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NON-DESTRUCTIVE TESTING OF A HISTORICAL VAULT USING GROUND PENETRATING RADAR METHOD

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Abstract

The article presents the results of research conducted in the Main Building of the Gdańsk University of Technology, which was destroyed in the World War II, reconstructed and included in the Register of Historic Buildings several decades ago. The study was carried out on the ceiling above the second floor, in the central part of the building at the 3rd level, in the hall in front of the Main Hall. The primary objective was to identify the geometry of the vault and assess the feasibility of detecting its internal structure using the non-destructive ground penetrating radar (GPR) method. A GPR system with a 2 GHz antenna was used for the study. Selected echograms (B-scans) in both scanning directions and tomographic maps at different depths were presented. The results indicate the presence of steel load-bearing beams in both directions, as well as a steel grid in the central part of the ceiling, while also mapping the boundaries of the vaulted structure. This research is particularly important due to the limited availability of technical documentation for the analysed area. The findings may be useful for planning future conservation or reinforcement work. The use of the GPR method has proven to be highly effective in such analyses.

Keywords:

Historical building;
Ground penetrating radar (GPR);
Non-destructive testing;
Historical vault.

1 Introduction

Historical buildings serve as valuable testimonies of the past, providing insights into the lives and achievements of previous generations [1]. Their analysis not only enhances our understanding of history but also enables the effective preservation of cultural heritage. For example, the study [2] presented the disposal system in the Novå Horka residence. The authors of the study [3] demonstrated that old houses from more than 100 years ago in the port of Bushehr were better adapted to the climate, emphasising the importance of traditional methods. Researchers of the truss structure of St. Bartholomew's Church in Mladočov [4] and the Roman Catholic Church of the holy Kozma and Damian in Abramová [5] showed that the geometric principles followed by historical designers allow for compliance with current design standards. Many of these structures hold architectural and historical secrets that can be revealed through modern research methods. Among these, non-destructive techniques are especially valuable, as they enable thorough diagnostics without altering the building's structure, which is crucial advantage, particularly when planning conservation work [6]. Recent studies also emphasize the importance of integrating historic structures into their urban environments, taking into account both heritage value and functional requirements [7]. Furthermore, the reliability of non-destructive diagnostic techniques, especially under variable environmental conditions, has been underscored in recent research, highlighting the need for cautious interpretation of the results [8].

Ground-penetrating radar (GPR) is a key tool in the investigation of historic structures. It has proven highly effective in detecting hidden anomalies across a wide range of construction elements, including walls [9-12], pillars [13], floors [14,15], or geotechnical structures [16,17]. This versatility makes GPR an indispensable technique in the conservation and diagnostic assessment of historical buildings. Previous studies have confirmed the effectiveness of GPR in a variety of applications. For example, in the diagnostic analysis of the Gdańsk Crane floor [18], anomalies detected through GPR were later verified during conservation and renovation works. In the structural assessment of the Malbork Castle, radar scans revealed significant damage requiring further analysis [19]. Furthermore, GPR has been successfully employed in the investigation of the former Piast Gymnasium in Brzeg, facilitating the identification of concealed architectural elements [20]. The GPR method has also been employed to evaluate the condition of wooden structural components, as evidenced in the case of the 19th-century church in Osiecznica, where the roof truss system was examined using non-destructive techniques [21].

This paper presents the results of ground-penetrating radar (GPR) investigations carried out on the ceiling structure of the historic Main Building of the Gdańsk University of Technology. The analysis allowed the identification of the internal structure of the vault and potential anomalies that may be relevant to both the preservation of the building and future conservation efforts. The findings presented in this study contribute to the broader application of non-destructive testing methods in the analysis of historic structures and highlight the importance of the GPR technique as a valuable tool for architectural diagnostics in heritage buildings.

2 Background of GPR

The Ground Penetrating Radar (GPR) method is one of the most advanced and versatile non-destructive techniques used in the diagnostics of building structures, including historic buildings. This innovative method, based on the emission and detection of electromagnetic waves, enables precise imaging of subsurface structures without the need to interfere with the examined object.

The fundamental principle of GPR operation involves the emission of electromagnetic pulses by a transmitting antenna and the registration of reflected waves by a receiving antenna. Electromagnetic waves passing through the medium under investigation are reflected or scattered at the boundaries of media with different electrical properties. The recorded signal creates a so-called radargram (also known as echogram), which, after appropriate processing, provides valuable information about the internal structure of the object.

In the context of diagnostics of historic structures, the GPR method gains particular importance due to its non-invasive nature. It allows for effective detection and localization of hidden structural elements, identification of voids and inhomogeneities in walls, as well as assessment of the technical condition of foundations and ground under the historic structures, without disturbing the historical substance of the building [22]. This is extremely important in the case of objects of high historical and cultural value, where traditional diagnostic methods could lead to irreversible damage. In recent years, significant progress has been made in the development of GPR data processing and interpretation techniques. The application of advanced filtering algorithms, migration, and numerical modelling allows for increasingly accurate analysis of the obtained results [23]. Moreover, the integration of the GPR method with other research techniques, such as ultrasonic tomography [24], thermography [25,26], or electrical resistivity tomography (ERT) [27] opens up new possibilities for comprehensive diagnostics of historic buildings.

3 Materials and methods

3.1 Description of the building

The Main Building of the Gdańsk University of Technology stands as one of the most valuable monuments of academic architecture in Poland. Built in 1904 to a design by architect Albert Carstens, it represents the Neo-Renaissance style that was highly regarded in European academic circles at the time. Its facades are decorated with intricately carved details, and its spacious interiors, with high vaultes and decorative elements, reflect the scientific and cultural aspirations of the era. The historical role of the building as a central hub for educational, administrative and research activities underscores its importance not only as an academic institution but also as a cultural landmark.

