

TECHNICAL CONDITIONS OF DIAMOND VAULTS IN POLAND

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Abstract

Diamond vaults represent the greatest achievement of the Gothic architecture. Only about 130 buildings with such vaults have remained to our times, including 30 buildings in Poland. Diamond vaults are less stiff than rib vaults, and consequently more prone to damage. This paper presents technical conditions of diamond vaults in Poland, their typical damage and repair methods.

Keywords: diamond vaults, cell vaults, gothic vaults, technical condition, damage to the vaults, vaults repair

1. INTRODUCTION

Masonry vaults intensively developed during the Gothic period (13th-16th centuries). It was the time when stellar, net, transitional, palm, fan and diamond vaults were formed [1, 2, 3, 4]. Crystal vaults, also known as diamond or cell vaults, are vaults with removed ribs. They represent the highest level of masonry techniques in the Middle Ages [4, 5, 6, 7]. These structures were formed for the first time in Albrechtsburg Castle in Meissen by the master builder Arnold von Westflane in 1471. Then, they became popular in Saxony, north-western Bohemia, Moravia, and in Poland (at first in Gdańsk at the turn of 15th and 16th centuries). Diamond vaults were occasionally formed in the area of current Slovakia, Lithuania, Latvia, Belarus, and the Königsberg District (Fig. 1). They were not popular in western and southern regions of Europe.

Only about 130 buildings with diamond vaults have remained to our times, including 35 buildings in Poland. A map presented in Fig. 1 shows 28 Polish cities where structures with diamond vaults are present. However, these vaults have been covered in many buildings. The following churches in Gdańsk have diamond vaults: St. Mary's Basilica in Gdańsk, St. Catherine's Church, Saints Peter and Paul's Church, St. Bridget's Church, over wall arcades in St. Bartholomew's Church, and over a cloister in the Franciscan friary. Diamond vaults can be also found in the Warmian Chapter's Castle and St. Jacobs' Co-Cathedral Basilica in Olsztyn, Town Hall and St. John's Church in Malbork, over a porch in the

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Cathedral of Holy Cross and in buildings of the Franciscan friary in Opole, and in Collegium Maius and Collegium Novum (erected in the 19th century) in Cracow. This paper focuses on technical conditions of diamond vaults in Poland.

