically, the undisturbed layers within the Graveyard vary.[10] Fine to medium-fine gravel and crushed stone are mainly recognisable on the surface and on the upper edge of the excavated profiles to a depth of 0.40 m (Fig. 2), which in some cases has protected the hill from the above-mentioned erosion. This natural stratum is often followed by a sometimes hard and salty clay layer with a thickness of up to 0.60 m, which in many cases lies on top of a further layer of gravel and crushed stone, which can also be up to 0.50 m deep. Another layer of looser clay with a thickness of 0.40-0.50 m follows. However, the sequence of layers in the area varies widely, and fine sand can often be found at ca. 1.00 m below the surface. These circumstances sometimes have an intense impact on the finds, affecting the bones the most. The anthropological finds, which on average lie at a depth of 0.80-1.00 m, but can also be deeper than 2.00 m, are better preserved in a softer environment than in a harder one. In some situations, the bones are reduced to a powder.[11] There are also extreme cases where the buried material is incrusted with the adjacent soil due to the capillary effect and the resulting salination.[12]

Although the excavation of the settlement by IsMEO (later IsIAO) under Maurizio Tosi began in 1967, it was 1972 when the first excavation work on the Graveyard started. Unlike the settlement area, which is often littered with ceramic sherds due to aeolian weathering, no discoveries were observed on the surface of the Graveyard. The remarkable point about this area is the absence of any recent destruction, a key scientific research requirement. The first Italian investigations lasted until 1978 under Marcello Piperno[13] and uncovered 230 graves with over 300 burials in an area of 3000 square metres. 1997 saw the start

9. Jux - Kempf 1983: 28ff.
10. Sajjadi 2003: 21ff.
11. In strong winds, it is hard not to inhale the bones if the powder is blown into your face while excavating.
12. See G9509 A and G9509 B (fig. 4 and fig. 21).
13. Piperno - Salvatori 2007: 9.

Fig. 1: distribution of use areas of Shahr-i Sokhta and central archaeological operations (based on Sajjadi 2003: 23, fig. 2).

Fig. 2: the eastern profile of square NFG showing the geological layers around a grave, which burial chamber edge (Grave Type 4 - Catacomb) can be seen reaching downwards from the surface to the left of the 2 m scale (compare fig. 22 c) (photo KRVAVAC by 2018).

of new excavations in the Graveyard, which continue to this day, with more than 700 more graves excavated under the overall direction of Sayyed Mansur Sayyed Sajjadi (ICHTO and RICHT). An international interdisciplinary archaeological campaign has been conducted since 2016 under the direction of Enrico Ascalone (MAIPS[14]). The present author participated in person in these campaigns as part of his PhD thesis.[15]

The project consists of collecting as much archaeological information as possible from the excavation area and the relevant storage facility. Of course, the emphasis was on the burials and finds from the Italian excavations of 1972-1978, many of which have been the subject of publications, most importantly M. Piperno and S. Salvatori (2007), who state that 'a detailed specification of the grave objects taphonomy might encourage and facilitate further and deeper analysis of their functional significance and the importance of ritual order which often seems to be the case'.[16] In this spirit, the results of the present author's PhD thesis will include an assessment of the data which will hopefully be of use for future archaeological work.

14. MAIPS - Multidisciplinary International Archaeological Project at Shahr-i Sokhta directed by Prof. Enrico Ascalone.

15. Prof. Adelheid Otto and Prof. emer. Michael Roaf of the University of Munich/Germany, LMU Ludwigs-Maximilians-University, Institute of Near Eastern Archaeology, are supervising the PhD thesis, entitled 'Moving Societies – Multivariate Analysis of the Graveyard of Shahr-i Sokhta'. https://www.en.vorderas-archaeologie.uni-muenchen.de/persons/phd-students/krvavac/index.html (01.03.2021).

Fortunately, it was possible to participate in the Graveyard excavations in 2018 and 2019. Unfortunately, for administrative reasons, access to the storage facilities housing the finds from the excavations of the last century was not possible, which is why a rescheduling was necessary and it was decided to concentrate on the discoveries from the most recent campaigns.

Heartfelt thanks are due to Enrico Ascalone and Seyyed Mansur Seyyed Sajjadi, who made it possible to participate in the archaeological campaigns in Shahr-i Sokhta, as well as to all the colleagues and friends of the excavation team for the many scientific discoveries, cultural impressions, adventures and delightful hours spent.

2. Investigations during the 2018 and 2019 Seasons in the Graveyards

In the 2018 campaign, excavations continued in Graveyard[17] square NFG (Fig. 3), where two graves, G9500 and G9501, had already been found. A further 8 graves containing 13 burials, G9502, G9503, G9504, G9505 A, G9505 B, G9505 C, G9506 A, G9506 B, G9507, G9508 A, G9508 B, G9509 A and G9509 B, were recognised. These were at different depths, the maximum being 2.15 m (478.40 m above sea level), and belonged to grave types 2 and 4.[18] In grave G9509,[19] a catacomb (grave type 4) measuring ca. 2.50 m (S-N) x 1.50 m (Fig. 4), two individuals were found, probably a mother (G9509 A) and her child (G9509 B), on the basis of the anthropological data.[20] Stratigraphic observation reveals that the two knees/*Patellae* of G9509 A touch the two ischial bones of the hip/*Oses ischiae* of G9509 B, and there is a ca. 1 cm gap between the two skulls/*Craniae*. Thus, the two individuals must have been buried at the same time or in immediate succession, because the anthropological *in situ* position of G9509 A shows that

17. Rajab Mohammad Zaruri has been in charge of the Graveyard excavations for years, and he and his team deserve the warmest thanks.
18. Sajjadi 2003: 26ff fig. 4 and Piperno - Salvatori 2007: 17 fig. M.
19. Graves G9509 A and G9509 B were excavated in order to create a 3D-Structure for the SfM Model (see Fig. 20).
20. The anthropological recovery and conservation of the burials discovered during the 2018 season were undertaken by Iranian researchers assisted by the present author and Serena Siena, to whom I extend my sincere thanks for her excellent cooperation and deep insight into anthropology.

Fig. 3: a) CAD-Plan of the Graveyard's main Excavation Area with the Italian (green) and Iranian (purple) Investigations. b) Detailed and partly 'Corrected' Position of the Examinations in the Northern Part (Compare Fig. 18). c) Detailed part of Square IRV showing the different layers created by merging all information, as structure, skeletal, finds, Decoration Motifs and further.

G9509 B was not disturbed. An alabaster vessel under the right elbow of G9509 A is the only sign that it was moved when G9509 B was enclosed. Both individuals were placed in a foetal position facing south with their heads facing east, B in front of A. A is a young adult (up to 30 years) and B an older child (8-12 years). Their bones were in generally good condition, except the western ones, the upper surface of which, as already described, was mainly covered by a calcined layer up to 2 cm thick.

A total of two alabaster vessels were found, first as described and the other on the southern edge of the grave. Furthermore, two Pear-Shaped Beakers were found on the burial's southern edge and two Biconical Small Jars on its western

edge. The separate burial G9504, which was of a male and was positioned above the other two, could be regarded as the third part of the family.[21]

A further 14 graves were discovered in square NAQ: G9600, G9601, G9602, G9603, G9604, G9605, G9606, G9607, G9608, G9609, G9610, G9611, G9612 and G9613, of which two were empty, and one was of a dog. Burial G9606[22] (Fig. 5) is of grave type 1 with the shape of a simple oval pit. Its edges were recognised at a depth of ca. 1.80 m. The human remains have a southeast-to-northwest orientation, measuring roughly 1.60 m (SE-NW) x 0.70 m. The foetal position is found again, this time with the head in the southeast facing northeast. Fortunately, the bones were in excellent condition except for the left hip/*Os ischium sinisterum*. The right hand/*Manus dextra*, with a sharply bent arm/*Membrum superius dextrum*, was found under the lower jaw/*Mandibula*, while the left was placed on the hip. Unfortunately, no artefacts were found, which makes dating very difficult. The individual was approximately 1.80 m tall, and anthropological analysis determines the sex as male, with a provisionally estimated adult age of 20-30 years. Due to the lack of grave goods, this grave could not be directly associated with any other burial.

3. Tachymetric survey and examination of the Graveyard for the creation of a CAD-based Plan

Topographic coordinates are essential for the proper use of a tachymetric plan based on CAD (Computer-Aided Design), as well as for 3D SfM Modelling and GIS and other software. In the course of the research and via contact with past and present excavation participants, it became apparent that only local coordinates were available. Fortunately, the excavation's topographer[23] helped to measure several points more precisely.[24]

21. Dating the burial is difficult because the vessels are highly incrusted.
22. G9606 was excavated by the present author in order to create a 3D Structure from Motion (SfM) Model (see Fig. 21).
23. Thanks are due to Giuseppe Minaya.
24. Special thanks are due to the Institute of Near Eastern Archaeology of the LMU and Prof. Adelheid Otto for the loan of the Leica Flexline TS06 R500 Plus Total Station for the 2019 Season.

Fig. 4: Square NFG - G9509 A and G9509 B (Compare 3D-Model Fig. 20) (photo M. Rahmani 2018).

Firstly, these include the central fixed points of the coordinate system, each quadrant of which measures 250 m along the edge, established by the Italian campaigns of the 1960s and 1970s and marked with concrete blocks. Secondly, the edges of the main excavation squares were traced during the Italian campaigns of 1972-1978 and the Iranian campaigns of 1997-2018. The third part of the data collection concerned the reference points for the 3D SfM Modelling of the newly discovered burials in the NAQ and NFG squares.

In total, over 450 different measurement points were recorded. Due to the lack of local reference points, it was necessary to take measurements with reference to the concrete blocks, in some cases at distances of over 750 m, in order to ensure their accuracy. In addition, verification measurements were taken in order to minimise the inaccuracy of measuring over large distances, which is mainly seen on the topographic DEM (Digital Elevation Model) (Fig. 6). In the end, these were performed by the present author with the prism attached to the tripod, as human assistance would have been too imprecise.

Fig. 5: Square NAQ - G9606 (Compare 3D-Model Fig. 21) (photo M. Rahmani 2018).

