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GEOLOGICAL HAZARDS IN ARCHAEOLOGICAL HERITAGE

BUILDING DAMAGE IN THE ROMAN *DOMUS* CASA DE LA EXEDRA AT ITALICA (SANTIPONCE, PROV. SEVILLA/E)

Natural hazards have always been present throughout human history (Kempe 2003). Generally, they are divided into two categories: climatic and geological. Examples for the latter category are earthquakes, land instability issues (e.g. avalanches, landslides, sink holes, sackungen), or volcanic eruptions. Climatic hazards include floods, blizzards, heat, frost, droughts, or forest fires. Some of these events may take place over a longer time span. In addition to this, there are secondary phenomena which appear after the catastrophe itself; tsunamis, liquefaction, and ground subsidence may follow an earthquake (Bryant 2006).

Natural hazards, as described in regard to cultural heritage sites (Hinzen/Schreiber/Yerli 2010; Hinzen/Schreiber/Rosellen 2013; Nicu 2017; Bosher et al. 2019), are a threat to archaeological monuments. The broad spectrum of geosciences can provide help in archaeological studies with understanding landscape evolution, dating methods, or material composition of monuments (Rodríguez-Pascua et al. 2011; Artioli/Quartieri 2016; Bubenzer/Forbriger/Siart 2018). In recent years, various studies using terrestrial laser scanning (TLS; LiDAR – light detection and ranging) surveying for archaeological purposes and conservation projects have been successful. TLS provides several benefits for application in the field of archaeological heritage. The sub-cm resolution and accuracy of these scans enable a highly-detailed analysis of the deformation to help with the understanding of the underlying processes (Pagounis et al. 2016), and has been applied widely (e.g. Entwistle/McCaffrey/Abrahams 2009; Fleischer/Hinzen/Schreiber 2010; Hinzen/Schreiber/Rosellen 2013; Teichner 2018). TLS is usually employed as a supporting technology, whether it is geodetic surveying or using it to create a 3D model of a building or structure for exact documentation, technical analysis or virtual restoring it to its former glory (e.g. al-Kheder/al-Shawabkeh/Haala 2009; Chen et al. 2016; Cheng et al. 2016).

The presented research focuses on the interaction between the structural mechanics of archaeological monuments and the ground settling induced damage due to their pedological and geological setting which has not been analysed in many cases (e.g. Ambraseys 2005; 2006; Silva et al. 2009; Rodríguez-Pascua et al. 2011). Therefore, the goal of this study is to use highly-detailed data acquired with the help of a TLS system to study structural damage to a Roman building, the Casa de la Exedra, in the city of Italica (Santiponce, prov. Sevilla/E). The scans are analysed for cracks, tilting walls, and other features which imply ground movement or deformation (Rodríguez-Pascua et al. 2011).

THE ROMAN SETTLEMENT OF ITALICA AND THE HISTORY OF ITS EXCAVATION

»*But he [Scipio] […] settled his sick and wounded soldiers in a town which he named Italica after Italy, and this is the native place of Trajan and Hadrian, who afterwards became emperors of Rome.*«
App. Ib. 6, 7, 38

The memory of Italica, lost after its abandonment in medieval times, was recovered from the 16th century onwards by the hand of prominent scholars of the time. In a very synthetic way, it should be noted that the first excavation works worth mentioning in Italica, come from the hand of Demetrio de los Ríos and Andrés Parladé (cf. **fig. 3**). The former carried out the excavations of the amphitheatre and the public bath building, the so-called Minor Baths, around the middle of the 19th century, while the latter excavated most of the private houses that are known today in the 1920s. The beginning of modern archaeological research in Italica took place in the second half of the 20th century, with outstanding works, whether excavation or research, initiated by Juan de Mata Carriazo, Francisco Collantes de Terán and Antonio García y Bellido. Since then, research on Italica has been very extensive, developing a large number of works focusing on different aspects related to the city.

The only testimony among the literary sources we have in relation to the founding of Italica is the one transmitted by Appian (Ib. 6, 7, 38), although of doubtful authenticity (Padilla Monge 2017). Appian describes the historical moment and circumstances of the birth of the Roman settlement, in an attempt to ennoble the city of origin of Emperor Hadrian. According to Appian, Publius Cornelius Scipio Africanus left the sick and wounded in a place called Italica after the victory over the Western Phoenicians in the Battle of Ilipa, near Italica.

The statute with which that first settlement was developed is not known, although the accepted proposal by most scientists is that it was originally conceived as a *vicus* and became a *municipium* in Augustan times. Later, the city itself requested from Emperor Hadrian to become a colony, then becoming the Colonia Aelia Augusta Italicensium (Caballos / Marín / Rodríguez Hidalgo 1999, 24-32; León 2020).

We hardly have archaeological evidence from the city of the Republican era. It is well known today that it was not an *ex novo* foundation, but was created from a pre-existing indigenous settlement (e. g. Amores Carredano / Rodríguez Hidalgo 1985; Rodríguez Gutiérrez / García Fernández 2016). Already from the end of the Republic and especially since the time of Augustus, the urban image of Italica can be clearly discerned. The most striking and best-preserved building of the Vetus Urbs is the theatre building. Of historical significance is an *opus signinum* mosaic mentioning Trajan's ancestor Marcus Trahius.

The great urban transformation of Italica occurred in the Hadrianic era, when the city was enlarged with the incorporation of a new urban district, which increased the city's extension considerably to the north-west. It was Antonio García y Bellido who coined the term »Nova Urbs« to designate the new Hadrianic neighbourhood, as opposed to »Vetus Urbs«, which according to the same proposal would designate the pre-existing city (**fig. 1**). Although, in order to understand the new city of Italica, it should be borne in mind that Hadrian's programme did not mean the mere juxtaposition of a new »neighbourhood« and the pre-existing city, but a thorough removal of the Vetus Urbs space, and the extension of the new Nova Urbs enclosure, now understood as a single urban complex (Hidalgo 2003, 104-105).

Hadrian's new district was equipped with an important set of new public buildings: the »Traianeum« (**fig. 1, 8**), an imperial cult temple consecrated by Hadrian to his adoptive father, Trajan, that acquires from an urban point of view the role of the forum in this zone, and, with it, a new public bath (Termas Mayores) (**fig. 1, 7**), which was added at least to the other thermal complex installed in the Vetus Urbs (Minor Baths). All of this was surrounded by a new wall (**fig. 1, 1**). In addition, the city was endowed with a new aqueduct and, next to it, an amphitheatre was built (**fig. 1, 2**). It had a very large spectator capacity, which significantly exceeded the estimated number of inhabitants of Italica. The physiognomy of the city is completed with a series of partially known private houses, their architectural and decorative features evidencing the high aristocratic level of its owners.

The clear link between this new city project and Emperor Hadrian meant that, once the emperor died, the project would enter into a progressive crisis, largely coinciding with what happened in the emperor's megalomaniac project in his villa in Tibur (Villa Adriana). As a result, and thanks to what has been proved in the geophysical survey carried out in Italica since the early 1990s (Rodríguez Hidalgo 1997; Rodríguez