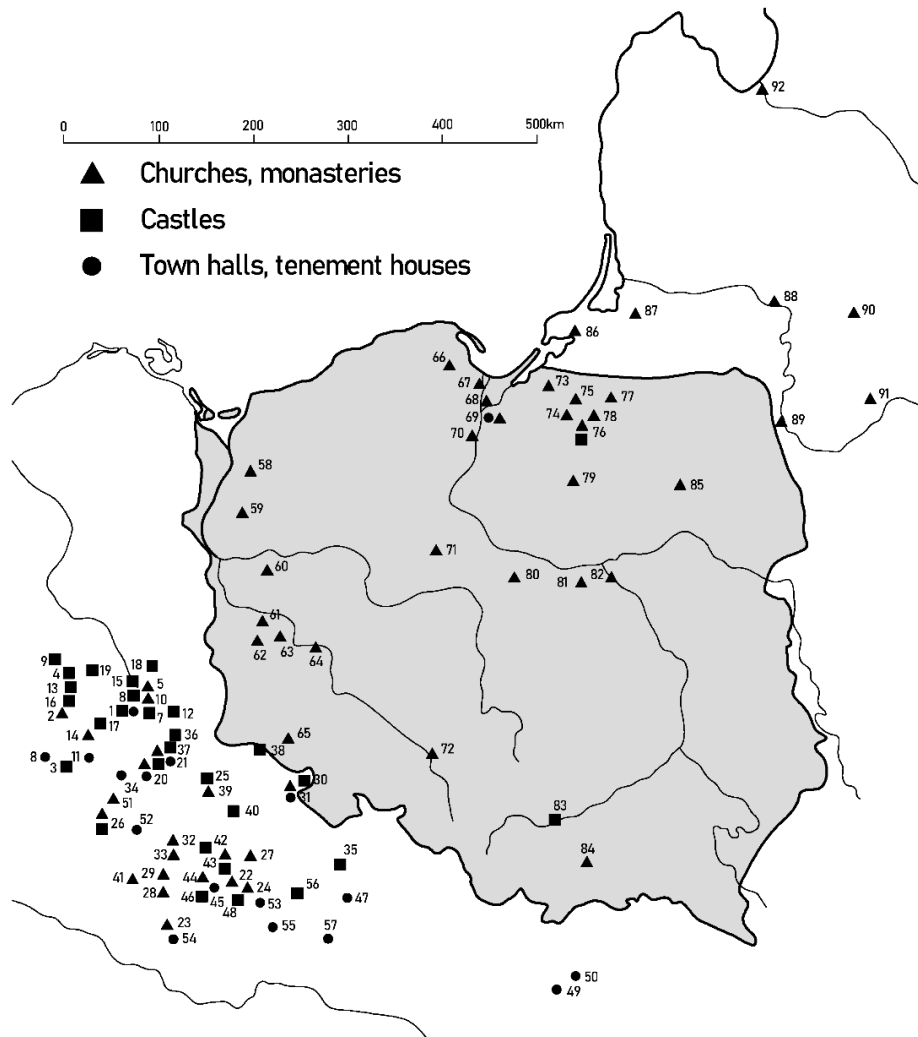


Fig. 1. Location of diamond vaults: 1 Meissen, 2. Rocknitz, 3. Sachsensburg, 4. Wurzen, 5. Grossenheim, 6. Schleinitz, 7. Tharandt, 8. Plauen, 9. Moritzburg, 10. Taubcnheim, 11. Annaberg, 12. Stolpen, 13. Trebsen, 14. Brandenburg, 15. Strehla, 16. Gndandstein, 17. Freiberg, 18. Frauenhein, 19. Zschorna, 20. Kadañ, 21. Chomutov, 22. Bechyně, 23. Kuglvejt, 24. Sobeslav, 25. Karlštejn, 26. Bor, 27. Tabor, 28. Nezamyslice, 29. Horažovice, 30. Kutneticka Hora, 31. Pardubice, 32. Bělčice, 33. Blatna, 34. Jachymov, 35. Pernštejn, 36. Doubravska Hora, 37. Bilina, 38. Hruby Rohozec, 39. Budnany, 40. Konopiste, 41. Velhartice, 42. Orlik, 43. Dobronice, 44. Čížová, 45. Pisek, 46. Stare Kestrany, 47. Ivančice, 48. Březnice, 49. Kremnica, 50. Banská Bystrica, 51. Ostrov, 52. Pizen, 53. Jindřichův Hradec, 54. Český Krumlov, 55. Slavonice, 56. Telč, 57. Znojmo, 58. Stargard, 59. Myślībórz, 60. Świebodziñ, 61. Stypułów, 62. Żagań, 63. Siecieborzyce, 64. Głógów, 65. Bukowiec, 66. Kartuzy, 67. Gdańsk, 68. Nowy Staw, 69. Malbork, 70. Pelplin, 71. Mogilno, 72. Opole, 73. Marianka, 74. Morağ, 75. Dobre Miasto, 76. Olsztyn, 77. Kętrzyn, 78. Barczewo, 79. Szreńsk, 80. Soboty, 81. Błonie, 82. Warszawa, 83. Kraków, 84. Nowy Sącz, 85. Łomża, 86. Königsberg, 87. Łabiewo, 88. Kovno, 89. Grodno, 90. Vilnius, 91. Malomolejków, 92. Riga

2. DESIGN OF DIAMOND VAULTS

The design of a diamond vault did not include ribs and had vault cells alternately sloped against the vault plane (Fig. 2). Such placement of vault cells formed sharp ridges with high stiffness, which replaced ribs. These ridges, also known as wires [8], or vault ridges [9] were shaped to form solid lines corresponding to the alignment of ribs in the arrangements similar to rib vaults. The most common ridges had stellar or net arrangement (Fig. 3). Geometry of diamond vaults resembles barrel or sail vaults, rarely pointed arch vaults. Diamond vaults are usually more flattened compared to Gothic stellar vaults.