Throughout its nearly century-long history, the building has undergone numerous modernizations, renovations and adaptations in response to dynamic technological changes and evolving user needs. During the Second World War, the building was severely damaged, necessitating a thorough post-war reconstruction and conservation of structural elements (Fig. 1). A section of the ceilings collapsed, primarily in the central part of the rear building, which housed, among other facilities, the library and the Main Hall. Both staircases in the central section of the building collapsed. Numerous facade details were also damaged [28,29]. The following decades brought further renovations aimed at adapting the building to modern operational standards while preserving its original architectural values. As part of these efforts, the facade details were reconstructed, the load-bearing structures were reinforced, and the technical installations were modernized, all of which required adherence to strict conservation guidelines due to the building status as a historical monument [28]. Contemporary conservation and modernization work poses a number of challenges for specialists, especially in terms of diagnosing the technical condition of key structural elements such as floors. As key structural elements, the floors of the Main Building require regular diagnostic testing to ensure the safety of users and maintain the integrity of the historic structure. The use of ground penetrating radar (GPR) is particularly important in this context. This method facilitates the non-destructive determination of the internal structure of floors, identifying potential voids, cracks or areas of material weakness, which is invaluable when planning conservation interventions. Accurate mapping of internal structural layers allows the selection of appropriate strengthening and renovation methods, while ensuring the preservation of the authenticity of the historic heritage.

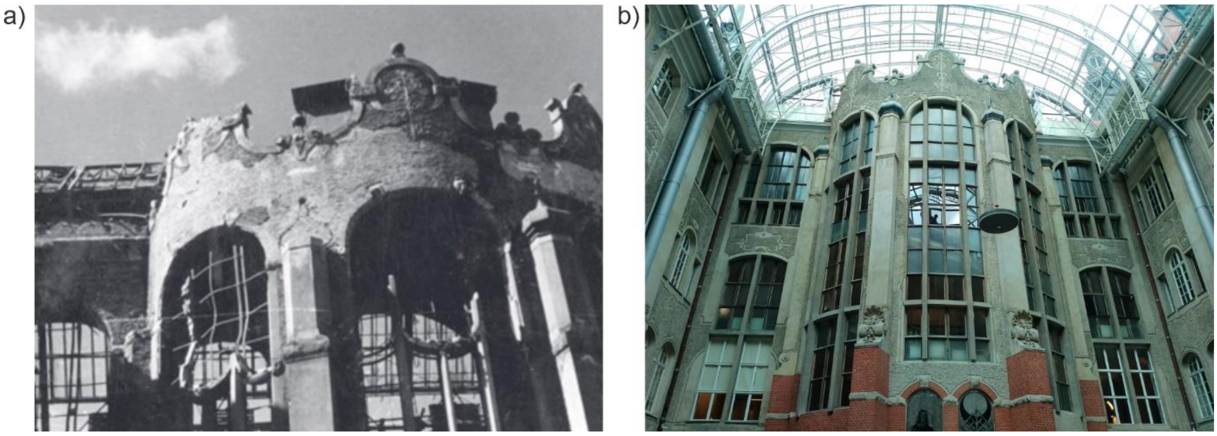

Fig. 1: Main Building of the Gdańsk University of Technology (link: https://ochronazabytkow.gda.pl/rejestr-zabytkow/rejestr-zabytkow-nieruchomych/): a) destroyed staircase in World War II [28], b) present-day view of the staircase.

The results of the conducted GPR surveys can serve as a valuable aid in the development of modernization strategies, enabling interdisciplinary collaboration between conservators, civil engineers, and material diagnostics specialists. This makes it possible to create a comprehensive image of the technical condition of the floors and identify their construction, which in turn allows for the implementation of remedial actions that minimize the risk of further damage and extend the lifespan of this unique building.

In response to the growing demands for the protection of cultural heritage, the incorporation of advanced diagnostic technologies such as ground penetrating radar technique represents a modern approach to heritage conservation. This strategy ensures that historic structures such as the Main Building of Gdansk University of Technology can be effectively preserved and maintained, balancing the need for structural integrity with the preservation of architectural and historical value.

3.2 Survey in the Main Building

The investigation was carried out in the Main Building of Gdańsk University of Technology, on the ceiling above the 2nd floor, i.e., at level 3rd. The place inspected is presented in Figures 2a and 2b. For the GPR survey, a rectangle measuring 1200 cm x 1020 cm was selected in the central part of the 3rd level. This research area (#A) was chosen to allow for unrestricted movement of the measuring equipment along predefined routes. To ensure comprehensive coverage, 52 longitudinal profiles (L1-L52) and 61 transverse profiles (H53-H113) were marked on the inspected area. Both longitudinal and transverse profiles were placed at 20 cm intervals. The sections of the floor subjected to the survey, together with the measurement routes described, are illustrated in Figure 3. The measurements were conducted using an IDS C-THRUE georadar system, which is equipped with four antennas, each operating at a central frequency of 2 GHz. This GPR is designed to provide high-resolution imaging, enabling precise detection of subsurface structures and anomalies. It has an effective penetration depth of several tens of centimeters, making it well-suited for analyzing subsurface features with high accuracy.

a) b) c)