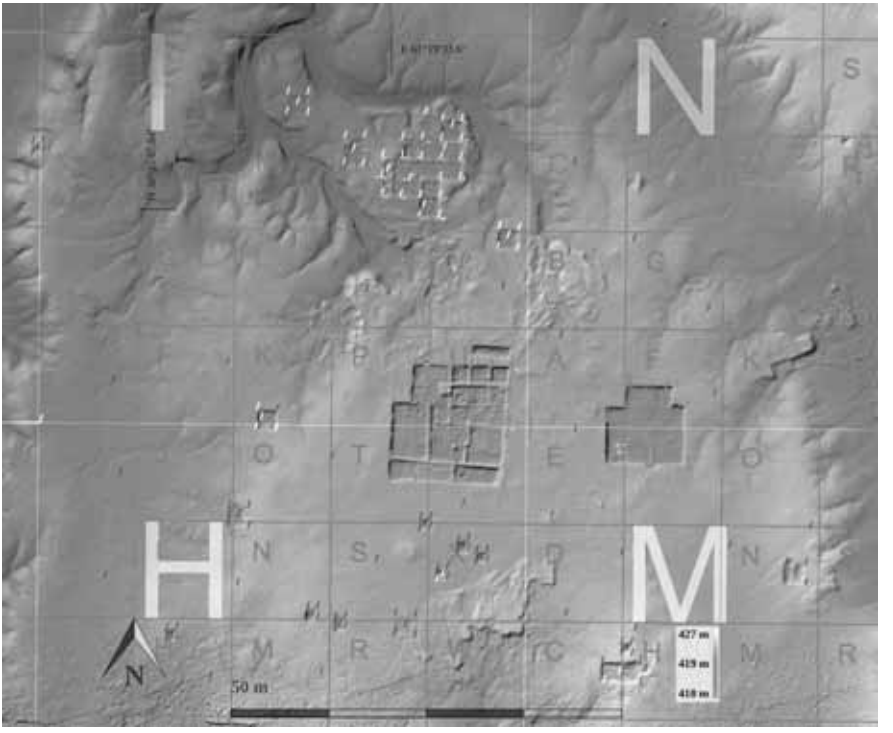


Fig. 6: DEM (Digital Elevation Model) shows the graveyard's northern topographic section and measured different tachymetric points (green, purple, grey) for various uses.

The work helped complete the digital mapping of the Graveyard, which the present author started and developed as part of his PhD thesis, initially focusing on the 1972-1978 Italian campaigns. By scanning various published plans,[25] the excavated squares and the burials' exquisite drawings, the framework was laid for the creation of a detailed CAD-based plan. The individual burials' correct position, together with their shape, bone remains and artefacts, were each placed in separate CAD layers in order to handle them as desired. Special attention was paid to the various ceramic forms, especially the decorative motifs,[26] which occur in large quantities and can provide accurate information about the time

25. Especially Piperno - Salvatori 2007.
26. Decorative motif will occasionally be shortened to DM in the text.

and type of use. Above all, the digital mapping enables data to be exported for use in GISs and other formats, and it optimises the integration of metadata with georeferencing for the visualisation of complex results. The site's division into a grid composed of squares measuring 250x250 m, 50x50 m and 10x10 m,[27] the smallest labelled with three letters, is highly commended. The same applies to the documentation of the finds, which was designed with this in mind, and the graves are labelled with reference to the 10 m squares, a system which is still applied by Iranian researchers today. Unfortunately, due to the enormous distances, their measurement caused problems because, on the one hand, the primary excavation grid is turned clockwise by about 0.49° to the north-south axis. On the other hand, the Graveyard's excavated squares are partly offset by up to 10 m in various cardinal directions. This issue makes it harder to geographically combine the various plans of the different excavation campaigns within a CAD environment, and above all to use applications supported by Global Positioning Systems such as QGIS (Quantum Geographic Information System).

The digital mapping was designed to be able to integrate new information as needed. However, because an essential aspect of the PhD thesis was the receipt of the latest .dwg files that Iranian colleagues had created with all the tombs excavated up to 2016 during the Iranian excavations, the individual CAD layers had to be synchronised. The synchronisation is possible because the same essential grid and coordinate system was used throughout the excavation campaigns.[28] In combination with each tomb's scanned drawings, each feature's correct position can be digitised and added to the existing scheme, creating a complete digital plan of the Graveyard. In this way, the excavated burial and settlement areas can be compared because the people who lived in the settlement were buried in the Graveyard, thereby establishing a connection between them.

27. Piperno - Salvatori 2007: 16 fig. L
28. Biscione et al. 1974: 32 fig. 5; Tosi 1983: fig. I; Piperno - Salvatori 2007: 16 fig. L; Sajjadi - Moradi 2015: 78 fig. 1a.

4. Study of the Artefacts

The pottery found in the Shahr-i Sokhta Graveyard (1123 finds) is highly varied and displays a variety of forms, with Truncated-Conical Bowls and Pear-Shaped Beakers being the most common, followed by Cylindrical-Conical Bowls, Biconical Small Jars and Ogival Jars, as well as other rarer variants (Fig. 7).

These represent only the results of the 1972-1978 Italian excavation campaigns, which were recovered from squares HNE, HRY, HTW, HYC, HYH, HYT, INK, IPQ, IPV, IPW, IRC, IRD, IRL, IRM, IRQ, IRR, IRV, IRW, IRX, IUB, IUC, IUP, IUQ, IUR, IUU, IWC, IWD, LNX, LSD and LSI.[29] The finds include imported Emir Grey Ware[30] from Southern Central Asia,[31] Mundigak,[32] Tepe Yahya/Bampur[33] and Nal.[34] In the published literature, settlement finds play the lead role in establishing the chronology and interregional contacts. Unlike the settlement finds, which are mostly fragmentary, the Graveyard pottery almost always consists of whole vessels deposed as unused grave goods. Thus, the Decorative Motifs, including secondary motifs and potter's marks, are exceptionally recognisable, since they appear in hundreds of different variants from all periods, on thousands of ceramic vessels. Excellent scientific work has been done to catalogue the Decorative Motifs and classify them into coherent groups with individual numbering and codification,[35] establishing the basis for further scientific work, including statistical analysis. The Decorative Motifs developed more intensively than the ceramic types, of which however they are often characteristic (Fig. 8).

Unfortunately, access to the finds from the 1970s excavations was impossible for administrative reasons. Therefore, it was necessary to observe finds from more recent excavations, which show exactly the same vessels with the same

29. Piperno - Salvatori 2007: 11-15 fig. B-K.
30. Piperno - Salvatori 2007; see SIS-Graves G716/2, G731/36, G754/8.
31. Sarianidi 1983: 186f and Biscione 1984: 69ff; see SIS-Graves G114/7, G706/4, G722/2.
32. Piperno - Salvatori 1983: 188f; see SIS-Graves G725 Inf./22 and G731/55, G731/56 ('Brandy Cups').
33. Mutin - Lamberg-Karlovsky 2013: Fig. 3.109; see SIS-Graves G725 Inf./51, G725 Inf./52, G731/41.
34. Piperno 1979: 128; see SIS-Graves G10/1&2, G55 Inf./1, G413/5.
35. Piperno - Salvatori 2007: 353-379 Decorative Motifs and Biscione-Bulgarelli 1983: 228-258. Other literature deals with vessel construction and the classification and codification of decoration motifs. See Gyselen - Lerouge 1983, Pracchia 1984, Nalesini 1984 and Moradi 2009.

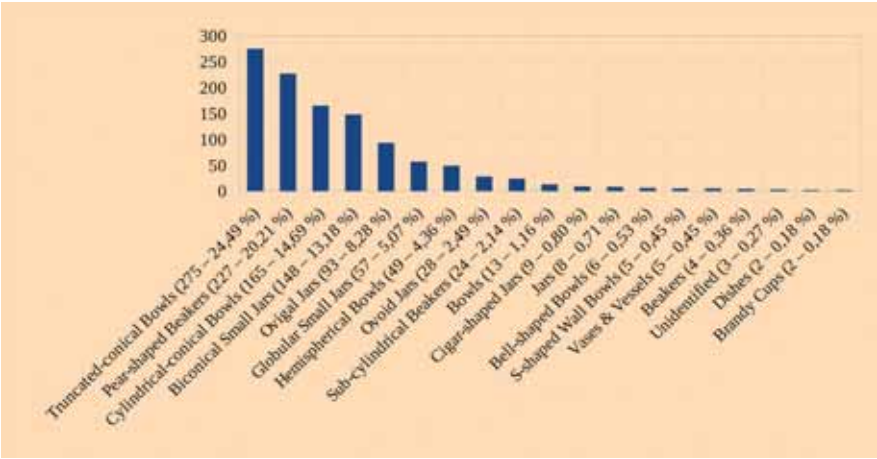


Fig. 7: total Ceramic Findings (1123) at the graveyard of Shahr-i Sokhta excavated by the Italian campaigns 1972-1978.

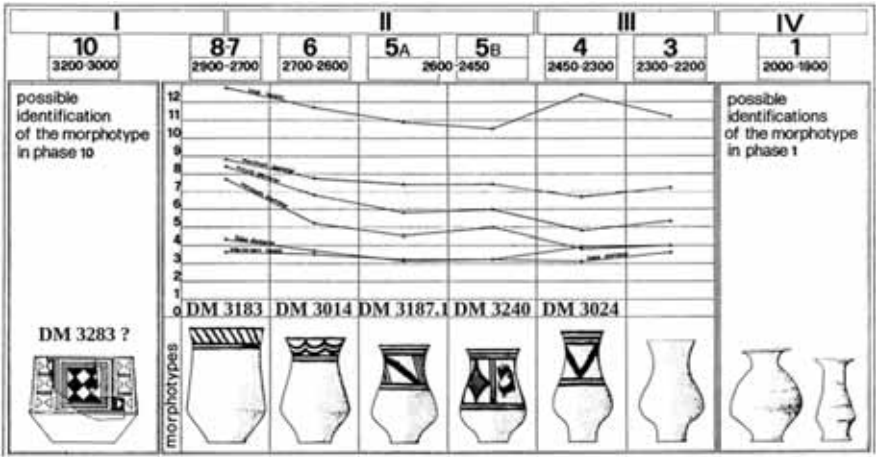


Fig. 8: chronological phases in correspondence with development of the Pear-shaped Beaker and its Decoration Motifs DM created with finds from the settlement (Vidale 1984: 88, fig. 11.7).

