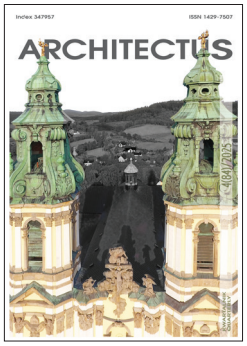

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Franciszek Hackemer*

The issue of structural failures at St Elizabeth's Church in Wrocław in the light of architectural surveys

Abstract

The article discusses unusual solutions of the Gothic structural system used in St Elizabeth's Church in Wrocław and their potential influence on the disasters that took place in its nave. The paper presents the results of stratigraphic surveys of the church walls, which show that its nave collapsed for the first time most likely during construction. Later, this part of the parish church suffered similar disasters twice more. The author's goal was to determine the reasons for these disasters (especially the least understood one – the first), identify their connection with the unusual placement of the flying buttresses, and find the reasons for using such a solution. The author also presented examples of similar load-bearing systems in buildings in Silesia, Alsace, Upper Rhineland, Baden-Württemberg, Bavaria, and the Czech Republic. Ultimately, study determined that the cause of the disasters was a change in the spatial design of the church from a hall or pseudo-basilica to a basilica with a very high clerestorium after its foundations had already been laid. The unusual location of the flying buttresses proved to be effective to a certain extent, although it had practically no analogies among the buildings from the areas previously considered as a source of inspiration for the Wrocław parish church. The previously postulated workshop connections with Czech churches were rejected. The reason for using this complicated construction system was assumed to be the desire to erect a nave of exceptional height, inspired by specific architectural structures from the Lake Constance and Rhine regions, mainly monasteries.

Key words: flying buttress, vaults, gothic architecture, St Elisabeth Church, Wrocław

Introduction

Located in the north-western corner of Wrocław's Market Square, St Elizabeth's Church has served as a parish church for centuries. Its main structure was built (in its present form) in the 14th century. One of the unique features of its architecture is the use of an unusual structural system in which low-set flying buttresses do not balance the thrust of the nave vaults. This solution shapes the character of the parish church's architecture. The result is the majestic height of the nave, relatively low side aisles, and the exposure of plain walls between the arcades and the windows of the main nave, while maintaining the synthetic, closed character of the external structure (Fig. 1). The high walls of the nave are deviated from the vertical (at the height of the vault support in bay 3 by approx. 14 cm), which indicates a certain imperfection in the structure.

The research presented in this paper is part of a broader effort spanning from 2021 to 2025, culminating in a monographic study of the history of Wrocław's parish church architecture[1]. It has provided a more complete understanding of the church's design and the issues that led to three structural failures in the building. This contributed to studies on load-bearing solutions in the church. The author's primary goal was to explain the causes of successive structural disasters (especially the first one), relate them to the problematic solution of the flying buttresses, and search for justification and analogies for such an unusual solution.

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[1] This monographic study is the author's doctoral dissertation, prepared under the supervision of Prof. Ewa Łużyniecka.

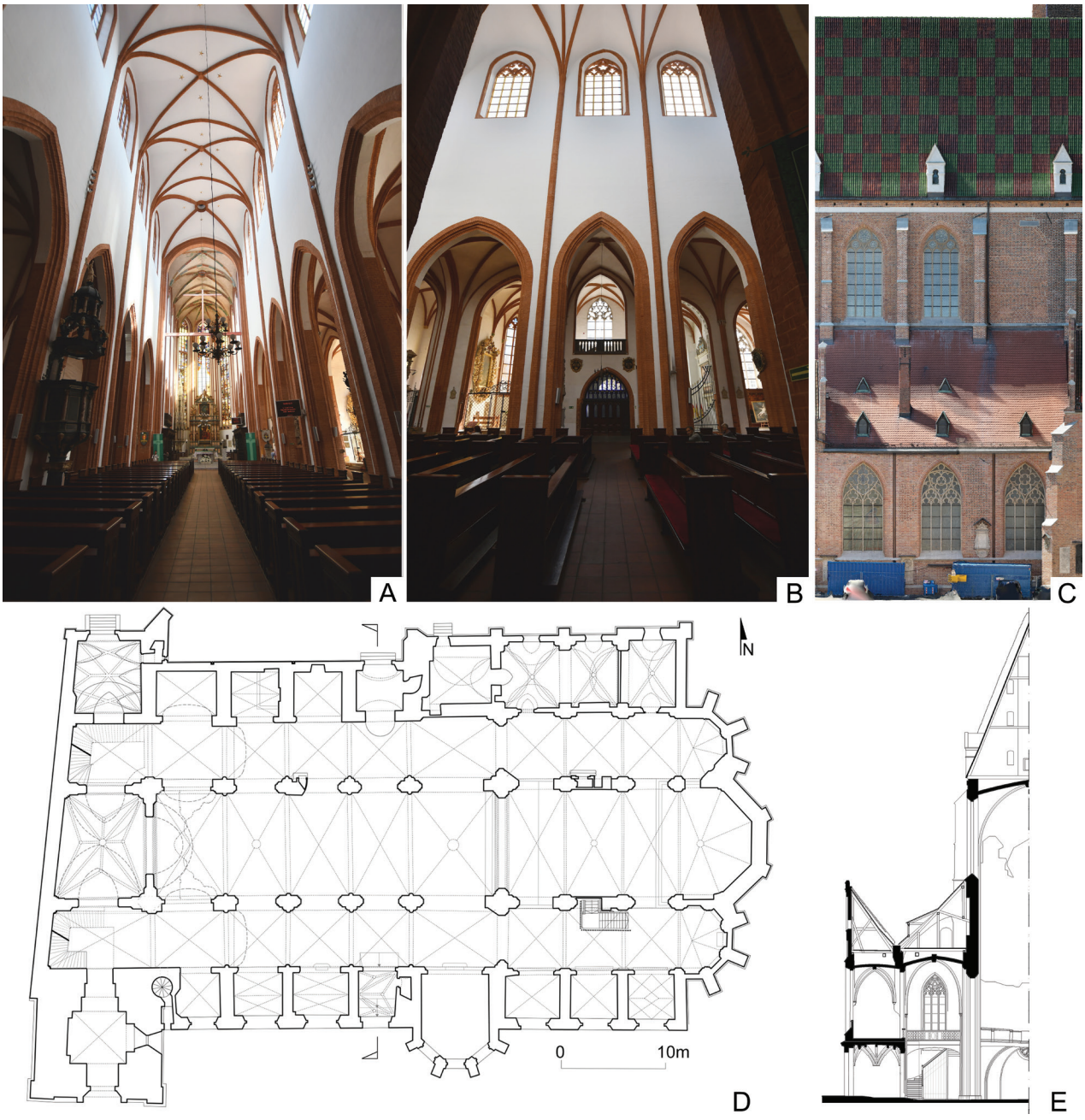

Fig. 1. St Elizabeth's Church in Wrocław: A – view of the interior of the main nave towards the east, B – fifth bay from the west of the nave, arcade (south), C – second, third, and fourth bays from the west in the north elevation (orthophotograph generated from a photogrammetric model), D – plan, E – cross-section through the fifth bay from the west (photo and elaborated by F. Hackemer)

