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CONSERVATION OF THE LATE ROMANESQUE SANDSTONE PORTAL OF THE CHURCH OF THE PREMONSTRATENSIAN CONVENT IN KRAKÓW, POLAND

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Abstract

The church of the Premonstratensian Convent in Kraków is an early brick structure with stone detail, dating to the mid-13th century. One of the most precious elements preserved of the original church is the monumental late-Romanesque portal made of sandstone. In the wake of the accrual of cultural layers outside the church in the following centuries, what used to be the main portal leading into the church found itself sunk in the ground up to half of its height. Additionally, the portal was covered by a baroque tower in the 17th century. That had a highly negative impact on the condition of the portal which currently urgently required undertaking interdisciplinary research and conservation works. The archaeological digs made it possible to uncover the complete portal, while the research aimed at defining the reasons and degree of damage to the stone. The research consisted in petrographic examinations, examination of the structure of decay caused by dampness and salt, and electric conductivity tests of the sandstone. The conclusions from the research provided the foundation for designing and implementing a conservation works strategy to save, preserve, and show this exceptional work to the public.

***Keywords**: 13th-century sandstone portal; Premonstratensian convent; Kraków; Poland; Multidisciplinary research; Damage; Restoration*

Introduction

Conservation of architectural heritage calls for individual approach to each item, and a strategy to investigate it, learn the reasons of its damage, and adopt optimal means and methods of restoration.

Related to the general problems of museology and the valorization of cultural heritage assets, in correlation with the nature and state of preservation of the structural components, were studied by [1-5], instead the aspects regarding the interaction between an architectural object and the environment can be found in another series of works recently published by [6-8]. Also, the concept of the work of art in relation to the restoration and preservation interventions

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were recently investigated by [9], paying attention to the current materials and technologies used for this purpose, which were presented in the other articles [10-13].

An example of such an approach are the interdisciplinary studies performed to conserve the 13th-century portal of the church of the Premonstratensian Convent in Kraków, in Małopolska (south-eastern Poland). The initial condition of the portal was catastrophic and required taking immediate action to stop the process of decay.

Nuns of the Premonstratensian (Norbertine) Order arrived in Kraków from Doxan in Bohemia late in the 12th century. The first monastery developments, whether raised or taken over by the nuns on their arrival in Kraków, remain unknown. However, the research has shown that the brick Church of St Augustine and St John the Baptist, with a monumental stone portal enclosing the main entrance for the congregation in its north face, was built around the middle of the 13th century. It was a portal projecting from the face of the wall and surmounted with a triangular gable. Its lavish architectural form consisted of moulded archivolt resting on a cornice supported on six thin columns with capitals decorated with buds and Attic bases set in the mouldings of the jambs (three on each side). The jambs set in a perspective were all founded on a common/shared plinth [14]. In Christian symbolism, the framing of the main entrance to the church used by the congregation was the gate separating the sacred from the profane, a mystical passage leading to an encounter with God, a symbol of the Gates of Paradise and also Christ himself [15, 16]. Creating constructions of impressive panache and richness of architectural detail, emphasising the symbolic significance of passing over the threshold to a sacred place, the medieval architects were aware of these. To emphasise the significance of the main entrance besides the lavish form, they also exploited the contrast between the red of the brick wall of the Kraków church and the bright colour of the sandstone.

The portal and its nearest vicinity underwent many changes from the 13th to the 20th century. The successive rising of the ground surrounding the church had the portal reworked and gradually sunk into the earthen embankments. In the 15th/16th century, the clear opening of the entrance to the church was significantly raised, which resulted in the removal of the central section of the archivolt and the slab of the tympanum. Later, during an overhaul of the church in the 17th century, the triangular gable was removed as well, and the whole portal was occluded with a baroque tower appended to the northern face of the church. Since that time the portal has been in the entry porch on the lowest floor of the tower. One of the latest interventions, possibly made already in the 20th century, was the replacement of one of the stone columns with a brick construction. Finally, due to the rising of the ground outside the church and also of its floor, the portal threshold was moved by approximately 1.5m up, compared to the 13th-century level. That made half of the original height of the portal submerged in the ground for the last 300 years. This unusual situation resulted in the disastrous state of the portal and has caused problems both for its conservation and display. It is also the reason why the strategy of research and conservation works has been a major challenge for the interdisciplinary team of experts set up to establish it. The more so, as the portal is a precious element of late-Romanesque architecture, preserved in its original site, and unique both for its form and its scale in the Małopolska Region, and one of few in Poland.

