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Research paper

The role of structural analyses and queries in recognizing damage causes and selecting remedies in historic buildings: case of the Dominican monastery in Lublin

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Abstract: The article presents the process of structural diagnostics of the Dominican monastery in Lublin. In order to establish the underlying cause of cracks, not only *in situ* investigations but also detailed analyses of documents were executed. Inventory drawings were examined in order to identify the building's structural system. The query of historical documents and city archives was carried out to understand the structure's performance. Conclusions were confronted with the crack pattern. It was established that the damage resulted from the original conditions of the structural system in place. These conditions were created in past, when the monastery incorporated sections of the medieval town wall into its structure.

The article details structural remedies applied in the course of rehabilitation. The introduction of supporting structures was the effect of a compromise between the necessity of ensuring structural safety and the demand for the minimum impact on the heritage site. The article aims to highlight that the structural assessment of the heritage asset is an investigative process. The work also emphasizes that in spite of numerous up-to-date methods helpful in the structural diagnostics of building structure, the conceptual analyses of the structural system still remain of vital importance. The query of historical documents helps in determining the structural system of a historic building, and *vice versa*, structural analyses assist in recognizing and supplementing the knowledge of the asset's history.

Keywords: damage, historic building, rehabilitation, structural diagnostics, structural system

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1. Introduction

1.1. Rehabilitation of historic buildings – challenges

The restoration of buildings listed as architectural heritage assets usually consists in the conservation or improvement of the technical condition of the fabric (masonry, vaults, wooden structural elements and plasters) as well as the renovation of architectural details. However, the aim of various present-day measures taken in the field of architectural heritage is not only the improvement of the technical condition of buildings. The measures are also connected with the rehabilitation, understood as the re-adjustment of the existing structure to new usage requirements or even new functions [1]. New wiring and sanitary (heating, ventilation and air conditioning) systems are introduced into buildings. Occasionally, a new function is also associated with the introduction of new loads.

The complexity of actions aimed at restoration and rehabilitation of heritage assets makes them not only of engineering but also of scientific nature [2]. Multi-disciplinary experts are engaged [3, 4] and modern testing methods are applied [5–7], however the traditional analyses are also useful [2]. The examination of the structure's history is one of the principal activities included [8] in the process.

All works focused on the historic buildings' rehabilitation should be coordinated and performed in compliance with the principal rule of ensuring the minimum impact on the architectural heritage asset and the preservation of the cultural and historical context [9]. This rule is in agreement with the idea of heritage resources, which were created in the past and should remain to inform present and future societies of that past. The assessment of a heritage resource gives information on its value and permissible changes in it. The structural assessment of an architectural heritage resource, understood as all investigations and analyses relating to its structure, gives information on safety and measures which should be undertaken to ensure safety and trouble-free prospective use of the historic asset.

The future safety of the heritage asset subjected to rehabilitation may be ensured only if the causes of damage are recognized, e.g. [2,7,10–15], and effectively dealt with. Therefore, detailed diagnostics constitute a *sine qua non* of successful rehabilitation.

Structural damage observed in historic buildings is of various origins. Degradations are primarily connected with aging and environmental impact or force majeure (e.g. seismic activity, hurricanes). In many cases, the failure may be attributed to differential settlement [6, 16–21] which results from weak or layered subsoil, different loads exerted onto the subsoil by individual parts of the building or different founding levels of the building's sections, as well as the subsoil being washed away or soaked. Failures caused by such differential settlement manifest by the cracking of structural elements.

1.2. Objective of the article and issues discussed

The article presents selected issues encountered during the rehabilitation of the Dominican monastery located in Lublin, Poland. The authors participated in the process in the character of experts in the field of structural problems during the diagnostics, design and construction.

The detailed investigation of four different structural issues which emerged in the same section of the monastery is described below. Although damage and crack patterns were different, the authors revealed that they resulted from the same root cause, i.e. the nonuniform structural system developed by builders in the 17th century when the expanding monastery incorporated certain sections of older walls into its structure, particularly the medieval town wall.

Diagnostic works concerning the Dominican monastery's structure were planned in accordance with ICOMOS recommendations [9] and were similar to those presented in [12, 13]. Therefore, the diagnostics preceded by history-related queries, included: geometrical inventory, uncovering the foundations, soil sampling and testing of soil parameters, *is situ* inspections: crack pattern identification, uncovering of vaults and core drilling of walls, measurement of masonry moisture, masonry sampling including stones, bricks and mortars and their laboratory testing (chemical and strength tests), strength analyses and calculations of structural members. Nevertheless, since the article focuses on the analyses of the structural system supported with data obtained from historic queries, details of laboratory tests were omitted (they were presented elsewhere).