Decorative Motifs and also come from the Graveyard.[36] These include a Pear-Shaped Beaker of Phase 7 with a broad shape, large opening, rough surface and Decorative Motif DM 3183 (Fig. 9), and another Pear-Shaped Beaker of Phase 4 with a narrow shape, narrow opening, smooth surface and Decorative Motif DM 3240 (Fig. 10). The Truncated-Conical Bowl, relatively tall with a small opening, smooth surface and Decorative Motif DM 3015, belongs to Phase 6 (Fig. 11). The three vessels are in Buff Ware.

Given the intense anthropological interest, genetic, C-14 and strontium samples were taken from the accessible bone material of the deposit,[37] with a view to determining the exact archaeological age, individual age, sex and possible kinship relations. In total, samples were collected from 47 burials, mainly from the 1997-2003 excavations, except for one from 1977, of which eight samples were taken to Italy for intensive study. The selection criteria were mainly the type of pottery and the presence of a cylinder seal, and the age and sex of the deceased.

5. 'Moving Societies - Multivariate Analysis of the Graveyard of Shahr-i Sokhta': application of multivariate/statistical methods: preliminary results

A range of multivariate statistical analyses, such as seriation, correspondence analysis, cluster analysis and others, can be applied in various fields of archaeology, 'die entweder auf chronologische, chorologische (= geographische) oder sozialen Faktoren basieren'.[38] Basically, the material to be studied is classified into types, 'as with all methods of numerical taxonomy'.[39] Knowledge of mathematical and statistical processes is essential,[40] and in order to handle the inevitable metadata, specialised programmes such as CAPCA[41] and GIS software are necessary.

36. Special thanks to Hossein Moradi for his helpful cooperation and scientific comments.
37. Thanks are due to Pier Francesco Fabbri, especially for his insightful anthropological explanations, and Giorgia Vincenti, who expertly collected the samples.
38. Janssen 2002: 225 (our translation from German) 'based on chronological, chorological, geographical or social factors'.
39. Roaf 1983: 10.
40. Bartholomew *et al*. 2008: 41-51 regarding Roaf 1983.
41. Madsen 2021; Eggert 2012: 241 and Kneissel 2010. https://www.archaeoinfo.dk/ CAPCA, which is an Excel macro explicitly written for archaeological purposes by an archaeologist and freely available, 'performs Principal Component Analysis, Correspondence Analysis and Metric Scaling [in] a Microsoft Excel environment'. Institutions of the Prehistoric and Early Historic Archaeology of Europe offer outstanding subject-specific solutions in computer-assisted combination statistical methodology.

Fig. 10: PSB with DM 3240 from G1640 and Inv.no 17266 (photo Krvavac 2019).

Fig. 9: Pear-shaped Beaker with DM 3183 and Inv.no 17364 (photo Krvavac 2019).

Fig. 11: Truncated-conical Bowl with DM 3015 from G5116 and Inv.no 17305 (Compare 3D-Model Fig. 23) (photo Krvavac 2019).

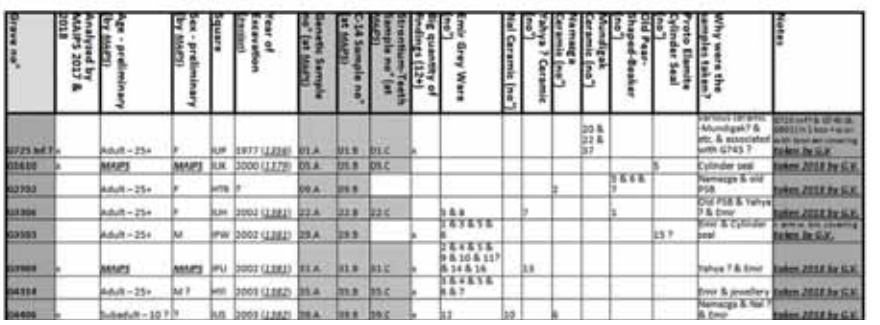


Fig. 12: anthropological samples of graves with high archaeological interest from the Seasons 1997-2003 for genetical, C-14 and Strontium-Analysis.

Specifically, analysis of graveyards has only recently been applied in Near Eastern Archaeology,[42] the dissertation by Janssen 2015 being very inspiring. The pre- and protohistoric archaeology of Europe[43] has a much longer tradition in this respect and often employs innovative methodology.[44]

As already indicated, the present author's PhD thesis is a reappraisal of the excavations of the Graveyard of Shahr-i Sokhta. The results of the Italian excavations of the period 1972-1978 are examined as a closed corpus. As far as possible, the results of the Iranian excavations conducted since 1997 will also be included in order to have a higher quantity of data. However, a scrupulous separation of the data sets is unavoidable, because although the two teams' documentation and publication systems generally coincide, there are differences.[45] Of particular value is the undisturbed situation of discovery. Moreover, the individual burials are rarely even disturbed by neighbouring ones, which indicates that they were placed with great care with respect to each other. Due to the Graveyard's long period of use, there must have been above-ground markers even for the oldest burials. Thus, each undisturbed grave ideally represents a 'geschlossenen Fund',[46] i.e. a kind of information capsule, sealed at the moment of deposition, and all the

42. Eickhoff 1993; Hachmann - Penner 1999 and Novák *et al*. 2000.
43. Eggert 2012: 203-241.
44. Gutsmiedl - Schümann 2010 and Hausmair 2015.
45. Similarities include the description of the finds and the type of information provided, and the systematics and typology of the finds. The differences concern excavation, survey methods and above all the language of the publications.
46. Eggert 2012: 209 (our translation from German) 'finds in a closed association'.

information found therein can be related to the buried person and in a broader sense to his or her social environment. Concerning the very high quantity of all the aspects mentioned, qualitatively robust results are guaranteed.

The chronological result is of extraordinary interest. A burial takes place at an exact point in time and is thus fixed. In comparison, a ceramic vessel has a *period* of use. Pottery vessels, especially those with a Decorative Motif, are excellently suited to subtle chronological determinations, and these appear with all types in high quantities in the SIS Graveyard. Seriation is appropriate in these cases, based on the 'unimodal model', of 'regelhaften Verhaltens, und zwar vom seltenen Auftreten über die höchste Verbreitungsphase hin zum Auslaufen des Typs'.[47] It is crucial that types, in this case, the Decorative Motifs, occur in high quantities and overlap in time, so that 'aus der Kombination der in einer Einheit vorkommenden Typen auf deren relative Datierung geschlossen werden kann'.[48] The graves have mainly been dated on the basis of the settlement chronology and its pottery and other data, or by means of parallels with other sites. A suitable combination will make it possible to determine and, in some cases, correct the dating.

5.1. Seriation of the Graveyard Squares excavated during the Italian Campaigns of 1972-1978: HNE, HRY, HTW, HYC, HYH, HYT, INK, IPQ, IPV, IPW, IRC, IRD, IRL, IRM, IRQ, IRR, IRV, IRW, IRX, IUB, IUC, IUP, IUQ, IUR, IUU, IWC, IWD, LNX, LSD and LSI

To collect data for the PhD thesis, naturally, the people in charge of the 1972-1978 excavations and their documentation, Sandro Salvatori and Alessandra Lazzari, were contacted.[49] The extensive communication that followed guided the understanding of numerous issues. The documentation pertaining to the SIS Graveyard finds of 1972-1978, including the catalogue numbers and sizes of the

47. Janssen 2003: 227 (our translation from German) 'regular behaviour, from the rare occurrence through the highest phase of distribution to the end of the type'.
48. Jannsen 2015: 15 (our translation from German) 'from the combination of the types occurring in a unit, their relative dating can be deduced'.
49. Special thanks to Sandro Salvatori for his valuable help and support, and to Alessandra Lazzari.

finds, dating and other important information, was converted into digital table[50] format in the 1990s. However, the analysis of the Graveyard presented in the PhD is mainly based on the Graveyard Catalogue dataset in M. Piperno and S. Salvatori (2007). Because there are discrepancies between the 1990s digital table and the publication, the entire table had to be reviewed and supplemented with the more detailed data from the later publication. Specifically, the numbering of the Decorative Motifs on the pottery had to be checked because there seem to have been varying versions over the course of the decades.[51] In the end, more than 50,000 pieces of archaeological information on structures and finds were individually examined. Only the graves, called objects, together with the vessels with Decorative Motifs,[52] are under consideration here, focusing on their central motif, considered as a variable.

In seriation, overlaps of objects and variables in at least two-fold combinations are necessary. That means that a burial (object) must contain at least two vessels with different Decorative Motifs (variable) and that the same Decorative Motif must appear on vessels in at least two burials to continue the chain of correspondence with further objects and variables.[53] If these conditions are not met, the burials and Decorative Motifs containing the information are mathematically eliminated. In addition, a weighting of individual characteristics is possible: 'Bei beiden [...] Verfahren - Korrespondenzanalyse und Seriation - handelt es sich um das multivariate statistische Verfahren (Kombinationsstatistik), die dazu dienen, eine zunächst schwer überschaubare Datenmange nach Ähnlichkeiten bezüglich der

50. Its abbreviation is 'SSINV', corresponding to Shahr-i Sokhta INVentario (Italian) or INVentory (English). A small part of the table can be seen in Cortesi *et al*. 2008: 19 Table 2.

51. Piperno and Salvatori 2007: 353-379, Decorative Motifs, and Biscione - Bulgarelli 1983: 228-258, Catalogue. On closer observation, some code numbers used in the cataloguing of the Decorative Motifs in the various publications are seen to have been skipped, probably for editorial reasons. The SSINV record follows its own numbering, with only partial correspondence to the publications.

52. On various types of vessels, the same Decorative Motifs appear repeatedly and are grouped. In general, the well-known Italian mineral water brand 'San Pellegrino', founded in 1899, serves as an example. The distinctive logo and bottle shape changed over time, depending on needs, content, quantity, fashion, etc., but the overall appearance is unmistakable.

53. As an exception, if there is only one variable, it can be duplicated rather than eliminated, but only if there is a high quantity of the same variable elsewhere in the dataset.

Vergesselschaftung zu ordnen'.[54] Of the original 177 graves and 277 decorative motifs, 91 and 71 are respectively related to each other after seriation (Fig. 13). In principle, the more diagonal the representation, the more coherent the correspondence, with the objects and variables placed in their rightful place.

