Shedding light on the Sudanese Dark Ages: Geophysical research at Old Dongola, a city-state of the Funj period (16th–19th centuries)

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Abstract

The article presents the results of magnetic and ground-penetrating radar (GPR) research carried out in Old Dongola in northern Sudan in 2018 and 2020, within the framework of a project designed to investigate the transition from Christianity to Islam taking place in the capital of the Nubian kingdom of Makuria. The integrated datasets from the application of two geophysical methods, of which one is the standard magnetic method used on sites in the Nile Valley and the other ground-penetrating radar, enhanced the archaeological interpretation, focused in this case on a reconstruction of the urban layout of the 16th–18th-century Funj settlement within the walls of the Dongola Citadel. The magnetic method, the effectiveness of which has gone unquestioned with regard to the study of silt architecture in the Nile valley, was successful in mapping the general outline of the settlement on the Citadel hill and in the quarter north of the walls. The GPR survey (450-MHz antenna) provided a much more detailed image of the street grid and was much more effective than the magnetic method in tracing the course of mud-brick walls in a sandy matrix containing baked brick rubble. Verification of the geophysical results through the excavation of selected parts of the Citadel not only satisfied the objectives of the archaeological project, which was to establish the overall street and building layout in the research area, but also confirmed the effectiveness of the two prospection methods applied in combination and the potential of integrated research with the use of the GPR and magnetic methods for the study of mud-brick and baked brick architecture on settlement sites in Sudan.

KEYWORDS
Funj period, GPR survey, magnetic survey, mud-brick architecture, Nubia, Old Dongola

INTRODUCTION

The remains of a Funj settlement from the 16th–18th centuries at Old Dongola are currently under study within the framework of a project designed to investigate the transition from Christianity to Islam taking place in the capital of the medieval Nubian kingdom of Makuria. Because of the sheer size of the site, non-invasive geophysical prospection was a necessary prerequisite to the archaeological excavation stage of the project. Considering the nature of the subsurface layers (mainly sand) and the character of the targeted...
architecture (a combination of sun-dried and baked brick made of Nile silt with high values of magnetic susceptibility), the magnetic method was felt to be the obvious choice, especially in view of the generally reported effectiveness of the method in such instances. However, taking into account the recent successful application of ground-penetrating radar (GPR) in similar circumstances prompted the decision to parallel the magnetic survey with GPR prospection.

The article presents the results of geophysical research carried out with these two methods in the Citadel area (in 2018) and to the north of it (in 2020) and compares them with the outcome of archaeological excavations, explaining how this newly acquired knowledge contributes to the goals of the project. On the geophysical side, it demonstrates the effectiveness of the GPR method in comparison with the magnetic results, opting for integrated research using both methods to enhance the archaeological interpretation.

2 | THE SITE: LOCATION, HISTORY AND PREVIOUS RESEARCH

The archaeological site of Old Dongola is located in Sudan, on the eastern bank of the Nile River, at 18° 13′ N, 30° 44′ E (Figure 1). Wadi Howar, an important communication route to Darfur and the sub-Saharan African interior, is on the opposite side of the river. The heart of the city of Old Dongola, referred to as the Citadel, is situated on an elevated outcrop of Upper Cretaceous ‘Nubian’ sandstone (Pachur & Kropelin, 1987).

Old Dongola was the capital of Makuria, which was one of the most important medieval African kingdoms. It emerged in the 4th–5th centuries as one of the three Nubian kingdoms in place of the former Meroitic Empire (Obluski, 2014). Around the mid-6th century, the kings of Makuria converted to Christianity; about a century later, they rebuffed an Arab invasion. The Arab expansion was probably the main factor behind the union of Makuria and the northern, neighbouring kingdom of Nobadia, leading to the emergence of one of the largest territorial states of the Middle Ages (Figure 1). The relationship with Muslim-ruled Egypt in the next centuries was not always easy, but there were no devastating wars (Seignobos, 2016). A turning point in Makurian history came at the end of the 13th century when the Mamluks seized power. The aggressive policy of the Makurian kings towards Egypt resulted in wars that ended with the installation of puppet Muslim rulers on the Makurian throne (Vantini, 1975, pp. 648–654). Dongola ceased to be the capital city around 1365, when the Makurian royal court relocated (Vantini, 1975, p. 699).