The article aims to show that drawing of conclusions regarding the cause of damage, based on the results of interdisciplinary investigations constitutes a valid scientific problem and that the identification of the structural system is crucial in the process. The proper identification of the structural system and its influence on the emerging damage still depends on the expert's experience and his conceptual i.e. creative and investigative work, which allows to colligate investigation results and draw conclusions. The up-to-date methods of scanning and 3D visualization constitute the paramount aid in the determination of the building's geometry and crack pattern [5, 7]. However, their results must be properly interpreted by expert leading to the identification of the structural system and its performance. The numerical calculations are also helpful in the assessment of the building's safety [5, 13]. However, they usually use materials' characteristics homogenized on the basis of the whole building's structure. It is a simplification which can lead to local underestimation of internal forces. In the cases of complex structures, erected in stages and of poor materials whose parameters vary not only in different structural elements but also within one wall, the precise determination of these parameters and the development of a reliable numerical model are difficult.

The article aims not only to emphasize the leading role of structural diagnostics in the assessment of the structural safety of the heritage asset, but also to highlight the role of structural analyses in recognizing and supplementing the knowledge of the building's history.

The article concludes with the specification of applied remedies. They consist in the introduction of supporting structures and strengthening measures as a result of a compromise between the necessity to ensure safety and the demand for the heritage asset's preservation.

2. Subject, scope and methodology of the study

2.1. Subject of the study

The Dominican monastery in Lublin is located near the edge of the Old Town Hill (Fig. 1, Fig. 2). The buildings are connected to form a complex. According to city archives [22], the basilica and monastery wings were built in stages starting from the 14th until 18th century when they received the present layout and form. The masonry gothic church with a nave and two aisles was founded in 1342 by Kazimierz Wielki, the Polish king. He also donated the area adjacent to the church and town wall (the "small courtyard" in Fig. 2a) to the monks.

Fig. 1. Present view of the Dominican monastery in Lublin from the foot of the Old Town Hill; the numbers designate locations described in this article: 1 – south-east corner, 2 – east wing, 3 – Tyszkiewicz Chapel, 4 – corner between the Chapel of the Immaculate Conception of the Blessed Virgin Mary and side-chapels

In the 16th century, the church was afflicted by fire on several occasions. The last of these events, the so-called "great fire of Lublin" of 1557, caused the collapse of a large section of the church. The rebuilding in the 17th century was based on the remaining gothic masonry and was executed in the renaissance style. Eight new side-chapels were added at that time.

In 1618, the monks signed an agreement with the town's authorities [22] which incorporated the monastery's buildings into the town's defensive system. The fortified Tyszkiewicz Chapel was founded outside the town wall (Fig. 2b, Fig. 6) in the axis of the nave and presbytery. The new monastery buildings incorporated buildings adjacent to the defensive walls. In addition, the part of the town wall became the foundation for the outer wall of a new building – the monastery "east wing". In the next stages of the monastery's development, the buildings surrounded the new square "large courtyard". The Chapel of the Immaculate Conception of the Blessed Virgin Mary erected at the beginning of the 18th century became the final building in the complex.

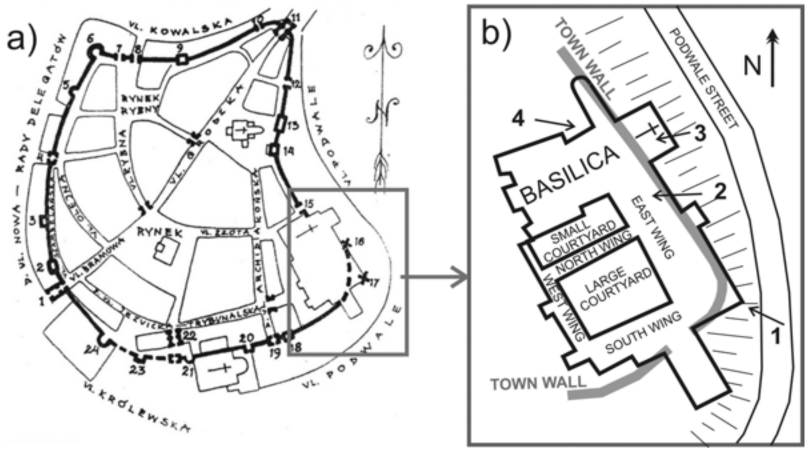

Fig. 2. The complex of the Dominican monastery in Lublin: a) location of the monastery in the Old Town inside the town walls in the 17th century – illustration by unknown author presented in the guidebook of Lublin [23]; the town wall is marked with the black bold line, the bold dash line denotes sections whose exact location was unknown up until restoration works; the town towers and gates are designated with numbers, b) present horizontal projection of the monastery with the outline of medieval town walls whose course was confirmed during restoration works. Places described in this article are designated as follows: 1 – south-east corner, 2 – east wing, 3 – Tyszkiewicz Chapel, 4 – corner between the Chapel of the Immaculate Conception of the Blessed Virgin Mary and side chapels

In the 19th century, after the partition of Poland, when Lublin was under Russian occupation, the church and monastery were destroyed. The east wing served as barracks for Russian soldiers. Dominican monks returned to the monastery in 1938 and started to restore the church. However, the process was interrupted by the outbreak of WWII. After the war, two of the monastery's buildings were used by an orphanage and the third by a theater for children.