Il. 1. Kościół św. Elżbiety we Wrocławiu: A – widok wnętrza nawy głównej w kierunku wschodnim, B – przęsło piąte od zachodu nawy głównej, ściana arkadowa (południowa), C – przęsła drugie, trzecie i czwarte od zachodu w elewacji północnej (ortofotografia wygenerowana z modelu fotogrametrycznego), D – rzut, E – przekrój przez piąte przęsło od zachodu (fot. i oprac. F. Hackemer)

State of research

The structural system of St Elizabeth's Church was the subject of interest of Werner Güttel. The author included his extensive description in the work of Ludwig Burgemeister and Günther Grundmann. The cited researcher drew attention to the very low point of embedment of the flying buttresses. On this basis, he suggested that the original design of the nave was to be much lower. He interpreted the niches in the wall above the arcades, visible in the attics of the side aisles, as planned window openings. Güttel also believed that the nave of the church was younger than the chancel. Furthermore, he suggested that the sixth bay of the nave collapsed even before the disaster of 1649, known from written records (Güttel 1933, 74, 80). Hans Tintelnot (Tintelnot 1951, 90–94) disagreed with the view that the nave had been raised at a later date, as did Jakub Adamski (Adamski 2017, 397). Supporters of this thesis included Czesław Lasota and Jerzy Rozpędowski (Lasota, Rozpędowski 1980, 64) and Marian Kutzner, who believed that the walls of the nave were raised to their full height after the completion of the chancel (Kutzner 1996, 28). Stanisław

Stulin, citing examples of many churches, mostly monastic, noted that hiding the flying buttresses under the roofs may have originated in Upper Rhine or Burgundy (Stulin 1982, 86). The majority of post-war researchers of the church did not address the issue of structural solutions or treated them very briefly. They were more interested in the issue of the order in which parts of the temple were built and, above all, its stylistic analogies (Adamski 2014a, 395–411, 448–454; Kutzner 1996, 19–52; Stulin 1982, 81–89). Little attention was paid to the structural system itself.

Stulin postulated Upper Rhine, Alsatian, and southern German roots for the architectural style of St Elizabeth's Church, citing many examples of analogous solutions for almost all elements of the building (Stulin 1982, 81–89). Kutzner linked the Wrocław parish church with the Cistercian church in Zlatá Koruna. This researcher even suggested that both buildings were erected by the same workshop (Kutzner 1996, 32, 33). Adamski, on the other hand, wrote extensively about the style of the nave, agreeing with Stulin on this matter and expanding on the concept of the Rhenish stylistic origins of the nave (Adamski 2017, 402–410). However, he agreed with Kutzner on the Czech origin of the polygonal responds.

Methods

The research presented in this article is part of a broader effort at St Elizabeth's Church. It primarily involved the use of stratigraphic analysis of the walls structure. Digital tools were used to support the research, including photographic documentation (including UAV), digital photogrammetry, LiDAR scanning, and 3D modeling.

Based on 1691 photographs, a textured mesh model of the exterior of the church was prepared using Agisoft Metashape Pro. It served as the basis for CAD inventory drawings and allowed for an in-depth analysis of the object. Crucial parts of the church interior were scanned. The entire building (including the interior) was inventoried in drawings of the facades, floor plans, and cross-sections.

In the next step, an attempt was made to search for objects that were analogous in terms of their structural solutions. Churches from Germany, eastern France, the Czech Republic, and Silesia, built around the same time as St Elizabeth's Parish Church, were taken into consideration. The selection focused primarily on buildings identified by researchers on the basis of similar details and other features, located in geographical regions considered crucial for the style of the Wrocław church. Measurements and visual inspections of elements belonging to the structural systems were carried out in the selected buildings. 3D scans of crucial parts were made, along with photographic and drawing documentation. Their comparison allowed for the establishment of connections with St Elizabeth's Parish Church in terms of structural solutions. The work was financed by a minigrant project for doctoral students at the Wrocław University of Science and Technology[2].

[2] Project: "A flaw in art or a trend worth the risk? The search for the origins of the unusual structural design of St Elizabeth's Church in Wrocław" nr 50SD/0018/24.

Results

The structural design of the church

In order to compare the structure of St Elizabeth's Church with similar buildings, one must first recognize its shape and attempt to determine what influenced its formation. The church is a three-nave basilica with 11 bays. It is characterized by a very large difference in height between the side aisles and the main nave. From the floor level (original) to the keystones, the height is 14.5 and 31 m, subsequently. All aisles have rib vaults. The horizontal composition of the force with which they press against the walls of the church is taken over by buttresses and flying buttresses. The letter were hidden under the roofs of the side aisles. This forced them to be embedded low in the wall, which would have been standard if it were not for the exceptional height of the clerestory. The wall of the nave above the roofs of the side aisles is 9.90 m high. Its windows have sills just above the edge of the roof and are approximately 7.00 m high. As a result, the point of support for the vault is significantly (4.50 m) higher than the flying buttress that is supposed to balance its thrust (Fig. 2). The ineffectiveness of this solution is obvious. The effect of the unbalanced thrust forces is the outward spreading of the walls, visible to the naked eye. This problem prompted 19th-century conservators to install a system of wooden anchors in the attic of the nave to connect the walls to the roof truss. It is not entirely certain whether this project was implemented, although a sketch of this solution (APW no. 167) and some traces in the wall that could testify to this have been made. The buttresses of the church have varied shapes. Some of them are quarter-circular (south side: bays 4/5, 7–10 from the west; north side: bay 1/2 from the west), while others are pointed.

Buttresses adjacent to the arcade walls rise on the flying buttresses. To some extent, they help balance the thrust forces. As they do not continue below the arches, this is known as the Gniezno system. Its use and connections with other buildings in Poland will be discussed in the section on analogies.

The foundations of St Elizabeth's church are partially visible in the church crypt (Fig 3). These include the foundations of the fifth pillar from the west on the north side of the nave and large sections of the strip and isolated footings supporting the arcades of the chancel. The foundations of the nave differ significantly from those of the chancel. They were created by filling a narrow excavation with erratic stones mixed with ceramic debric and light, yellowish lime mortar (Fig. 3A). The lower parts of the chancel foundation were also constructed in this way. However, brick isolated footings for the pillars were erected on the strip created in this way (Fig. 3B). They are made of bricks measuring 25.5–27 × 11–13 × 8–9 cm in a flemish bond. It is therefore clear that the design of the church's foundation was changed during construction. It is worth noting here that at the same time, a decision was made to raise the usable level of the chancel by about 1.3 m above that designated for the nave. The nave originally had a floor level of approximately 118.80 m above sea level, while the chancel was 120.10 m above sea level. The isolated footings of its pillars were covered with a thick layer of sand (Lasota, Piekalski 1996, 17, 18).