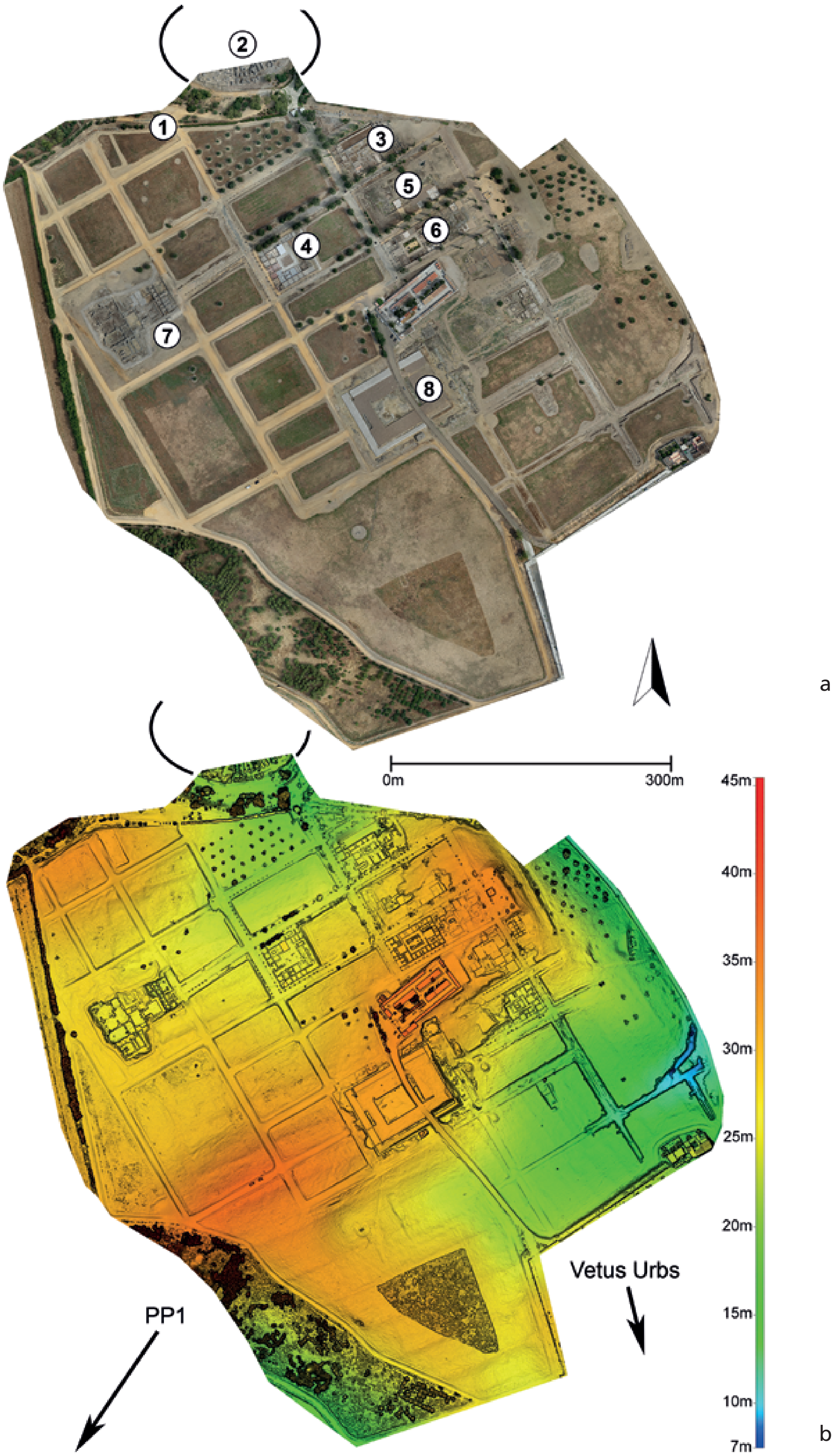

Fig. 1 Italica (Santiponce). Orthophoto (**a**) and DEM (**b**) of the Nova Urbs. – **1** city wall. – **2** amphitheatre. – **3** Casa de la Exedra. – **4** Casa del Planetario. – **5** Casa del Neptuno. – **6** Casa de los Pájaros and Casa del Patio Rodio. – **7** Termas Mayores. – **8** »Traianeum«. – PP-1 = modern urbanisation. – (Modified after Salzmann 2016, fig. 2).

Hidalgo/Keay 1995; Rodríguez Hidalgo et al. 1999; Teichner/Hermann/Mertl 2016; Hidalgo et al. 2018; in print), a good part of the *insulae* that conformed Hadrian's extension of the city were never constructed, the project of the new city thus remaining unfinished. Damage appeared soon after construction had finished with evidence of poor-quality repairs at the Casa del Planetario and Casa del Neptuno becoming apparent (see fig. 1, 4-5 for building locations) (Luzón 1982). The Nova Urbs seems to have been partially abandoned within the second half of the 3rd century, not even a generation after being erected (Keay 1988; Rodríguez Hidalgo/Keay 1995).

Today an open-air museum managed by the Conjunto Arqueológico de Itálica is located within the grounds of the former Nova Urbs, while the modern city of Santiponce largely occupies the site of the Vetus Urbs. Also located within the grounds of the Nova Urbs is the modern cemetery of Santiponce (fig. 1, between 6 and 8).

THE NATURAL ENVIRONMENT

The Roman city of Italica is located in the current municipality of Santiponce, only 10 km NW of Seville, Andalusia, Spain. As in most parts of the southern Iberian Peninsula, this area experiences a Mediterranean, Csa-style climate, characterised by hot and dry summers followed by mild winters with heavy rains (Peel/Finlayson/McMahon 2007).

Santiponce lies on the west bank of the Guadalquivir River (the ancient Baetis), which drains large parts of Andalusia and the Sierra Morena before ending in the Gulf of Cádiz. The natural environment and the vicinity of the river were important for the Roman choice of site. Italica was located on the shore of the Guadalquivir River (Borja et al. 2018; Borja/Borja/Jiménez 2018), a route of communication and export of agricultural and mining products of the Roman province of Hispania Ulterior Baetica. Over time, the riverbed moved away from the city, one of the reasons for its crisis and decline.

THE SPECIFIC NATURAL SETTINGS IN THE ITALICA-SANTIPONCE REGION

The Blue Marls (*Margas Azules*)

The Tertiary deposits on which the Roman city of Italica was built (fig. 2) possess certain geotechnical parameters that are vital to this study. These generally limey units consist of marls, calcarenites, sandstones, and sandy silts with a thickness of about 200-220 m (de Torres 1972). According to the current geotechnical map of Spain, the *Margas azules* are an »acceptable« ground to build on, although the slope should not be steeper than 10 % regarding its settling and expansive characteristics (IGME 1975).

The marls are described as blue (*Margas azules*, Tm^{Bc}_{12}). The marine blue clays have been deposited during the Tortonian to the Messinian stages. Its blue colour derives from weathered iron hydroxides and pyrites, along with a higher organic matter content. Geotechnical parameters of *Margas azules* were studied in detail by Rena Stehn (2010) and André Vollmert (2010) in the neighbouring city of Carmona, ancient Carmo. They determined that the cohesive soil is classified as an intermediate to plastic clay with a stiff to slurry consistency index. The activity index IA (i. e. soil shrinkage or swelling potential) of the samples is within the category of normal active soils. The clays are susceptible to plastic deformation under increased load, such as heavy buildings in a new city district. Moreover, with IA classified as »normal active«, the clays may swell during periods with increased precipitation, such as the winters in southern Spain.

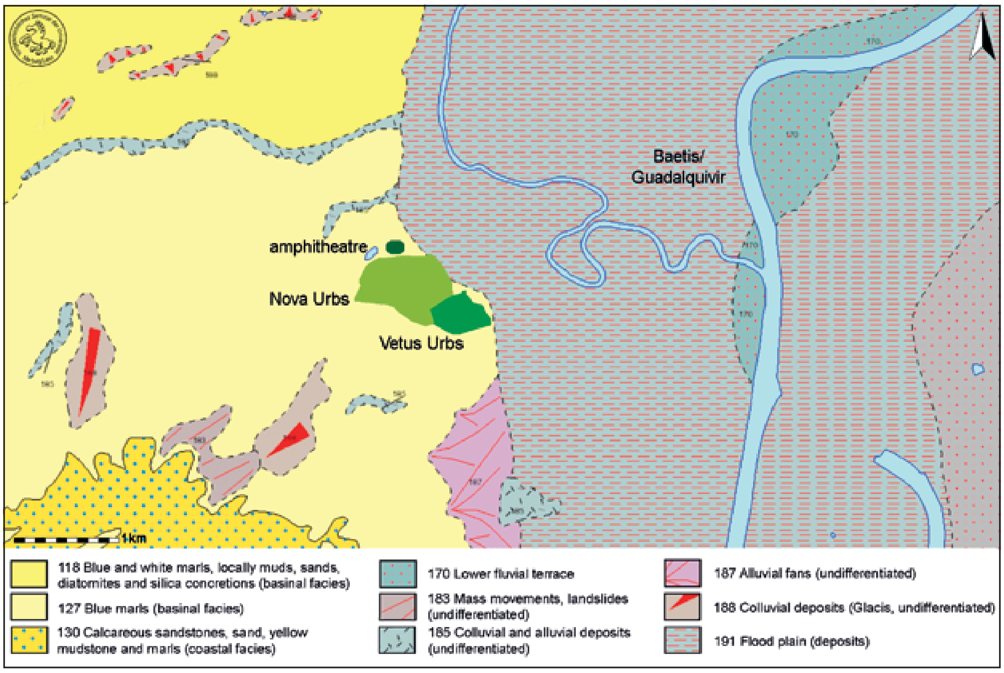

Fig. 2 Geological map of the Santiponce area. The Roman city of Italica. Indicated are the Vetus Urbs (green), the Nova Urbs (light green) and the amphitheatre (dark green) which are located on the edge of the river/floodplain. – (Adapted from the Mapa Geológico de España. Magna 50 Hoja 984 [Sevilla], igme.maps.arcgis.com [8.7.2022].