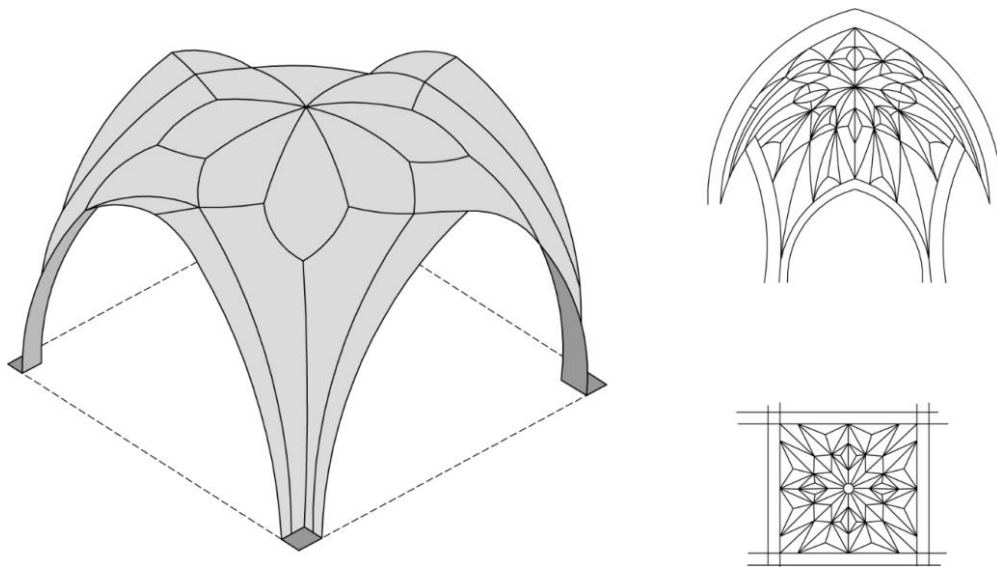


Fig. 2. Diamond vaults

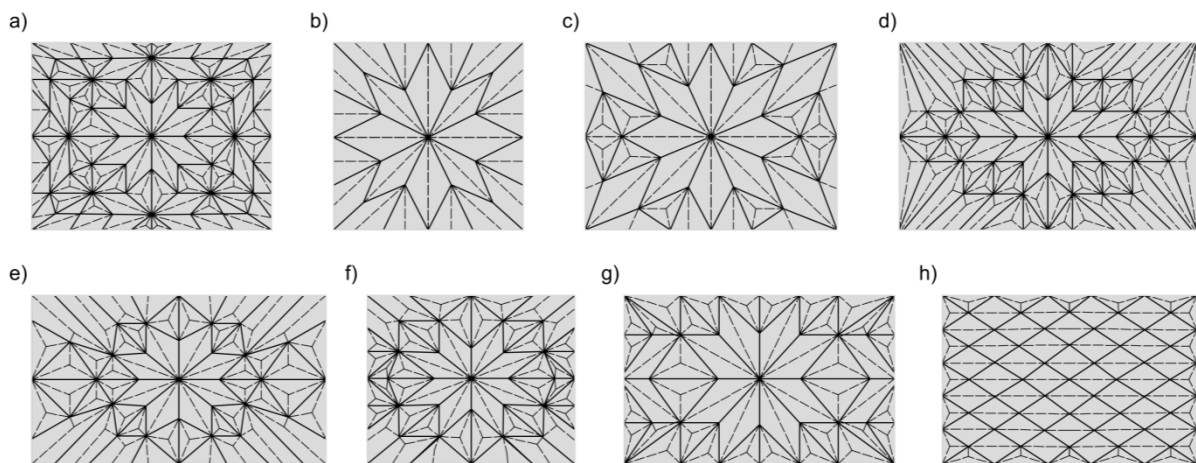


Fig. 3. Arrangements of ridges in diamond vaults: a) Gdańsk, St. Mary's Basilica b) Gdańsk, St. Catherine's Church, c) Gdańsk, St. Peter and Paul's Church, d) Vilnius, Bernadine Church, e) Kętrzyn, St. George's Basilica, f) Łomża, Cathedral of Archangle Michael, g) Barczewo, St. Anne and Stephen's Church, h) Olsztyn, St. Jacob's Basilica

Besides main ridges, diamond vaults also have intermediate ridges (marked with dashed lines in Fig. 3). They divide space between main ridges into smaller fields and provide their stiffness.

Diamond vaults were usually made from brick or stone. An inclination angle of vault cells against the level was determined by a type of the applied material. This angle in brick vaults is usually 45° , and in the majority of stone vaults it is even greater. Diamond vaults in Poland were usually made of brick, whereas the Czech and Saxon vaults were usually made of stone responsible for sharper ridges. A thickness of diamond vaults is generally equal to a half of the brick. Sometimes, they had a thickness of one brick at main bottom ridges by placing adequately masonry units (Fig. 4).

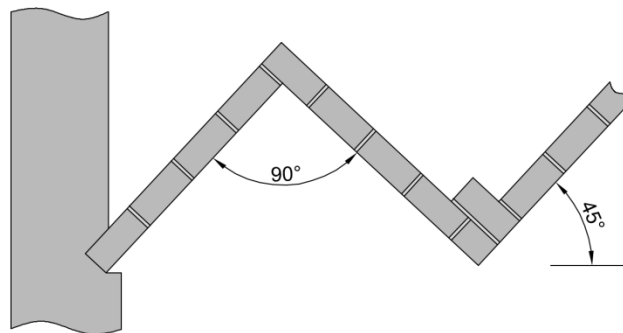


Fig. 4. Methods of shaping ridges of diamond vaults

Gothic vaults were formed by master builders obligated to keep their work in a professional secret. The development of new ceiling structures led to a decreasing need to build such vaults, and their construction principles became forgotten [10]. Researchers have been debating for years about old techniques of performing diamond vaults. A method of their building was researched by Ranisch [11] already at the end of the 17th century (Fig. 5).

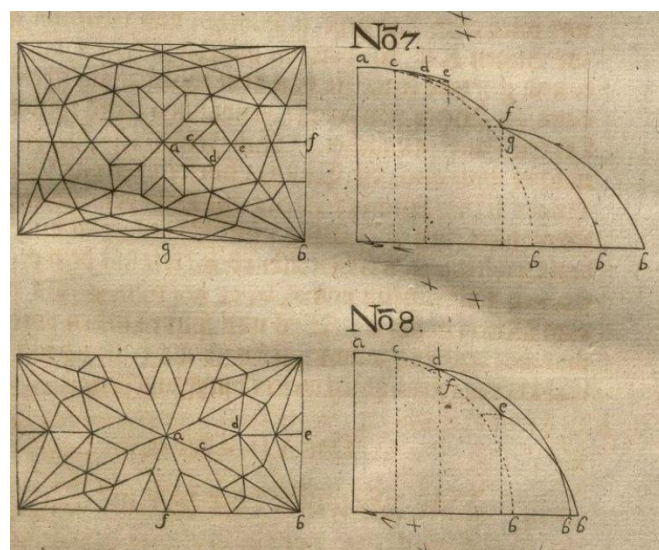


Fig. 5. Drawings of diamond vaults in St. Mary's Basilica in Gdańsk by Ranisch [11]

Currently, many attempts have been made to measure geometry of these vaults and reconstruct them [12, 13, 14, 15, 16, 17]. Diamond vaults undoubtedly required centring placed below main ridges [8, 9]. Other ridges were probably shaped on supports from planks stretched in centrings, and experienced bricklayers could perform smaller areas at once. Fully boarded roof was applied in diamond vaults, the curvatures of which eliminated the use of centrings. Instead of crossing ridges in these vaults, which was difficult to perform, one flat element, that is, centring was used.