The next three centuries are called the Dark Ages in Sudanese history since even less is known about events in Nubia than for the medieval period (Adams, 1977, p. 592). With the decline of the Makurian (15th century) and Alwan (16th century) kingdom, city-state political entities proliferated in the Middle Nile valley between Aswan and Khartoum. In the second half of the 16th century, the kingdom of Makuria was politically divided into two major regional powers: the Ottoman Empire in the north and the Funj sultanate further south (Alexander & Adams, 2018, p. 21). This partition survived until the beginning of the 19th century when the Egyptians and the English invaded Sudan and established their rule over the country.

By the beginning of the 19th century, Old Dongola had become known to European travellers and explorers (Żurawski, 2001), but archaeological investigations did not start until the second half of the 20th century. In 1964, the Polish Centre of Mediterranean Archaeology of the University of Warsaw was granted a concession by the Sudanese government in gratitude for the Polish Centre’s help in salvaging Nubian monuments in the early 1960s (Michałowski, 1966).

Research indicates that Old Dongola was founded in the 5th to early 6th centuries (Godlewski, 2013). The city gradually developed, reaching roughly 200 ha in size during its heyday in the 10th–12th centuries. The nature of the Old Dongola agglomeration and its spatial organization have yet to be fully investigated and understood. Even so, a general picture can be presented (Figure 2). The area referred to as the Citadel covered approximately 4 ha and was surrounded by strong walls consisting of a core of sun-dried brick faced with stone (Figure 3). Elite architecture on the Citadel hill included palaces, churches and residences. Domestic buildings spread in the area directly south of the Citadel. The district to the north with two large churches, the Church of the Granite Columns (Gartkiewicz, 1990) and the Cruciform Church (Godlewski, 2013), is called the ecclesiastical quarter. Further north, an
A residential quarter 2 km long lay east of the churches. Further east, the border between the valley and the desert is dense with medieval cemeteries. Two monasteries stood on the outskirts of the city: the Monastery on Kom D and the Monastery on Kom H (Obluski, 2019). The church and western annexes of the monastery on Kom H house the largest collection of African medieval wall paintings preserved in situ. One of the best-preserved buildings in Dongola, the oldest preserved mosque in Sudan, is located east of the Citadel (Obluski et al., 2013).

The appeal of non-invasive survey methods is understandable in view of the size of the site. In the 1980s, Old Dongola became a testing ground for aerial photography using different kinds of kites. Low-altitude images helped to clarify the layout of features discovered during ground surveys of the site and to fill out plans of excavated structures. The environmental setting of the site was examined on images taken from higher altitudes ( Żurawski, 1993).

The first geophysical survey at Old Dongola was carried out with a proton magnetometer in 1989 and 1990 in an area where surface traces indicated pottery production (Misiewicz, 1992). A series of kilns not visible on the surface were registered at this time. In 2009, Tomasz Herbich used a fluxgate gradiometer to survey a settlement from the Makurian period north of the Citadel. The overall orientation of the architectural remains was mapped, including in some cases also the layout of particular buildings (Godlewski, 2013).

Research in Dongola entered a new phase in 2018 with a project funded by the European Research Council. The primary objective of the ‘UMMA: Urban metamorphosis of the community of a Medieval African capital city’ project is a study of social processes taking place in the liminal period of the kingdom of Makuria. The goal is to deliver the first synthesis on this topic, thus setting a cornerstone for research on the social history of the precolonial Middle Nile Valley.

The project focuses on two processes: religious conversion and migration. Both are scrutinized from two perspectives: household and community. The aim of the research is to answer questions, such as the following: Is the urban layout of Old Dongola between the 15th and 19th centuries AD different from the earlier urban landscape of Old Dongola and other medieval Nubian cities? Can ethnic and social diversity be traced in domestic architecture? This project may also help to address some general questions: What are the indicators of Islam and Islamization? Is the presence of religious buildings one of them? Answers to such questions require archaeological research over a large urban area, making non-invasive prospecting methods indispensable. Methods already applied include aerial photography from a drone, a detailed orthophoto map, a digital topographic map and a wide-area geophysical survey. The results of the latter prospection are presented in this article.