The Effects on the Architecture

Massive damage to the building walls and pavements is visible today in the Hadrianic district of the Roman city (Nova Urbs), first attributed in the 1960s to earthquakes and landslide movement through the centuries (García y Bellido 1960, 79). Since the 1970s and 1980s, however, the cracks and deformation of the Roman architecture have been linked to plastic and expansive clays, the so-called *arcillas expansivas* with the capacity of shrinking and deforming into deep cracks during the hot and dry summers and swelling during the mild and rainy winters (Ayala Carcedo et al. 1986, 55-56; Jaramillo/de Justo/Romero 2000, 539; Pinto Puerto/Guerrero Vega 2012, 23). In the scientific literature, especially that of the 1970s and 1980s, this phenomenon is also called *bujeo-* or *bugeo*-effect (Blanco 1978, 15; Pellicer/Hurtado/La Bandera 1982, 27; Abad 1982, 139. 147; Pellicer 1982, 211. 216; Canto 1982, 235-236; Ayala Carcedo et al. 1986, 25). Its impact was impressively demonstrated to the responsible archaeologists and heritage managers in a storage building for the mosaics, erected in 1972, that showed strong cracks after only three years of construction (Luzón 1982, pl. VI.1). Comparable destructions are observed in the archaeological museum of Italica and in the guardhouse. The damage left obviously a strong impression on the archaeologists because the geological setting of the Nova Urbs was then interpreted quite rapidly and concordantly as one of the main reasons for the abandonment of the city probably after only one generation (Luzón 1975, 35; Blanco 1978, 14-15; Luzón 1982, 78; Keay 1988, 133-134).
In contrast, others did not follow this hypothesis arguing that the *bujeo*-effect could not have existed during Roman times (e.g. Canto 1985, 146-147). The classical admiration for Roman technology, claiming that the Roman engineers would not have been that careless to build an entire city on such unstable grounds, has been put forward. Searching for other explanations Alicia M. Canto (1985) assumed that there had to be a higher degree of humidity in Roman times. Further, in her opinion, the change of the riverbed of the Guadalquivir would have caused dehydration of the soil and, therefore, the so-called *bujeo*-effect, especially

since the 17th and 18th centuries. In conclusion, it was only in modern times that the damaging factor of the expansive clays occurred (Canto 1982, 236 note 14; 1985, 146-147; 1999, 160-162). Based on this argumentation other scientists also concluded that the negative effect of the Miocene expansive clays did not exist in Roman Italica or was highly overestimated (Blázquez 2005, 17; Arteaga et al. 2016, 96).
If the humidity had been higher in Roman times as Alicia M. Canto (1985, 146-147) postulated, the water content of the clay would have constantly been kept at a higher level than today. While this elevated and constant water content would have prevented any swelling and shrinking of the clays, the plasticity would also have been increased. Depending on how much pore water was present in the clays in antiquity, the clay plasticity would have been elevated to such an extent that it would not have been possible to erect several heavy multi-floor buildings on top of it. As a conclusive observation, we argue that the effect of the expansive clays is a permanent geotechnical issue and not due to a different climate in Roman times or changes in the local drainage system.
In 2000, a team of scientists in the field of building structures and soil engineering analysed the destructive effects of the expansive clays by comparing the Nova Urbs of Italica and the adjacent modern urbanisation PP-1 of Santiponce (**fig. 1**) of 1989. After only ten years of construction, the new houses showed severe structural damage caused by the deforming soils. The main problem for the recently built houses of PP-1 are gardens set too close to the buildings, permeable pavements, and, lastly, the pile foundations without adequate protection (Jaramillo / de Justo / Romero 2000, 541-543). The study concludes that the Roman architecture was more appropriate than the modern one to reduce the effects of the expansive clays using broad porticoes, quite flexible fundaments of *opus caementicium* and the mortar bed of the mosaic floor.
Another hypothesis to demonstrate the technical knowledge of the Roman engineers in protecting the buildings of Italica from the destructive potential of the expansive clays was set up in a study treating the »reinforced column shafts« of the largest known building of the Nova Urbs, the »Traianeum« (Rodríguez Gutiérrez et al. 2016, 13). Experts from archaeology and architecture (Jaramillo / de Justo / Romero 2000; Rodríguez Gutiérrez et al. 2016) suggested that the remarkably high use of metallic dowels and staples used in the column shafts could be interpreted as a preventive architectonical method to stabilise the public complex of the Nova Urbs against mobile clays. Again, the soil mechanics are not questioned. The technical solution implemented in the »Traianeum« points to the *bujeo*-effect, and possibly to the Roman technical knowledge of periodic mobile clays.
The geological effects in the Nova Urbs of Italica have been mixed up in the archaeological debate and previous discussions. One is the constantly shrinking long-term effect provoked by the *Margas azules* including the soils forming on this substrate (vertisols), and the other is the swelling or shrinking capacity of the expansive clays of the surface related to the water content changing with the seasons. While the latter destructive effect can be minimised by avoiding permeable soils near the walls of buildings like porches (Jaramillo / de Justo / Romero 2000), the constant shrinking and swelling processes are accelerated by heavy loads and may have a permanent destructive impact on the buildings.

THE ARCHAEOLOGICAL HERITAGE

Structural damage is clearly visible at several ruins within the Nova Urbs of Italica. These damages can be observed in different public buildings, such as the amphitheatre. Its large structure of *opus caementicium* and *quadratum* was also affected by subsoil problems. Likewise, these damages are observed in the houses, e. g. many fractures in the brick walls of the Casa de la Cañada Honda. But the most affected building with significant structural damage is the Casa de la Exedra.

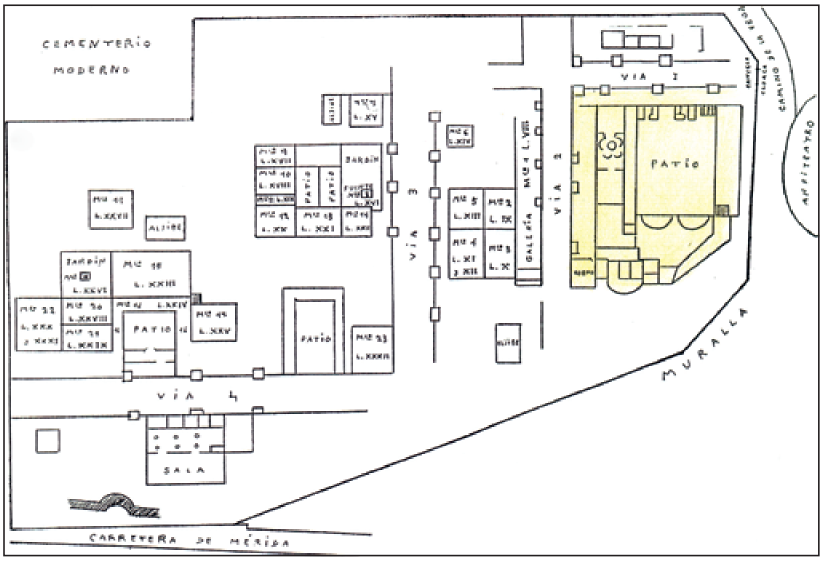

Fig. 3 Italica (Santiponce). Sketch of the excavation of A. Parladé in the Nova Urbs during the 1920s. Highlighted in yellow is the Casa de la Exedra, next to the city wall (»muralla«) and the amphitheatre (»anfiteatro«). – (After Conde León 1987, pl. 14).

A CASE STUDY: THE CASA DE LA EXEDRA

The Casa de la Exedra is located in a prominent situation of Italica's Nova Urbs (**fig. 1**) on the *cardo maximus* and next to the city gate leading to the amphitheatre and to the road towards the north leading to Emerita Augusta.

Research History of the Casa de la Exedra

Excavations in the Casa de la Exedra were carried out by Andrés Parladé between the 1920s and the beginning of the 1930s, completing the excavation of the entire house. The building was interpreted first as a private palace (**fig. 3**) and later as part of a public bath.