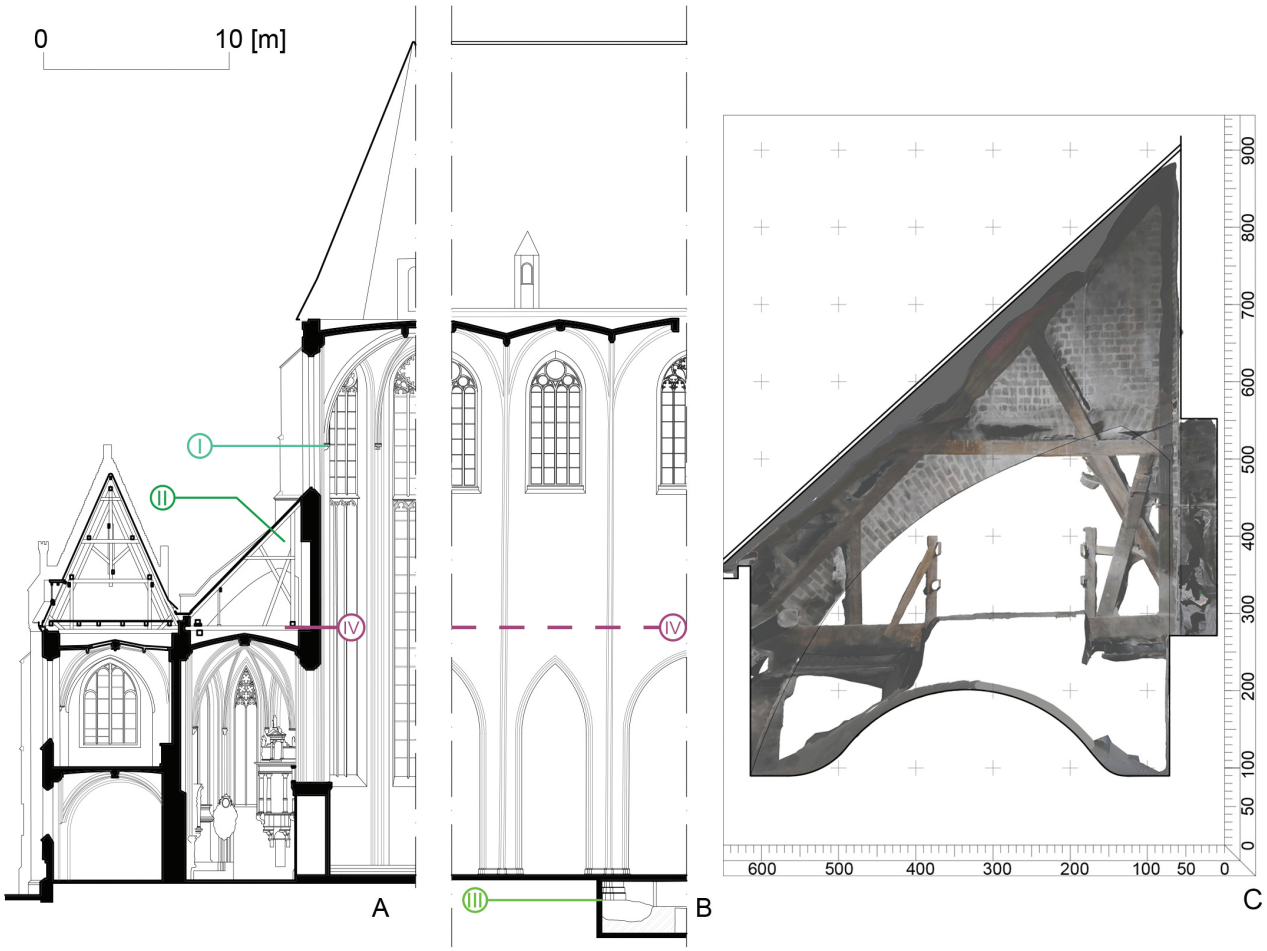

Fig. 2. Cross-sections of St Elizabeth's Church in Wrocław: A – transverse (eastward through the eighth bay from the west), B – longitudinal in the northward direction, C – flying buttress between the seventh and eighth bays from the west on the north side. I – main nave vault corbel, II – flying buttress, III – original floor level (nave), IV – probable height of the walls established as part of the hall concept (orthophotography generated from a photogrammetric model; compiled by F. Hackemer)

Il. 2. Przekroje kościoła św. Elżbiety we Wrocławiu: A – poprzeczny (w kierunku wschodnim przez przęsło ósme od zachodu), B – podłużny w kierunku północnym, C – łuk oporowy między przęsłami siódmym i ósmym od zachodu po stronie północnej. I – wspornik sklepienia nawy głównej, II – łuk oporowy, III – pierwotny poziom posadzki (korpus), IV – prawdopodobna wysokość przegród arkadowych założona w ramach koncepcji halowej (ortofotografia wygenerowana z modelu fotogrametrycznego; oprac. F. Hackemer)

The nave of the church was probably originally designed as a hall church or, less likely, a pseudo-basilica or even a basilica with a small clerestory. This is evidenced by traces in the western bay of the church – capitals on the front wall. This issue has been discussed in more detail by earlier researchers of the church (Stulin 1982, 81–84; Kozaczewska-Golasz 2015, 232; Adamski 2014a, 313–315). It is not directly related to the topic of the paper, which focuses on the ultimately realized structure. However, it seems that the foundations are a common element of the unrealized and realized nave. Most likely, they were built, at least in large part, during the construction of the building according to the original design. Regardless of the reconstruction of the spatial layout of the originally planned nave, there is no doubt that its foundations were adapted to a much smaller load.

The pillars of the church generally have a consistent plan, which differs between the chancel and the nave only in terms of vertical articulation. In both cases, the arcades are negatively profiled in identical way. The responds of the nave are half octagonal, on the side aisles superimposed on simply (quarter-circular) profiled pilaster strips. In contrast, there are no responds in the chancel. Instead, the pillars are flanked on both sides by pilaster strips, and the vaults rest on corbels at their apex (Fig. 4).

Although the details of St Elizabeth's Church were usually considered separately for the nave and the chancel, the overall architectural character remained consistent for both parts. The layout, proportions of the naves, consistency of the structure, and the general design of the construction system all contribute to a very uniform building. However, Güttel noticed a stratigraphic division between the sanctuary and the nave about 40 cm west of the chancel arch. This junction of walls does indeed exist. In addition, the researchers described the shape of the flying buttress arches as one of the distinguishing features – quarter-circular in the chancel and pointed in the nave (Güttel 1933, 74). This is quite surprising, as this division is now completely illegible. As already mentioned, quarter-circular arches are found in both parts of the building. The alteration of these parts of the church in the years after 1933, when the researchers'

Fig. 3. Foundations of the pillars of St Elizabeth's Church in Wrocław: A – nave, B – chancel (orthophotos generated on the basis of a photogrammetric model; elaborated by F. Hackemer)

Il. 3. Fundamenty filarów kościoła św. Elżbiety we Wrocławiu: A – korpus, B – prezbiterium (ortofotografie wygenerowane na podstawie modelu fotogrametrycznego; oprac. F. Hackemer)

study was published, would have been documented, and the face of the wall shows no signs of any secondary changes. Therefore, this should be considered a mistake.

Structural failures

The first structural failure that left traces occurred most likely during the construction of the church. This is evidenced primarily by the junctions of the walls in the fifth and sixth bays from the west. On the south wall of the nave, a secondary filling of a previously existing gap in the wall is visible from the outside. It runs vertically on the right side of the fifth buttress of the nave from the west (Fig. 5). This junction proves that further sections of the wall were added from the east to the existing wall of the fourth bay. This addition reached approximately the line of the chancel arch. This edge is marked primarily by the arch of the former entrance to the staircase, which existed until the 19th century in the sixth bay. It is accessible in the attic of the main nave, above the vaults (Fig. 5). It was built along with the wall in which it is located, but its eastern part rests on a chiselled, previously existing brickwork. This seam is also visible from the outside, above the mentioned arch and the nearby buttress. In the exterior wall of the south nave, in the attic, the seam between the walls can also be seen in the fifth and sixth bays.