The geophysical survey was carried out in two adjacent areas: inside the Citadel and in the area north of it (Figure 4). The northern and north-eastern sections of the defences were excavated
(Godlewski, 1994), whereas the line of the south-eastern and southern parts of the fortifications was reconstructed based on local ground topography on the assumption that the wall would have followed the edge of the hill. The exposed part of the wall rose to a height of 10 m on the outer, northern side; the inside face is still largely hidden under sediment. Inside the Citadel area, the ground slopes down toward the Nile, building outlines discernible in several places under mounds of blanketing sand (Figure 3). Earlier excavations in the south-eastern part of the Citadel have demonstrated cultural strata reaching down 6 m below the surface (Godlewski, 2015a). North of the Citadel, the ground slopes down gently to the north. Preliminary results of auger coring in this area (currently under study) suggest an accumulation of cultural strata. The area covered by geophysical research is located between buildings from the Funj period clinging to the walls of the Citadel from the outside and the churches uncovered in earlier excavations further to the north.

5 | METHODOLOGY OF GEOPHYSICAL RESEARCH

The geophysical methods selected for this research are standard practice in non-invasive archaeological prospection and as such have an extensive literature discussing principles and applications (e.g. Aspinall et al., 2008; Conyers, 2012; Fassbinder, 2017a; Schmidt et al., 2015). The magnetic method was an obvious choice dictated by the nature of the building materials used at Old Dongola—sun-dried brick made of Nile silt—and the composition of surface layers. The magnetic susceptibility of Nile silt, which is due to the iron oxides in it and which is $5 \times 10^{-3}$ SI in the region of Nubia, was discovered already by Albert Hesse surveying the Old Kingdom fortress at Mirgissa in Nubia (Hesse, 1967, 1970). This property has made the magnetic method highly efficient in tracing architecture in dozens of surveys carried out on ancient sites in the Nile Valley (Fassbinder, 2017b; Herbich, 2003, 2019; Spencer, 2012). The other building material in use at Old Dongola, but to a far lesser extent, is baked brick; it is characterized by thermoremanent magnetization reaching $10 \times 10^{-3}$ SI (Bevan, 1994). The accumulated deposits in which these building remains are found consist mainly of sand, which can show magnetic susceptibility growing to $1.5 \times 10^{-3}$ SI due to minerals with a high content of iron oxides, but the overall magnetic contrast between the two kinds of bricks and the sandy matrix is sufficiently strong to register anomalies related to the brick structures. By the same, however, the magnetic result can become heavily disturbed by concentrated scatters of brick rubble, especially if the fragments are baked brick, considerably limiting the usefulness of this method. This and the results obtained by the German Archaeological Institute (DAI) at the Meroitic-period site of Hamadab near Meroe
(150 km downstream from Khartoum; Ullrich & Wolf, 2015) led the authors to consider the GPR method for the project in Old Dongola. The integrated results of the two methods were intended to give a much fuller picture of the urban layout in this part of the ancient city.

The magnetic survey in Old Dongola was carried out using two different fluxgate gradiometers: Geoscan Research FM256 (in the Citadel and on its south-eastern side) and Bartington Grad 601-2 (north of the Citadel, Figure 4). Measurements were taken at intervals of 0.25 m along lines 0.5 m apart, in grids of 20 × 20 m. An area of approximately 4.1 ha was mapped in the Citadel and an additional 2.1 ha outside the fortifications. To improve the clarity of the magnetic result, concentrations of baked brick lying on the surface, swept clean by wind erosion, were cleared (a total volume of roughly 100 m³) before undertaking the measurements. This also improved the coupling of the GPR antenna to the ground. The GPR data were collected from an area more or less matching the magnetic survey, both inside and outside the Citadel walls—approximately 3 ha in the Citadel and 1.9 ha in the foothills north of the Citadel (Figure 4). A Malå GX instrument was used, equipped with a HDR-shielded antenna of 450-MHz centre frequency. The antenna was moved along parallel lines spaced 0.5 m apart, with a sampling interval of 2 cm, using the same grid as in the case of the magnetic survey. In the first season, the antenna was moved on a skid with a measuring wheel; however, it tended to slip on the sandy slopes causing errors in the odometer readings. A four-wheeled, rough terrain cart was used in the following season.