The direct reason for starting the work on the portal in 2019–2021 were the many years of neglect and lack of conservation, and the drastic acceleration of the process of decay that aggravated in the last decade. The portal had never been subjected to archaeological and architectural research before, nor to any conservation following contemporary standards and protocols of scientific research. It must, however, be noted that the first description and reconstruction of the original form of the portal was made by Władysław Łuszczkiewicz in 1874 [17]. The current reconstruction was possible thanks to the minor archaeological investigation that the eminent Polish art historian and conservator made by one of the jambs of the portal. As, alas, Łuszczkiewicz was unaware of the significance of the sequence of the ground layers he discovered, he did not document it. In this way, one of the hints for dating the portal and determining its transformations was lost. The first results of architectural research covering the entire church were only published in 2015, together with a preliminary reconstruction of its form in the mid-13th century [14]. No conservation work on the portal had been conducted by 2019.

The scope of works carried out in 2019–2021 was extensive. First of all, archaeological research explored the accrual of layers of earth inside the tower, down to the level of the portal foundations, which disclosed its complete and original form (Fig. 1). It was accompanied by architectural, geological, petrographic, chemical and conservation studies.

Fig. 1. The condition of the portal before the works in 2019 and after the completion of archaeological research in 2020

This article presents the methods and results of the interdisciplinary studies of the material used for the construction of the portal, and of its nearest vicinity. The purpose of the study was to diagnose the causes of the damage, and to develop optimum methods for saving the portal for its conservation and protection against further damage, and to define the conditions of its display. This was a complicated pioneering task as a section of the portal had long been sunk in the ground, and prior research was missing.

With respect to the importance of the portal, the research conducted on the portal was mostly non-destructive. However, to obtain comprehensive information, the scope of research was extended so as to include destructive tests of the walls of the 17th-century porch.

Experimental Part

State of the portal before the multidisciplinary research. Types and symptoms of damage

In 2019 the degree of damage to the portal was highly extensive, and the progressing decay was ever more intensively effacing the form of its detail. The lack of research and conservation would have led to irretrievable loss of some of the portal substance. The first type of damages were the visible and extensive losses resulting from the flaking of the surface of the material, powder fragmentation of the layers close to the surface, and the detachment of sections of the stone [18] (Figs. 2–5). The local staining and damage of the plaster, a typical symptom of the negative impact of moisture present in the structure of the walls, were visible in the porch housing the portal [18, 19]. With the disintegration of the layers of stone close to the surface of the portal, and the risk of elevated dampness, the condition of the portal was tentatively connected to the presence of water-soluble salts in the stone structure. Moreover, apart from the local salt crystallisations, visible to the naked eye, the damages intensified in the section close to the floor (i.e. its level before the excavation of the lower sections of the portal) that is in the first section where moisture could have evaporated, and salt could have crystallised [18-23]. The destructive process quite likely lasted for years, as illustrated by the later brick infill that replaced one of the stone columns. It was also noted that the decay of some stone blocks probably resulted from their structure. The visible large crystals of framework grains made the impression of interlocking, with the simultaneous low cement content [24-28]. Thus weakened, the structures were more vulnerable to damage.

A range of preliminary activities were conducted prior to embarking on specialist research. The conclusions from those influenced the final list of research performed.

Fig. 2. A section of the portal, with visible decay of the material and the brick infill replacing a section of t the former column. Condition before the removal of the bottom parts

Fig. 3. A section of the portal, with visible damage of the elements of the portal jamb. Condition before the removal of the bottom parts

Fig. 4. Damages of the stone column capital

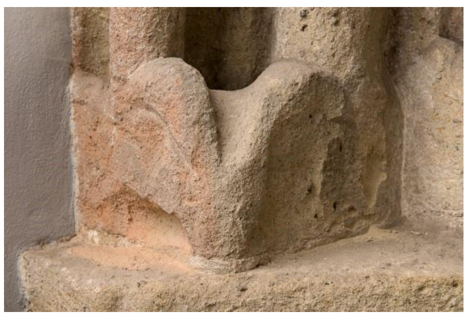

Fig. 5. Damage of the wavy archivolt base

During the preliminary works, thick sealing cement plasters were discovered in the porch. The fact allowed posing a claim that the moisture present in the walls used the porous sandstone of the portal for venting its excess. A phenomenon that accelerated the decay. It was also determined that an additional reason why some sections of the walls were soaked with water was the leakage through or between the metal sheets covering the porch and the resulting penetration of walls with water splashes. The preliminary works included video inspection of the sewage, water, and rainwater installations around the portal and the northern section of the church, which ruled out absorption of water by the portal resulting from loss of tightness in any of these installations. Making the geotechnical boreholes directed attention to the problem of high moisture levels in the ground in the direct vicinity of the portal [29-33]. That could give rise to the capillary drawing of moisture from the ground and the absorption of water by the portal and the adjacent sections of the walls [26].