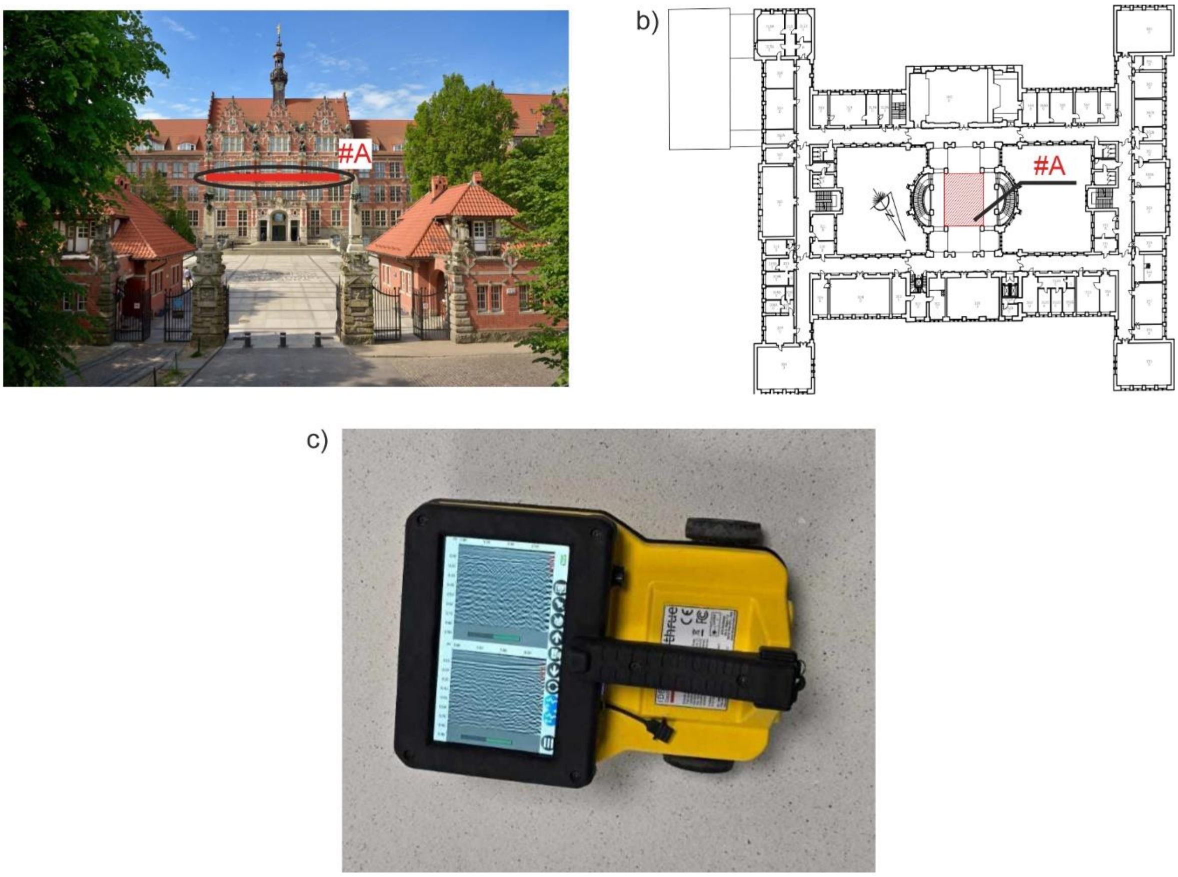

Fig. 2: Measurement area #A: a) location of the ceiling, b) marking on the 3. floor plan, c) ground penetrating radar used in measurements.

4 Results and discussion

The initial inspection of the ceiling from below, i.e., from the 2nd level, clearly indicates the presence of anomalies in the form of variations along the length of the edges of the cross-ribbed vaults. Furthermore, several metal rods support suspended lighting fixtures at the centre of the ceiling (Fig. 3), which will also manifest as anomalies due to the magnetic properties of steel.

Figure 4 presents echograms for three selected longitudinal profiles: L2, L17, L21, L26, L36 and L51. In profile L2, characteristic subsurface disturbances are visible at approximately 3.00 m and 8.50 m along the length. Both disturbances exhibit hyperbolic reflections at a depth of approximately 25 cm, indicating the presence of longitudinal inclusions. These are most likely the steel load-bearing beams of the ceiling, positioned above the vaulted sections and aligned with the column axes. Additionally, the boundary between the arched ceiling segments can be observed: smaller arches symmetrically positioned on both sides of the profile, with a lower boundary extending to approximately 2.80 m and an arch rise at a depth of around 0.6 m, and a larger central arch extending from approximately 3.80 m to 8.00 m, with an arch rise at a depth of about 45 cm. The gaps between the arches, where no anomalies are detected, correspond to the locations of the columns and, consequently, to the presumed locations of the steel beams. The lower surface of the ceiling is well-maintained, suggesting that a reinforcing steel mesh was installed during renovation work. This is supported by subsurface disturbances observed beneath the arch edges on the radargram. There is also a single hyperbolic anomaly at approximately 5.80 m along the profile and at a depth of 5 cm. This anomaly appears in the same location across all profiles from L1 to L26, covering half of the surveyed area. It can be inferred that this corresponds to an electrical conduit for the suspended lighting system beneath the ceiling. Anomalies corresponding to the presence of steel girders are also observed in profile L17, the locations of which are entirely consistent with those in profile L2. However, in this measurement path, the arch geometry is no longer visible. Instead, linear inclusions appear at depths of 8 cm and 20 cm along the entire profile, indicating the presence of a continuous disturbance along this path. A similar situation is observed in profile 36, which is symmetrical to the centreline. This suggests the presence of two beams running parallel to the longitudinal measurement paths, likely serving as girders. Radargram 26, representing the measurement path crossing the centre of the investigated area, indicates the presence of a beam grid in the middle of the ceiling. This is evidenced by disturbances appearing at approximately 1.00 m intervals, beginning at radargram 18 (at a distance of 3.40 m from the starting point), corresponding to ten steel beams. The locations of these disturbances coincide with the previously observed two repeating beams. In the scans where these ten anomalies are visible, the vaulted segments are no longer present, suggesting that the grid of beams has a structural reinforcement function.