The magnetic data were processed using Geoplot 4 software (Geoscan Research, 2018). Processing included application of the destagger algorithm, interpolation to a 0.25 by 0.25 m grid and low pass filtering with a Gaussian weighing within a radius of 2 on both axes (Aspinall et al., 2008). ReflexW software (Sandmeier, 2020) was used to process and visualize the GPR data from the Citadel. The processing sequence comprised several steps for enhancing data legibility and obtaining maps of use for archaeological interpretation (Goodman et al., 1995). After import to the software, individual profiles were assigned to local coordinates of the profiles using a manually generated geometry file. Then, the profiles were adjusted to the correct

![Figure 5](https://wileyonlinelibrary.com)
lengths, which eliminated the odometer errors. The start time was moved by 7 ns on each profile. Using bandpass butterworth filtering, the low and high frequency components of the signal were attenuated, reducing noise and improving the readability of the data in the useful signal range. The bandpass parameters (300–2700 MHz) were fitted by “trial and error”. Background removal filtration was used to remove longitudinal noise from the profiles. Gain was adjusted manually. In the GPR data from Old Dongola, several reflection hyperbolae were used for velocity analysis, time-to-depth conversion and migration using a FK migration procedure. It is to be noted that the actual depth levels of the resulting images are approximate due to the non-homogeneous nature of the tested soil. Finally, a set of 40 greyscale time slices showing a sum of absolute amplitudes was computed using a linear weight interpolation within the window of 0–80 ns. Data from the northern side of the Citadel, collected in the second season, were processed using Wave by gpr.software, but the applied filtration parameters were similar. Another way of computing time slices was used; amplitude maps were generated by means of kriging, preceded by a spline envelope algorithm. The resulting maps appear visually smoother. In both cases, the low reflective areas were presented as bright tones and the high reflective ones as dark ones.

The magnetic and GPR data were georeferenced to the WGS 84 Pseudo-Mercator (EPSG: 3857) coordinate system for analysis and further use in a GIS environment.

6 | MAGNETIC SURVEY RESULTS

6.1 | The Citadel

The data from the magnetic survey enabled a closer investigation of the urban layout inside the Citadel area. The degree to which the magnetic image was disturbed depended on the amount of baked bricks in the surface strata. Anomalies caused by the presence of baked bricks are most visible in the northern part of the area and the least—meaning the image of structures is the clearest—on the south-eastern side (see Figure 5). Linear anomalies corresponding to walls show a uniformly increased magnetic field strength (not exceeding 2–3 nT), which corresponds to mud-brick as a building material, and spot anomalies with values reaching 10–15 nT, which reflect baked brick. Earlier excavations have demonstrated the use of a mix of sun-dried and baked bricks in one structure; hence, anomalies corresponding to a wall can have more varied intensity in one section than in another. Therefore, the geophysical data from the two zones can be read as baked brick being used more extensively in the architecture of the northern part of the Citadel area and practically not at all on the south-eastern side; the absence of indications of baked brick debris in the sand covering this area suggests that walls in this part were built of mud-brick alone.

The magnetic image of the area within the Citadel reveals an irregular agglomeration. Several anomalies can be interpreted with a high degree of likelihood as streets and open areas on an irregular plan. The clearest images outlining streets can be seen in the southern part of the research area: a north–south street starting in the south-eastern part (eastern part of Squares B2 and C2 in Figure 6a), turning southwest (Squares C2–D1), which is evidently a continuation of Street U62 excavated earlier on the border between Archaeological Zones 1.1 and 1.2 (Figure 6b). Based on its course traced in the geophysical data, this street appears to be the main route of communication along the north-eastern side of the Citadel, going all the way to the northern end (observed between C6 and A4 in Figure 7a). The layout of the streets’ network can be derived from the magnetic data also in the central and western parts of the research area. A street running NW–SE, by the south-western edge of the research area, should be viewed as the most important passage between the northern and southern parts of the city (Squares A1–E3 in Figure 7a). A street lining the Citadel circuit wall on the eastern side was also observed (Squares C4–D4 in Figure 6a).