Materials

The portal was built entirely of sandstone. The jambs and the cornice were made of horizontal slabs of stone arranged together into wide horizontal bands. The archivolt was arranged of short, fluted sections of stone, whose geometry was adapted to their semi-circular setting. The shafts of each column were made from a separate block of sandstone, and one of them was later replaced with brick elements. All the elements were connected with lime-sand mortar. Faint traces of whitewash and a layer of paint were discovered on the surface of the stone. Research of the build-up demonstrated that, in the bottom sections of the portal, they dated back to the 20th century, while those on the archivolt were probably of earlier origin [34].

Methods

Specialist studies of the portal were divided into the following groups:

• petrographic examination of the building material (sandstone) used for the portal

• studies of the dampening of the surfaces of the stone of the portal and walls of the porch, the structure of the walls of the porch, with monitoring of humidity and temperature inside the porch

• examination of the water-soluble salts in the structure of walls of the porch, stone surfaces of the portal, and the brick infill.

Petrographic examination of the building material

One of the first activities was the macroscopic observation of the building material. The assessment was extended to determine the present of calcium carbonate on the surface of the stone elements of the portal. It was assessed by observing the reaction of a drop of 10% hydrochloric acid solution which reacts rapidly and energetically to the presence of $CaCO_3$ forming carbon dioxide gas. Detailed petrographic examinations were carried on three samples (2, Np-2 and 1) with the use of a Jenapol (Carl Zeiss Jena) polarising transmitted light microscope. The quantitative petrographic composition of the sandstones was determined by the point method with an Eltinor 4 integration table. In each microscope sample, at 0.3mm distance with 300 measurement points defined to determine the type of grain component and cement in each.

Studies of the dampening of the surfaces of the stone of the portal and walls of the porch, the structure of the walls of the porch, with monitoring of humidity and temperature inside the porch

Measuring electric conductivity can be used as a non-destructive method for determining the causes of material deterioration. For this purpose, all constituent stones of the portal were tested. Their electric conductivity was measured with a portable Protimeter Surveymaster (General Electric) measuring device measuring moisture when gently pressed to the surface. This method, originally developed for measuring moisture in wood, allows to draw conclusions about hygroscopic salts and moisture. The measurement results describe the actual percentage of moisture. In materials other than wood, the measurements use percentages equivalent to wood moisture content, known as % Wood Moisture Equivalent (%WME) [21].

The research on the dampness of porch wall surfaces involved mass (absolute) humidity measurements in locations situated throughout the interior of the porch. A hygrometer LB-796, using the capacitive method (measuring the dielectric constant) was used for the purpose.

The examination of the moisture in the porch wall structure was a destructive examination. The samples of the wall surrounding the portal were collected on four depths from nine holes (with the exception of B1 and E2 holes, Fig. 6). The collected material was examined by the drying-and-weighing method, using a Radwag MA50/1.R moisture analyser. Boreholes were drilled with a carbide chisel. The material for examination was collected from the borehole with a punch. To avoid fluctuations in moisture content caused by drilling, top layers of samples were removed [20].

Monitoring of humidity and temperature was performed by measuring relative humidity, air temperature and surfaces inside the porch. The measurements were made with a Voltcraft Dual Laser IR-SCAN-350RH pyrometer. On average, one set of measurements was taken each month during a calendar year.

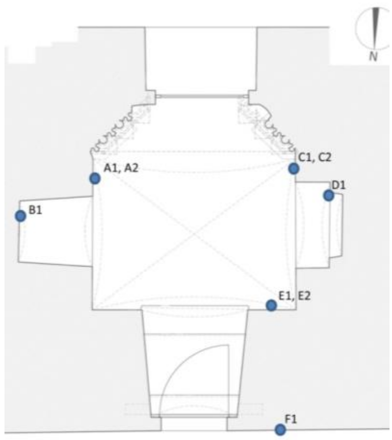

Fig. 6. The plan of the porch by the portal of the Church of St Augustine and St John the Baptist in the complex of the Premonstratensian Convent in Kraków's district of Zwierzyniec. Blue marks the locations of boreholes used to collect samples for examining dampness and salt contamination of the walls by the portal

Examination of the water-soluble salts in the structure of walls of the porch, stone surfaces of the portal, and the brick infill

Testing for water-soluble salts in the structure of the porch walls was conducted by collecting samples from the same boreholes where the dampness of the wall structure was examined. This eliminated the need to drill successive boreholes. Samples were collected from nine boreholes at two depths (Fig. 6). The examination consisted in extracting salts contained in the obtained samples with the stationary extraction method. First, the material (cca. 2g) was ground in an agate mortar, and 20 ml of distilled water was added. After 24h the suspension was decanted, and the presence of cations and anions in the filtrates was determined with flame, drop, and microcrystalloscopic methods. Moreover, the approximate number of carbonates dissolved in the water was determined with indicators using colour changes for determining concentrations [34].