All buildings returned to the Dominicans in the 1990s. In 2001, the rehabilitation of the church and the whole monastic complex commenced. The realization of works was supported in the framework of EU funds and was co-financed by the Polish ministry and authorities of the city and province of Lublin. The project focused not only on the conservation and restoration of buildings, altars, polychromes, architectural details etc., but the rehabilitation under the motto: "The Monastery in the Heart of Town". It means that besides the sacral and ceremonial role, the monastery is intended to serve as the cultural center for a variety of events: theological and scientific discussions, concerts, meetings, exhibitions; the Dominican Museum with a tourist route was developed. One of the buildings was also intended to become a social center where children and their parents, as well as the elderly may spend time.

The multi-disciplinary activities were conducted under the supervision of an architect, archeologist and conservator, who led parallel investigations in the scope of their disciplines.

All solutions of structural strengthening, also those described in the article, were discussed with them and finally accepted by the Province Conservator of Monuments.

At the moment of writing this article, the process is almost finished. The works in the basilica and three wings (east, west and north) were completed.

2.2. Scope of investigation

The investigation discussed in the article was designed and executed in the scope of the project of the Dominican monastery's rehabilitation mentioned in Section 2.1, following the architectural concept by Urszula Cieplińska and Jacek Cieplińki. The structural restoration and strengthening of the buildings constituted a vital part of the project. The process was undertaken because the technical condition of masonry walls, vaults and domes, as well as timber structures was poor. A multitude of cracks, losses of mortar, voids, wet and salted sections were observed in masonry. It should be emphasized that the material used by the original builders was of poor quality. The masonry's limestone elements were weak and absorbable, which is characteristic of the material obtained from local quarries. In many zones, the masonry was a mixture of limestone and bricks in varying proportions. In certain sections clay mortar was used in lieu of lime one. Several voids due to mortar degradation were found.

The study focuses upon structural diagnostics executed by the authors prior to the rehabilitation design and construction. Special attention was devoted to the recognition of the causes of damage, particularly cracks.

The present article describes the part of the work pertaining to the east wing of the monastery.

2.3. Methodology

In order to establish the causes of cracks, detailed in situ investigations were executed, including the identification of the building's materials and their parameters (strength, humidity, salinity), local uncovering of foundations and soil investigations. The results were described elsewhere [24,25]. Afterwards, cracks in walls and vaults (pattern, widths, depth) were identified and inventoried. The next stage constituted the examination of inventory drawings available from Dominican archives (floor projections and cross-sections) and focused on the identification of the building's structural system. Additionally, the query of historical documents and city archives [22] concerning the monastery was carried out. The results were confronted with the crack pattern. Despite such detailed analyses, certain factors became evident or proven only once structural restoration works commenced.

The article also outlines remedies applied as the result of structural investigations. The restoration methods included arranging the new supporting structures (concrete and steel ones), structural strengthening of masonry with injections of trass-lime-based materials, sewing the cracks with helical stainless steel bars and application of CFRP and GFRP composite.

3. Results of structural investigations and discussion

On the basis of the structural investigation it was found that some of the damage and cracks in the monastery's east wing and the basilica emerged as a result of the older walls having been incorporated into the complex, particularly the town wall. This took place during the monastery's expansion in the 17th and 18th century. Four instances of defects caused by the incorporation process are described below: 1 – cracking in the south-east corner, 2 – cracking of the vaults above the first floor in the monastery's east wing, 3 – destruction of vaults above the crypts in the Tyszkiewicz Chapel, 4 – damage in side chapels adjacent to the corner between the Chapel of the Immaculate Conception of the Blessed Virgin Mary and side chapels (the designation of the instances follows the designation in Fig. 1 and Fig. 2b). In addition to the d amage and its causes, the applied remedies are described.

3.1. Cracking in the south-east corner resulting from the monastery's expansion outside the town wall

Strong damage emerged in the monastery's south-east corner: several wide cracks crossing the whole masonry width (the example is shown in Fig. 3a and Fig. 3b) as well as bursting and cracking of the vaults above the ground and first floors which were the continuation of wall cracks (Fig. 3c).

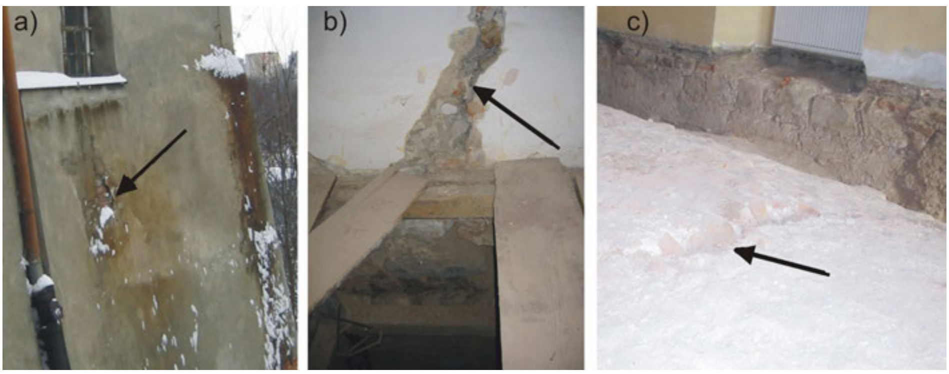

Fig. 3. Examples of cracks in the south-east corner of the monastery: a) and b) the same crack in the south wall photographed from the outside and inside, c) burst of the barrel vault above the ground floor

As mentioned above, the monastery was incorporated into the town's fortification system in the 17th century. The walls of the added east wing were erected partly on the town wall itself. Fig. 2a shows the layout of the Lublin Old Town with the defensive wall surrounding it after the expansion of the monastery. This layout corresponds with the knowledge from before the monastery's rehabilitation works and comes from the Lublin guide book from 2000 [23]. The bold continuous line indicates the documented position of the town wall. The dash line indicates the presumed position of the wall inside the east wing of the monastery.