3. DIAMOND VAULTS IN POLAND

Saxon, Czech, and Polish diamond vaults are different. In Germany and Austria they only covered small areas. And they were not used in churches. In the Czech Republic, diamond vaults are not generally separated into spans. Main ridges are in a plane of the four-pointed star. These vaults usually have the geometry of a lunette vault, locally with lowered keystones [9, 8, 18].

First vaults in Poland were formed in churches in Gdańsk. However, according to some sources cloisters in Collegium Maius in Cracow had been constructed earlier. St. Mary's Basilica in Gdańsk was vaulted by a master builder Henryk Hetzel in the years 1499-1502, St. Catherine's Church was vaulted in ca. 1500, and St. Peter and St. Paul's Church was vaulted in the years 1514-1516. Aisle arcades were formed in these churches. The separation into bays is also clearly visible. St. Mary's Basilica has nearly all types of Gothic vaults, and diamond vaults were constructed over aisles (Fig. 6). Diamond vaults in St. Catherine Church are also over aisles (Fig. 7), a porch, and two chapels. Diamond vaults in St. Bridget's Church are over the chancel and the lower chapel (Fig. 8).



Fig. 6. Diamond vaults over aisles in St. Mary's Basilica in Gdańsk



Fig. 7. Diamond vaults over an aisle in St. Catherine's Church in Gdańsk

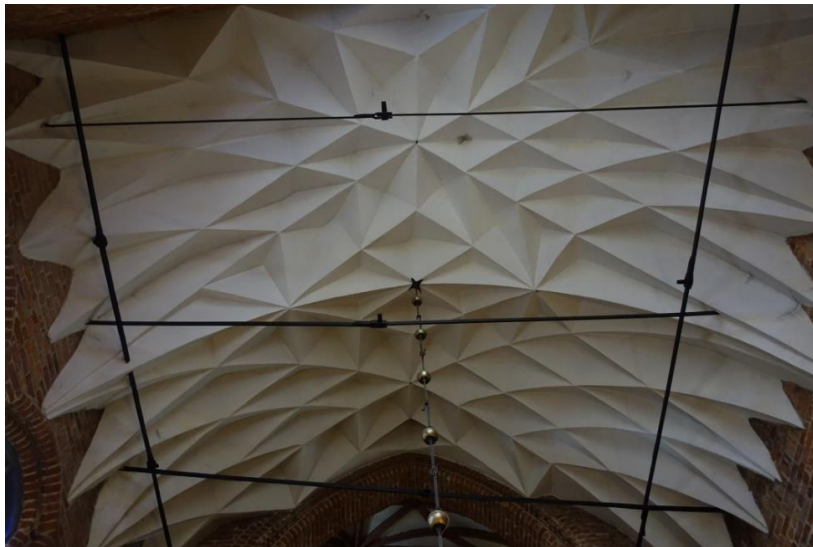


Fig. 8. Diamond vaults over the chapel in St. Bridget's Church

A master builder Matz from Gdańsk was very active in Pomerania and Warmia and Masuria. He vaulted St. John's Church in Malbork in ca.1500 r. (two large vault fields – Fig. 9a, and narrow vaults over window niches have remained until today), aisles in St. Joseph's Church in Morağ in 1503 (Fig. 9b), and a church in Marianka and Collegiate Basilica of St. John in Kętrzyn in 1515 (Fig. 9c). The latter church is exceptional as the diamond vaults were used over all naves, not only aisles.