Verification of the result is indispensable. For this purpose, the SSINV data set was used for the burials because 47 have already been dated to the various phases based on the settlement chronology (Fig. 13: Yellow column 'SSINV Dated 1999 - Graves (Phase)'). The remaining 44, which have not, are also now ordered since they are related to the previously dated ones (Fig. 13: Turquoise column 'Seriation 2021 Ordered - Graves'). Finally, an overall relative chronological sequence of burials can be obtained (Fig. 13: Yellow and turquoise column 'SSINV 1999 and 'Seriation 2021 Ordered - Graves (Phase)'). It is noticeable that the phase sequence is highly consistent, with individual outliers such as G0413, which was dated very early in SSINV, or G0712, which was dated very late. Ultimately, changes will probably have to be made here. An additional verification of the order is possible based on the excavation documentation for multiple burials. For example, 'the order of burial in this group of tombs may have been as follows from the earliest to the most recent: G 22 E (C); G 22 E (B); G 22 (A); G 22 D; G 22 A; G 22 B and C'.[55] The relative chronological sequence is correct, as shown by the fields marked in red (Fig. 13: Graves column 'Shahr-i Sokhta Graveyard – Italian Campaigns 1972-1978 Grave Number'), with G0022E - ABC as the oldest, G0022D in the middle and G0022B the most recent burial. Grave G0022A is excluded from the seriation because it has only one painted vessel and G0022C is

54. Janssen 2015: 15 (our translation from German) 'Both [...] methods - correspondence analysis and seriation - are multivariate statistical methods (combination statistics) that serve to sort an initially difficult-to-understand mass of data in accordance with similarities concerning the relationships'. For an example of seriation, see ibid. p.43 Abb. 6.

55. Piperno - Salvatori 2007: 62. Grave G0022E - ABC on p. 66f Figs. 118 and 119 plays a significant role. In addition to the non-inventoried vessel G22E/2 with DM 0055, which occurs only once in the entire data set and is thus eliminated, it contains the decisive vessel G22E/1 Inv. no. 6488 with DM 3183, which unfortunately only appears once, as in Graves G16/3 Inv. no. 6213, 54 Fig. 81 and G703/2 Inv. no. 7952 p.236f fig. 553. DM 3183 appears in Graves G0044 and G0749INF twice (G44/7 Inv. no. 6284 and G44/8 Inv. no. 6285, 99 fig. 197; G749 Inf./5 Inv. no. 8522 and G749 Inf./16 Inv. no. 8533 p. 318f, fig. 758 and fig. 759) and a total of 8 times in the whole data set. In order to keep G22E, given its important role in the data set, DM 3183 was mathematically duplicated, as in G0016, G0703 and G0746.

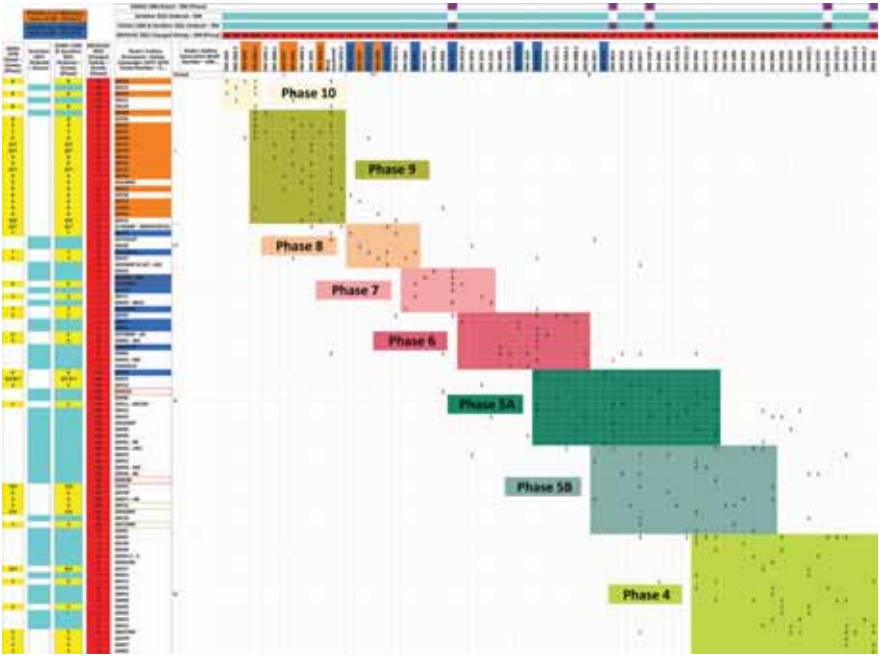


Fig. 13: seriation Table of Data based on Correspond Analysis of the Graveyard of Shahr-i Sokhta - Italian campaigns 1972-1978 (Grave- & Decoration Motif DM-Numbers according to Piperno - Salvatori 2007). Yellow fields: SSINV 1999 Dated - Graves (Phase) Dating by Settlement Excavation Data. Purple fields: Vidale 1984: 99 Fig. 11.7 - Fig. 8. Dated - Decoration Motif (Phase). Turquoise fields: Seriation 2021 Ordered - Graves and DM. Orange fields: Bonora *et al.* 2000: 503 Fig. 5 - Fig. 14. Dated Graves & DM - (Period I). Blue fields: Bonora *et al.* 2000: 500 Fig. 3 - Fig. 15. Dated Graves & DM (Period II). Red bordered fields: Special Stratigraphic Situation of the Graves G22 (Piperno - Salvatori 2007: 62). Green bordered fields: Dated Graves by Salvatori - Tosi 2005: 283, 286f. Red fields: Krvavac 2021 Changed Dating - Graves & DM (Phases). Main Area: Phasing of the Seriation.

excluded because it was empty. Adding to this is the parallel consideration of the Decorative Motif results, for which there are fewer possibilities for comparison. Fig. 8 shows an illustration of a somewhat older chronology table from Vidale 1984, in which some Decorative Motifs are directly related to the phases or periods.[56] Among them are DM 3283(?),[57] DM 3183, DM 3014, DM 3178.1, DM 3240 and DM 3024, all except the first also appearing in the result of the seriation (Fig. 13: Purple row 'Vidale 1984 Dated - DM Phase') and in the correct relative chronological order. The majority of the remaining Decorative Motifs were placed in relation to each other and the burials by analysis alone (Fig. 13: Turquoise row 'Seriation 2021 Ordered - DM'). Finally, the complete sequence of the 'Decorative Motifs' relative chronology is evident (Fig. 13: Purple and turquoise row 'Vidale 1984 and Seriation 2021 Ordered - DM').

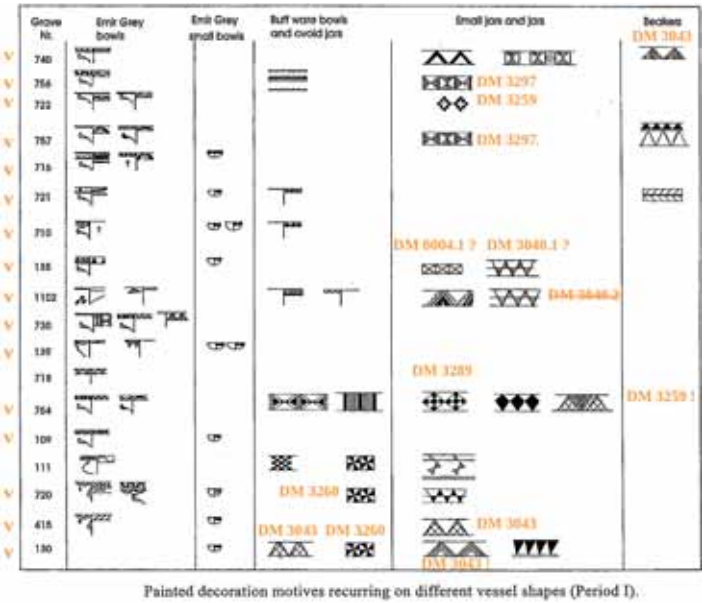
Under Sandro Salvatori's direction, a statistical analysis of the oldest graves and their finds was carried out. The result of the cluster analysis was a similarity matrix that 'strongly indicates [...] a sharp separation of Period I (phases 10 and 9) graves from those of phases 8-7'.[58] A large part of the graves and Decorative Motifs from Period I (Fig. 14 marked in orange with G0740, G0756, G0722, G0757, G0716, G0721, G0710, G0135, G1102, G0730, G0139, G0754, G0109, G0720, G0415, G0130 and DM 3043, DM 3297, DM 3259, DM 0004.1(?), DM 3040. 1(?), DM 3289, DM 3260)[59] and Period II (Fig. 15 marked in blue with G0107, G0406, G0741, G0738SUP, G0022E - ABC, G0746, G0749INF, G0723, G0055SUP and DM 3202.6, DM 3105.1, DM 3111.1, DM 3176. 1, DM 0003, DM 3183, DM 3278, DM 0002) can be found in the seriation in Fig. 13 (Fig. 13: Orange fields 'Bonora *et al.* 2000 Dated Graves & DM - (Period I)' and blue fields 'Bonora *et al*. 2000 Dated Graves & DM - (Period II)'). As expected, they

56. For more recent dating, see Salvatori - Tosi 2005: 281.
57. DM 3283 (?) is neither listed in Piperno - Salvatori 2007: 353-379 Decorative Motifs nor in Biscione - Bulgarelli 1983: 228-258 Catalogue. It is probably a sherd of the Central Asian type from early Period I.
58. Bonora et al. 2000: 501.
59. It should be noted that in Bonora et al. 2000: 500, fig. 3 and 503, fig. 5, not all tombs and Decorative Motifs are depicted, and some DMs are probably marked incorrectly with special characters in Fig. 14 and Fig. 15.

are found in the oldest area, i.e. at the top left of the seriation table in Fig. 13 (Orange and blue fields in Graves column 'Shahr-i Sokhta Graveyard - Italian Campaigns 1972-1978 Grave Number' and Decorative Motifs column 'Shahr-i Sokhta Decoration Motif Number - DM...'). The postulated separation between the periods is undoubtedly evident. However, there are also decorative motifs that occur in both periods, such as DM 3105.1, DM 3259, DM 3111.1, DM 3289, DM 3176.1 and DM 3014.1, which appear for the first time in late Period I and attest to continuity with Period II, which again raises the question of which period Phase 8 belongs to (Fig. 16),[60] with G0413, as described below, demonstrating the problem.