During the works aimed to strengthen the building's foundation zone, medieval limestone masonry was uncovered. This medieval masonry constitutes the foundation in the long section of the building (Fig. 4b, Fig. 4d). Its character varies in different sections: beginning with rubble work, *via* a layered wall (outer layers from regularly placed limestone elements and rubble work inside) up to uniform limestone masonry. In the corner, the course of the wall from the 17th century and the course of the medieval masonry do not overlap. The medieval masonry is located inside the building. It is probably the "missing" part of the town wall (Fig. 4b, Fig. 4c).

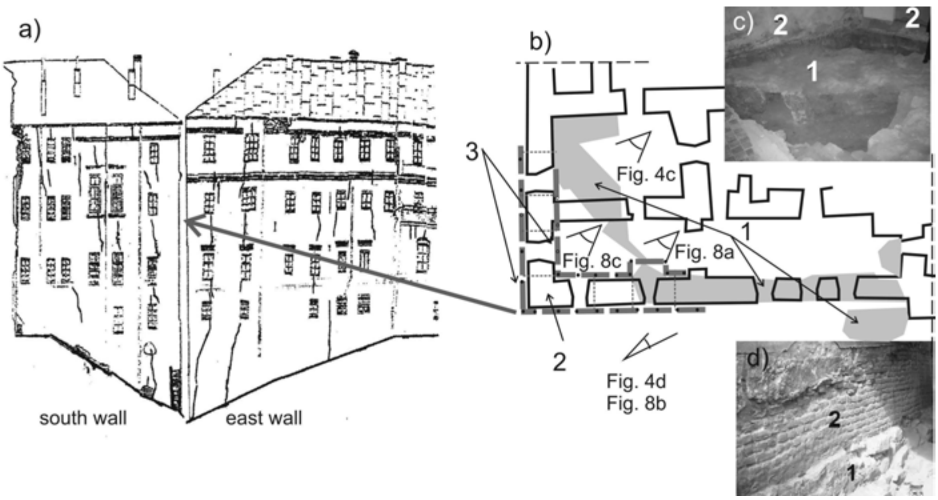

Fig. 4. South-east corner of the monastery: a) crack pattern of the corner, b) course of the medieval walls uncovered during structural restoration works and the course of the applied supporting structures, c) uncovered medieval wall inside the building, d) uncovered medieval outer wall. Numbers indicate the following: 1 – medieval wall, 2 – wall from the 17th century, 3 – course of the underground micropiled structure strengthening the foundation, introduced during structural restoration works

To conclude, the outer wall was founded in a non-uniform manner – virtually the full length of the wall stands on the medieval wall, whereas the corner of the structure was founded directly on the subsoil. It should be emphasized that the corner was founded 3.0–4.0 meters deeper than the medieval wall. It stands on the top of a loess layer. Above the loess layer, up to the level of the ground floor, outside and inside of the building, a layer of uncompacted embankment was revealed. The characteristic feature of loess is that after soaking its strength drops and strain rapidly grows. Water infiltrated to the loess under the corner wall via the embankment, which resulted in the corner's settlement. This in turn caused the shear of the wall above the zone where of the foundation's condition varied (Fig. 3, Fig. 4a). This entailed the bursting and cracking of vaults.

3.2. Cracking of the vaults above the first floor in the east wing resulting from the non-uniform structural system

A detailed analysis of the horizontal projections of the monastery's east wing was performed. It was discovered that the support of the vaults and ceilings has a different course in the individual stories and sections (Fig. 5a, Fig. 5b). As far as the area between