The architecture mapped as a result of the magnetic data interpretation of the area is contiguous and often allowing a single house to be fully traced without complementary excavation to verify the results (see a ground plan outlined in Square D2 of Figure 7a). House entrances and inner passages are traced more frequently, especially in the south-eastern part of the studied area. High-intensity spot anomalies of oval shape, not exceeding 1–2 m on the longer axis, can be seen inside individual units. These anomalies correspond to fireplaces, suggesting food preparation as the chief purpose of these units (this particular interpretation is based on experience in reading similar data from other sites; e.g., Herbich et al., 2007).

6.2 | Zone north of the Citadel

Remains of architecture could be traced in the geophysical survey data only in the south-western corner of the area (Square D2 in Figure 8a). This included the ground plan of a building with dimensions of about 30 by 35 m. Three open spaces that could reflect courtyards were observed, the middle one with three rooms alongside it and the northern one with units along the northern side, in line with chambers previously excavated in the eastern part of the complex and dated to the Funj period (Godlewski, 2015b). The observed disturbances in the magnetic image of the rest of this zone indicate some form of adaptation of the ground to settled habitation, but the layout of the anomalies does not support a clear reconstruction of the settlement layout. The low intensity of anomalies by the eastern border of the zone indicates extensive use of sun-dried mud-brick for building in this sector (see Figure 8a, Squares B4–D4). The presence of dipolar anomalies in the north-western part indicates the use of baked bricks.

7 | GPR SURVEY RESULTS

7.1 | The Citadel

The GPR prospection data complemented the magnetic survey in reflecting the settlement layout within the Citadel walls and provided
extra data for reconstructing the plans of individual houses. Time slices to a depth of 2 m gave a more reliable image of the streets compared with that traced on the magnetic maps (Figures 9 and 10). The street running along the north-eastern side of the Citadel could be followed almost in its entirety. Its southern end connected to a street marked as Street U62, excavated in Zones 1.1 and 1.2 (see Figures 7b–d and 9). GPR data clearly indicated walls on both sides of the street (see Figure 7c,d, e.g., in B5) which was not always the case in the magnetic result. Based on the GPR survey result, the street could be traced running farther to the northern part of the Citadel, turning west and following an east–west line at a distance of 30 to 50 m from the enclosure wall (see Figures 9 and 10). An analysis of

FIGURE 6  The southern part of the Citadel (for the location, see Figures 5 and 9): (a) comparison of the magnetic data, (b) archaeological excavation plan and ground-penetrating radar (GPR) time slices at the approximate depth of (c) 50–60 and (d) 90–100 cm [Colour figure can be viewed at wileyonlinelibrary.com]
the time slices showed with greater precision the course of a street nearer to the river, connecting the northern and southern parts of the city; this passage had been traced in the magnetic data (see Figure 7, in E3, D2 and A1). A crossing street between the two long tracts was also observed, extending a 10-m-long section that could be traced in the magnetic data from the centre of the Citadel (see Figure 7a, south-western corner of D3). The GPR data revealed a series of turns in the course of this street, including a change in direction from EW to NS (see Figure 7c,d, middle part of Square D4). The GPR data also confirmed the course of a street in the southern part of the Citadel, proposed on the basis of the magnetic map, supplementing it with an image of its turn toward the northwest (Figure 7c,d, Square D1). The curved running of some of the streets within the settlement undoubtedly reflects the oval outline of the Citadel mound itself.

The picture of buildings in the southern part of the Citadel, in an area where the magnetic anomalies indicated sun-dried brick as the predominant material and no baked brick clusters to cloud the image, was also more detailed in the GPR data (see Figure 7c,d). Additionally, the GPR data confirmed the location of the later city wall on the southern and south-eastern side of the Citadel, suggested on the basis of the magnetic survey results.