On the north side, however, it is more difficult to find signs of the disaster. On the exterior of the main nave wall, in the sixth bay from the west, there is a characteristic trace of double brick headers. At the bottom, it runs from west to east, vertically in the middle, and then returns westward at the height of the window arch (Fig. 5). Double headers occur quite often in the walls of the church. Their sequences can be observed in places where two walls built in different time meet. This is the case, for example, at the bottom of the junction between the tower and the south aisle. The western edge of the addition, which may have existed in the fifth bay, is now difficult to determine. This part of the church was destroyed in a later disaster (1649) and rebuilt, which may have obscured the traces. However, in the eastern part of the fifth bay, a vertical strip of machine-made bricks measuring approximately 27 × 13 × 8.5 cm is visible in the wall, which is the result of conservation treatments in the second

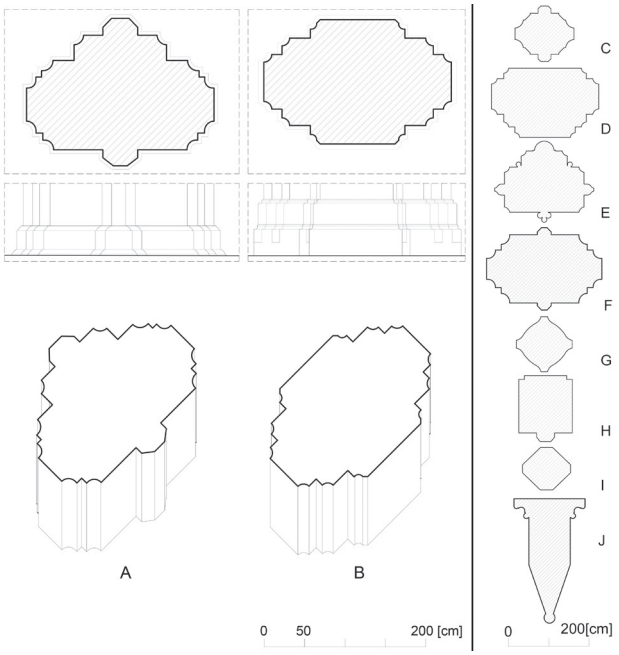

Fig. 4. Pillars of St Elizabeth's Church in Wrocław, plan, side view of the plinth, and axonometric view of the shaft: A – nave, B – chancel. Plans of pillars of formally similar churches: C – Cistercian church in Złota Korona, D – Cistercian church in Lubiąż, E – Our Lady before Tyn church in Prague, F – parish church of St Peter and Paul in Legnica, G – St Maurice church in Soultz, H – Dominican church in České Budějovice, I – Cistercian church in Kaisheim, J – Cistercian church in Salem (body) (compiled by F. Hackemer)

Il. 4. Filary kościoła św. Elżbiety we Wrocławiu, rzut, widok cokołu i widok aksonometryczny trzonu: A – korpus, B – prezbiterium. Rzuty filarów kościołów zbliżonych formalnie: C – cysterski w Zlatej Korunie, D – cysterski w Lubiążu, E – Matki Bożej przed Tynem, F – fara św. Piotra i Pawła w Legnicy, G – św. Maurycego w Soultz, H – Dominikanów w Czeskich Budziejowicach, I – Cysterski w Kaisheim, J – cysterski w Salem (korpus) (oprac. F. Hackemer)

half of the 20th century (Il. 5). Perhaps originally there was a wall seam in this place, which was rebuilt due to its poor condition.

Another element reveals a secondary addition to the space between the fourth and seventh bays from the west. It is a massive arch in the thickness of the southern main nave

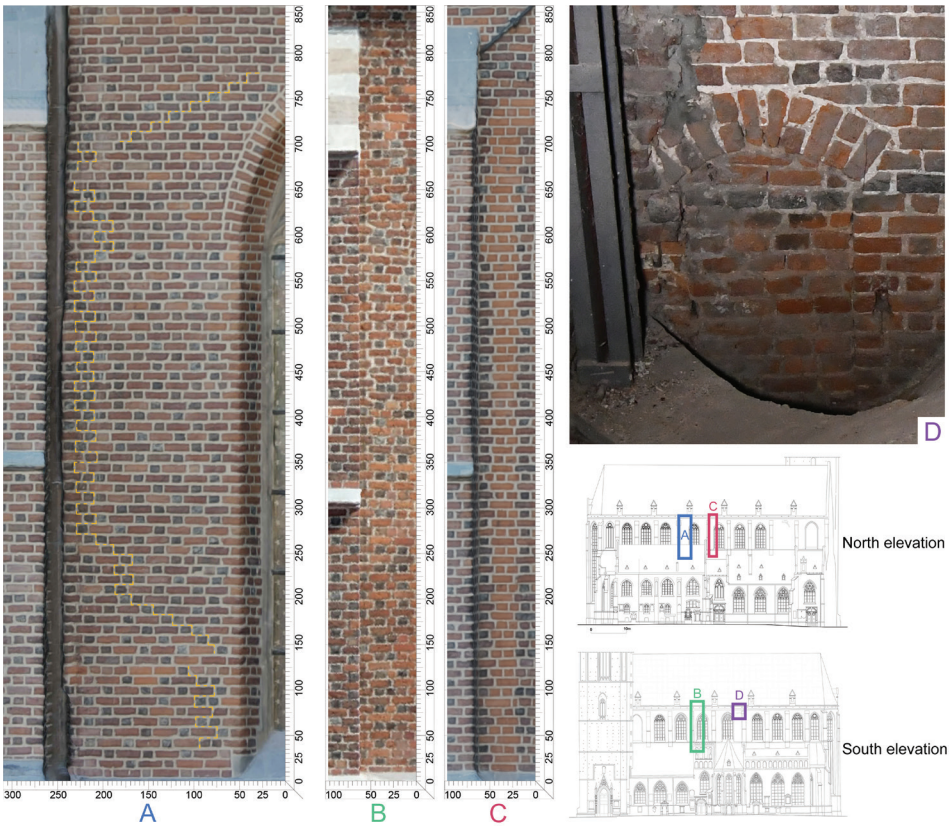

Fig. 5. Visible seams of the walls of the nave in bays five and six on orthophotos from the photogrammetric model:
A – north wall, bay 6,
B – south wall, bay 6,
C – north wall, bay 5,
D – arch of the former staircase opening in the south wall of the nave (from the interior, main nave attic)
(elaborated by F. Hackemer)

Il. 5. Widoczne styki murów korpusu w przęśle piątym i szóstym na ortofotografiach z modelu fotogrametrycznego:
A – ściana północna, przęsło 6,
B – ściana południowa, przęsło 6,
C – ściana północna, przęsło 5,
D – łęk otworu dawnej klatki schodowej w ścianie południowej nawy głównej (od wnętrza, strych nawy)
(oprac. F. Hackemer)

wall above the arcades. It was stretched between the fourth and sixth pillars from the west (Fig. 6). It is clearly visible in the attic of the south nave. It was built simultaneously with the wall in which it is embedded, as evidenced by the lack of traces of chiselling. This can only be explained by the assumption that at the time of its construction, both pillars that it connects already existed.