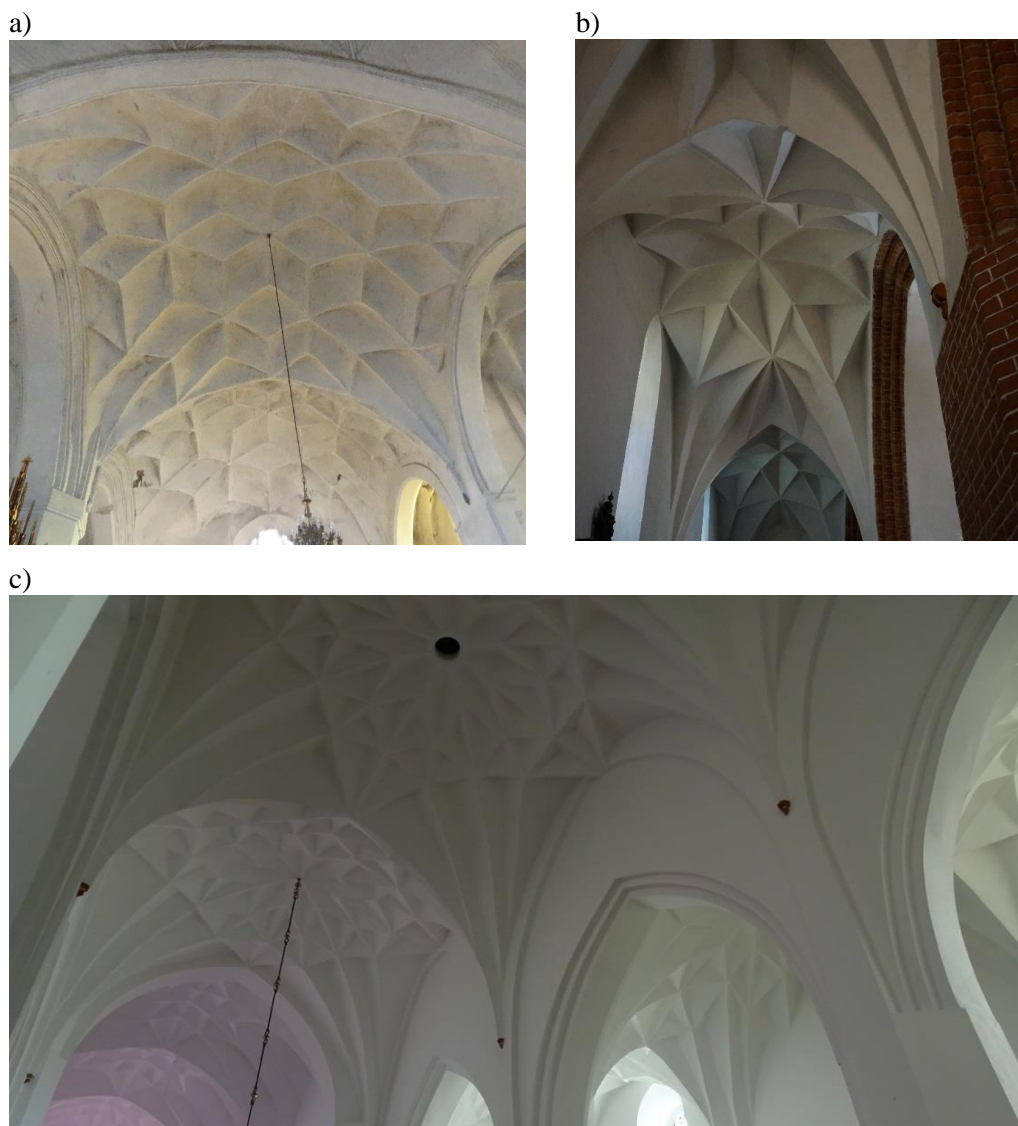


Fig. 9. Diamond vaults performed by the master builder Matz: a) St. John's Church in Malbork, b) St. Joseph's Church in Morąg, c) Collegiate Basilica of St. John in Kętrzyn

Vaults like those in Morąg can be also found over aisles in St. Anne and Stephen's Church in Barczewo (built after 1544 – Fig. 10), and vaults in Łomża, Mazovia resemble those in Kętrzyn. Another master workman from Gdańsk, Antoni Schultes formed the diamond vault over a northern part of the transept in Cistercian Abbey in Pelplin in 1557 (Fig. 11). He is also assumed to be an author of vaults in the former Bernadine friary in Warsaw (nowadays the parish buildings of St. Anne's Church). Diamond vaults are over the corridor and two two-field areas. Each vault has different arrangement of main ridges (Fig. 12).



Fig. 10. Diamond vaults over the chapel in St. Anne and Stephen's Church in Barczewo



Fig. 11. Diamond vault over a northern part of the transept in Cistercian Abbey in Pelplin