7.2 | Zone north of the Citadel

The results of the GPR survey at the northern foot of the Citadel are more difficult to interpret than the results obtained within its walls. This may be related to the state of preservation of architectural structures there. Nonetheless, time slices at different depths supplied sufficient information to determine the street layout, which appears to be a regular grid of straight lines with an NNW–SSE orientation (see Figure 8c,d). The difference compared with the irregular layout of

FIGURE 7 The central part of the Citadel (for the location, see Figures 5 and 9): (a) comparison of the magnetic data, (b) archaeological excavation plan and ground-penetrating radar (GPR) time slices at the approximate depth of (c) 50–60 and (d) 90–100 cm [Colour figure can be viewed at wileyonlinelibrary.com]
streets on the Citadel could be due to the absence of topographical restrictions, such as those constituted by the Citadel defences.

With regard to the building complex identified in the magnetic data of the south-western corner of the site (Figure 8c,d, Square D2), the time slices gave a clearer and more detailed view of the ground plan of individual rooms, especially in the northern courtyard, where irregular anomalies caused by baked bricks had distorted the magnetic data. Buildings of rectangular or trapezoidal shape and different size could be outlined in the central and northern parts of the area. The longest structure, the north-eastern side of which is approximately 35 m long, is traced in the centre of Square C3; it is also found on the eastern side of a complex identified in the magnetic data. Another complex can be observed in the north-western corner of the site, in a part of the magnetic map showing extensive disturbances on the border of Squares A2 and A3 and on the border of Squares B3 and B4.

Architectural remains are not reflected in the GPR data from the southern part of the research area where the ground rises toward the walls of the Citadel. This could be caused by a thicker accumulation of aeolian sand and higher attenuation of the electromagnetic wave caused by silt content in the sand. A higher silt content could be due to erosion of mud-brick architecture.

8 | ARCHAEOLOGICAL VERIFICATION AND DISCUSSION

Archaeological verification of the results of the geophysical surveys on the Citadel took place in 2019 and 2020. Excavations uncovered an area of over 4000 m² in nine sectors, providing solid grounds for assessing the effectiveness of the geophysical methods for the
purposes of the project as well as in terms of a wider application on archaeological sites of similar characteristics.

In Zones 1.2, 1.3 and 1.4 (see Figures 4, 6b and 11) in the southern part of the Citadel, the objective was to reveal a section of the city large enough to draw general conclusions about settlement in the Funj period. The excavations unearthed typical residential houses consisting of multipurpose rooms and storage units grouped around courtyards. Many of these building ground plans can be traced in the magnetic and radar images. For example, the suggested layout of walls in Zone 1.3 (see Figure 6, Squares B2–C2) proved correct. The rooms were grouped north and south of the courtyard, which was separated from the street by a wall. The building material also turned out to be the anticipated mud-brick. Buildings in Zone 1.4, south of Street U49 (see C2 and D2 in Figures 6b and 11), which corresponded to magnetic anomalies with a higher magnetic field gradient, turned out to be made of baked brick. In this case, however, the building plans revealed in the magnetic survey data were more detailed, and the suggested course of the street was confirmed. In Zones 1.3 and 1.4, the uncovered sections of Streets U62 and U49, which were also fully registered by the geophysical survey, totalled approximately 60 m in length. The width of the street ranged from 2 to 2.5 m. Excavations also confirmed minor details of the geophysical data, such as slight changes in the shape of a street; for example, a shift of the southern border (by about 2 m) observed in the southern part of Square C2 (see Figures 6b and 11). However, the GPR method was more effective in tracing the streets: both sides were revealed thanks to the clarity of the images of walls standing on either side of it, regardless of the building material (see Figure 6c,d).

Excavations in Zones 1.7 and 1.8 at the southern end of the Citadel tested the southern fortifications which ran in a broken line (see Figure 6, Squares D4–E3), better observed on the magnetic map. The high intensity of the anomaly corresponding to the southern wall was effected by its considerable height (more than 4 m of the height revealed in the trench; Figure 12), set off by the contrasting image of the
sand fill gathered against its face on the outside. Dipolar anomalies visible along the northern face of the wall were caused by the remains of a baked brick facing. These fortifications, however, appear to be of 17th–18th centuries date. The results of the excavation confirmed the image of a section of the street clearly outlined on the magnetic map (see Figure 6a, Square D4; Street U121 in Figure 12). Wherever the excavation revealed baked and sun-dried bricks used in combination in a single structure, the choice of building material turned out to be conditioned by the availability of a given brick rather than a structural requirement. Baked bricks appear to be sourced from structures of the earlier Makurian period (Maslak, 2015).