Traces in the church walls prove that the sixth bay and part of the fifth bay were built later than the adjacent parts of the church on both sides. The assumption that this is the result of the planned sequence of works is difficult to defend. It seems relatively unlikely that most of the nave and the entire chancel were erected to their full height, leaving a free space between them. This part of the church most likely collapsed and was rebuilt.

It is not easy to determine the exact time of the disaster. Dating the construction of the nave and chancel of the church has posed difficulties for researchers and is quite broad. Determining the approximate time of their construction was part of the research on the stratigraphy of the church and will be presented in the author's doctoral dissertation. However, some information should be mentioned. The rebuilt walls were made in the flemish bond from bricks measuring 25.5–27 × 12–13 × 8.5–9.5 cm on beige-colored lime mortar, with visible lumps of calcium. These materials and technique are very similar to those used in the chancel and nave of the church. The pattern of the seams in the northern wall of the main nave, which can be seen from exterior, is quite irregular (Fig. 5) and can probably be considered a direct trace of the collapse. In contrast, in the south wall, the seam is exactly vertical (Fig. 5). Therefore, it does not repeat the line of the rupture. It should be assumed that at the time of the disaster, the southern wall of the main nave had not yet reached its full height. The vertical seams are remnants of its construction within the fifth and sixth bays with some delay. The builders continued work on the adjacent bays, bricking up the window area while rebuilding the damaged parts. The collapse of the fifth and sixth bays, which were under construction at the time, most likely took place when the northern wall of the main nave was already completed, while the southern was still being raised by a clerestory.

The matzeva used as a floor slab under the base of the fifth pillar from the west on the north (Figs. 3, 7) is of particular interest. It is worth mentioning the year 1345, when John of Bohemia abolished the 30-year-old inviolability of the Jewish cemetery, allowing the use of tombstones in the construction of the city's fortifications. These slabs appeared in many buildings in Wrocław from that period (Wodziński 1996, 197, 198). The matzeva under the pillar of the nave could date from after 1345. This cannot be known for certain, but it seems very likely. It is difficult to imagine that after the collapse of two bays of the nave, the pillar was demolished down to the floor slab and then rebuilt without strengthening the foundations. It can rather be assumed that the lower parts of these supports were built around 1345. The disaster must therefore have occurred later. It should also be remembered that at the time of the collapse of the nave bays, the chancel had already been raised at least to the level of the window sills.

The cause of the disaster can be attributed to the poor foundation of the pillars. This is evidenced primarily by the arch in the southern wall of the main nave, which relieves the load on the pillar below it. The builders must have been aware that the collapse of two bays of the nave was caused

by excessive load on the supports. The foundations of the nave (at least in large part) were most likely built as part of the initially planned hall or pseudo-basilica structure. They were designed to bear much smaller loads than those resulting from the construction of the enormous height of the nave (Fig. 2 IV). After the modification of the design, the load on the foundations more than doubled. The collapse of the church was caused by the insufficient load-bearing capacity of the foundations, not by the low setting of the flying buttresses.

Another disaster that took place in St Elizabeth's church was the collapse of large sections of the nave and north aisle on August 10–15, 1649 (Luchs 1860, 6). In 1627, the walls of this part of the church were additionally burdened with organs, which was considered to be the cause of the disaster. Three northern pillars collapsed, along with the wall above them and the vaults built on it (Güttel 1933, 80). Reconstruction began immediately. Records from 1649 show payments to stonemasons, as well as fees for beer and food for bricklayers and carpenters (Bimler 1936, 73). The names of the masters leading the work are known: Hans Hentsch, Friedrich Wolff, and David Roch. On August 23, Joachim Wolffgang, the builder of the Legnica fortress, arrived in Wrocław to inspect the church. The work was completed in 1653 (Güttel 1933, 82).

In 1856–1857, the interior was renovated under the supervision of building counselor von Roux. Unfortunately, this work caused another disaster. After removing the plaster from the southern wall of the main nave, cracks were discovered. It was decided that repairs were necessary, and wooden supports were erected to secure the arcades. After removing one of the pillars (the second from the west), the two adjacent pillars (the third and fourth from the west) collapsed, bringing down the vaults of the south aisle. Reconstruction work began again immediately. The nave of the church was put into use as early as 1858 (Güttel 1933, 85, 86).

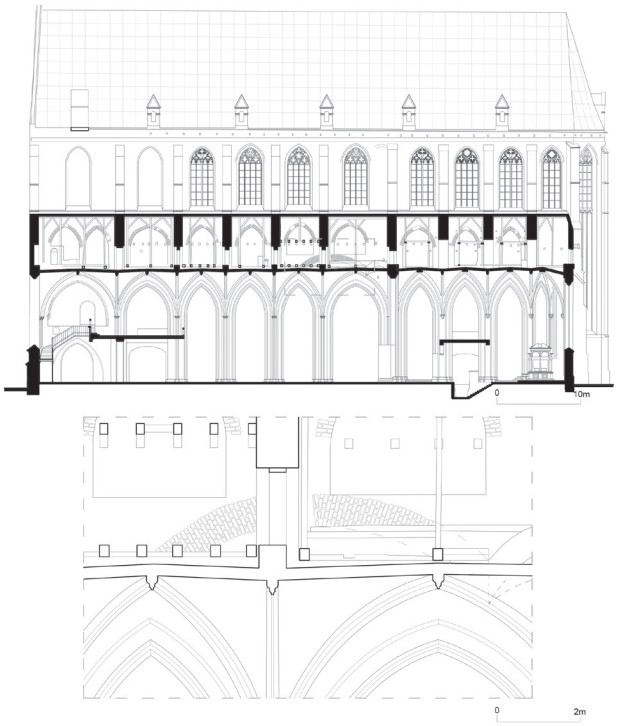

Fig. 6. The structural arch in the southern arcade wall on the cross-section through the south nave and a detail of the arch (elaborated by F. Hackemer)

Il. 6. Łęk oporowy w południowej ścianie arkadowej na przekroju przez nawę południową oraz detal łęku (oprac. F. Hackemer)

Fig. 7. Fraction of a matzeva used as a floor slab under the fifth pillar from the west in the north aisle (elaborated by F. Hackemer)

Il. 7. Fragment macewy użytej jako płyta posadzkowa pod piątym od zachodu filarem nawy północnej (oprac. F. Hackemer)

Analogous buildings

The structural systems of the analogous buildings cited by previous researchers of St Elizabeth's Church are not entirely uniform. Of course, all of them are basilicas, but they differ in the presence and location of flying buttresses.