Juan de Mata Carriazo (1935) carried out the first detailed study of the building, interpreting its northern part as a public *palaestra* or *gymnasium* and its southern part as a guest house next to the city entrance. Antonio García y Bellido in his well-known book »Colonia Aelia Augusta Itálica« (1960, 94-104) identified a luxury residence, following Juan de Mata Carriazo's interpretation of the northern area as a *gymnasium* or *palaestra* (**fig. 4**). Years later, Al-

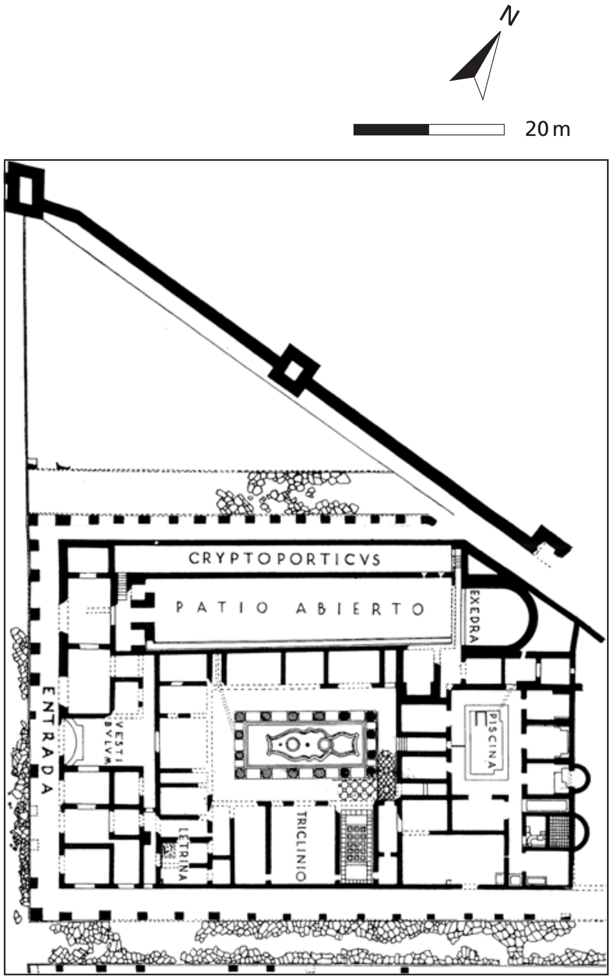

Fig. 4 Italica (Santiponce). Floor plan of the Casa de la Exedra with surrounding streets and section of the 2nd century AD wall. – (Modified after García y Bellido 1960).

Fig. 5 Italica (Santiponce). Orthophoto of the Casa de la Exedra and the section of the city wall just north of the mansion, taken using an UAV. Spatial resolution is 5.3 cm per pixel. – (After Salzmann 2016, fig. 2).

berto Balil (1973) thoroughly analysed the building, considering it one of the best examples of the peristyle houses in Hispania, highlighting the African influence on some of its elements. He emphasised the importance and exceptionality of the house by having its own baths, a circumstance that links the characteristics of the *domus* and the importance of the owner. Lourdes Roldán (1988; 1991; 1993), analysed the house from the perspective of its construction techniques. The building was interpreted as a luxurious house and the exceptionality of the use of *opus caementicium* in the construction stressed, discarding the possible interpretation as a public building. José Manuel Rodríguez Hidalgo (1991) proposed the interpretation of the house as the headquarters of Italica's *collegium iuvenum*. This interpretation has been followed mainly by local researchers. Recent activities in the house have focused on conservation and restoration work which was necessary because of its unprotected exposure to the weather. Thanks to these works, it has been possible to review and restore especially the mosaic of *opus sectile* preserved in one of the rooms arranged south of the house [1].

Analysis of the Architecture of the Casa de la Exedra

The building is arranged in a trapezoidal *insula* of around 2,176 m² (68 m × 32 m) (**fig. 5**), as a consequence of the need to adapt its shape to the layout of the city wall. The irregular plan of the *insula* determines the floor shape of the building, which, in turn, adapts to the trapezoidal shape. Due to the hillslope topography, the single building units are organised on different terraces and linked by staircases. The house opens to the *cardo* like others in the Nova Urbs with access to *tabernae* that had a separate access from the porch of the street (**figs 4-5**).

The house entrance in form of a tripartite access in *exedra* gave access to a large hall, with two lateral *alae*. The residential space is separated from this entrance block by a narrow transverse corridor, which in relation to the southern section would most likely constitute the hollow of the staircase that would allow the upper floor of the house to be reached.

Like other houses of Italica, the Casa de la Exedra is organised with a peristyle at its centre, around which most of the rooms are arranged. The peristyle has a paved space with bichrome geometric mosaics (García y Bellido 1960; Mañas 2011, 28) and is supported by cruciform pillars, on which arches would have been arranged towards the open space of the courtyard and edge vaults on the corridors. The solidity of this roof confirms the idea of a second floor. Among the rooms that are open to the peristyle, it is possible to identify *cubicula* and various representation rooms. The large room that opens in the centre of the south corridor stands out, forming the *triclinium*. It was paved with a mosaic that is very poorly preserved. A band of ceramic tiles indicates where the *lecti* were placed (Mañas 2011, 26). The room located to the east was paved with an *opus sectile* pavement (cf. **fig. 10**) and is dated to the beginning of the 3rd century (Carriazo 1935, 313-314; García y Bellido 1960, 94. 133; Mañas 2011, 26-27; Gutiérrez 2006, 159). On the west side, there is a latrine (**fig. 4**), decorated with the famous mosaic showing a Nilotic theme, with representation of pygmies, dolphins, fish and plant elements (Blanco/Luzón 1974, 45; Mañas 2011, 25-26).

The eastern area of the house, which is located on a higher terrace, is organised around a courtyard with a pond in its centre. A series of rooms, among which a small *balneum* can be identified (García-Entero 2005, 711-717), opens around this space.

In the northern wing of the house, a separate architectonic unit can be identified, to a large extent semi-independent from the rest of the house. This part is made up of a very elongated rectangular space, which has a central *viridarium* (**fig. 6**). The northern side, which served as the facade of the house on that wing, was made up of a porticoed corridor, supported by a *cryptoporticus* that allowed solving the problems of height difference of the sloping ground on which the house is arranged. The *cryptoporticus* was accessed by two stairs located at the ends, its interior (**fig. 7**) illuminated by flared windows. The head of this long garden was defined by an *exedra*, which gives the house its name. It is covered by a solid vault of *opus caementicium* containing reused Dressel 20 amphorae as a constructive element (**fig. 8**).

Fig. 6 Italica, Casa de la Exedra. Photograph of the *viridarium* (»patio abierto« in **fig. 4**). In the background the collapsed vault of the *exedra*, that gives the house its name. – (Photo R. Hidalgo-Prieto).

Fig. 7 Italica, Casa de la Exedra. Eastern end of the *cryptoporticus* next to the *exedra*. – (Photo R. Hidalgo-Prieto).

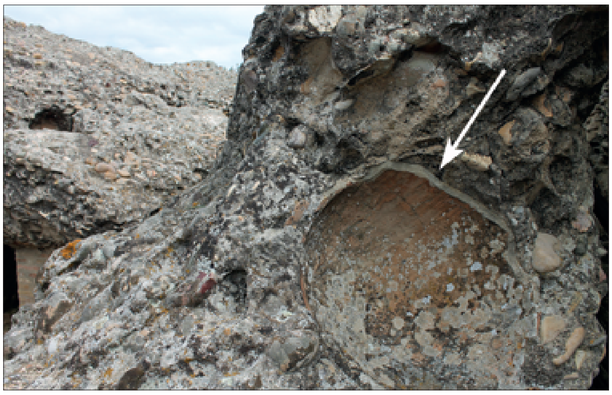

Fig. 8 Italica, Casa de la Exedra. Detail of oil amphora (Dressel 20) embedded in the *opus caementicium* of the *exedra*. – (Photo R. Hidalgo-Prieto).

It would be necessary to carry out new excavations to confirm this, but the presence of two tanks in the back of the *exedra* and its typology suggest that the *exedra* most likely had fountains in its internal perimeter[2].

Chronology and Function of the Building

The chronology of this house, particularly of the time of construction, its occupation and abandonment is difficult to assess, as the excavations have practically left no stratigraphic information. For the time of construction, the most reliable criterion is the dating of the mosaics, especially with respect to the mosaic of pygmies and cranes, dated to the middle of the 2nd century AD by comparison with the mosaic of the neighbouring Casa de Neptuno (Balil 1969; 1971; Blanco 1975; Blanco/Luzón 1974; Mañas 2011, 25-26). In the foundations of the mosaic in the Casa de Neptuno, a Hadrianic coin was found, that allows dating the pavement after 134 AD (García y Bellido 1960; Luzón 1975). Although the mosaics do not necessarily date from the construction time of the house, the characteristics of the bricks used for the construction of the building (**fig. 7**) also point to Hadrian's reign (León 1977). A similar chronology is provided by studying the wall paintings, dated to the end of the 2nd century or the beginning of the 3rd century AD (Abad 1975, 884), and the *opus sectile* pavement, dated to the beginning of the 3rd century AD[3].
Regarding the interpretation of this building, the possibility of locating Italica's *collegium iuvenum* here has been raised (Rodríguez Hidalgo 1991). However, as it has already been revealed by various researchers (Gros 2001, 180-184; Hidalgo 2003, 116-117; García-Entero 2005, 717; Mañas 2010, 84-85; 2011; Goffaux 2012, 212-214; García-Entero/Hidalgo 2016, 470), no evidence or sufficient arguments have been provided to confirm such a hypothesis. In the absence of epigraphic evidence, the only criterion that can be counted is really the one that provides the building's own architecture, which in no way allows its identification as the headquarters of a *collegium*. Without ever forgetting the originality of the house, all its elements must be understood in the context of the uniqueness that all the residential buildings of the city of Italica exhibit (Casa del Planetario, Casa de los Pájaros, Casa de la Cañada Honda, etc.). This was most likely influenced by the privileged position of its promoters in line with what happened in much of the city's public architecture (García-Entero/Hidalgo 2016, 470).