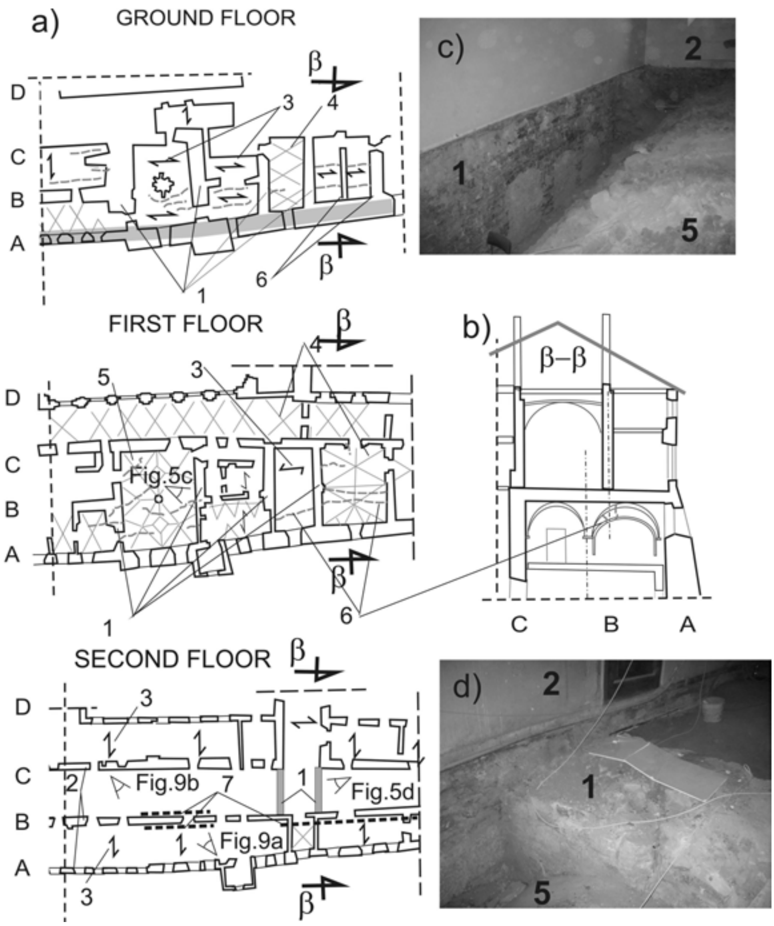

Fig. 5. Analysis of the load-carrying system of the monastery's east wing: a) horizontal projections of the ground, first and second floors with crack pattern b) cross-section of the building, c) wall with openings uncovered during the ground floor vault restoration, d) upper edge of the transverse wall uncovered during the restoration of vaults above the first floor. Numbers indicate the following: 1 – transverse load-carrying walls in the basement and first floor and their upper edge uncovered in the second floor, 2 – parallel load-carrying wall from the 17th century, 3–arrows indicating the direction of barrel vaults load bearing, 4 – cross vault, 5 – lierne vaults, 6 – cracks of the vault loaded with longitudinal wall, 7 – course of steel frames supporting the ceiling introduced during structural restoration works

"A" and "C" axes is concerned, in the section where the outer wall stands on the town wall, this can be summarized as follows:

– ground floor: vaults are supported on the walls perpendicular to the outer one,
– first floor: vaults are supported on the transverse walls except one lierne vault supported on the central column and surrounding walls,
– ceilings covering the second and third floor are supported on the longitudinal walls: outer one and one parallel to it.

This may suggest that the transverse walls between "A" and "C" axes in the ground and first floor (see Fig. 5) are remnants of older buildings adjacent to the town wall, which were incorporated into the monastery in the 17th century. It should be emphasized that the existence of these buildings was unclear earlier and only the rehabilitation works confirmed their presence. They were uncovered during a temporary removal of backfill from vaults.

Fig. 5c shows the remnants of the building (a transverse wall with openings) uncovered during the basement vault's restoration. Fig. 5d shows the upper edge of the transverse wall uncovered in the second floor. These remnants were recognized by the researcher of architectural heritage to be the walls of a medieval tower [26].

In Fig. 5, the pattern of cracks in vaults above the ground and first floor is shown with a broken gray line. The cracks are parallel to the longitudinal walls. This allows to deduce that the differential settlement of longitudinal and transverse (loaded with heavy vaults) walls was the cause of cracking of vaults and walls.

The analysis of projections shown in Fig. 5 indicates that the builders not only incorporated the older buildings between "A" and "C" axes into the structure, but also added a new part between "C" and "D" axes. In this location, they arranged the vaults supported on the longitudinal walls. The ceilings above the second and third floor are supported on the longitudinal walls as well. What is more, the wall in "B" axis runs above certain vaults and is supported on flat arches arranged on its bottom edge. However, with the passage of time, one of the arches settled and loaded the vault. This resulted in vault cracking right below the wall (the cracks are marked in Fig. 5 with number 6).

3.3. Cracking of the vaults of the crypts in the Tyszkiewicz Chapel due to unbalanced vaults thrust

The dome of the Tyszkiewicz Chapel burst meridionally due to an air raid in 1939. The damage of barrel vaults in the crypts under the chapel was noticed at the same time. Therefore, the vault damage was attributed to the bombardment as well.

However, during structural diagnostics, it was found that the cause of the vaults' destruction is much more complex. Two crypts directly abutting on the town wall from the outside, supported on one internal wall (Fig. 6c, Fig. 6b), are of a different width. Therefore, the vaults' spans are also different (the vault of the seven meter span is flat, whereas the vault of the four meter span is elevated). The calculations of vaults were executed assuming the "arch" scheme of vaults, their loading with the weight of the altar, stone floor, backfill and self-weight, as well as the tested stress-strain parameters of masonry, treated as the elastic material. These calculations confirmed that the thrust of the wide vault is twice the thrust of the narrow one. Such differential thrusts induced the horizontal force to be exerted on the internal load-carrying wall towards the narrow crypt, which resulted in a non-uniform stress distribution in the wall section as well as under its foundation. The wall was founded in the weak uncompacted embankment. Therefore, the overloading in the zone of the maximum stress and wall rotation occurred. This explained the observed horizontal cracks running virtually along the whole length of crypts: in the brick joint of the internal wall in the level of the wide vault's support (visible from the side of the narrow crypt Fig. 6c), and in the top section of the wide vault (Fig. 6d).