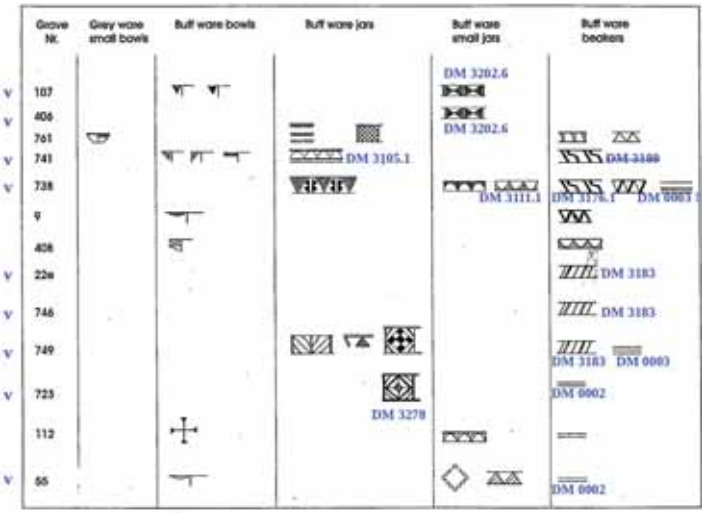
Typical of Phase 10 are DM 1063 and DM 3202.3, with DM 0004.1 clearly attesting to a clear transition to Phase 9 as it occurs in nine graves, and DM 3260 conceivably showing a secondary one. DM 3202.1, DM 3008.1, DM 3297, DM 3008.5, DM 1053, DM 3040.1 and DM 1054.1 occur only in Phase 9, thereby characterising it. It is necessary 'to point out the presence, in Grave 413, of a jar with ear lugs, decorated with a frieze filled with two superimposed chains of solid lozenges [...], possibly recalling the nose lugs of the Jemdet Nasr period'.[61] The finds from G0413 represent the interregional connections of the Shahr-i Sokhta Graveyard, and are thus useful for establishing a more exhaustive chronology (Fig. 13: Green bordered block in Graves column 'Shahr-i Sokhta Graveyard - Italian Campaigns 1972-1978 Grave Number - G...'). DM 3271[62] on the jar is unique in the analysed data, so it was eliminated, but the grave was placed in the seriation (Fig. 13) at the end of Phase 9, since it has, as mentioned, Decorative Motifs typical of Phase 9 (DM 3008.5 and DM 3040.1), which it seems are the last of their kind. Nevertheless, G0413 includes DM 3014.1 as a new Decorative Motif, which is mainly attributed to Phase 8 and later phases and very probably marks a *terminus post quem*. G1003INF - ABCDEFGHIJKL shows a very similar situation, with DM 1053 and DM 1054.1 as the last of Phase 9 and DM 3176.1 as

60. Salvatori - Tosi 2005: 284.
61. Salvatori - Tosi 2005: 283.
62. Piperno - Salvatori 2007: 221f G413/1 Inv. no. 7037 DM 3271.



Painted decoration motives recurring on different vessel shapes (Period I).

Fig. 14: similarities (orange marks) of analysed burials and DM with Fig. 13 (Bonora *et al*. 2000: 503; Fig. 5).



Painted decoration motives recurring on different vessel shapes (Period II).

Fig. 15: similarities (blue marks) of analysed burials and DM with Fig. 13 (Bonora *et al*. 2000: 500; Fig. 3).

typical of Phase 8. Further concentration on these points for future analysis is necessary. Phase 7 has slight overlaps with Phase 8 and Phase 6, and the typical representative is DM 3183, together with the already mentioned special grave G0022E - ABC. In Phase 6, only DM 3006, DM 3228.1 and DM 3202.6 appear in this phase alone. DM 0003 occurs in Phase 8, but mainly Phase 6 and Phase 5, and consists, however, only of two simple parallel lines at the vessel rim, enabling its consideration as an example of 'sog. „Durchläufer', also Typen, die über mehrere Phasen hinweg im Fundmaterial vertreten sind'.[63] We may cite two 'Durchläufer' here: DM 0017 occurs in Phases 8, 6, 5A, 5B and 4, while DM 3003 occurs in Phases 6, 5A, 5B and 4. The division of Phase 5 into two parts is quite permissible, as Phase 5A shares Decorative Motifs DM 3053.1, DM 2008.1 and DM 0065 with Phase 6, and Phase 5B shares Decorative Motifs DM 3056 and DM 3161 with Phase 4. Overall, DM 0016, DM 3015 and DM 3236.1 are unique to Phase 5, with DM 3278, DM 3178.1 and DM 2081 unique to Phase 5A, and DM 1065 and DM 1008 unique to Phase 5B. A closer look at 'graves 731 and 725 inf. [...] points to a Phase 5b/beginning Phase 4 date for both'[64] (Fig. 13: Green bordered fields in Graves column 'Shahr-i Sokhta Graveyard - Italian Campaigns 1972-1978 Grave Number - G...'), and the vessels are seen to have interregional connections with Tepe Yahya Period IV C. However, the two graves pose challenges for the seriation because they both have unique pottery finds that are eliminated from the analysis along with the Decorative Motifs.

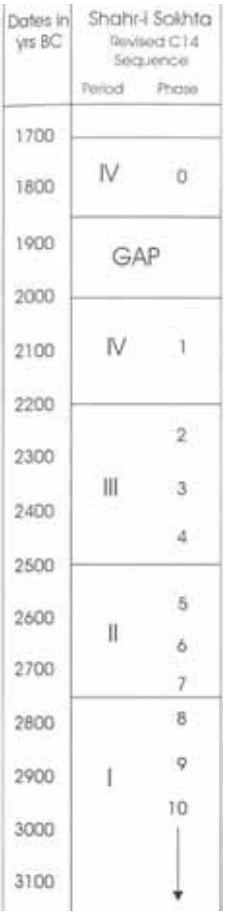


Fig. 16: Salvatori - Tosi 2005: Fig. 12.

63. Gutsmiedel - Schümann 2010: 24 (our translation from German) so-called 'through-runners', i.e. types that are represented in the finds over several phases'.
64. Salvatori - Tosi 2005: 286.

Changing DM 3231.3[65] in Grave G0731 (G731/24) Inv. no. 8063 to DM 3236.1,[66] which is highly similar and can be seen as a variant, created a match with G0010 (G10/8) Inv. no. 6133,[67] which also has DM 3236.1. The DM was thus doubled, allowing its placement in the seriation,[68] but further investigation is necessary. Phase 4 shares other characteristics with phase 5B, and it features DM 3240 and DM 3160.1. DM 3162.6, DM 3166.1 and DM 3024, located in the lower right corner of the seriation (Fig. 13), play a unique role, possibly suggesting Phase 3. This phase is difficult to grasp due to the quantitative absence of vessels with Decorative Motifs, but the distinctive zoomorphic potter's marks on 'period III motifs'[69] may be of use.

As has already been noticed, the relative chronology of burials and decoration motifs is changed by the seriation result (Fig. 13: Red column 'Krvavac 2021 Changed Dating - Graves (Phase)' and red row 'Krvavac 2021 Changed Dating - DM (Phase)'). Additional research will entail targeted analysis to resolve specific issues. As frequently shown, quantity is more significant for the quality of the results than single extraordinary finds.

6. GIS-based Digital Mapping of the Results

The next step was the mapping of the results obtained. Using CAD, the various maps and the structure and find layers, an exact basis was created. This included the very extensive corrected table of the features and finds and the classification of the burials into chronological phases obtained by the seriation. Using QGIS,[70] it is easy to visualise all these data together (Fig. 17). As previously recognised,[71]

65. Piperno - Salvatori 2007: 292 G731/24 Inv. no. 8063, fig. 686 and Piperno - Salvatori 2007: 371, decorative motifs.
66. Piperno - Salvatori 2007: 371, decorative motifs.
67. Piperno - Salvatori 2007: 40 G10/8 Inv. no. 6133, fig. 45.
68. Prof. emer. Michael Roaf (personal communication) said that it would make sense to group together some of the very similar decorative motifs listed, as the typification may be excessive in some cases.
69. Sajjadi 2015a: 12.
70. QGIS 2021 https://qgis.org/en/site/forusers/download.html (01.03.2021). The open-source version, QGIS 3.18 Zürich, was used after preparing the necessary layers with CAD.
71. Bonora et al. 2000: 513, fig. 14 and fig. 15.

the oldest burials are found in the south (HTW, HYC, HYH, HYT, IPQ, IPV, IPW, IUB, IUC, IUP, IUQ, IUR, IUU), i.e. the squares excavated by the Italian Campaigns (Fig. 17: Yellowish shades corresponding to Phases 10, 9 and 8).

Only two Phase 8 burials are present in the northern area. Phases 7 and 6 (Fig. 17: Red shades) occur rarely but are scattered throughout the area. Representatives of Phases 5A, 5B and 4 (Fig. 17: Green shades) are found in the south but mostly in the north (INK, IRC, IRD, IRL, IRM, IRQ, IRR, IRV, IRW, IRX, IWC, IWD).

Indeed, the Shahr-i Sokhta Graveyard is enormous, and surprises await the forthcoming excavations and analyses, especially when the results of the Iranian excavations are added. The areas around squares IPQ, IPV, IPW, IUB, IUC, IUP, IUQ, IUR, IUU, which were once isolated in the south, were extensively excavated by the Iranian campaigns, and are now joined up (Fig. 3).[72] Thus, the assumption that the oldest burials were first laid out in a largely random fashion, buried at a distance from each other or in local groups, appears to be confirmed. Over time, later burials filled in the gaps, resulting in the present densely packed conformation. Information from the discoveries, such as burial depth and form and the position of the grave goods, can provide more insight into this question.