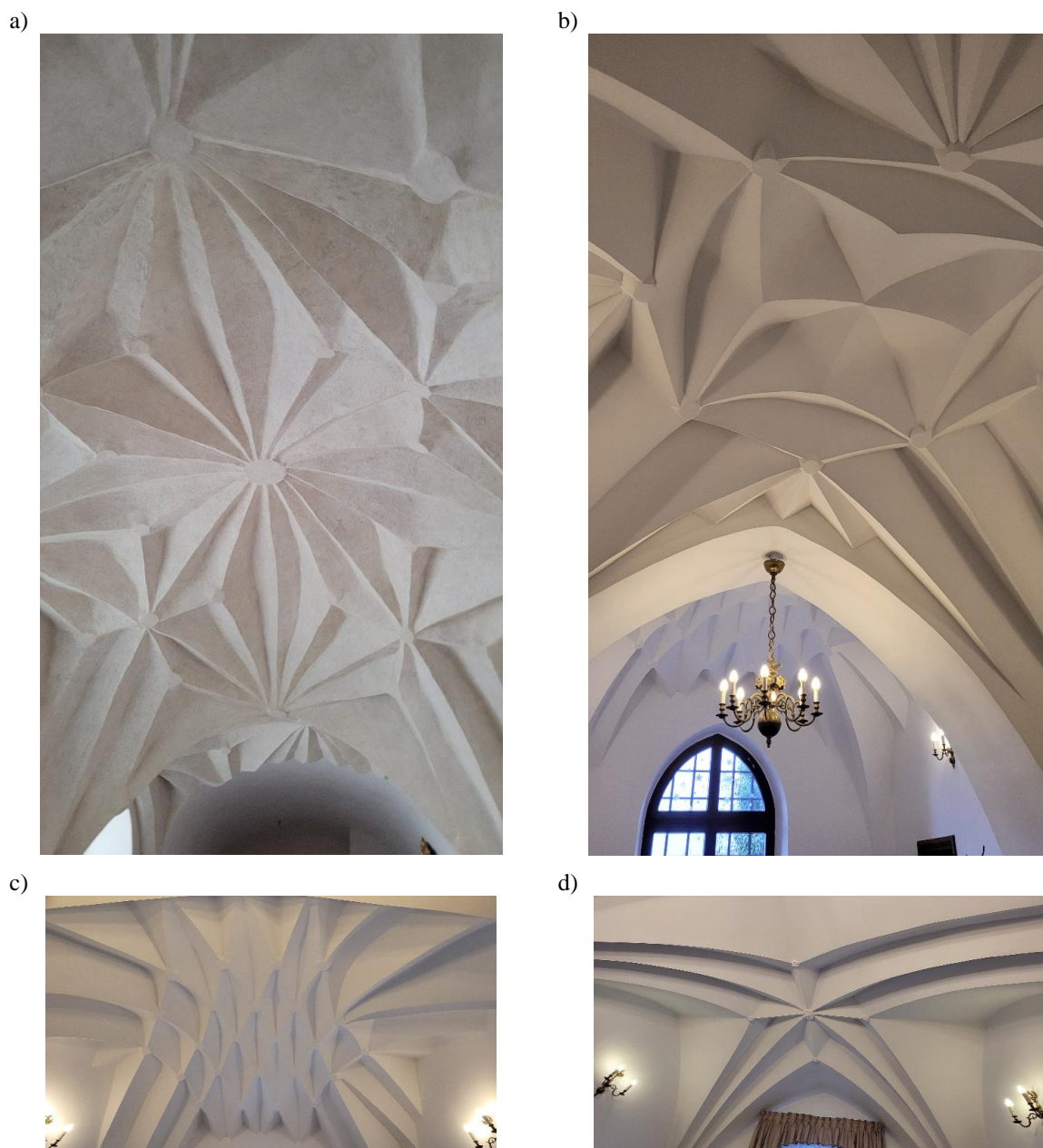


Fig. 12. Diamond vaults in the former Bernadine friary in Warsaw (nowadays the parish buildings of St. Anne's Church). a) a corridor, b) a southern area, c) a detail of the vault in the south-eastern area, d) a detail of the vault in the central area

Diamond vaults in Olsztyn can be found in the former refectory and a chamber of the Grand Master in the Warmian Chapter's Castle (Fig. 13) and over aisles in St. Jacob's Basilica (Fig. 14). Vaults in the Basilica have stellar and net arrangement of main ridges and a form of sail vaults.

At the frontier of Greater Poland and Kujawy, diamond vaults are over aisles in the Church of the Holy Apostle John, and in the premises of the Order of Friars Minor Capuchin in Mogilno (Fig. 15).

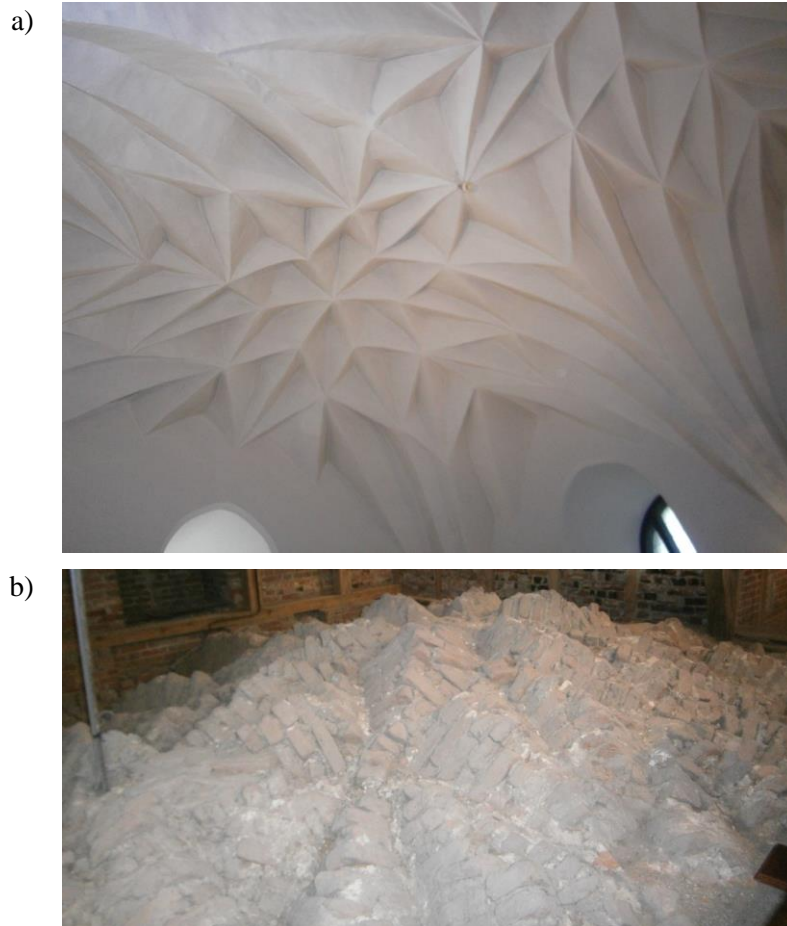


Fig. 13 Diamond vaults in the Warmian Chapter's Castle in Olsztyn: a) bottom view, b) top view