Excavation in the central part of the site, in Zone 1.5 (see Figure 4), verified the nature of an extensive structure registered in Squares D5–D6 and E5–E6 (see Figure 7), which was interpreted as the remains of a church based on the uncovered fragment. The inner partitions, observed solely in the magnetic image, refer to changes introduced in the Islamic period, whereas an outer wall of the building of evidently earlier date, embedded in deeper lying cultural strata, was observed only in the GPR data. The high-intensity anomalies on the

**Figure 10** Ground-penetrating radar (GPR) time slices at the approximate depth of (a) 50–60, (b) 60–70, (c) 130–140 and (d) 170–180 cm in the Citadel area [Colour figure can be viewed at wileyonlinelibrary.com]

**Figure 11** Oblique aerial image of the excavated area in the southern part of the Citadel (Zones 1.1–1.4; for the location of the zones, see Figure 4) [Colour figure can be viewed at wileyonlinelibrary.com]
FIGURE 12  Structures excavated in Zones 1.7 and 1.8 (for the location of the zones, see Figure 4); inset: structures in Zone 1.7 and Street U121 viewed from the east; note the baked brick lining of the mud-brick wall in the foreground (orthophotomap by A. Chlebowski, photo by M. Reklajtis) [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 13  Structures unearthed in Zones 1.10 and 1.11 (for the location of the zones, see Figure 4); inset: structures in the eastern side of Street U23; note the evidence for the simultaneous use of baked brick and mud-brick in the same wall (orthophotomap by A. Chlebowski, photo by M. Reklajtis) [Colour figure can be viewed at wileyonlinelibrary.com]
magnetic map, observed by the north-eastern wall, corresponded to what turned out to be the remains of an apse of baked brick, which is suggestive of church architecture. If so, then it would be the largest sacral building discovered in Nubia so far, the diameter of the apse being approximately 6 m compared with the 4.5 m recorded for apses of the largest known Nubian churches from the area north of the Citadel (Gartkiewicz, 1990).

In Zones 1.10 and 1.11 in the northern part of the Citadel (see Figures 4, 7b and 13), where building remains are preserved on the ground surface, the disturbance of the magnetic data in the zone south of the architecture turned out to be caused by baked brick rubble in the surface layer (see Figure 7a, Square C2). A band of complex anomalies parallel to the south-western wall, observed west of the building, corresponded to a wall of baked brick constituting the north-eastern edge of Street U123 (Figures 7b and 13). A continuation of this street is clearly indicated by GPR data owing to the large contrast generated by walls present on both sides of the street (see Figure 7c,d, Squares A1 and D2).

In summary, the excavation results can be correlated with the mapping of the urban layout derived from the geophysical data, showing the course of streets and buildings’ walls inside the settlement on the Citadel and in the quarter to the north (Figure 14). Comparing particular time slices, no evident change of the settlement layout in the latest phase could be detected in relation to chronologically earlier periods insofar as demonstrated by the geophysical data. No public buildings could be identified with the exception of the one large, presumably public building detected in Zone 1.5, which is however of pre-Islamic date. Structures observed in the north of the Citadel hill have yet to be excavated; hence, nothing precise can be said of their dating. Regarding structures in the south-western corner of the survey area (see Figure 8, Square D2), they are dated to the Funj period based on excavation results. The orientation of the street plan outlined for this area by the results of the geophysical survey is different from that within the Citadel but corresponds to the general orientation of streets from the Makurian-period settlement located to the north of the surveyed zone (initially identified in excavations and later confirmed by a magnetic survey in 2009; see Godlewski, 2013). Based on a similar orientation of the two, the buildings on the northern, lower part of the slope can be dated to the Makurian period. During Funj times, the urban layout of this part of the town does not seem to have changed in any significant way.