7. 3D-Visualisation

Archaeology is also destruction. The context of finds must be excavated appropriately and documented in order to ensure traceability for present and future researchers. In Graveyard Archaeology especially, and in the absence of a fixed building structure, precise surveying is indispensable, as the individual burials often appear to be freely distributed with respect to the direction of excavation. After the skeleton level has been reached, the burials remain open only for a short time in order to document them photographically, possibly from several positions, draw them and describe them. Afterwards, the finds are recovered, and

72. Sajjadi 2015b: 14 fig. 12.

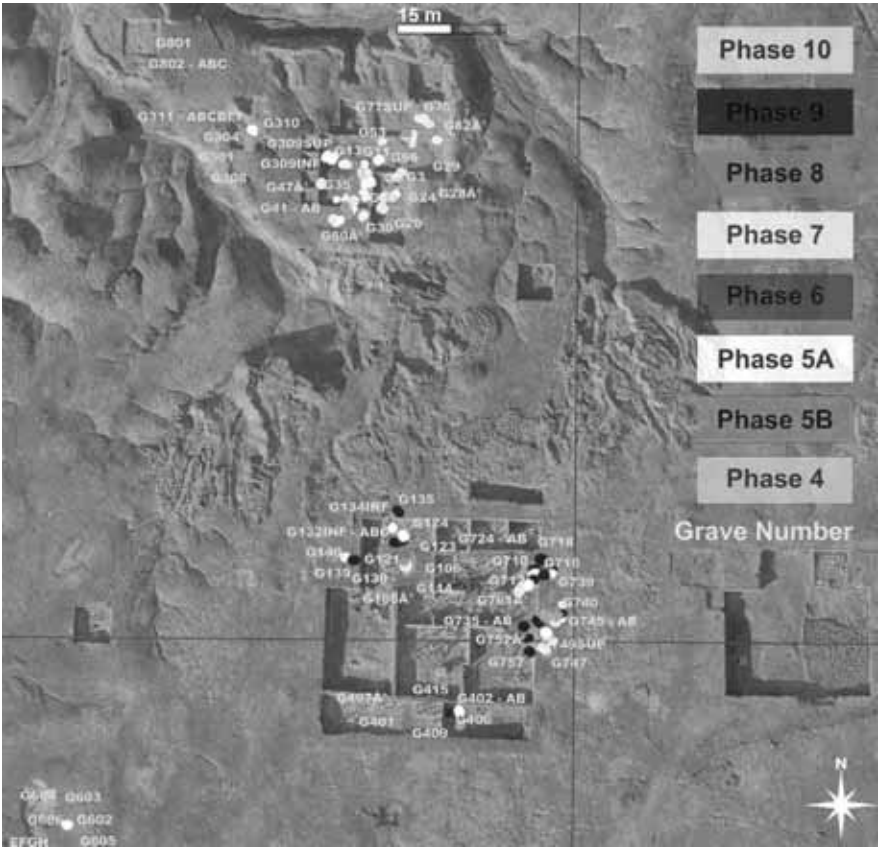


Fig. 17: GIS-Plan based on the CAD-Layers showing the chronological dating. Each analysed and remaining grave of the Seriation on Fig. 13 is shown. The Phases and their colours are set analogously. It is evident that the older graves (Phases 10, 9, 8) are in the more southerly area, those of middle age (Phases 7, 6) in both and the youngest (Phases 5A, 5B, 4) primarily in the north.

the context of the find disappears forever. This two-dimensional description has to give way to 3D-Documentation, whose aim and main advantage is the precise observation of the find in retrospect, since 'three-dimensional reconstruction is the automatic or assisted generation of a 3D-Model that is a precise copy of a real object'.[73]

In the meantime, photogrammetry 'has become a cost-effective and versatile technique that is currently widely applied for three-dimensional documentation of archaeological heritage sites'.[74] Similarly, it has long been possible to quickly record the 3D structure of an object to be documented, thanks to the 'remarkable technological leap [...] with both a substantial increase in the possible frequency of three-dimensional terrain surveying and the ease in which associated methods can be applied'.[75] An archaeologist always has a camera and can use simple gadgets to enable the use of SfM (Structure from Motion) models, focusing on lighting conditions and sharpness when taking photographs. If possible, a light camera[76] with a fixed focal length should be used, in order to be able to record images of the terrain and medium-sized structures with an autopole. Photographs of small objects need to be taken from an exact distance. Successive overlapping images must be acquired using appropriate methods in order to correctly create the 3D models afterwards with the proper software,[77] since 'Structure from Motion' entails calculating 3D-Surfaces with 2D image information acquired from a number of different perspectives. In addition, 'Structure from Motion beschreibt den Prozess der 3D Oberflächenberechnung mit 2D Bildinformationen aus unterschiedlichen Perspektiven. Damit 3D Punkte aus 2D Bilddaten berechnet werden können, ist es zuerst notwendig den Bildverband zu orientieren. Dies geschieht durch eine Kombination von photogrammetrischen Algorithmen. Im speziellen sind dies die Merkmalspunktdetektion und -extraktion, Zuordnung homologer Punktepaare, relative Orientierung von Bildpaaren, robuste Schätzer

73. Torres *et al*. 2012: 1.
74. Brandolini *et al*. 2020: 34.
75. Micheletti *et al*. 2015: 1.
76. A Sony Alpha 6300 4K camera with a Sony Ø49 E 2.8/16 0.24m/0.8ft lens was used to capture the 3D SfM-Models shown below.
77. Plets *et al*. 2012: 886-890, fig. 2 and fig. 3; Nikolaeva 2018 for methods and practical usage.

zur Ausreißerdetektion und die Bündelblockausgleichung'.[78] Thus, local or GPS-oriented tachymetric reference points specify the 3D-Model and can be connected to other measurements or model objects for mapping and visualisation.

8. 3D SfM (Structure from Motion) Terrain Models

The Northern 'Italian Squares' (Fig. 18)

One terrain model represents the area of the earlier Italian Graveyard excavation squares (IRL, IRM, IRQ, IRR, IRV, IRW, IRX, IWC and IWD) and the later Iranian additions (IRS, IRU and IWE). Even though more than 40 years have passed since the last excavation work, one of the Italian campaigns main excavation areas is still visible. The largest of the early campaigns' contiguous excavation areas is shown in detail in Figs. 3a, 3b and 3c.

A total of 1178 photos were taken from a height of approx. 3.00 m, systematically walking across the area in rows and aligned with 1369040 tie points. From this, a dense cloud with 45631790 points and a 3D-Model with 1014039 faces were created. For reference, 16 points were measured tachymetrically at the corners of the respective squares.

Workshop 26 (Fig. 19)

Situated in the middle of the settlement area, Workshop 26 extends over an area of approximately 55 m (E-W) x 50 m. The prominent corridor in the middle characterises the area and suggests a secular function. To protect against erosion, the architectural remains, which are up to more than 2 m high, were covered with raffia and clay plaster. The intricate, angular spatial structure presented difficulties for the creation of a 3D-Terrain Model. In accordance with a consistent system, the corners of all individual rooms were photographed in parallel paths across the terrain.[79]

78. Tud 2021 (our translation from German) 'Structure from Motion describes the process of calculating a 3D surface using 2D image information acquired from various perspectives. To calculate 3D points from 2D image data, it is first necessary to orientate the image composite using a combination of photogrammetric algorithms for feature point detection and extraction, assignment of homologous point pairs, relative orientation of image pairs, robust detection of outliers and bundle block adjustment'.

79. 3D SfM models based on photography performed by a drone can cover a larger area, but the precision is not sufficient for smaller-scale situations.

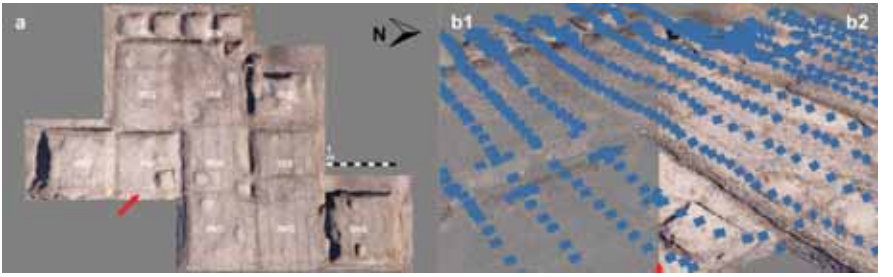


Fig. 18: SfM a) The planar Orthomosaic of the 3D-Model (1014039 faces) at the quadrants IRL, IRM, IRQ, IRR, IRS, IRU, IRV, IRW, IRX, IWC, IWD, IWE with the tachymetric Reference Points (16). b1) The aligned Tie Points (1369040) amidst the Camera Positions (1178). Merged with b2) The Densecloud (45631790) and other Camera Positions.

Fig. 19: SfM a) The planar Orthomosaic of the 3D-Model (68684549 faces) at Workshop 26. b) The Dense Cloud (42748842) with the aligned Camera Positions (972). c) An isometric Orthomosaic with the tachymetric Reference Points (67). d) Detailed Orthomosaic of the Corridor.

Thus, a total of 972 photos were taken, aligned with 624904 tie points. The dense cloud has 42748842 points and the 3D model 68684549 faces. A group of 67 tachymetrically measured points is used for reference.

9. Application of 3D-SfM to Graves

G9509 A and G9509 B - Fig. 20

The double burial G9509 A and B (Fig. 4), probably of a mother and child, produced a very satisfying 3D-Model. The preparation of the remains proved to be particularly difficult, as the two persons, the grave goods and the lower part of the grave itself were very heavily encrusted, hindering recognition of the details, which can be seen especially in the skull of G9509 A.

A total of 353 photographs were taken, aligned with 388547 tie points. The dense cloud has 99776831 points and the 3D model 4668803 faces. Four points were tachymetrically measured for reference.

G9606 (Fig. 21)

Quite outstanding is G9606, whose skeletal remains were very well preserved but unfortunately were not accompanied by grave goods. The SfM method can be used to obtain unique perspectives from a range[80] of positions. Fig. 21a is a merged image of two different photographs with a local DEM (a1) where the edge of the burial pit can be seen very well, more clearly than in the photorealistic planar orthomosaic (a2) or the photograph of the grave itself (Fig. 5). Moreover, the bones are sharply delineated. Fig. 21b and Fig. 21c show orthomosaics of the skull seen from different angles, in which the growth sutures and teeth are clearly visible. The unique position of the right hand under the mandibula can also be seen. Finally, Fig. 21d shows a detailed orthomosaic of the lower postcranium and pelvis. The enormous advantages of 3D representation, which enables any observation position to be simulated and extracted, are seen clearly here. This facility is of the highest archaeological and anthropological interest.