Fig. 14. Diamond vaults over an aisle in St. Jacob's Basilica in Olsztyn

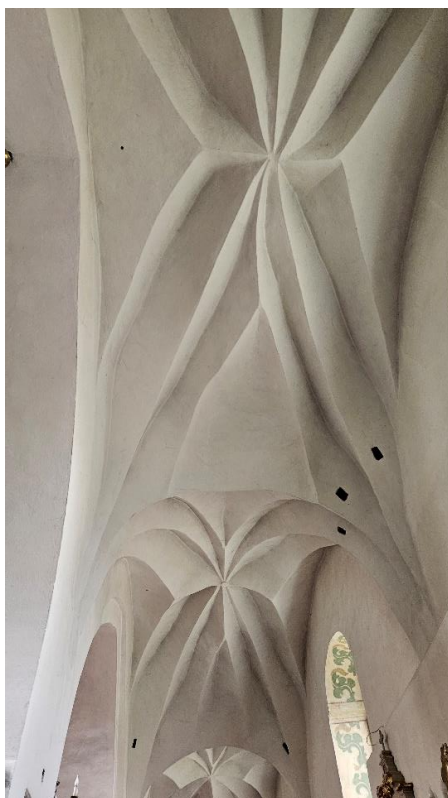


Fig. 15. Diamond vault over an aisle in Church of the Holy Apostle John in Mogilno

In Western Pomerania, crystal vaults can be found in the chapels of the church of St. John the Baptist in Stargard (fig. 16) and in the buildings of the former Dominican monastery in Myślibórz (fig 17). Further south, diamond vaults can be seen in the parish church of St. Michael the Archangel in Świebodzin (fig 18).



Fig. 16. Diamond vault of one of the chapels of the church of St. John the Baptist in Stargard



Fig. 17. Diamond vault in the buildings of the former Dominican monastery in Myślubórz



Fig. 18. Diamond vault in the church of St. Michael the Archangel in Świebodzin

Diamond vaults in Silesia are in Opole in the buildings of the Franciscan friary and in the porch in the Cathedral of Holy Cross (Fig. 19). In Cracow diamond vaults were formed over cloisters in Collegium Maius (Fig. 20a) and over an entrance to Collegium Novum erected over 350 years later (Fig. 20b). In Małopolska, crystal vaults can also be found in part of the porch in St. Margaret's Basilica in Nowy Sącz (fig. 21).



Fig. 19. Diamond vault over the porch in the Cathedral of Holy Cross in Opole

a)



b)



Fig. 20. Diamond vaults in Cracow: a) Collegium Maius, b) Collegium Novum



Fig. 21. Diamond vault in part of the porch in St. Margaret's Basilica in Nowy Sącz

4. TYPICAL DAMAGE AND REPAIR PROBLEMS

Compared to Gothic rib vaults, diamond vaults are less stiff. Their makers were probably aware of that fact as diamond vaults were not generally formed at spans exceeding 7.5 m. Therefore, diamond vaults are usually observed above aisles in churches. Collegiate Basilica of St. John in Kętrzyn is an exception as all naves were vaulted in that way (Fig. 9c).

Lower stiffness means greater susceptibility to damage and structural collapses. Causes of damage, and even collapse of vaults usually are: natural ageing processes of materials, non-uniform settlement, fires, and military conflicts [20, 21, 19]. Non-uniform settlement was responsible for collapse of the majority of late Gothic diamond vaults in St. John's Church in Malbork in 1534 (remained two spans shown in Fig. 8a, and small spans in window niches). They were replaced with rib vaults. Diamond vaults in the church of the former Bernardine friary in Przasnysz were destroyed during World War I. In 1944 during war, the fortified Orthodox Church with a diamond vault was destroyed in Supraśl.

The obligation to maintain relevant technical conditions of historic buildings is directly regulated by the Act on the Protection and Care of Monuments. However, repair actions are sometimes performed in a wrong way. It is extremely important to plan properly repair works and use relevant techniques and materials [22].

Technical conditions of diamond vaults in structures in Poland are usually good. Sometimes plasters are damaged as in case of St. Jacob's Basilica in Olsztyn (Fig. 22).