ARCHITECTURAL ENGINEERING AND DATA COLLECTION AT THE CASA DE LA EXEDRA

Building Materials

There are mainly two techniques of wall construction recognisable at the Casa de la Exedra: the walls of the northern building unit – including the *exedra*, the *viridarium* walls, the porticoed corridor and the *cryptoporticus* – as well as of the peristyle with its northern and eastern wing are built of a core of *opus caementicium* and faced on both sides with bricks (*opus testaceum*) (**fig. 7**). Most of the walls are about 50 cm thick whereas the *exedra* is about 1.60 m thick. The depth of the foundations varies between approximately 30 and 60 cm except for the *exedra* building which has a more solid and deeper foundation. The *caementa* used in the *opus caementicium* walls are medium-sized pebbles of 6-12 cm. For the foundation of the *exedra*, limestone was used (Roldán 1993, 182-197. 285-297).
A different technique is employed in the southern wing of the peristyle as well as in the eastern part of the house on the higher terrace. The *opus caementicium* walls there have no brick facings and the pebbles of the concrete are set in quasi-rows which alternate regularly with rows of bricks (Roldán 1993, 291 fig. 75). Bricks are also used on jambs and corners to strengthen the walls. The Casa de la Exedra is the only building in Italica where this type of *opus mixtum* walls is applied (Roldán 1991; 1993, 326).
A special technique of *opus caementicium* is used in the vault of the *exedra* where reused amphorae were inserted (**fig. 8**). As an explanation for the fallen vaults, Antonio García y Bellido argued that the inserted

strength compressive	[MPa] tensile	elastic module [GPa]	number of samples	reference
4.6 ± 1.4	–	2.7 ± 0.9	9 cylinders	Giavarini et al. 2006*
3.8	0.8 ± 0.1	–	52 discs	Jackson et al. 2009
14.7 ± 9.2	–	–	36 prisms	Lamprecht 1987
3.6 ± 2	0.73 ± 0.05	2.9 ± 1.8	2 blocks	Samuelli Ferretti 1996*

Tab. 1 Compiled mechanical fracturing properties of *opus caementicium*. The values for the compressive strength overlap at about 5.5 MPa and those of the tensile strength at 0.74 MPa; the elastic module averages 2.7 GPa. »–« means no value or information provided. *From Brune et al. 2010, fig. 7.

amphorae had weakened the whole structure due to them being put in the haunch of the vault and being set too close to each other (García y Bellido 1960).

The semi-dome of the Casa de la Exedra using Dressel 20 amphorae fits well in the group of 2nd century vaults (Caballos / Marín / Rodríguez Hidalgo 1999, 78; Lancaster 2005, 68-85). The *exedra* has a diameter of 6 m and is buttressed by a barrel vault and embedded in the building structure of the house. Neither the position of the amphorae in the haunches of the vault nor their juxtaposed arrangement were unusual and they did not have a destabilising effect. The collapse of the semi-dome and the barrel vault was therefore more likely caused by ground subsidence or sliding accelerated by the heavy load of the *opus caementicium* vaultings than by architectural factors. In addition, a supposed use of water for the fountains in the *exedra* and a supposed planted *viridarium* in the lower terrace in front of the *exedra* could also have had a strong impact on the surrounding walls causing a massive cracking, especially visible in the *cryptoporticus* wall.

DISCUSSION OF THE *OPUS CAEMENTICIUM* OF THE CASA DE LA EXEDRA

Leaving the special constructional feature aside, we can therefore differentiate between prefabricated building components and components completed on the site of the Casa de la Exedra. All important supporting formwork elements consist of Roman *opus caementicium*. It was used in the construction of walls and building foundations of the *domus*. Buildings constructed of this concrete have been able to absorb energy from long-term ground settling, and in some cases even several earthquakes (e. g. Silva et al. 2009), for almost two millennia while remaining largely intact on a structural scale. The mineralogical composition of the *opus caementicium* used during the Hadrianic expansion of Italica was studied in detail, and it was concluded that the concrete used is rich in quartz, calcite and phyllosilicates (biotite-like mica and clay minerals) (Ontiveros-Ortega / Rodríguez-Gutiérrez / Navarro 2016, tab. 2). While the lime binder share may be very low or very high in certain samples, in general, the Italican mortar composition is around 1:4 whereas the lime weight ratio given by Vitruvius is 1:3 (2, 5,1). The materials used for construction were sourced locally: alluvial sands from the Guadalquivir, which are high in quartz and fragments of igneous rocks and *Margas azules*, and lime from a calcarenite quarry near the city of Alcalá del Río – both find their use in the Italican *opus caementicium* (Ontiveros-Ortega / Rodríguez-Gutiérrez / Navarro 2016, esp. 211).

There have not been many studies performed on the mechanical fracturing properties of *opus caementicium*; a selection of published results is displayed in **table 1**. Although these types of concrete are heterogeneous in nature, both with regard to their composition and to their origin[4], the properties determined are still all within the same order of magnitude.

Fracturing within the walls of the Casa de la Exedra occurs on several scales (**fig. 9**). On a structural scale (~m), tensile cracks tend to form perpendicular to the direction of the main force. Due to the

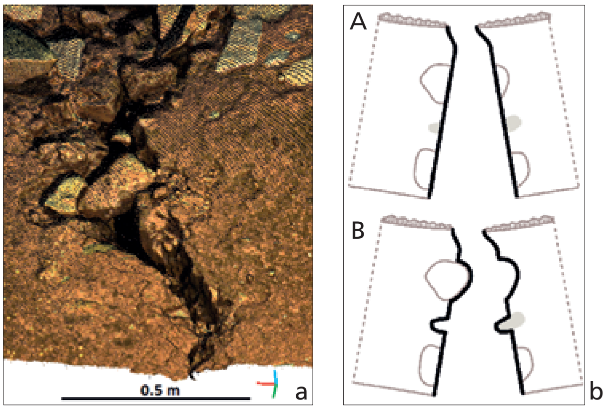

Fig. 9 Italica, Casa de la Exedra. **a** fracture of the Roman mortar. – **b** schematic drawing of fracturing processes: A: G_F (energy release $rate_{fracture}$) of the surrounding mortar is greater than the G_F of the components. – B: the fracture follows the perimeter of the individual components, as their fracture energy is greater than that of the mortar. – (Modified after Brune et al. 2010, fig. 7).

heterogeneous composition of the mortar, micro-scale fractures tend to form along the perimeter of larger components within the concrete (**fig. 9b**, B) (Brune et al. 2010). The fracture process zone starts with many micro-cracks situated at the crack tip of a larger crack, which transfers stress and disperses energy (Hu/Wittmann 1992). As larger cracks grow, the micro-cracks merge and provide continuity to the existing crack (Hillerborg 1978). For Roman concretes in general, large fracture energies and low tensile strengths are a reasonable assumption. In the damaged structures in the Nova Urbs, the fracture energy of the individual components has to be greater than that of the binding mortar, as the crack trajectory tends to form around these components (often quarzitic and of fluvial origin, **fig. 9b**, B) instead of cracking through them. The tensile strength of mortar and brickwork plays an important role in archaeo-seismology. The process described above and observed in Italica is typical for a »slow deformation« by creep, whereas impulse-like pervasive fractures are mainly generated during earthquakes and seismic shaking (Rodríguez-Pascua et al. 2011).

Structural Damage Mapping (LiDAR and TLS)

For the exact spatial coverage of the visible shifts, subsidence and building deformation, tension cracks and other damages, a TLS survey of the Casa de la Exedra was carried out in spring 2017 using a phase-based FARO Focus^{3D} X 330 TLS device[5]. All scans were performed in sunny and dry weather and at close- to mid-range (several metres distance). TLS is a form of ground-based LiDAR (light detection and ranging) surveying. TLS commonly consists of measurements of one-dimensional two-way travel times t_{tw} between a scanning station and a reflectance point in a well-defined direction. Thus, the beam is relatively well localised, even at longer ranges (Smith 2015). Using a built-in GPS, the coordinates of the scanning location are given and the point cloud can be georeferenced during post-processing. In addition to measuring distances, the intensity of the reflected signal and, with an integrated or coupled camera, RGB colour values of each point are collected. LiDAR data, in our case TLS, is very precise when it comes to measurements collected from it. The individual determined dip/dip values are generally within the normal range of error when compared to physical compass measurements done in the field (Wiatr et al. 2013). LiDAR is also more precise than SfM (Structure from Motion) models when it comes to (structural) geology or archaeological applications (Cawood et al. 2017). The data collected using a mobile phone in the field is also reliable (Allmendinger/Siron/Scott 2017), as structural data resemble those of the LiDAR.
At the Casa de la Exedra, multiple overlapping scans from different scan positions were undertaken with the aim to minimise data shadows, i.e. gaps in the acquired data due to irregular topography or building features. Ten different scanning locations were chosen throughout the ruins of the mansion to create a high-resolution 3D model of architectural and deformational features. The quality of the scans is comparable to photography quality (**fig. 10**).