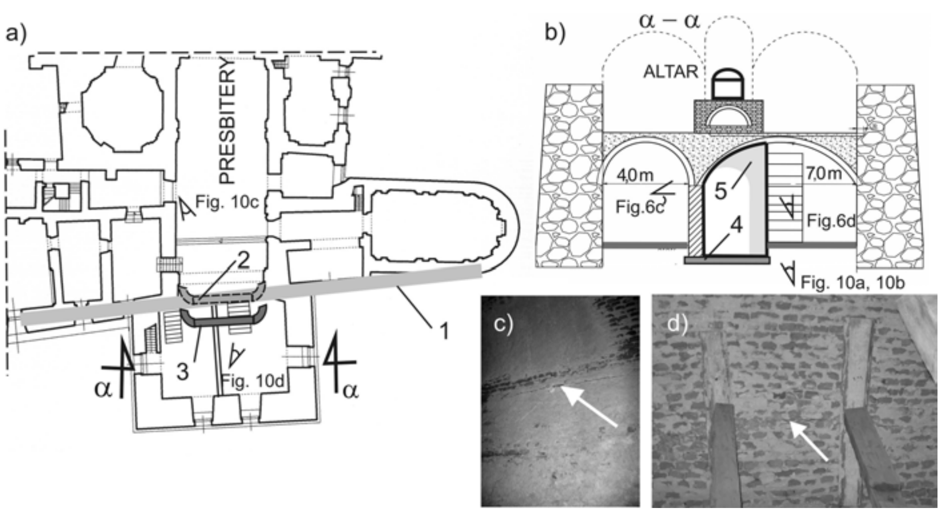

Fig. 6. Structural system of the crypts of the Tyszkiewicz Chapel: a) projection of a part of the basilica with the course of the town wall (1) and locations of the altar: the presumed initial position (2) and present position (3), b) cross-section of crypts with the location of the altar and strengthening structures: widening the foundation of internal wall (4) and concrete structure supporting the vault (5), c) horizontal crack in the internal wall in the level of the wide vault support visible from the narrow crypt, d) wide vault supported by wooden shores and the crack in its top section

The unexpected factor increased the load and consequently, the unbalanced thrust. As mentioned above, the Tyszkiewicz Chapel was built outside of the town wall and outside the front wall of the initial church. It may be supposed that the high altar was then put on the town wall (Fig. 6c). However, during the structural restoration works it was found that the altar is placed not on this wall, but inside the layout of the chapel and crypts. It was moved from the town wall into the chapel. Timber beams were put under the altar. However, with the passage of time, due to their deflection and biological corrosion, the altar's dead load (assessed to be more than 15 tons) was exerted onto the backfill and consequently onto the vaults.

3.4. Corner between the Chapel of the Immaculate Conception of the Blessed Virgin Mary and side-chapels

The Chapel of the Immaculate Conception of the Blessed Virgin Mary was erected at the beginning of the 18th century. It is perpendicular to the church and disturbs the order of the facade and structure (Fig. 1, Fig. 2b).

Originally, the town gate, the so-called ”Butcher’s Gate” existed in the location where the chapel is at present (Fig. 2b, Fig. 7a). It was a part of the path running next to the basilica leading from the Town Market away from the city. It also performed as the drain of liquid waste from the town’s butcheries. The chapel crossed the path, putting a stop to this unpleasant neighborhood (Fig. 7b, Fig. 7c). However, the chapel began to act as a dam for rainwater and sewage flowing from the Old Town Hill. The loess which constitutes the subsoil in the corner between the basilica and the chapel soaked. This resulted in the settlement of chapels adjacent to the path, particularly the Ossolińska Chapel, and emergence of cracks in walls, vaults and the dome (Fig. 8).