One of the most important characteristics of St Elizabeth church external shape is location of the flying buttresses under the roofs of the side aisles. This solution, or even abandonment of their use, was quite common in Germany and France (Cistercian churches in Lahr, Kaisheim, and Salem, the parish church in Soultz, Dominican and Franciscan churches in Regensburg). The principles of shaping the articulation of walls in interiors can also be linked to temples with this solution. This refers primarily to leaving a plain wall between the window sills and the arcading (St Pierre-le-Jeune in Strasbourg, St Lawrence in Nuremberg, the parish church in Soultz, Thann and Nabburg, the Cistercian churches in Lahr and Kaisheim, the Franciscan and Dominican churches in Regensburg, St Martin's in Colmar, and the collegiate church in Freising). Some of these buildings also feature a similar method of profiling the arcades and articulating the walls (Fig. 8). In terms of the overall appearance and proportions of the interior, as well as to some extent the details, there are numerous similarities between the parish church in Wrocław and many buildings in the Upper Rhine, Baden-Württemberg, and Bavaria. The monastery churches of Kaisheim, Salem, and Regensburg stand out in this respect, as apart from certain internal similarities, they have structures shaped in a synthetic, restrained manner. This is more reminiscent of Silesian buildings than the fragmented

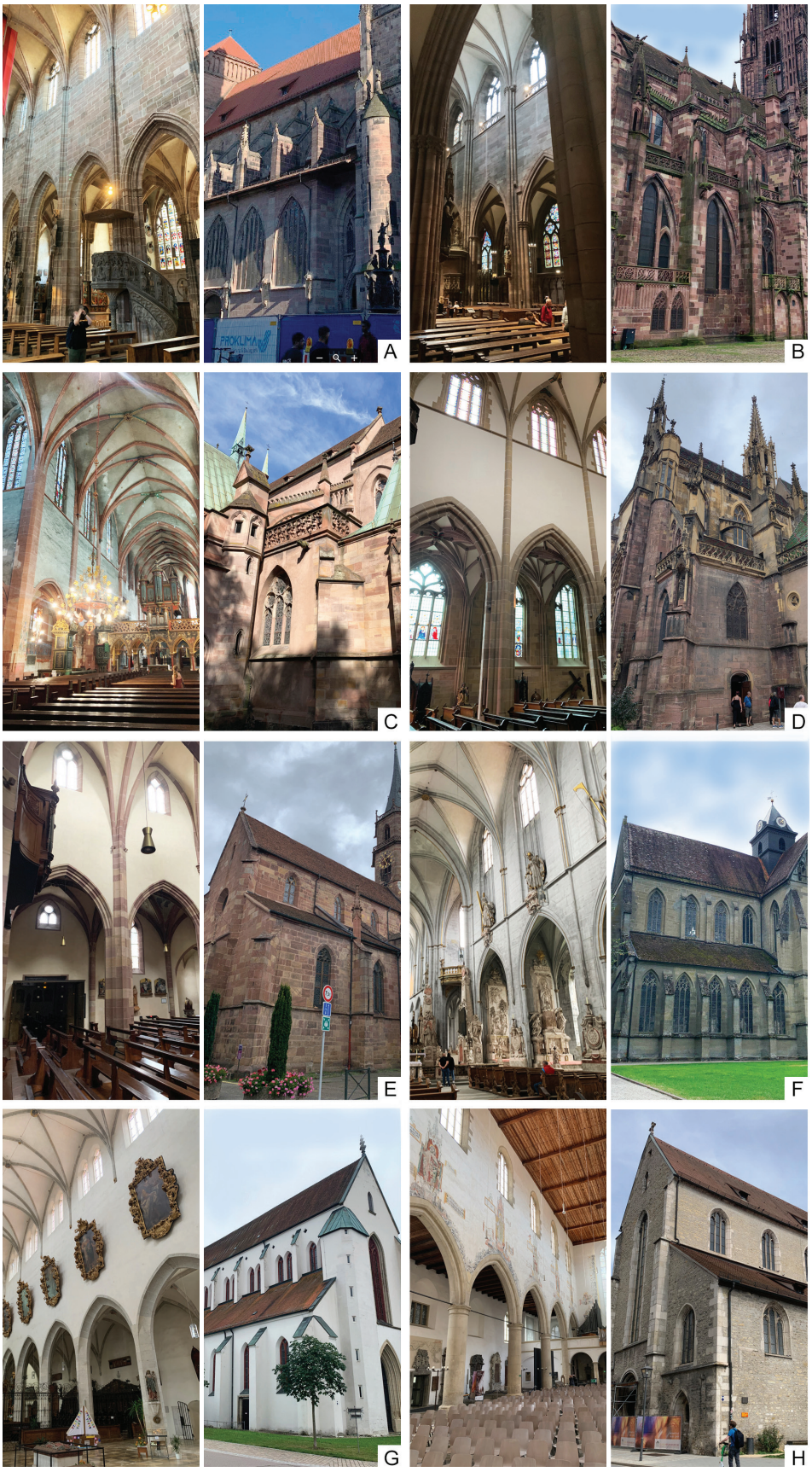

Fig. 8. Views of main nave walls, external buttresses and flying buttresses of churches in Germany and France bearing stylistic similarities to St Elizabeth's Church in Wrocław:
A – St Lawrence church in Nuremberg,
B – Freiburg Minster,
C – St Pierre-le-Jeune church in Strasbourg,
D – St Theobald church in Thann,
E – St Maurice church in Soultz,
F – Cistercian church in Salem,
G – Cistercian church in Kaisheim,
H – Franciscan church in Regensburg
(photos by F. Hackemer)

Il. 8. Widoki ścian arkadowych i zewnętrznego systemu przypór i łuków oporowych kościołów Niemiec i Francji noszących cechy stylowego podobieństwa do fary św. Elżbiety we Wrocławiu:
A – św. Wawrzyńca w Norymberdze,
B – katedralnego we Fryburgu Bryzgowijskim,
C – St Pierre-le-Jeune w Strasburgu,
D – św. Teobalda w Thann,
E – św. Maurycego w Soultz,
F – cysterski w Salem,
G – cysterski w Kaisheim,
H – franciszkański w Ratyzbonie
(fot. F. Hackemer)

forms known from churches with other functions. Examples include the churches of St Lawrence in Nuremberg, the cathedral in Freiburg im Breisgau (originally a parish church), St Martin in Colmar, and St Theobald in Thann (Fig. 8).

Most of the monastery churches mentioned here have a conventional design (Fig. 9). Although usually hidden, the flying buttresses are at the correct height thanks to the lower clerestories. Sometimes (the nave in Salem), a system of

extending the buttresses by adding them to the pillars of the nave so that they reached the floor was used. Such solutions were missing in the Dominican church in Regensburg, which led to visible (more so than in St Elizabeth's church) deviations from the vertical. However, this is a much smaller building. In contrast, in the Franciscan church in the same city, no vaults were built at all, and the majestic basilica was covered with ceilings. The tendency of monastery builders to hide the flying buttresses naturally forced the use of buttresses at the pillars or the reduction of the difference in height between the nave and the aisles and the overall scale, or the abandonment of vaults.