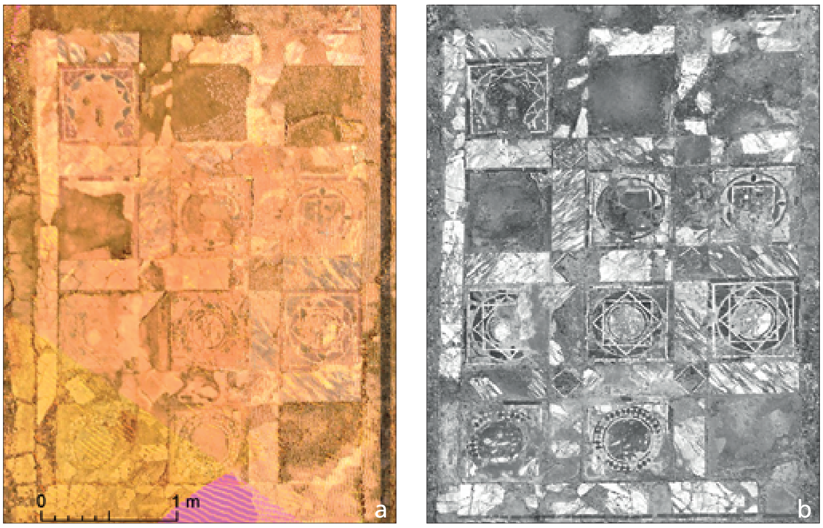

Fig. 10 Italica, Casa de la Exedra. **a** T-LiDAR of the *opus sectile*-style mosaics in the room just north-east of the *triclinium*. – **b** photo of the same decorated floor. – (After Mañas 2010).

The scans produced two data sets: one of the whole building (fig. 11) and the neighbouring section of the city wall and another of the thin *cryptoporticus* (see fig. 4). The generated floor plan ranges from the western wing of the peristyle courtyard to the eastern wing of the *balneum*. The lower entrance level of the Casa de la Exedra with the *vestibulum* and the *tabernae* is not part of this plan. The data sets were merged and georeferenced before being further processed. All following work on the data sets was done using the open-source software package CloudCompare (version 2.9.beta) developed by Daniel Girardeau-Montaut (2017).

After eliminating noise like reflections, errors, dust particles, insects and points of no interest, the size of the scans was reduced by 56,787,877 points or 39.2 % for the Casa de la Exedra data set, and by 34,560,836 points or 36.0 % for the *cryptoporticus* one. The cleaned data sets are now easier to handle due to their reduced size. By spatially subsampling the scans to 1 mm, the data sets were further reduced in size. A point-to-point distance of 1 mm provides a robust digital framework and data set to obtain and evaluate structural data with reduced computer specifications, thus speeding up all following steps.

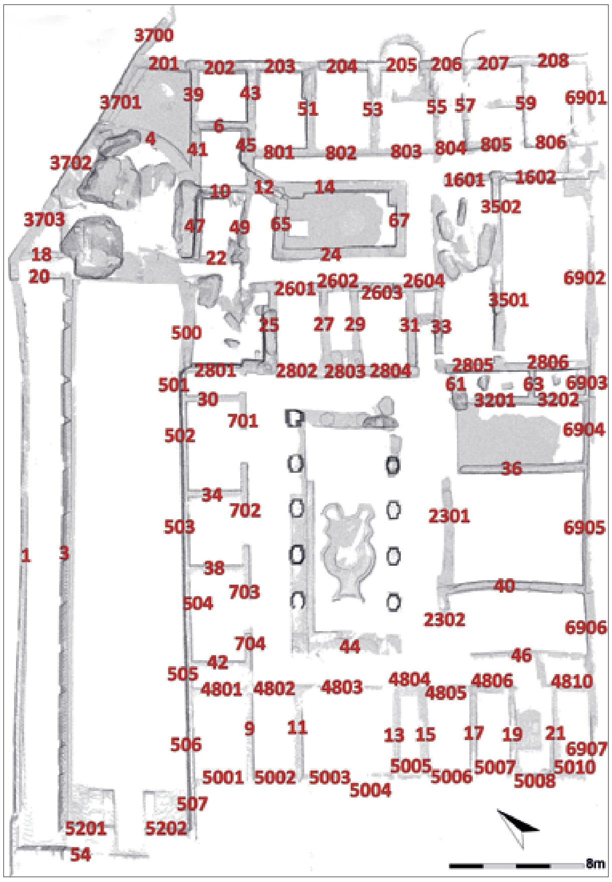

Fig. 11 Italica (Santiponce). General plan of the Casa de la Exedra, based on the TLS scan in 2017 with a total number of 120 wall segments distinguished. – (Plan A. von Schéele).

The plug-in tool ccCompass, developed by Samuel T. Thiele et al. (2017), was used to measure the structural damages of the Casa de la Exedra, e.g. cracks in walls, in a georeferenced orientation. The plug-in, comparable to a geological compass, records the dip direction and azimuth angle of a plane or plunge and the trend values of a lineation, depending on the operating mode. For lineation measurements, the start and end

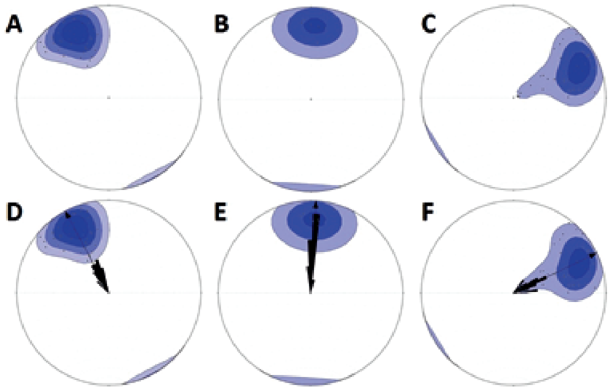

Fig. 12 Stereonets and roseplots of fracture measurements from the Casa de la Exedra at Italica (Santiponce). **A** and **D** represent plots of walls running NW/SE; **B** and **E** plane measurements collected in the field; **C** and **F** walls running NE/SW. Contours included after Kamb (significance 2, interval 5). For the roseplots, bin size is 5°. – (Graphic A. von Schéele).

coordinates of each line are registered; for planes, the centre point and radius used in calculating the plane are recorded. Based on this virtual 3D model, a total of 120 wall segments have been structurally determined, as shown in **figure 11**. 42 of these were discarded from further analysis because of poor scanning quality. Out of the remaining 78 walls, 23 are crack-free and were not further investigated. Within the remaining set of walls, a total number of 111 cracks can be made out, which were further studied. The numbering system for the walls (see **fig. 11**) is that walls running NE/SW are given an odd first number, while walls running NW/SE are even-numbered. For three- and four-digit numbers, the latter two digits represent segments of a wall (e.g. 505 or 5007 are segments of the walls 5 or 50 respectively).

Direct measurements of the object of interest are preferred. However, in most cases of the scans of the Casa de la Exedra, recording dip/dip values of planes is not possible due to the lack of sufficient scanning quality – even in the non-subsampled data sets – or due to the non-planar appearance of the cracks within the walls or floor. Instead, two lineations of the same plane are measured, from which the strike and dip direction of the plane can be determined. To provide a statistical basis on which the movement direction of the Casa de la Exedra is determined, and to limit any erroneous data collected, 15 measurements each for the strike-corresponding and dip-corresponding lineation are recorded.

Stereonet and roseplots showing the results of the fracture and joint measurements are displayed in **figure 12**, where the data has been grouped according to the wall where the measurement was taken: A and D represent even-numbered walls, C and F odd-numbered walls. Additionally, plots B and E show stereonets and roseplots from plane measurements collected in the field using the application GeoID for iOS mobile devices. All stereonets were created and evaluated using the software StereoNet (version 9.9.6) developed by Nestor Cardozo and Richard W. Allmendinger (2013).

NW/SE-running walls of the Casa de la Exedra display cracks with a strike of 061° (azimuth) while the joints NE/SW-walls have a strike of 153° (**tab. 2**). The trend value for the mean vector listed in **table 2** corresponds to the dip direction of the mean fracture plane. Both series of fractures and joints are perpendicular to each other (within 1.8°, precision and error).