With respect to the historical value of the portal, no destructive tests could be conducted on it. For this reason, only a qualitative examination of water-soluble salts was possible. The material collected was naturally dusting from the surface of the stones. Detailed information on samples No.1÷4 collected from locations in the portal is presented in Table 1.

The content of the chief water-soluble components was determined on the grounds of their concentration in an aqueous extract of the samples taken. The extract was prepared by adding a certain amount of distilled water to a known amount of previously crushed and averaged sample. In the obtained water extract, the concentrations of Cl^-, NO_3^-, and SO_4^{2-} were determined by ion chromatography (IC) with the use of a DX-100 (DIONEX) chromatograph, and the concentrations of Na^+, K^+, Mg^{2+} and Ca^{2+} by inductively coupled plasma atomic emission spectrometry (ICP-AES) with the use of an OPTIMA 7300DV (PERKIN-ELMER).

Table 1. Description of the samples collected from the portal for the qualitative examination of water-soluble salts

Sample number	Sample description
No. 1	Stone: sandstone, approx. 142÷150cm above the current floor level; sample collected from the dusting surface.
No. 2	Stone: sandstone, approx. 30÷50cm above the current floor level; sample collected from the dusting surface.
No. 3	Brick, approx. 10÷40cm above the current floor level; sample collected from the dusting surface of the brick infill.
No. 4	Stone: sandstone, approx. 20÷50cm above the current floor level; sample collected from the dusting surface.

Due to the secondary nature of the brick infill, a decision was reached to perform destructive tests on it to reveal the degree of salt concentration at different depths in the brick. Five samples were taken from the following depths: 0÷1cm, 1÷2cm, 2÷4cm, 4÷6cm, and 6÷8cm. The drilling dust was ground up, dried at 60°C, and then weighed. The sample material was then mixed with distilled water. The ratio of dry material to water was 1:100. The sample was subsequently mixed in water, the electric conductivity of the sample was measured with sension5 (Hachcompany), and the liquid was filtered off. The remaining sample residue was dried again and measured. The measuring accuracy was +/-0.0001g.

Results and discussion

Petrographic examination of portal stone

Macroscopic observations of the building material (stone) of the portal distinguished two colour varieties of sandstone, with different intensity of green-grey and yellow-grey colour, and three types of grain size: fine, medium, and coarse, as well as conglomerate. The fine-grained sandstones are mostly compact predominantly have high calcite content, the medium-grained sandstones mostly have high calcite content, and the coarse-grained and conglomerate sandstones are mostly calcite-free and mostly of low compactness.

Fine- and medium-grained sandstones of green-grey colour with calcite content, most of them compact, have been well preserved (Fig. 7).

Fig. 7. Breakdown of the sandstones used for the jambs of the portal according to their colour, grain, and presence of calcium carbonate

They were chiefly used for the base and plinth of the portal. Some of the fine-, medium-, coarse-grained, and conglomerate sandstones of low or no calcite content of green-grey and yellow-grey colours are compact while others are hardly compact and crumbling. They were used for the columns and their capitals, and the archivolt.

Microscopic observations show the sandstones in samples 2 and Np-2 similar to each other, and significantly different from sample 1. The differences are in feldspar content and, which is important from the point of view of further conservation works, in the content and type of cement (Table 2).

Table 2. Petrographic composition of sandstones in the portal of the Church of St Augustine and St John the Baptist in Kraków by % of the volume

Sample No	Quartz	Feldspars	Rock detritus	Micas	Organic elements	Other components	Clay cement	Carbonate cement
2	69.4	7.0	8.3	2.7	0.0	2.3	10.0	0.3
Np-2	66.4	6.0	7.7	2.0	0.0	1.3	16.3	0.3
1	40.0	1.0	5.3	0.3	7.7	1.0	1.3	43.4

Sandstones in samples 2 and Np-2 have strongly packed clastic material, which results in numerous intrusions and intergranular contacts (Fig. 8).