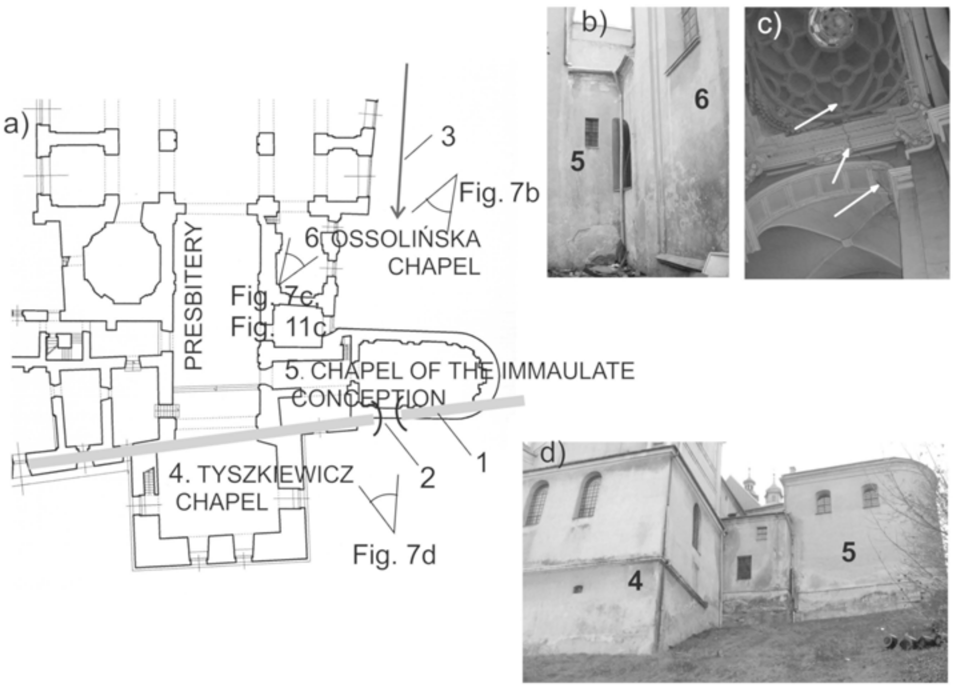

Fig. 7. Location of the Chapel of the Immaculate Conception of the Blessed Virgin Mary: a) projection of the basilica, b) view from the inside of the Old Town, c) view from the outside of the Old Town Hill. Numbers indicate the following: 1 – town wall, 2 – Butcher’s Gate, 3 – direction of water and sewage flow, 4 – Tyszkiewicz Chapel, 5 – Chapel of the Immaculate Conception of the Blessed Virgin Mary, 6 – Ossolińska Chapel

Fig. 8. South-east corner of the east wing in the Dominican monastery: a) and b) the micropiled structure supporting the corner – the internal and external grid beams photographed under construction (1 – east wall, 2 – micropiled structure), c) present view of the restored corner room in the ground floor (the wall shown in Fig. 3b), d) present view of the restored corner room in the first floor

3.5. Remedies

The choice of remedies was based on the assumption that they should ensure the safety of the structure loaded with enlarged loads on the one hand, and that they should exert the minimum impact on the architectural heritage and historical context on the other. Two types of remedies were applied: the structural strengthening of masonry and supports for damaged structural elements.

The structural strengthening of masonry was necessary due to its poor condition (see Sec. 2.2). In order to strengthen the walls, vaults and domes, the voids between limestones and bricks as well as cracks were injected with mineral trass-lime-based material, recommended by e.g. [27]. The material is compatible with historic masonry. In addition, wide cracks were sewn with helical stainless steel bars, whose effectiveness was proved by e.g. [28].

The structural masonry strengthening proved insufficient in light of the determined causes of damage. The introduction of supporting structures was necessary (Figs. 8, 9, 10, 11). These structures were as neutral and small as possible following the rule of ensuring the minimum impact on the architectural heritage. The figures below also show the present views of the discussed sections of the monastery.

The south-east corner (Sec. 3.1) was supported on the reinforced concrete micropiled structure, hidden in the soil. The decision was motivated by the fact that the repeated measurement of the cracks' width proved that they were not stabilized. The corner and the zone where walls take course outside the town wall were connected by two reinforced concrete underground beams joined via the historic wall with tensioned tendons [25]. The beams were supported with micropiles (Fig. 4b, Fig. 8a, Fig. 8b).

The rehabilitation design scheduled a change in timber ceilings above the second and third floor into fire-resistant ones, replacement of the roof's steel sheets with ceramic tiles, and the adaptation of the unused space under the roof for dwelling purposes. All these changes were connected with the increase of the load exerted onto the load-carrying wall in "B" axis and the vault under it (Sec. 3.2). It was decided that the increase in the load should be avoided by the arrangement of new two-storied steel frames, which transfer the excess load onto the transverse walls again and prevent the propagation of cracks in the vault (Fig. 5a, Fig. 9).

Fig. 9. Steel structures unloading the vaults in the east wing of the Dominican monastery founded on the transverse first floor wall: a) one of steel frames under construction, b) present view of the corridor in the second floor lined with the steel frame (1 – longitudinal wall standing on the vault, 2 – steel frame, 3 – ceiling above the second floor)

Fig. 10. The Tyszkiewicz chapel: a) and b) concrete structure in the crypt supporting the wide vault under the high altar, under construction and now (1 – rebuilt part of the vault, 2 – supporting concrete arch, 3 – original part of the vault), c) present view of the Tyszkiewicz Chapel's interior with the reverse of the high altar, d) present view of the high altar and the Tyszkiewicz Chapel behind it

The damaged wide vault in the crypt under the Tyszkiewicz chapel (Sec. 3.4) was partially rebuilt or strengthened in the zone outside the altar's location. Calculations mentioned in Sec. 3.3 proved that the section of the vault supporting the altar has insufficient bearing capacity for the fulfilment of the ultimate limit states conditions. Unfortunately, the temporary unloading of the vault by removing the altar for the restoration time was impossible, would allow the introduction of effective strengthening. Therefore, the supporting structure was introduced under the altar (Fig. 6b, Fig. 10). The strengthening of the crypt's structure was supplemented with widening the foundation of the internal wall.