Apart from southern German and eastern French buildings, Czech churches were another source of inspiration mentioned in the literature. Undoubtedly, the profiling of the pillars in Zlatá Koruna, the design of the arcades in České Budějovice, and the half octagonal responds in both buildings bring to mind the temple in Wrocław. Kutzner considered the churches in Zlatá Koruna and Wrocław to be the work of a single workshop. Other researchers had different views (Stulin 1982, 82–89; Adamski 2017, 402–410). Resistance to such a direct connection between the buildings seems entirely justified. The profiling of the pillars and the half octagonal responds may indeed give the impression of very similar architecture, but it should be noted that the way in which the loads are transferred from the vaults is completely different. There are currently no flying buttresses in Zlatá Koruna, but in the older, northern parts of the nave (the first three bays), they were probably located above the roof of the aisle. They were only abandoned during the reconstruction after the destruction of the temple (Mareš, Sedláček 1918, 203; Libal 2001, 576). It is difficult to find any craftsmanship connections between the two buildings. The Cistercian church is made of stone, which means that the method of its construction clearly differs from that used in the brick architecture of Silesia. In St Elizabeth's parish church, a very high level of masonry can be seen from the earliest stages of its construction. Cleanly laid junctions, a regular bonds, and very skillfully developed corners testify to the high level of craftsmanship at work there. Experienced bricklayers worked there, which does not confirm the workshop connections between the two buildings. Similarly, the method of bricklaying in the few brick sections (e.g., buttresses in the attics) of the Dominican church in České Budějovice seems very distant from the skilled bricklaying of St Elizabeth's church.

Among Czech churches, a certain similarity can be seen in the case of the Church of Our Lady before Týn in Prague, whose overall spatial layout, scale and proportions are most reminiscent of the architecture of Silesian parish churches (Fig. 10). However, it is most likely younger than the church of St Elizabeth (Čevonová Pařízková 2021, 31–39; Prix 2006), so as such it rather became part of a common trend together with it. Inspiration from Silesian churches cannot be ruled out either.

It is also worth mentioning the temples of northern Poland, where the so-called Gniezno system was used – the cathedral in Gniezno, as well as the Cistercian temples in Oliwa, Koronowo, Pelplin, and St James's Church in Toruń (Zachwatowicz 1934–1935, 187). However, all these temples have correctly balanced vaulting forces. Additional parts based on flying buttresses provide further support for the already correctly designed structure, unlike in St Elizabeth's church. It is also worth noting here that Adamski recently argued convincingly that the architecture of Gniezno

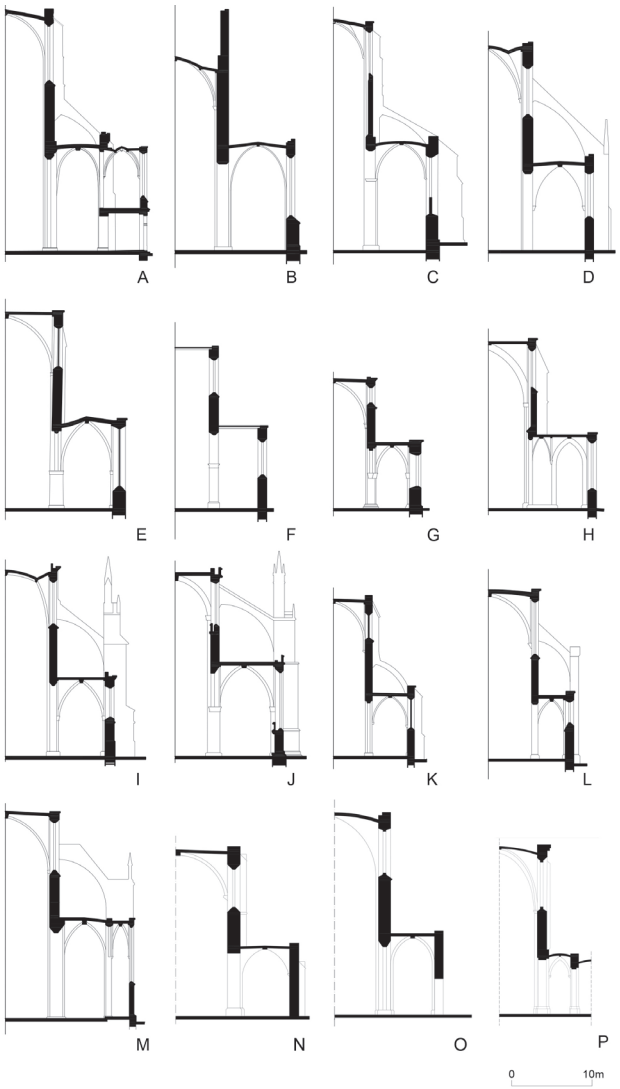

Fig. 9. Sketches of structural systems on cross-sections of the churches discussed: A – St Elizabeth's church in Wrocław, B – St Stanislaus and Wenceslaus church in Świdnica, C – St Nicholas' church in Brzeg, D – St Peter and Paul's church in Strzegom (nave), E – Dominican church in Regensburg, F – Franciscan church in Regensburg, G – Cistercian church in Lahr, H – Cistercianchurch in Salem, I – St Theobald church in Thann, J – Cathedral in Freiburg im Breisgau, K – Cistercian church in Kaisheim, L – St Pierre-le-Jeune church in Strasbourg, M – St Lawrence church in Nuremberg, N – Dominican church in České Budějovice, O – Cistercian church in Zlatá Koruna, P – Cistercian church in Lubiąż (compiled by F. Hackemer)

Il. 9. Szkice systemów konstrukcyjnych na przekrojach poprzecznych omawianych kościołów: A – św. Elżbiety we Wrocławiu, B – św. Stanisława i Wacława w Świdnicy, C – św. Mikołaja w Brzegu, D – św. Piotra i Pawła w Strzegomiu (korpus), E – dominikańskiego w Ratyzbonie, F – franciszkańskiego w Ratyzbonie, G – cysterskiego w Lahr, H – cysterskiego w Salem, I – św. Teobalda w Thann, J – katedralnego we Fryburgu Bryzgowijskim, K – cysterskiego w Kaisheim, L – St Pierre-le-Jeune w Strasburgu, M – św. Wawrzyńca w Norymberdze, N – dominikańskiego w Czeskich Budziejowicach, O – cysterskiego w Zlatej Korunie, P – cysterskiego w Lubiążu (oprac. F. Hackemer)

Fig. 10. Views of arcades, external buttresses and flying buttresses of Czech churches, bearing stylistic similarities to St Elizabeth's Church in Wrocław: A – Cistercian church in Zlatá Koruna, B – Dominican church in České Budějovice, C – Franciscan church in Jindřichův Hradec, D – Our Lady before Týn church in Prague (photo by F. Hackemer)

Il. 10. Widoki ścian arkadowych i zewnętrznego systemu przypór i łuków oporowych kościołów czeskich, noszących cechy stylowego podobieństwa do fary św. Elżbiety we Wrocławiu: A – cysterskiego w Zlatej Korunie, B – dominikańskiego w Czeskich Budziejowicach, C – franciszkańskiego w Jindřichův Hradec, D – Marii Panny przed Tynem w Pradze (fot. F. Hackemer)

Cathedral has Silesian origins. The Gniezno system itself was used not only in St Elizabeth's Parish Church, but also in Brzeg, at the Dominican monastery in Wrocław, and in Głogów (Adamski 2014b, 161, 162). It therefore seems that considering the aforementioned buildings in northern Poland as the origin of the solutions used in the Wrocław church is unjustified.