For the 3D documentation, 442 photographs were taken, from which 217005 tie points were created. The dense cloud consists of 33500051 points, and the

80. DEM - Digital elevation model based on 3D computer graphics.

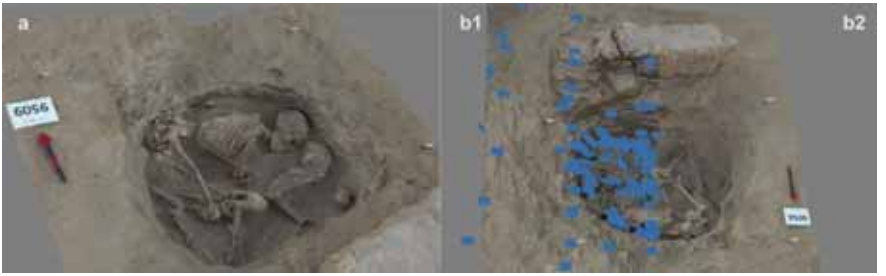


Fig. 20: SfM a) Isometric Orthomosaic of the 3D-Model (4668803 faces) of Grave G9509 A and B at Square NFG (Compare Fig. 4). b1) The aligned Tie Points (388547) amidst the Camera Positions (353). Merged with b2) The Densecloud (99776831) and the tachymetric Reference Points (4).

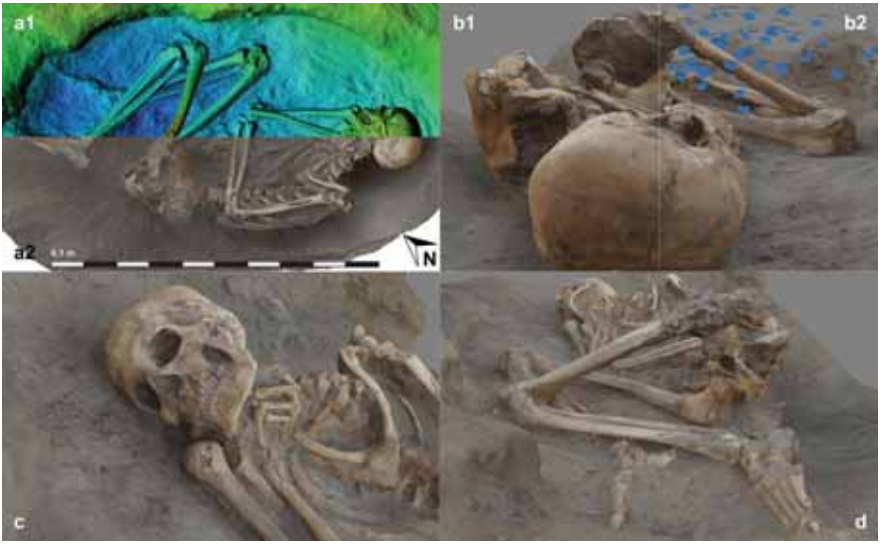


Fig. 21: SfM a1) DEM (3564x4005) of Grave G9606 at Square NAQ showing the edges of Grave Type 1 – Simple Pit. Merged with a2) Planar Orthomosaic of the 3D-Model (2103428 faces) (Compare Fig. 5). b1) Detailed Orthomosaic. Merged with b2) Dense Cloud (33500051) amidst the Camera Positions (442) and tachymetric Reference Points (4). c) Detailed Orthomosaic of the *Cranium*. d) Detailed Orthomosaic of the *Pelvis* and lower *Postcranium*.

3D model has 2103428 faces. For reference, four points were tachymetrically measured. The DEM has a size of 3564x4005 pixels, at 0.418 mm/pixel.

Grave in square MEY (Fig. 22)

The reconstructed grave in square MEY,[81] covered with raffia and clay plaster to protect against erosion, shows another possibility of SfM. First, a local terrain model of the grave and the burial shaft was created. In the second step, a model of the grave was created using suspended light sources and merged with the first using reference points, enabling 3D virtual entry to the tomb despite the destruction. The generated profile, which shows a typical Type 4 grave, is extraordinary (see Fig. 2).

A total of 262 photographs were taken, from which 146784 tie points were created. The dense cloud has 29893620 points and the 3D model has 1992898 faces. Eight points were tachymetrically, measured for reference.

10. 3D SfM applied to small finds

Truncated-Cone Bowl (Fig. 23)

Photorealistic orthomosaics were generated of the truncated conical bowl from Grave G5116 with Inv. no. 17305 and DM 3015 (see Fig. 11). The profile and all possible viewing positions are represented, with the potter's mark on Fig. 23c being particularly striking. Drawn on millimetre paper, precisely positioned tachymetric target marks served as virtual reference points.

In total, 52 photographs were taken, which were aligned with 23743 tie points. The dense cloud has 1307427 points and the 3D-Model has 261454 faces. Overall, 4 virtual reference points were set.

11. Conclusion

The *graveyard* of Shahr-i Sokhta is exceptional and offers various possibilities for investigation, not only in itself but also in a wide-ranging regional and cross-

81. When the photos were taken for the 3D SfM modelling in December 2018, the grave was completely intact. In December 2019, it was almost destroyed by brief but heavy rain, which caused the edges of the shaft to collapse.

Fig. 22: SfM a) Planar Orthomosaic of the 3D-Model (1992898 faces) of a restored grave at Square MEY (Compare Fig. 2 and Fig. 4). b1) An isometric Orthomosaic with a view into the chamber. Merged with b2) The Dense Cloud (29893620) amidst the Camera Positions (262) and the tachymetric Reference Points (8). c) Negative Profile Orthomosaic showing the Grave Type 4 - Catacomb. d) Foto of the destroyed grave after heavy rain.

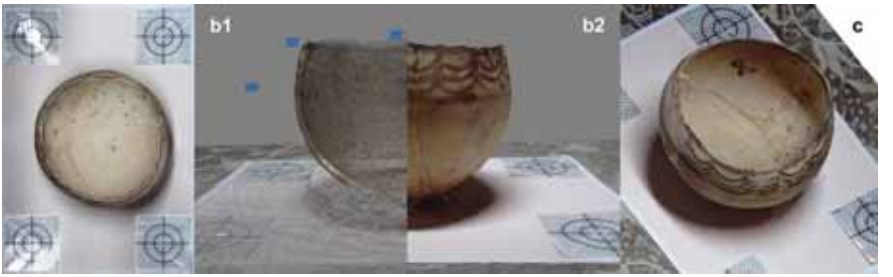


Fig. 23: SfM a) Planar Orthomosaic of the 3D-Model (261454 faces) of a Truncated-Conical Bowl with DM 3015 (Compare Fig. 11). b1) Tie Points (23743) amidst the Camera Positions (52) and Reference Points (4). Merged with b2) Orthomosaic of the Profile. c) Isometric Orthomosaic showing a Potter's Sign on the inside.

border context. For the ongoing excavation work, the compilation of SfM 3D Documentation, which is now standard practice, together with adequate surveying, provides a significant opportunity to collect large quantities of data and process them digitally. The associated finds, especially unique artefacts such as the game from tomb G731[82] or the artificial eye from tomb G6705, can be viewed from a new archaeological perspective thanks to the 3D display. This cost-effective method, which has a low error rate, is suitable for large-scale documentation.

The quantity of data on finds from the graveyard of Shahr-i Sokhta since 1972 is impressive but it poses challenges in terms of observing them in an all-

82. Piperno - Salvatori 2007: 294, G731/48 Inv. no.8087, fig. 691.

encompassing context and relating them to each other. Multivariate/statistical analysis can handle these metadata and, if used correctly, reveal inherent patterns with which to interpret them. In this way, chronological difficulties can be resolved more easily.[83] It is possible to correlate the results of the analysis with those of the settlement, since the same painted vessels are found in both areas. The ongoing excavation work in the 'Eastern Residential Area' is yielding chronologically useful data on the settlement's early phases (10, 9 and 8), complementing the work conducted on Area 33, which concerns the middle phases, enabling the establishment of chronological markers with which to calibrate the seriation. This work will also provide support for further analysis, especially when the Iranian excavations' datasets are added. Likewise, C14 data also has the potential to provide assistance. Careful mapping of the finds may also yield sociological answers, since the people buried in the graveyard lived in the settlement.

The once centrally located settlement with diverse international connections is difficult to access nowadays, a fact which has probably also saved the site from destruction. This circumstance has been very advantageous for the intensive scientific investigations carried out so far and makes it possible to start something new. The management of the site and the finds ensures their survival while ensuring adequate presentation. Shahr-i Sokhta's extraordinary situation has secured it a place on UNESCO's World Heritage List.[84]

83. Jarrige *et al*. 2011: 29.
84. Shahr-i Sokhta (Islamic Republic of Iran) (C 1456), The World Heritage Committee, Decision: 40 COM 7B.38 (40th Session, Istanbul/UNESCO 2016).

Bibliography

Ascalone, E., 2020. Shahr-i Sokhta Excavations. *Ash-sharq, Bulletin of the Ancient Near East, Archaeological*, *Historical and Societal Studies* 4, Archaeopress Publishing, Oxford, 1-56.

Bartholomew, D., Steele, F., Moustaki, I., and J. Galbraith, 2008. Analysis of the multivariate social science data. In *Statistics in the Social and Behavioral Sciences Series*, CRC Press, Boca Raton/New York/Abingdon.

Biscione, R., 1984. Baluchistan Presence in the Ceramic Assemblage of Period I at Shahr-i Sokhta. In B. Allchin (ed.), *South Asian Archaeology 1981*, Cambridge, 69-84.

Biscione, R., and M.G. Bulgarelli, 1983. Painted Geometrical Decoration on the Shahr-i Sokhta Buff-Ware: Approach to a Systematic Classification. In M. Tosi (ed.), *Prehistoric Sistan 1* (= Reports and Memoirs XIX 1), Roma, 211-258.

Biscione, R., Bulgarelli G. M., Costantini, L., Piperno, M., and M. Tosi, 1974. Archaeological Discoveries and Methodological Porblems in the Excavation of Shahr-i Sokhta, Sistan. In (ed.), *South Asian Archaeology*, 1973, Leiden, 12-52.

Bonora, G.L., Domanin, C., Salvatori, S., and A. Soldini, 2000. The Oldest Graves of the Shahr-i Sokhta Graveyard. In M. Taddei and G. De Marco (eds.), *South Asian Archaeology 1997*, CITTà, 495-520.