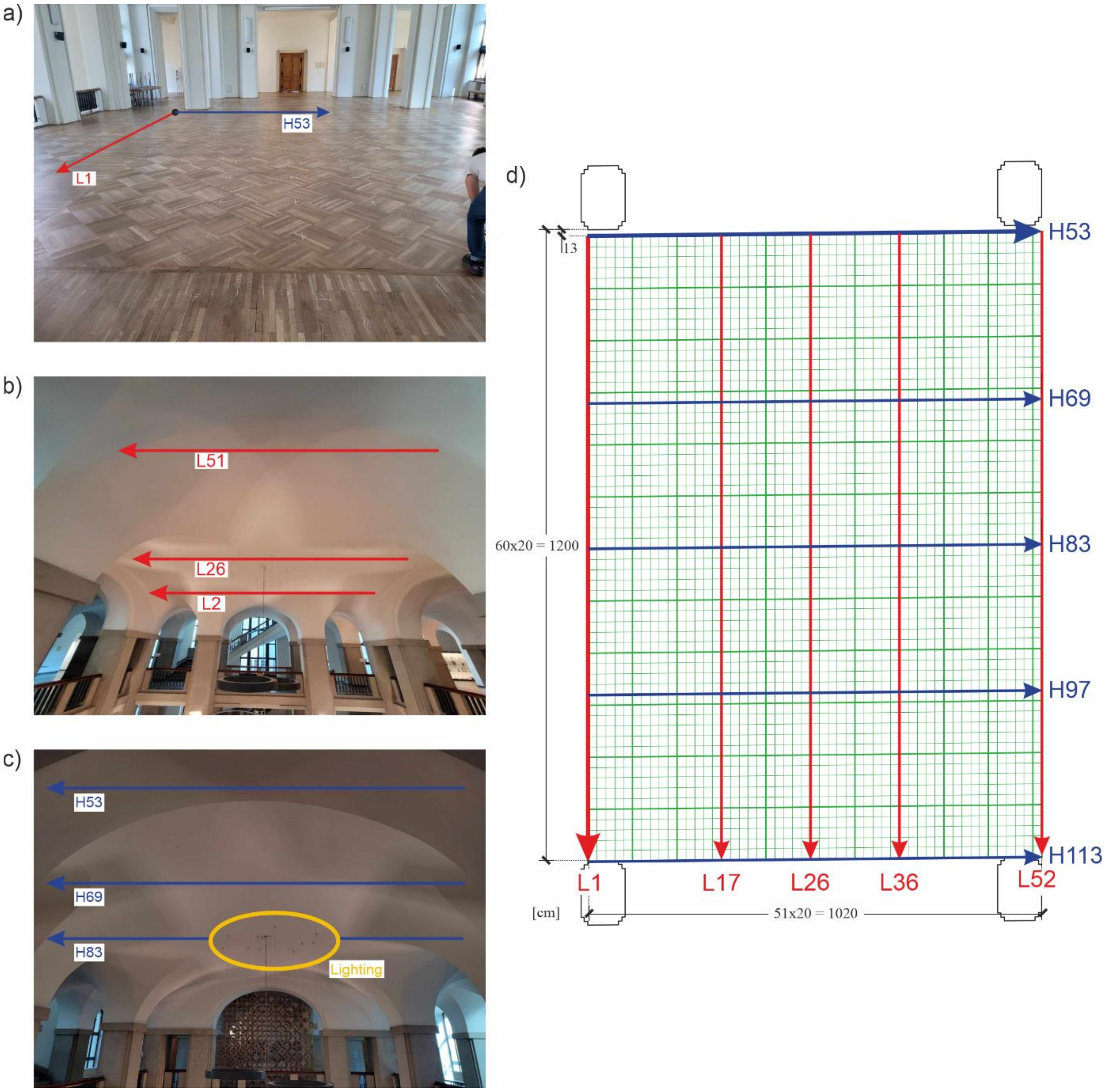

Fig. 3: Measurement area #A: a) ceiling location, b) view of the ceiling from below – selected longitudinal profiles with a visible arched ceiling, c) view of the ceiling from below – selected transverse profiles with a visible arched ceiling and marking lighting, d) marking in the 3. floor plan.