9 | CONCLUSIONS

Practically, the entire layout of the city was revealed by the results of the GPR and magnetic surveys, and the observations were subsequently verified by archaeological excavation. Old Dongola in the 16th–18th centuries was densely filled with domestic compounds built along an irregular network of streets. This matches the descriptions of travellers, for example, Evliya Çelebi, who stated that there were 650 houses in the Citadel and 3000 outside it (Çelebi, 1994,
Typical house plans are based on a two-room module: one multipurpose room and a storage room at the back (Obłuski & Dzierzbicka, 2021). In some cases, they create larger clusters most probably reflecting kinship, that is, extended families. The egalitarian urban layout of the Funj-period city contrasts with that of the earlier Makurian capital, which gathered huge residences, palaces and churches in an elite district on the Citadel. However, the dense and irregular domestic architecture seems to parallel Nubian medieval towns like Meinarti (Adams, 2001, 2002), Kulubnarti (Adams, 2011) and Debeira West (Shinnie & Shinnie, 1978). The results of excavation of the Funj-period remains have not revealed any clear ethnic or social diversity so far, with the houses invariably composed around the same basic components of plan. The southern extent of the latest city wall appears to repeat the earlier line of defences, differing from it in size and materials used. The construction of this new wall in the late medieval period suggests that the earlier one had lost its functional usefully, possibly because of extensive sand accumulation.

The geophysical results gave no grounds for identifying any apparently religious buildings, even though according to Çelebi (1994, p. 151), Dongola in 1672/1673 had seven Friday mosques, nine houses of prayer and six schools. Only one Friday mosque is known today, located east of the Citadel, and it is the oldest preserved mosque in Sudan. However, mosques were frequently absent from the urban landscape of Sudanese cities, for example, not a single mosque was found at Shendi, a Funj-period city at the junction of the Atbara and the Nile (Crawford, 1951, p. 61). It would indicate a slow encroachment of Islam into the lives of the Dongola population, as well as a low level of institutionalization of religious life in the Funj period.

The partly excavated street network can be traced in the geophysical data. One of the main streets within the city walls ran parallel to the later line of fortifications, forming a kind of circuit street. Shorter streets ran across the Citadel, following a more or less east–west orientation. The irregular street grid visible in the GPR data might suggest the absence of predefined planning in the Funj period within the walls of the Citadel. It is much different from some regularly planned medieval Nubian settlements like Ikhmindi or Sheikh Daoud (Obłuski, 2014). It is moreover consistent with the GPR result for the earlier urban layout down to a depth of about 2 m indicating relatively minor changes to the organization of space inside the Citadel of Old Dongola from about the 16th century until the end of habitation in this part of the site.

The results of the geophysical survey at Old Dongola fully confirmed the potential of the GPR method for the study of brick architecture at sites located in the Nile valley. Simultaneous use of the magnetic and GPR methods on hybrid mud-brick and burnt-brick architecture provided the possibility to identify different building materials on the basis of the geophysical data. At the same time, it showed that this kind of research is effective not only in dry alluvial deposits (as in case of results of the survey in Hamadab, Ullrich & Wolf, 2015) but also on sand-covered plateaus adjacent to the Nile valley. At sites with similar geological conditions and similar architecture, the GPR method effectively complements and can even replace magnetic surveying. For the sake of an example, the medieval Christian site in Bawit (Middle Egypt), which a topographical survey estimated at roughly 50 ha, was mapped with the magnetic prospection method, but disturbed surface layers in some parts of the site (caused by local digging for fertilizer in the upper cultural strata, a procedure common in 19th and early 20th-century Egypt: see Bailey, 1999, or by dense accumulations of potsherds on the surface) made a reconstruction of the urban layout impossible (see Herbich & Benazeth, 2008).

The observations presented above allow the authors to state that the results of the GPR method as applied in Old Dongola, compared with the results of the magnetic survey for the same area, provide an opportunity to collect more extensive data on layout of settlements located along the Nile valley and thus a better understanding of the functions of individual parts of settlements, a more precise determination of their extent.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in relation to this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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