Brandolini, F., Cremaschi, M., Degli Esposti, M., Lischi, S., Mariani, G., and A. Zerboni, 2020. SfM-Photogrammetry for fast Recording of Archaeological Features in Remote Areas. *Archeologia e Calcolatori* 31/2, Istituto di Scienze del Patrimonio Culturale del C.N.R. Roma, 33-45. http://www.archcalc.cnr.it/journal/id.php?id=oai:www.archcalc.cnr.it/journal/A_C_oai_Archive.xml:1088 (01.03.2021)

Cortesi, E., Tosi, M., Lazzari, A., and M. Vidale, 2008. Cultural Relationships Beyond the Iranian Plateau: the Helmand Civilization, Baluchistan and the Indus Valley in the 3rd Millennium BCE. *Paléorient* 34/2, 5-35.

Eggert, M.K.H., 2012. *Prähistorische Archäologie, Konzepte und Methoden*, 4. Auflage, A. Francke Verlag, Tübingen/Basel.

Eickhoff, T., 1993. *Grab und Beigabe, Bestattungsriten der Nekropole von Tall Aḥmad al-Ḥattū und anderer frühdynastischer Begräbnisstätten im südlichen Mesopotamien und in Luristān*, Münchener Universitäts-Schriften 14, Profil Verlag, München/Wien.

Götzelt, T., 2002. Buchbesprechungen und Anzeigen. In Hakemi, A., *Shahdad. Archaeological Excavation of a Bronze Age Centre in Iran*, Archäologische Mitteilungen aus Iran und Turan, Band 34, Dietrich Reimer Verlag GmbH, Berlin, 455-462.

Gutsmiedl-Schümann, D., 2010. D*as frühmittelalterliche Gräberfeld Aschheim-Bajuwarenring*, Materialhefte zur Bayerischen Vorgeschichte A 94, Verlag Michael Lassleben, Kallmünz/Oberpfalz.

Gyselen, R., and W. Lerouge, 1983. Project for a Descriptive Analysis of the Geometrical Ornaments on Shahr-i Sokhta II-III Pottery. In M. Tosi (ed.), *Prehistoric Sistan 1,* Reports and Memoirs, Volume XIX 1, IsMEO, Rome, 265-302.

Hachmann, R., and S. Penner, 1999. *Kamid el-Loz, Der eisenzeitliche Friedhof und seine kulturelle Umwelt*, Saarbrücker Beiträge zur Altertumskunde 3, Verlag Dr. Rudolf Habelt, Bonn.

Hakemi, A., 1997. *Shahdad, Archaeological Excavations of a Bronze Age Center in Iran.* Reports

and Memoirs, Volume XXVII, IsMEO, Rome.

Hausmair, B., 2015. *Am Rande des Grabs, Todeskonzepte und Bestatungsritual in der frühmittelalterlichen Alemannia*, Sidestone Press, Leiden.

Kneissel, J., 2010. *Übungsblatt zur Korrespondenzanalyse CAPCA Version 2.1*, Verlag Christian-Albrechts-Universität, Kiel.

Janssen, U., 2002. *Die frühbronzezeitlichen Gräberfelder von Halawa, Shamseddin, Djeniye, Tawi und Wreide am mittleren Euphrat. Versuch einer Datierung und Deutung sozialer Strukturen anhand multivariater statistischer Verfahren (Korrespondenzanalyse und Seriation*. Ugarit-Forschungen 34, Ugarit-Verlag, Münster, 223-314.

Janssen, U., 2015. *Gesellschaften im Wandel, Funerärer Aufwand und soziale Wirklichkeit im frühstaatlichen Mesopotamien und Ägypten anhand von Grabbefunden aus Ur und Kafr Tarkhan*, Schriften zur vorderasiatischen Archäologie Band 10, Harrasowitz Verlag, Wiesbaden.

Jarrige, C., and V. Lefèvre (eds,), 2005. *South Asian Archaeology 2001*, Éditions Recherche sur les Civilisations, Paris.

Jarrige, J.-F., Didier, A., and G. Quivron, 2011. Shahr-i Sokhta and the chronology of the Indo-Iranian regions. *Paléorient* 37/2, 7-34.

Jux, U., and K.E Kempf, 1983. Ulrich/Karl Eugen. Regional Geology of Sīstān (Southwest Afghanistan). In M. Tosi (ed.), *Prehistoric Sistan 1*, Reports and Memoirs, XIX/1, IsMEO, Rome, 5-61.

Madsen, T., 2021. https://www.archaeoinfo.dk/ (01.03.2021)

Micheletti, N., Chandler, J.H., and S.N. Lane, 2015. Structure from Motion (SfM) Photogrammetry, British Society for Geomorphological Techniques, Chapter 2, Section 2.2, Loughborough.
https://www.geomorphology.org.uk/sites/default/files/geom_tech_chapters/2.2.2_sfm.pdf (01.03.2021)
Moradi, H., 2009. Pear beaker Shape of Shahr e Sokhta (Lyvanhay-e Golabi Shekl). In S.M.S. Sajjadi (eds.), *Seventeen Essays on Shahr-i Sokhta*, Cultural Heritage, Handicrafts & Tourism Organisation of Sistan and Baluchistan, Tehran, 241-266.
Mutin, B., and C.C. Lamberg-Karlovsky, 2013. *The Proto-Elamite Settlement and its Neighbors, Tepe Yahya Period IVC*, Oxbow Books, Oxford/Oakville.
Nalesini, O., 1984. Social implications of the morphological variability of the decorative motifs of Shahr-i Sokhta II Buff ware: an outline. *South Asian Archaeology VI*, 1981, University Press, Cambridge, 108-117.
Nikolaieva, A., 2018. *Realisierung eines virtuellen 3D-Spaziergangs durch eine historische Werkstätte mittels Computer Vision, Bachelorarbeit*, Hochschule für angewandte Wissenschaften, Fakultät für Geoinformatik, München.
https://www.ldbv.bayern.de/file/pdf/13691/Bacheloarbeit_Anna_Nikolaieva.pdf (01.03.2021)
Novák, M., Oettel, A., and C. Witzel, 2000. *Der parthisch-römische Friedhof von Tall Šēḫ Ḥamad /Magdala* (= BATSH 5), Harrassowitz Verlag, Berlin.
Piperno, M., 1979. Socio-economic Implications from the Graveyard of Shahr-i Sokhta. In M. Taddei (ed.), *South Asian Archaeology 1977*, Napoli, 123-139.
Piperno, M., and S., Salvatori, 1983. Recent Results and New Perspectives from the Research at the Graveyard of Shahr-i Sokhta, Seistan, Iran. *Annali dell'Istituto Orientale di Napoli* 43, 173-191.
Piperno, M., and S. Salvatori, 2007. *The Shahr-i Sokhta Graveyard (Sistan, Iran). Excavation Campaigns 1972-1978*, Roma.
Plets, G., Gheyle, W., Verhoeven, G., De Reu, J., Bourgeois, J., Verhegge, J., and B. Stichel-Baut 2012. Three-dimensional Recording of Archaeological Remains in the Altai Mountains. *Antiquity 86*, Antiquity Publications Ltd., University Press, Cambridge, 884-897.
https://www.academia.edu/1922635/Three_dimensional_recording_of_archaeological_remains_in_the_Altai_Mountains (01.03.2021)
Pracchia, S., 1984. Preliminary Analysis of the Shahr-i Sokhta II Buff Ware Painted Figuration: Some Preservation for a Systematic classification. In B. Allchin (ed.), *South Asian Archaeology 1981*, Cambridge, 98-107.

Qgis 2021, *Q Geographic Information System*, https://qgis.org/pt_BR/site/ (01.03.2021)
Roaf, M., 1983. Sculptures and Sculptors at Persepolis, Iran. Volume XXI, *Journal of the British Institute of Persian Studies*, London.
Sajjadi, S.M.S., 2003. Excavations at Shahr-i Sokhta. First Preliminary Report on the Excavations of the Graveyard 1997-2000. *Iran* 41, 21-98.
Sajjadi, S.M.S., 2009. *Seventeen Essays on Shahr-i Sokhta*, Cultural Heritage, Handicrafts & Tourism Organisation of Sistan and Baluchistan, (Persian), Tehran.
Sajjadi, S.M.S., 2015a. Potter's Signs of Shahr-i Sokhta: Their Functions and Meanings, Modares Archaeological Research. *Journal of Scientific Union of Archaeology* 5/10-6/11, Mehregan, Tehran, 11-40.
Sajjadi, S.M.S., and H. Moradi, 2015. Excavations at Buildings Nos. 1 and 20 at Shahr-i Sokhta. *International Journal of the Society of Iranian Archaeologists* 1/1, Winter-Spring 2014, The Society of Iranian Archaeology, Tehran, 35-49.
Salvatori, S., and M. Tosi, 2005. Shahr-i Sokhta Revised. In F. Jarrige (ed.), *South Asian Archaeology 2001*, 281-292.
Sarianidi, V.I., 1983. The Pottery of Shahr-i Sokhta I and its Turkmenistan Connection. In M. Tosi (ed.), *Prehistoric Sistan 1* (= Istituto Italiano per il Medio ed Estremo Oriente, Reports and Memoirs XIX 1), Roma, 187-198.
Sarianidi, V.I., 2007. *Necropolis of Gonur,* Kapon, Athens.
Schmitt, R., 1996. Drangiana. Encyclopaedia Iranica 7/5, Routledge, London/New York, 534-537.
Torres, J.C., Arroyo, G., Romo, C., and J. de Haro, 2012. 3D Digitization using Structure from Motion, CEIG - Spanish Computer Graphics Conference 2012, The Eurographics Association, Jaén.
https://www.academia.edu/2021718/3D_Digitization_using_Structure_from_Motion (01.03.2021)
Tosi, M., 1983. *Prehistoric Sistan* 1, Reports and Memoirs, Volume XIX/1, IsMEO, Rome.
Tud 2021, Institute of Photogrammetry and Remote Sensing, Technical University Dresden.
https://tu-dresden.de/bu/umwelt/geo/ipf/photogrammetrie/studium/materialien/software_sfm?set_language=de (01.03.2021)
Vidale, M., 1984. The Pear Shaped Beaker of Shahr-i Sokhta: Evolution of a Ceramic Morphotype during the Third Millennium. In B. Allchin (ed.), *South Asian Archaeology 1981*, Cambridge, 81-97.