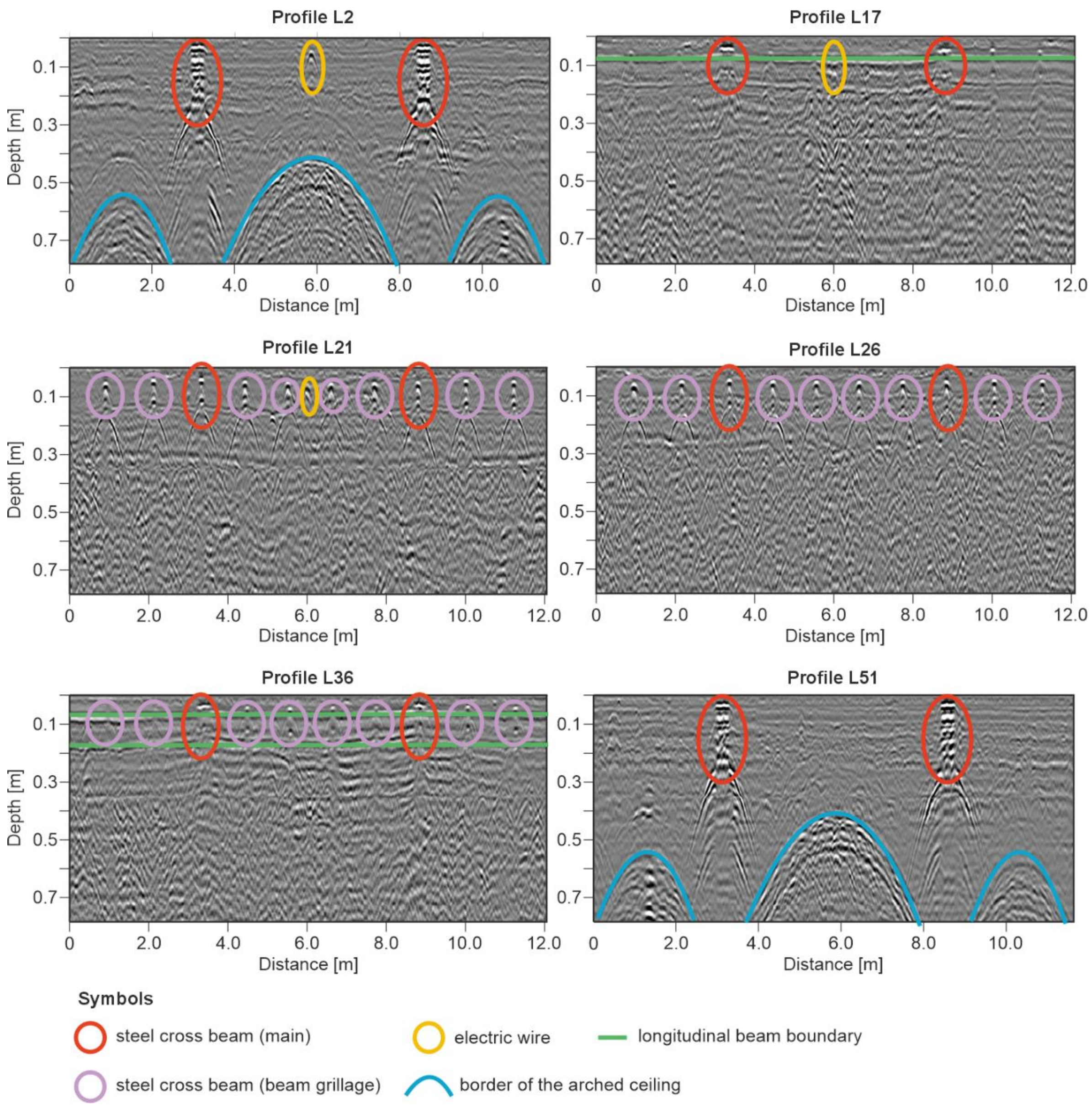

Fig. 4: Analysis of the selected radargrams in the longitudinal direction (explanation in the text).

Fig. 5 presents echograms recorded for selected transverse measurement paths. In echograms H53 (first transverse scan) and H83 (scan through the centre of the measurement area), as well as in most of the scans, disturbances in the form of two hyperbolas are visible at approximately 3.40 m and 7.20 m. Their locations correspond to the longitudinal profiles L17 and L36, where linear inclusions were identified. This indicates the presence of two main beams running in the longitudinal direction (previously mentioned girders). Both hyperbolas appear at a depth of approximately 20 cm, probably corresponding to the beam edges, which also aligns with the linear inclusions observed in profiles L17 and L36. At shallower depths, strong disturbances caused by the presence of steel are visible. The echograms clearly show the arched boundary of the ceiling between the disturbances corresponding to the steel girders. Furthermore, both the upper and lower boundaries of the arch can be distinguished (e.g., profiles H74, H100), probably indicating the presence of brick infill between the beams (similar to a Klein ceiling). The difference between the edges of these arches at their extremes is approximately 15 cm. Radargram 69 corresponds to a measurement path located along one of the two main transverse beams. This is evidenced by the presence of linear inclusions along the entire profile, as well as the distance of this path from the starting point (3.20 m) which approximately corresponds to the hyperbolas observed in the longitudinal profiles. A similar situation is observed in echogram H97, which corresponds to a profile symmetrical to H69. In addition, linear inclusions can be observed in selected transverse measurement paths in the central parts of the echograms (between the main hyperbolas). These paths coincide with the transverse beams of the grid structure in the central part of the ceiling.