The mean vectors for the 3D cloud of poles were computed using StereoNet. Trend values for these vectors are listed in **table 2** along with the confidence intervals as proposed by Robert Butler (1992). Overall, the precision factor κ for these mean vectors is low, especially for the LiDAR data (corresponding stereonets A/D and B/E), meaning the data is spread across a section of the sphere.

stereonet	trend [°]	strike [°]	κ [-]	θ50 [°]	θ63 [°]	θ95 [°]
A/D	331.4	061.4	22.9	14.1	16.9	29.3
B/E	063.2	153.2	10.3	21.0	25.2	43.6
C/F	003.4	093.4	79.8	7.6	9.1	15.7

Tab. 2 Statistical analysis of the computed mean vectors shown in **figure 12** along with their respective precision factors κ calculated using the method developed by Fisher 1953. Values for θ were calculated after Butler 1992.

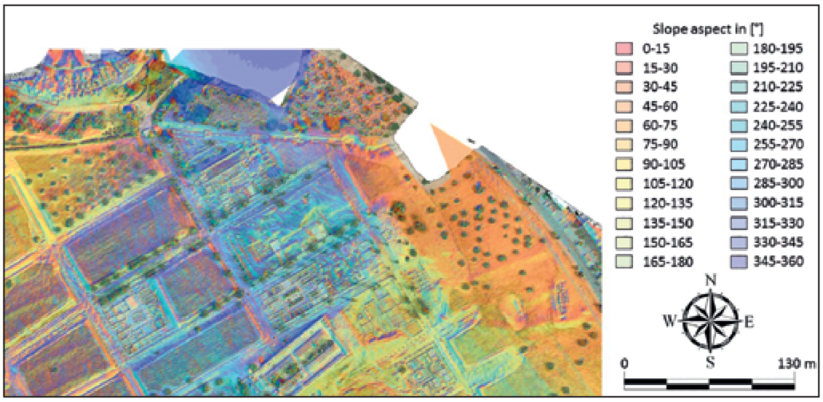

Fig. 13 Italica (Santiponce). Slope aspect of the ground beneath the Nova Urbs. The aspect was determined using ArcGIS (version 10.5) from a DEM created by the Marburg University Team in 2015. – (After Teichner 2016).

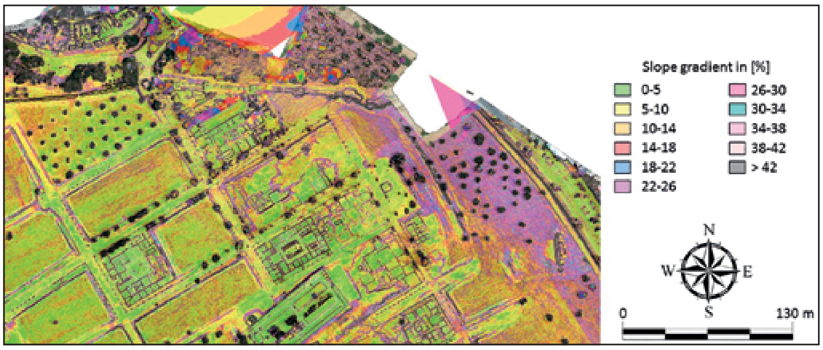

Fig. 14 Italica (Santiponce). Slope gradient of the ground beneath the Nova Urbs. The gradient was determined using ArcGIS (version 10.5) from a DEM created by the Marburg University Team in 2015. – (After Teichner 2016).

The standard deviation of the individual measurements, both with regard to the trend and plunge values for the respective measurements, is on average below 5° for the dip direction and below 3° for the dip angles. Thomas Wiatr et al. (2013) concluded that measurements taken from LiDAR data diverge from field data by ±005/03; the total error for our LiDAR data collected in Italica is ±010/06.

GIS and DEM

GIS (geographical information system) and DEM (digital elevation model) were employed to determine the slope aspect and gradient of the topography around the Casa de la Exedra in order to determine the direction of ground movement from fractures. Two tools incorporated into the ArcGIS software package (version 10.5) developed by ESRI were used for this: »Slope« to determine the gradient, and »Aspect« to determine the direction of the slope facing. Both tools derive their output from a DEM. An ultra-high resolution one (5.3cm per pixel) of the Nova Urbs of Italica, as shown in **figure 10a** together with an orthophoto in an equally high resolution was created by the Marburg University Team in 2015. The DEM was created using the SfM technique from aerial photographs shot by an UAV.

The calculation of the slope aspect and gradient (**figs 13-14**) shows that the slope at the Casa de la Exedra faces NW-NNW (azimuth 330-360°). The gradient is estimated at roughly 10-18% referring to 6-10° inclination, regarding Roman and later landscape modifications. The angle of repose in the *Margas azules* is much lower, of course a function of water content, vegetation and loading (e.g. by buildings). A probably not reconstructed indication of creeping slopes is found in the NW corner of the Casa de la Exedra within the pavement of the *cardo maximus*. The pavement of paving tiles is warped and folded due to creep (**fig. 15a**),

Fig. 15 **a** Italica (Santiponce). Tiled pavement of the *cardo maximus* in front of the Casa de la Exedra. Note the folding due to the creep towards the NW (red arrow indicates slide). – **b** Baelo Claudia (Bolonia). Tiled pavement of the *decumanus maximus*, the deformation was interpreted as earthquake damage. – (Photos K. Reicherter).

folds strike NE-SW and indicate a NW slip or creep within the basal rocks, here made up of blue marls (*Margas azules*) of the Neogene. Usually, Romans tiled the main roads in the cities with perfect fits as in Baelo Claudia (prov. Cádiz/E) (**fig. 15b**). A comparison with the pavement of the *decumanus maximus* of Baelo Claudia, which has been deformed by an earthquake (Silva et al. 2009), shows that cracks and break-outs especially at corners indicate a horizontal acceleration. These break-outs and cracks associated with liquefaction and settlement of underlying sands in Baelo Claudia are typical earthquake damage (Rodríguez-Pascua et al. 2011). In Italica, we could not observe these impulse-like deformation structures but slow deformation processes folding the pavement. As a consequence, we interpret the damage as creep induced by plastic deformation of soils/rocks of the *Margas azules*. The slip direction coincides with the crack patterns observed within the walls of the Casa de la Exedra. The relation suggests that the deformation occurred relatively fast after the construction of both, the Casa de la Exedra and the *cardo maximus*.

DISCUSSION

The results from the analysis of the structural damage observed in the Casa de la Exedra enable an ascertainment of the extent, velocity and timing of the deformation to the buildings and streets in the Nova Urbs of Italica. Most of the damage observed is related to slow deformation processes and not to earthquakes. Slip and creep of heavy constructions on plastic and expansive clays, here the Neogene blue marls, caused cracks, folds and tilting. The open cracks and the delineated deformation directions listed in **table 2** and plotted in the stereonets **D** and **F** in **figure 12** are perpendicular to each other, corresponding to the right angle at which the walls are built. The direction of the tensile stress, which produces these fractures and joints, parallels the orientation of the ground movement by creep. Fracture planes develop perpendicular to the main acting tensile stresses. Therefore, the main stress direction has to lie within the acute angle of these two idealised walls.

In addition to the survey of the structural damage to the Casa de la Exedra, an analysis of the slope on which the mansion was built was carried out (**figs 13-14**). The aspect of the slope (NW-NNW) does match the above-proposed movement direction of the Casa de la Exedra. First of all, the ground, on which the

Nova Urbs is built was anthropologically deformed during its construction roughly two millennia ago (e. g. by the *cardo maximus* construction). The site was also used for agriculture until the 1970s (Luzón 1975, 20; Salzmann 2016) and has since then been converted into an open-air museum, requiring further ground stabilising efforts so that the present-day hill faces in a different direction than the natural one would.
Although the building conditions of the *Margas azules* are »acceptable« (IGME 1975), this categorisation takes modern construction techniques and proper foundations into account. However, in nearby Carmona, the identical lithology caused major landslides and building deformation (Silva et al. 2013). The Hadrianic expansion of Italica was probably sped up and the mortar used in the foundations did not have enough time to harden properly before being completely submerged and having a building constructed on top of it. As a general rule, the mechanical and fracture properties of *opus caementicium* increase with the time it is allowed to cure (Brune et al. 2013). As a result, these foundations were probably generally of poor quality. The bedrock of Italica however, consisting of the *Margas azules* unit, is not stable to begin with.