The remedy applied in order to eliminate the cause of the damage in north side chapels (Sec. 3.4) was a new drainage system in the area adjacent to the basilica. The structural restoration, besides the injection and sewing of the cracks in walls, vaults and the dome, included the application of GFPR and CFRP composites in order to strengthen the hoop of the dome of the Ossolińska Chapel (Fig. 11). The effectiveness of GFRP and CFRP composite strengthening was proved for historic masonry, particularly for arches and vaults, based on several studies, e.g. complied in [29]. This solution gives good results, also in comparison with today's widely developing TRM systems [30]. Nevertheless, due to the recognition of the disadvantages of CFRP composites gluing to historic masonry (difference of stress-strain characteristics and creating a barrier for moisture evaporation), only the lower half of the dome and, what is more, only strips of surface were covered with composites. The solution allowed the steam permeability. Before the composites' application, the whole surface was covered with trass-lime-based material. In order to "soften" the difference between masonry and CFRP moduli of elasticity, the first composite layer constitutes GFPR (Fig. 11a), which was the basis for CFRP (Fig. 11b).

Fig. 11. The Ossolińska Chapel restoration: a) application of GFRP composite as the first layer, b) CFRP composites after strengthening, c) present view of repaired and restored arch and vault

The strengthening measures described above ensured the safety of the east wing of the monastery. No new cracks and deformations in the building loaded with the enlarged loads nor damage in paintings on the dome's surface were observed for 5 to 15 years (the period depends on the time of execution of the particular remedy), which proved that they were correctly chosen.

4. Conclusions

The article discusses four consequences associated with the incorporation of older walls into the structures. All of these cases were revealed by the authors during the restoration of the Dominican monastery in Lublin. The authors proved that in the 17$^{\text{th}}$ century the town wall and masonry adjoining it were partly used as the foundation for a new building and partly incorporated into the interior of the new structure.

The disadvantageous structural situation was aggravated by unfavorable subsoil conditions (soaking loess and uncompacted embankment) and poor quality of building materials. The detailed structural investigations shown that although all examples come from the same building complex and are connected with the walls of the same origin, each of them constitutes a separate case and demands individual analyses and solutions.

The detailed familiarity with the causes of the damage allowed the project to be successfully completed. The present trouble-free and safe use of the strengthened monastic structures, after several years from the completion of the rehabilitation works, proved the relevance and validity of the selected solutions. They were the effect of a compromise between the necessity of the structural safety and demand for the minimum impact on the heritage asset.

The restoration process described in the article shows that in the cases of complex historic buildings, the up-to-date diagnostic methods are valuable but the creative analyses of investigation's results are of still of vital importance.

It may be concluded that the diagnostics of a heritage asset should be based on detailed analyses of the structural system and its performance. These analyses are both of expert and scientific nature. Queries of historical documents help in the determination of the structural system, and *vice versa*, structural analyses help in the recognition and update of the knowledge of the building's history. The above conclusions are justified by the example of the Dominican monastery rehabilitation process.

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Rola analiz konstrukcyjnych i kwerendy historycznej w ustaleniu przyczyn uszkodzeń i wyborze metod naprawczych budynków zabytkowych, na przykładzie klasztoru oo. Dominikanów w Lublinie

Słowa kluczowe: budynek zabytkowy, diagnostyk konstrukcyjna, rehabilitacja, system konstrukcyjny, uszkodzenie

Streszczenie:

W artykule przedstawiono proces diagnostyki konstrukcyjnej klasztoru oo. Dominikanów w Lublinie. Dla określenia przyczyn uszkodzeń budynków zrealizowano nie tylko badania *in situ* oraz obliczeń konstrukcyjnych, ale także szczegółową analizę dokumentów historycznych. Przeanalizowano rysunki inwentaryzacyjne w celu ustalenia układu konstrukcyjnego. Kwerenda dokumentów historycznych i archiwów miejskich pomogła zrozumieć pracę statyczną obiektu. Wnioski z tych analiz były konfrontowane z obrazem zarysowania. Stwierdzono, że uszkodzenia wynikały z „warunków początkowych" systemu konstrukcyjnego – podczas rozbudowy klasztoru w przeszłości wbudowano weń pierwotne średniowieczne mury obronne.

Opisano także zastosowane środki naprawcze. Zastosowane konstrukcje wsporcze były kompromisem pomiędzy koniecznością zapewnienia bezpieczeństwa konstrukcji a wymaganiem minimum ingerencji w tkankę historyczną.

Celem artykułu jest także wykazanie, że diagnostyka konstrukcyjna budynków zabytkowych jest procesem koncepcyjnym. Podkreślono, że pomimo istnienia wielu współczesnych metod pomocnych w diagnostyce budynków, analizy koncepcyjne systemu konstrukcyjnego mają podstawowe znaczenie.

Kwerenda dokumentów historycznych pomaga w zidentyfikowaniu układu konstrukcyjnego budynku zabytkowego i vice versa – analizy konstrukcyjne pomagają w rozpoznaniu i uzupełnieniu wiedzy o zabytku.

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