Extending the clerestory so high that the existing flying buttresses do not balance the pressure of the vault is completely unusual. This should come as no surprise, given its ineffectiveness. Nevertheless, it was repeated in Silesia. We refer here to the parish churches in Brzeg and Świdnica (Fig. 9). In these buildings, the point of embedment of the buttresses is vertically distant from the point of pressure of the vaults (in Brzeg by approximately 6 m). What is particularly interesting is that in the 16th century, the original vaults in the church in Świdnica collapsed as a result of a fire and were rebuilt much lower, creating a kind of fake, blind clerestory (Pilch 1978, 266, 267). The reason for this decision by the builders is unknown, but perhaps they were aware of the danger posed by the previous solution.

Cross-sections of the churches in Brzeg and Wrocław reveal similar proportions and structural design principles (Fig. 9). However, the church dedicated to St Nicholas differs significantly in terms of detail, with particular emphasis on octagonal pillars without profiling, which is why it was rarely mentioned in the context of its Wrocław counterpart. Nevertheless, it seems that the similarity in the design of the external structure as a synthetic form of a basilica without visible flying buttresses, together with the very high clerestory, indicate at least some inspiration from the Wrocław parish church. This is possible because the construction of

the temple in Brzeg began when St Elizabeth's Church was almost completed, and continued into the 15th century (Kutzner 1980, 82).

A detail very similar to the forms known from St Elizabeth's parish church was used in the church of St Peter and Paul in Legnica. We are talking about a comparable form of the plinth with half octagonal pilasters and arcade profiling. As a result, the parish church in Legnica seems to be the closest Silesian analogy to the building in Wrocław, despite the striking difference in the proportions of the interior. However, this discrepancy results from a change in the design at a late stage of construction. This could have taken place after 1341 (Adamski 2017, 495), perhaps around 1360–1378 (Stulin 1982, 90). Thus, it could have occurred after the collapse of part of the nave of St Elizabeth's parish church. This event must have had an impact on other buildings in Silesia. It is possible that the structural failure of the Wrocław church influenced the change in construction plans in Legnica. Under this assumption, the Legnica nave would have been designed as an almost exact copy of the nave of St Elizabeth's Church, but after a revision of the concept, it was limited to the form known today. Due to the very uncertain dating of both events, this assumption must remain in the realm of speculation, but it is worth considering.

Conclusions

The research revealed that most of the foundations of the nave were built during the implementation of the hall design. The weak rubble trench foundation, which was intended to bear the load of much lower walls, was not suitable for the partitions that were actually built. This was the cause of the first (and most likely the next two) disasters at St Elizabeth's Church. This is confirmed by the absence of any such incidents in the chancel, whose structure is essentially a repetition of the solutions used in the nave, with the exception of the reinforcement of the foundations.

The direct workshop connections with the church in Zlatá Koruna postulated by Kutzner are not confirmed by the masonry and structural system of either building. It would be more appropriate to agree with Stulin and Adamski that these churches belong to a group of buildings inspired by the achievements of workshops from the Lake Constance and Rhineland regions. However, it seems that Kutzner's general observation regarding the "monastic" character of the architecture of the Wrocław parish church is justified to some extent. Churches whose external structures are synthesized, compact basilicas with hidden (or no) flying buttresses are mostly monastic buildings. Their influence on St Elizabeth's Church led Kutzner to conclude that the aim of the Wrocław patriciate was to erect a temple that stood in opposition to the aristocratic traditions of gothic cathedral architecture. According to the researcher, the inspiration from Cistercian architecture was primarily due to the characteristic spirituality of the bourgeoisie (Kutzner 1975, 64–68; 1996, 50–52). The question of the validity of such a far-reaching statement cannot be resolved solely through the architectural research presented here.

The assumption made by Güttel, according to which the nave was initially supposed to be lower, is not confirmed by the masonry. There is no doubt that the pointed niches in the arcade walls in the attics of the side aisles are a structural element and not the remains of windows. Their purpose is to reduce the weight of the wall by reducing its thickness in areas of lesser structural importance. Perhaps the builders did indeed originally plan to extend the window area slightly lower. This is a quite plausible explanation for the difference in the height of the starting points of the vaults and the flying buttresses. However, we have no evidence to confirm this.

The unusual design of St Elizabeth's Church structure was most likely not a mistake, but rather an attempt to achieve a specific expression of external and internal architectural form. This, in turn, was probably a reflection of the architecture emanating from centers, especially monasteries, on Lake Constance and the Rhine, although obviously adapted to local conditions and possibilities. The influence of monastic buildings from these regions (probably through the mediation of the less distant temples of Regensburg or Lubiąż) should be attributed to the concealment of the flying buttresses under the roofs and the overall synthetization of the structure. At the same time, the builders of the Wrocław temple sought to achieve a majestic height for the nave, which led to a rather dangerous but ultimately stable solution. Interestingly, it was adopted in Silesia in the churches in Brzeg, Świdnica, Legnica (partially) and Strzegom.

The analyses conducted concerned the buildings most frequently mentioned in the literature and those located in their regions. In further research on St Elizabeth's Church, other buildings erected around 1300 in Central and Western Europe should be subjected to similar analyses, with particular emphasis on the Baltic temples of Hanseatic cities. It is also necessary to conduct in-depth research on the architecture and construction of other 14th-century Silesian parish churches, with particular emphasis on the church in Legnica. Its comprehensive stratigraphy would allow for verification of the concept suggested here regarding the modification of the design after the disaster at St Elizabeth's Church.

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Streszczenie

Problematyka katastrof budowlanych kościoła św. Elżbiety we Wrocławiu w świetle badań architektonicznych

Tematem artykułu są nietypowe rozwiązania gotyckiego systemu konstrukcji zastosowane w kościele św. Elżbiety we Wrocławiu i ich potencjalny wpływ na katastrofy, jakie miały miejsce w jego korpusie. W pracy przedstawiono wyniki badań stratygraficznych murów kościoła, dzięki którym wykazano, że jego korpus zawalił się po raz pierwszy najpewniej jeszcze podczas budowy. W późniejszym czasie ta część fary ulegała podobnym katastrofom jeszcze dwukrotnie. Celem autora było ustalenie powodów tych katastrof (zwłaszcza najsłabiej rozpoznanej – pierwszej), określenie ich związków z nietypowym umieszczeniem łuków oporowych oraz odnalezienie przyczyn zastosowania takiego rozwiązania. Przedstawił też przykłady analogicznych rozwiązań systemów przenoszenia obciążeń wśród obiektów Śląska, Alzacji, Górnej Nadrenii, Badenii-Wirtembergii, Bawarii oraz Czech. Ostatecznie ustalił, że przyczynę katastrof stanowiła zmiana koncepcji przestrzennej kościoła z halowej czy pseudobazylikowej na bazylikową o bardzo wysokiej strefie okiennej już po wykonaniu jego fundamentów. Nietypowe położenie łuków oporowych okazało się do pewnego stopnia skuteczne, choć praktycznie pozbawione analogii wśród obiektów z terenów rozważanych dotychczas jako źródło inspiracji dla fary wrocławskiej. Wykluczono postulowane wcześniej związki warsztatowe z kościołami czeskimi. Za przyczynę użycia kłopotliwego systemu konstrukcyjnego przyjęto chęć wzniesienia nawy o wyjątkowej wysokości przy jednoczesnej inspiracji konkretnymi obiektami architektury znad Jeziora Bodeńskiego i Renu, głównie o funkcjach klasztornych.

Słowa kluczowe: łuki oporowe, sklepienia, architektura gotycka, kościół św. Elżbiety, Wrocław