CONCLUSION AND OUTLOOK

The undertaken archaeological analysis of the Casa de la Exedra demonstrates that the building was a Roman *domus* and not a *collegium iuvenum*. The extravagance of the house corresponds perfectly to the prevailing taste of the Hadrianic time and the privileged social position of the inhabitants building their new homes in the Nova Urbs. The chronology of the Casa de la Exedra has been discussed controversially. Undoubtedly, the *terminus post quem* for the Nova Urbs (and its houses) is the Hadrianic period. The early end of most of the Nova Urbs and the Casa de la Exedra in the middle of the 3rd century is caused by a number of reasons counting historical, social, architectural, and geological difficulties among the most important.
The issue of ground subsidence in the Nova Urbs of Italica is known and has been mentioned before: John Richardson remarks that »the hill, on which [Italica] is placed consists of highly unstable clay« (Richardson 1996, 224). Expansive (»unstable«, after Richardson) clays may prove a danger to buildings erected on them, due to the risk of these buildings subsiding or sliding (Peduto et al. 2017).
The conclusion of Simon Keay that »[t]he architects responsible for the planning of the new town had not fully appreciated the unstable soil conditions at the site« (Keay 1988, 134) is in question. Our study underlines, that the destructive effect of the expansive clays existed already in Roman times and caused severe damage. The documented preventive measure to stabilise the columns of the »Traianeum« by metallic dowels and the evidence of reparation work in different *domus* indicate the destructive power of the geological conditions.
The next step concerning the damage to the Casa de la Exedra is to determine the rate of movement and relate it to climatic events (rain / dry periods). Repeated TLS and SfM monitoring is a cheap method to determine changes in such a case. Some sections of the mansion have been reconstructed in the meantime (e. g. the central fountain or wall 7) so these should be monitored as well, as they already show immense open cracks and deformation (e. g. by gypsum marks or cheap crack-monitoring systems). In conclusion, the sliding and creeping is an ongoing process, affecting the unearthed parts and hidden structures in the subsoil, and needs to be quantified with regards to the preservation of Roman Italica.
In summary, the inhabitants of the Casa de la Exedra had to cope with a gradient of the terrain of more than 10 %, the geotechnological problems of the *Margas azules* in the city with a constant shrinking rate, especially under heavy load, which existed also in Roman times. The monitoring of cultural heritage sites and archaeological excavations should be continued to enhance preservation and minimise future damage to the objects.

Notes

1) https://www.europapress.es/esandalucia/sevilla/noticia-avanzan-trabajos-consolidacion-mosaico-casa-exedra-italica-20180827171109.html (8.7.2022).

2) The *exedra* scheme with vaults and fountains in its internal perimeter and arranged at the head of an elongated garden reminds us of the architecture of the Villa Adriana (García-Entero / Hidalgo 2016, 469). It is best represented by the well-known Canopus-Serapeum complex, while obviously the colossal proportions and the great central *euripus* basin mark a difference between the Villa Adriana and the Casa de la Exedra. The similarity is much greater if we compare the *exedra* in the Casa de la Exedra with the lesser-known »summer triclinium« of the »Palazzo« (Hidalgo 2018; 2020), which shows together with the Canopus-Serapeum the reproduction of the same typology on different scales (Cinque / Lazzeri 2010, 62-63).

3) This pavement has recently undergone a restoration process, which has provided important new insights about the room, currently under study by S. Vargas Vázquez.

4) The studies mentioned in table 1 were performed on samples collected from different parts of the Roman Empire, e. g.: H.-O. Lamprecht (1987) conducted his tests on samples from the Rhineland and Eifel regions whereas M. D. Jackson et al. (2009) collected their samples from Trajan's Market in Rome.

5) The FARO Focus3D X 330 operates at a wavelength of 1,550 nm and has a 360° horizontal and 300° vertical field of view. Its acquisition range is 0.6-330 m at an angular accuracy of 0.009° and a measurement speed of 122,000-976,000 points per second depending on the distance (the closer the object, the more points per second are recorded). A built-in GPS receiver provides georeferencing for the captured point cloud with a ranging error of ± 2 mm. The integrated 70-megapixel camera captures the point's RGB value.

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Zusammenfassung / Summary / Résumé

Geologische Risiken im archäologischen Erbe. Gebäudeschäden in der römischen *domus* Casa de la Exedra in Italica (Santiponce, prov. Sevilla / E)

Durch Setzungsdifferenzen ausgelöste Bauschäden, die durch instabile Böden und Fundamente verursacht werden, sind ein erhebliches Problem. Sie stellen eine kontinuierlich steigende Gefahr dar, und zwar nicht nur für die kritische Infrastruktur, sondern gleichermaßen auch für alle antiken oder modernen Gebäude. Es ist entscheidend, die Ursache, die Geschwindigkeit und die Richtung des Abrutschens und des Absenkens zu verstehen und zu bestimmen, um die notwendigen Gegenmaßnahmen zum Schutz von Kulturdenkmälern oder heutigen Gebäuden in Angriff nehmen zu können. Die römische Stadt Italica (Santiponce) im Süden Spaniens und am nördlichen Stadtrand von Sevilla gelegen, steht im Mittelpunkt dieser Fallstudie. Die Stadt wurde auf plastischen Tonen aus dem Miozän, den *Margas azules*, errichtet, die bei erhöhter Belastung zum Kriechen, Rutschen und Verformen tendieren. In Verbindung mit der geringen Zugfestigkeit des römischen Betons traten innerhalb eines Jahrhunderts Bauschäden an den in kurzer Zeit errichteten Gebäuden im neuen hadrianischen Stadtviertel, der Nova Urbs, auf. Diese konnten für die Casa de la Exedra exemplarisch untersucht werden. Terrestrische Laserscandaten (TLS) halfen dabei, die Bauschäden, d. h. die Brüche und Risse, in der Casa de la Exedra zu kartieren und zu klassifizieren. Im Ergebnis ließ sich eine Gleitrichtung des gesamten Gebäudes nach N (NW-NE) feststellen, offensichtlich das Resultat des Anschwellens und Zusammenziehens der plastischen Tone der *Margas azules*.

Geological Hazards in Archaeological Heritage. Building Damage in the Roman *Domus* Casa de la Exedra at Italica (Santiponce, Prov. Sevilla / E)

Structural damage induced by settlement differences due to soils and foundations is an increasingly significant danger, not only to critical infrastructure but equally to all modern and ancient buildings alike. Understanding and determining the cause, rate and direction of the sliding and subsidence is important when planning the necessary steps to protect cultural monuments or modern buildings. The Roman city of Italica (Santiponce) in southern Spain, situated on the northern outskirts of Seville, is focused upon in this case study. It is built on top of Miocene blue loams, *Margas azules*, which are prone to creep, slide and deform under increased loads. Combined with the low tensile strength of the Roman concrete, structural damage appeared within a century within the fast-constructed buildings in the new Hadrianic city quarter, Nova Urbs. This could be studied at the Casa de la Exedra. Terrestrial laser scan data (TLS) helped to map and classify structural damage, i. e. fractures and cracks in the Casa de la Exedra. A sliding direction of the entire building towards the N (NW-NE) has been detected and is interpreted as the swelling and shrinking of the blue loams of the *Margas azules*.

Risques géologiques dans le patrimoine archéologique. Dommages aux bâtiments dans la *domus* romaine Casa de la Exedra à Italica (Santiponce, prov. Sevilla / E)

Les dommages structurels induits par les différences de tassement dues à la faiblesse des sols et des fondations constituent un danger majeur croissant non seulement pour les infrastructures critiques mais aussi pour tous les bâtiments modernes et anciens. Comprendre et déterminer la cause, le taux et la direction du glissement et de l'affaissement est important pour planifier les mesures nécessaires à la protection des sites du patrimoine culturel ou des bâtiments modernes. La ville romaine d'Italica (Santiponce) dans le sud de l'Espagne, située à la périphérie nord de Séville, est l'objet de cette étude de cas. Elle est construite sur des argiles plastiques du Miocène, les *Margas azules*, qui ont tendance à fluer, glisser et se déformer sous l'effet de charges accrues. Combinés à la faible résistance à la traction du béton romain, les dommages structurels sont apparus en un siècle sur les bâtiments construits rapidement dans le nouveau quartier de la ville d'Hadrien, Nova Urbs. Ce phénomène a pu être étudié à la Casa de la Exedra. Les données de balayage laser terrestre (TLS) ont permis de cartographier et de classer les dommages structurels, c'est-à-dire les fractures et les fissures de la Casa de la Exedra. Une direction de glissement de l'ensemble du bâtiment vers le Nord (NW-NE) a été détectée et est interprétée par le gonflement et le retrait des argiles plastiques des *Margas azules*.

Traduction: J. Chameroy

Schlüsselwörter / Keywords / Mots-clés

Hispanien / Kulturerbemanagement / Geogefahren / römische Architektur / römische Häuser / Stadtplanung / Geoarchäologie

Hispania / heritage management / geological hazards / Roman architecture / Roman houses / urban planning / geoarchaeology

Hispanie / gestion du patrimoine culturel / géo dangers / architecture romaine / maisons romaines / planification urbaine / géoarchéologie

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