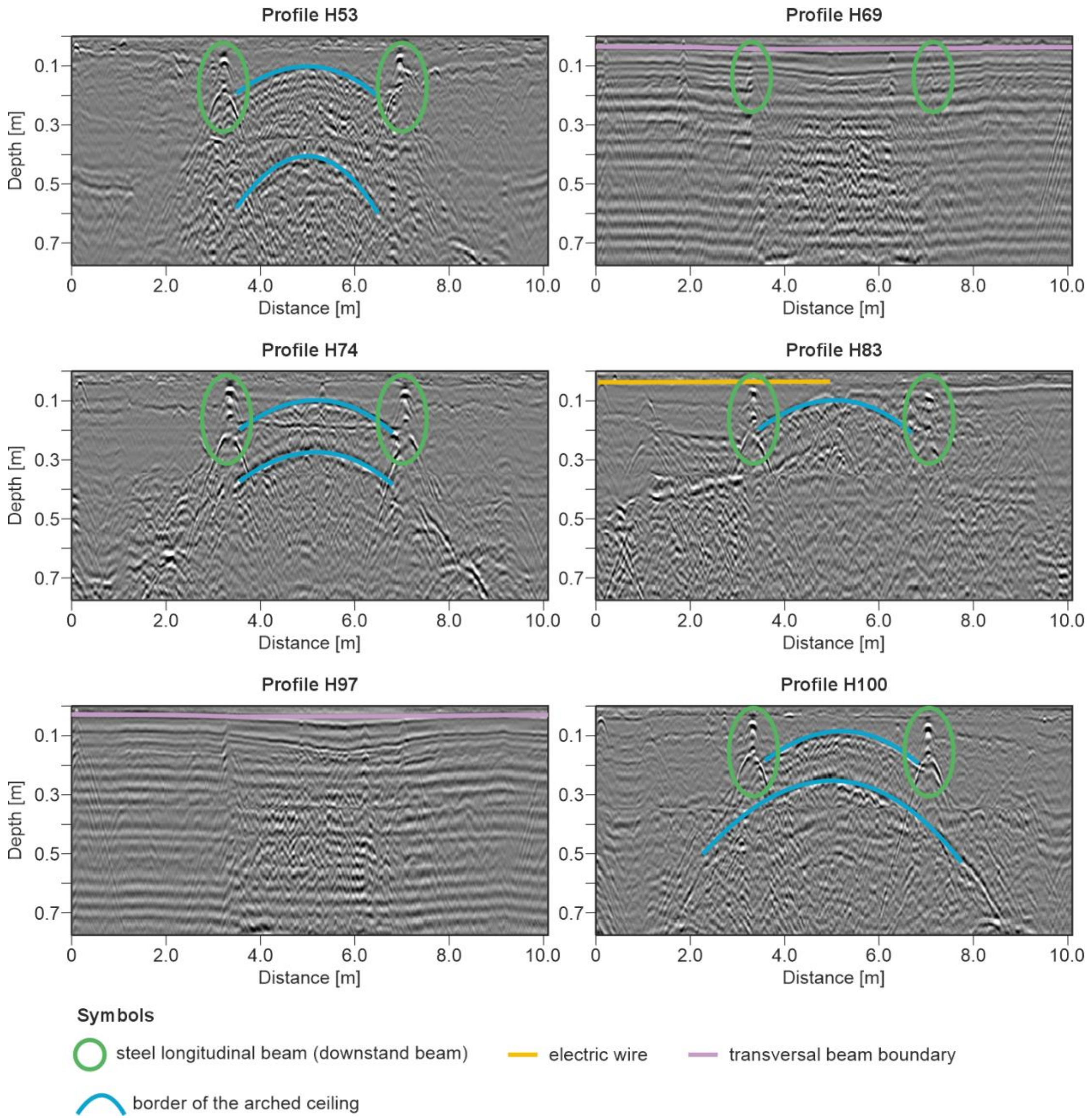

Fig. 5: Analysis of the selected radargrams in the transverse direction (explanation in the text).

Fig. 6 presents tomographic images for selected depths. At a depth of 1 cm, just below the floor, rectangular shapes are visible, which may correspond to the boundaries of the floor layers. At greater depths, up to 35 cm and in some cases up to 45 cm, the grid structure of the beams can be clearly seen: two longitudinal beams, two main transverse beams and additional transverse steel beams in the central part of the floor supported by the beams. At a depth of 20 cm, the beam edges are visible, corresponding to the hyperbolic reflections observed in the longitudinal scans. At a depth of 40 cm, the boundaries of the ceiling become visible, beginning in the central part of the structure where the largest vault is located. At the maximum depth of 75 cm, the full geometry of the arched ceiling is shown in both directions, together with the positions of the columns from the 2nd level, the space between the smaller arches and the largest arch in the longitudinal direction.

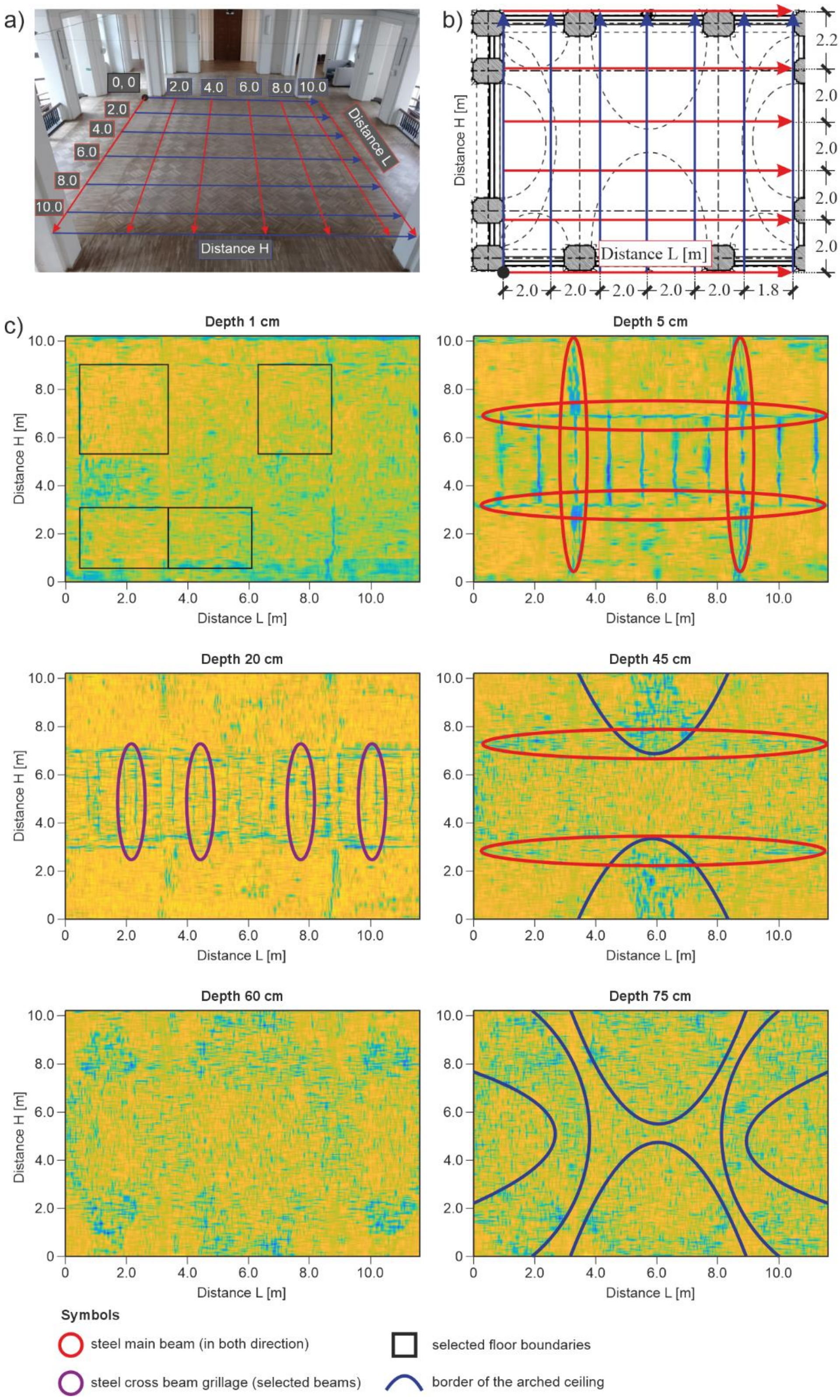

Fig. 6: Examples of tomographic maps obtained from measurements (c) (explanation in the text) with a measurement area marked in the top view (a) and on the 2nd floor plan (b).