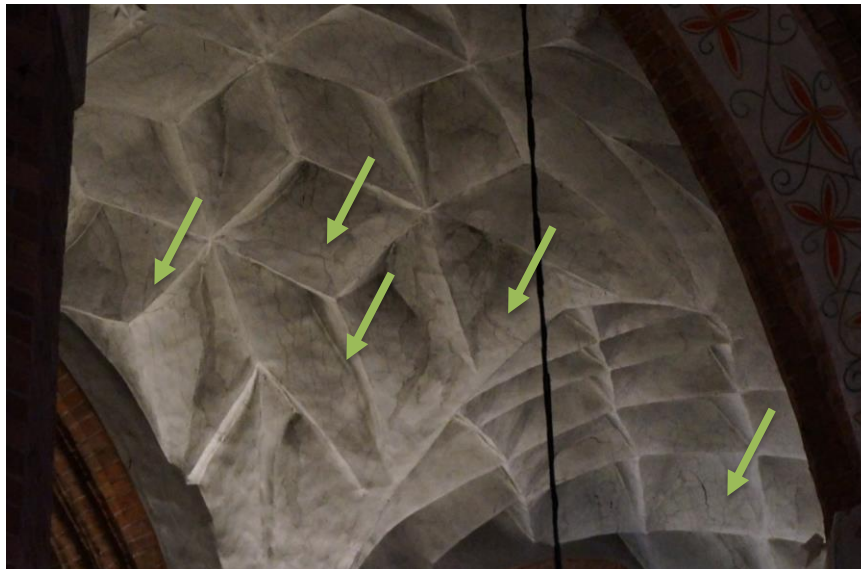


Fig. 22. Cracks in diamond vaults in St. Jacob's Basilica in Olsztyn

However, some buildings face structural problems, as in St. John's Church in Malbork (Fig. 23÷27). A source of these problems is rooted in the past. During the 1st Polish-Swedish war, the enemy army wanted to blow up the wall around the nearby, then Polish, castle in Malbork. They dug a miner tunnel running through the bank at the bottom of the church, on the side of the river Nogat. The tunnel, however, did not have a strategic meaning during attempts to seize the castle, but in fact it weakened the bank and foundations of the church. After a short time these conditions led to the structural collapse. The western wall of the church collapsed with the last bay (then the church was shortened by that last bay). The roof

fire in 1649 caused serious damage to the vaults. In some bays they even partially collapsed. It should be also mentioned that Prussia regulated the water level in the river Nogat in the years 1900-1917. Consequently, walls of the Great Refectory in the middle ward collapsed. It could also affect the foundations of St. John's Church. The war in 1945 destroyed roofs and the top (wooden) floor of the tower and some vaults. Town buildings surrounding the church were demolished, which could also affect its stability. Currently, works are performed to restore the proper technical conditions of diamond and rib vaults. Cracks are stitched and injected, and plasters are restored (Fig. 28). The most damaged vaults have been strengthened from the top with the FRCM system (Fig. 29). This type of strengthening seems to be the most appropriate for seriously damaged vaults [23, 24].



Fig. 23. Cracks in diamond vaults in St. John's Church in Malbork



Fig. 24. Cracks in rib vaults in St. John's Church in Malbork



Fig. 25. Crack in rib vaults in St. John's Church in Malbork (photo by M. Jackiewicz)



Fig. 26. Cracked ribs in rib vaults in St. John's Church in Malbork

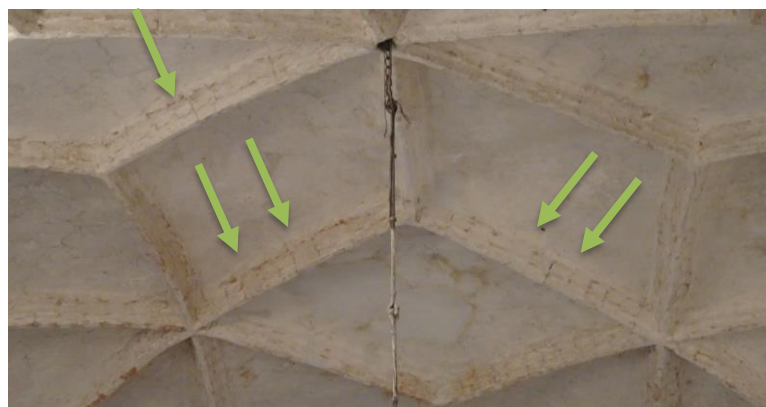


Fig. 27. Cracked ribs in rib vaults in St. John's Church in Malbork



Fig. 28. Restoration works performed underneath the rib vaults in St. John's Church in Malbork



Fig. 29. Application of the FRCM system to top ribs in the rib vaults in St. John's Church in Malbork (photo by M. Jackiewicz)

Restoration works in narrow window niches with diamond vaults revealed painted wall decorations from the medieval period (Fig. 30). They were also restored (Fig. 31). Fig. 32 shows restored rib vaults.



Fig. 30. Painted wall decorations from the medieval period uncovered in window niches in St. John's Church in Malbork



Fig. 31 Restored medieval paintworks in window niches in St. John's Church in Malbork

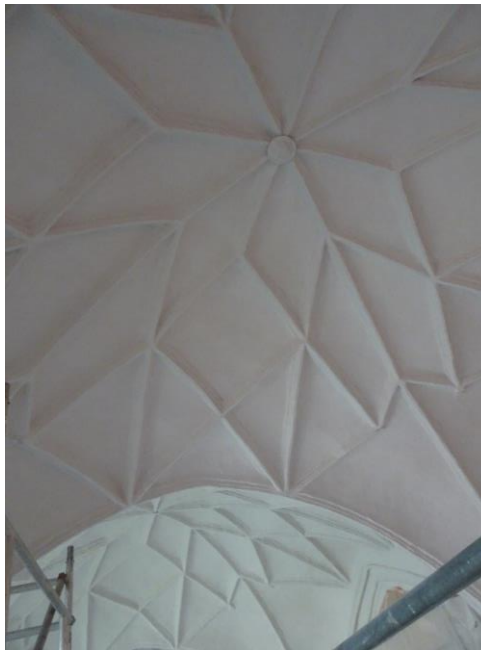


Fig. 32. Restored rib vaults in St. John's Church in Malbork

5. SUMMARY

Diamond vaults were the final stage of the development of the Gothic vaults. They are unquestionably the most explicit vault structures. In areas with such vaults, the light creates very interesting visual effects as they are composed of many small vault cells with prismatic recess.

Few buildings had installed diamond vaults, and even fewer have survived until present times. These structures have to be maintained in the proper technical conditions. To preserve them for future generations, these vaults need regular restoration works.

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