5 Conclusion

The Main Building of the Gdańsk University of Technology is a monument of significant architectural and structural value. Built at the beginning of the 20th century, it represents an important example of academic architecture and the engineering achievements of that time. Understanding its construction provides valuable insights into the historical development of technical education and construction practices in Gdańsk.

This article presents the results of non-destructive testing conducted in the Main Building. The analysis focused on anomalies detected in the cross-ribbed vaults, particularly in the arched sections of the vault and the beam grid. The study was carried out using the ground penetrating radar method, utilizing a 2 GHz radar. The results were presented in the form of tomographic maps and echograms (B-scans). The analysis of the longitudinal and transverse profiles provided important information about the internal structure of the ceiling. The echograms revealed the presence of steel beams, girders, and additional reinforcing elements, which were likely introduced during previous renovations. The radargrams indicated the existence of a beam grid in the central part of the ceiling, consisting of longitudinal girders, transverse steel beams, and a probable brick infill between the structural elements, resembling a Klein ceiling. Additionally, anomalies corresponding to electrical wiring for suspended lighting were identified. Tomographic imaging at different depths confirmed these observations. At shallower depths, the steel beam grid was visible. At greater depths, the boundaries of the arched ceiling fragments were revealed, particularly in its central part, where the largest arch is located. The deepest scans (up to 75 cm) enabled a full representation of the vault geometry and column locations, considering the space between the smaller and larger arches in the longitudinal direction.

In summary, GPR proved to be an effective method for inspecting structural elements within historic buildings. However, interpretation of the results requires specialist knowledge and experience, particularly in the absence of original building documentation. Data analysis should take into account the capabilities of the measurement antenna, the main parameter of which is frequency, which directly affects the accuracy of the investigation and the effective penetration depth. The results presented in this article contribute to a better understanding of the structure of the Main Building of the Technical University of Gdansk, supporting conservation efforts and possible future renovation work.

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References

[1] Ł. DROBIEC, "Technical Conditions of Diamond Vaults in Poland," *Civil and Environmental Engineering Reports*, vol. 34, no. 3, pp. 100–119, Jul. 2024, doi: 10.59440/ceer/191066.
[2] L. AUGUSTINKOVÁ, "An Investigation of Historic Structures of Nová Horka Castle in Studénka (CR)," *Civil and Environmental Engineering*, vol. 19, no. 1, pp. 17–29, Jun. 2023, doi: 10.2478/cee-2023-0002.
[3] N. MOZAFARI and M. ALIMARDANI, "Climate Adaptability of Old and New House in Bushehr's Historical Texture," *Civil and Environmental Engineering*, vol. 16, no. 2, pp. 249–258, Dec. 2020, doi: 10.2478/cee-2020-0024.
[4] P. KRUŠINSKÝ, J. GOCÁL, M. HOLEŠOVÁ, and E. RACKOVÁ, "Proportional and Structural Analysis of the Historical Truss of Church of St. Bartholomew in Mladočov," *Civil and Environmental Engineering*, vol. 17, no. 2, pp. 698–705, Dec. 2021, doi: 10.2478/cee-2021-0069.
[5] P. KRUŠINSKÝ, E. CAPKOVÁ, J. GOCÁL, and M. HOLEŠOVÁ, "Geometric and Static Analysis of the Historical Trusses in Roman Catholic Church of the Holy Kozma and Damian in the Abramová Village," *Civil and Environmental Engineering*, vol. 11, no. 2, pp. 136–141, Dec. 2015, doi: 10.1515/cee-2015-0017.
[6] S. ŚWIĄTEK-ŻOŁYŃSKA and M. NIEDOSTATKIEWICZ, "Technological Considerations of Periodic Repair Works of Concrete Industrial Floors," *Civil and Environmental Engineering Reports*, vol. 35, no. 1, pp. 50–67, Jan. 2025, doi: 10.59440/ceer/195261.
[7] F. S. SHAKER and R. M. MUSA, "THE POTENTIALS OF INTEGRATION IN THE HISTORICAL KHAN OF AL-EXANDRIA-BABYLON," *Civil and Environmental Engineering*, vol. 20, no. 2, pp. 837–861, Dec. 2024, doi: 10.2478/cee-2024-0062.
[8] O. Y. JABIR, H. M. OLEIWI, and A. A. SULTAN, "RELIABILITY OF NON - DESTRUCTIVE TECHNOLOGIES IN CORROSION DETECTION OF REINFORCED CONCRETE STRUCTURES," *Civil and Environmental Engineering*, vol. 18, no. 1, pp. 137–147, Jun. 2022, doi: 10.2478/cee-2022-0013.
[9] Z. T. DEGER and G. TASKIN, "A novel GPR-based prediction model for cyclic backbone curves of reinforced concrete shear walls," *Eng Struct*, vol. 255, Mar. 2022, doi: 10.1016/j.engstruct.2022.113874.

[10] S. NEGRI and M. A. AIELLO, “High-resolution GPR survey for masonry wall diagnostics,” *Journal of Building Engineering*, vol. 33, Jan. 2021, doi: 10.1016/j.jobe.2020.101817.

[11] D. ANGELIS, P. TSOURLOS, G. TSOKAS, G. VARGEMEZIS, G. ZACHAROPOULOU, and C. POWER, “Combined application of GPR and ERT for the assessment of a wall structure at the Heptapyrgion fortress (Thessaloniki, Greece),” *J Appl Geophy*, vol. 152, pp. 208–220, May 2018, doi: 10.1016/J.JAPPGEO.2018.04.003.

[12] M. RUCKA, J. LACHOWICZ, and M. ZIELIŃSKA, “GPR investigation of the strengthening system of a historic masonry tower,” *J Appl Geophy*, vol. 131, pp. 94–102, Aug. 2016, doi: 10.1016/J.JAPPGEO.2016.05.014.

[13] J. LACHOWICZ and M. RUCKA, “Diagnostics of pillars in St. Mary’s Church (Gdańsk, Poland) using the GPR method,” *International Journal of Architectural Heritage*, vol. 13, no. 8, pp. 1223–1233, Nov. 2019, doi: 10.1080/15583058.2018.1501117.

[14] M. RUCKA, E. WOJTCZAK, and M. ZIELIŃSKA, “Interpolation methods in GPR tomographic imaging of linear and volume anomalies for cultural heritage diagnostics,” *Measurement (Lond)*, vol. 154, Mar. 2020, doi: 10.1016/j.measurement.2020.107494.

[15] C. Ç. YALÇINER, Y. C. KURBAN, and E. ALTUNEL, “Research using GPR into the cause of cracks and depressions in the floor of the gallery of Hagia Sophia Museum,” *Constr Build Mater*, vol. 139, pp. 458–466, May 2017, doi: 10.1016/j.conbuildmat.2017.02.036.

[16] D. BEBEN, W. ANIGACZ, and J. UKLEJA, “Diagnosis of bedrock course and retaining wall using GPR,” *NDT & E International*, vol. 59, pp. 77–85, Oct. 2013, doi: 10.1016/J.NDTEINT.2013.05.006.

[17] J. HUGENSCHMIDT and A. KALOGEROPOULOS, “The inspection of retaining walls using GPR,” *J Appl Geophy*, vol. 67, no. 4, pp. 335–344, Apr. 2009, doi: 10.1016/J.JAPPGEO.2008.09.001.

[18] M. ZIELIŃSKA, M. RUCKA, E. WOJTCZAK, T. CIBOROWSKI, and M. STEFFENS, “Non-destructive Diagnostics of the Floor in the Gdańsk Crane Using Ground Penetrating Radar,” *Wiadomosci Konserwatorskie*, vol. 2023, no. 76, pp. 129–140, 2023, doi: 10.48234/WK76CRANE.

[19] Ł. DROBIEC and S. KOZŁOWSKA, “Wstępne nieniszczące badania posadzki i ścian w PałacuWielkich Mistrzów na zamku średnim w Malborku,” *Przegląd Budowlany*, vol. 95, no. 1–2, pp. 60–66, Feb. 2024, doi: 10.5604/01.3001.0054.3607.

[20] P. FRĄCKIEWICZ, K. RASZCZUK, and J. JASIEŃKO, “Identification of Alternations in the Structure of Historical Masonry Walls Using the GPR Method Accompanied with Architectural Survey in the Former Piast Gymnasium in Brzeg,” *Civil and Environmental Engineering Reports*, vol. 34, no. 4, pp. 32–42, Oct. 2024, doi: 10.59440/ceer/191566.

[21] J. DROBIEC and B. NOWOGOŃSKA, “Non-destructive Testing of Wooden Elements in Historic Buildings - An Example of Testing a 19th Century Roof Truss Structure,” *Civil and Environmental Engineering Reports*, vol. 34, no. 3, pp. 154–164, Jul. 2024, doi: 10.59440/ceer/190825.

[22] N. IŞIK, F. M. HALIFEOĞLU, and S. İPEK, “Detecting the ground-dependent structural damages in a historic mosque by employing GPR,” *J Appl Geophy*, vol. 199, p. 104606, Apr. 2022, doi: 10.1016/J.JAPPGEO.2022.104606.

[23] J. LACHOWICZ and M. RUCKA, “3-D finite-difference time-domain modelling of ground penetrating radar for identification of rebars in complex reinforced concrete structures,” *Archives of Civil and Mechanical Engineering*, vol. 18, no. 4, pp. 1228–1240, Sep. 2018, doi: 10.1016/J.ACME.2018.01.010.

[24] M. RUCKA, E. WOJTCZAK, and M. ZIELIŃSKA, “Integrated application of GPR and ultrasonic testing in the diagnostics of a historical floor,” *Materials*, vol. 13, no. 11, Jun. 2020, doi: 10.3390/ma13112547.

[25] C. BISCARINI, I. CATAPANO, N. CAVALAGLI, G. LUDENO, F. A. PEPE, and F. UBERTINI, “UAV photogrammetry, infrared thermography and GPR for enhancing structural and material degradation evaluation of the Roman masonry bridge of Ponte Lucano in Italy,” *NDT & E International*, vol. 115, p. 102287, Oct. 2020, doi: 10.1016/J.NDTEINT.2020.102287.

[26] S. POZZER, Z. OMIDI, A. EL REFAI, F. LÓPEZ, C. IBARRA-CASTANEDO, and X. MALDAGUE, “Passive infrared thermography for subsurface delamination detection in concrete infrastructure: Capabilities,” *Constr Build Mater*, vol. 419, Mar. 2024, doi: 10.1016/j.conbuildmat.2024.135542.

[27] A. RUSSOLILLO *et al.*, “Unveiling a hidden fortification system at ‘Faraglioni’ Middle Bronze Age Village of Ustica Island (Palermo, Italy) through ERT and GPR prospections,” *J Appl Geophy*, vol. 220, Jan. 2024, doi: 10.1016/j.jappgeo.2023.105272.

[28] J. SZCZEPAŃSKI, “Architecture of the Gdańsk University of Technology Ensemble 1904-2018” (Architektura zespołu Politechniki Gdańskiej 1904-2018), pp. 1-224, 2019.

[29] S. NIEWITECKI, ”The history of a one beam” (Historia jednej belki), *Pismo PG*, vol. 4, pp. 40-43.