The mineral composition of these sandstones is dominated by quartz (a share reaching nearly 70%), while the other granular components constitute only a few percent, the clay cement is present in only slightly higher concentration, and carbonate cement in minimum amounts. The sandstone in sample 1 has a rich basic carbonate cement, whose share exceeds 40% and separates the clastic components (Fig. 9). It is a fine- and fairly even-grained sandstone with predominant grain size around 0.3mm and including grains of up to 1mm. Its main clastic component is quartz in sharp-edged and semi-sharp-edged grains.

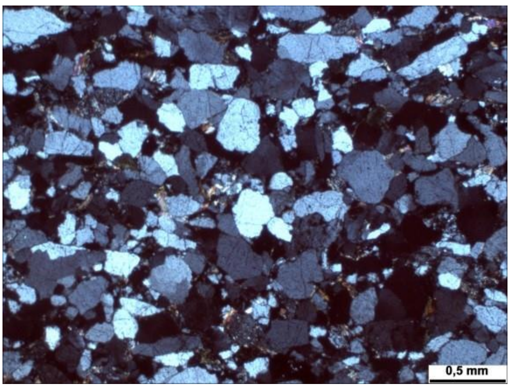

Fig. 8. Sandstone from the church of the Premonstratensian Convent in Kraków (sample 2). Microphotography, cross-polarised light

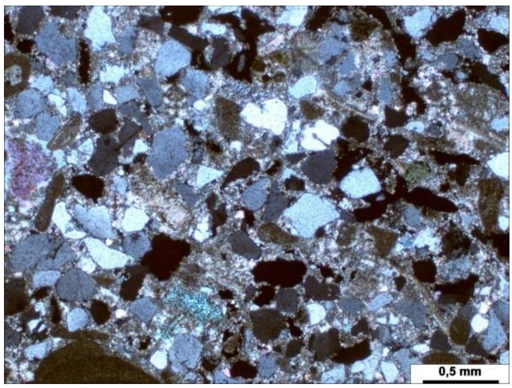

Fig. 9. Sandstone from the church of the Premonstratensian Convent in Kraków (sample 1). Microphotography, cross-polarised light

Examination of dampness of the stone surfaces of the portal and the porch walls, the porch wall's structure; monitoring of humidity and temperature inside the porch

The results of measurements of electric conductivity (surface dampness) within the portal jambs are presented below (Fig. 10).

The lower parts of the portal and the left-hand jamb, in particular the brick portal infill and a section of portal base adjacent to it, conduct electricity better. Electric conductivity of materials depends on a number of factors, including the density of the tested material and the share of hygroscopic salts. However, it is moisture that provides the main factor influencing the results, and therefore the image obtained can be considered an indication of dampness within a particular item [24, 25].

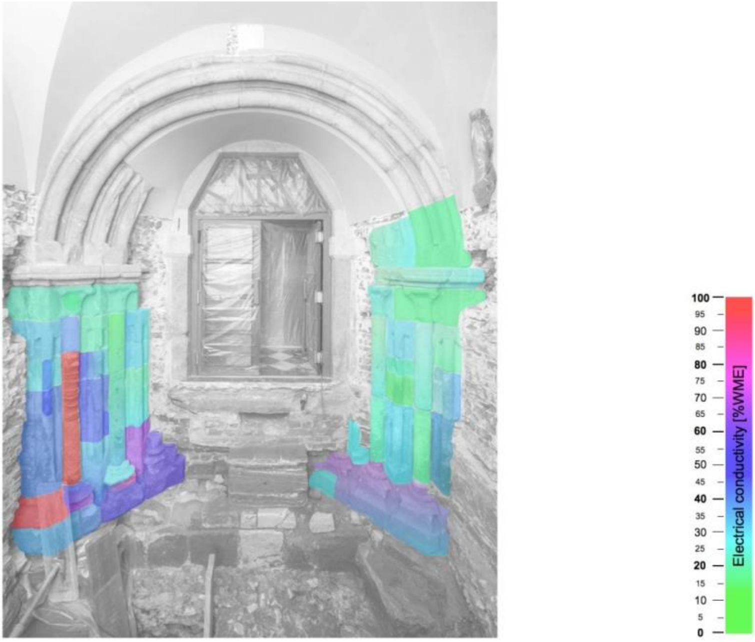

Fig. 10. Results of tests of electric conductivity of the stones of the portal

In a study of the dampness of the porch wall surfaces, the following ranges dampness described in the literature can be taken as reference: dampness at 0÷3% – acceptable wall dampness, 3÷5% – increased wall dampness, 5÷8% – moderately damp wall, 8÷12% – severely damp wall, and over 12% – wet wall [19]. Relatively high moisture levels were recorded on wall surfaces, with the results ranging from 1% to 20%. The dampness was higher in the lower parts of the walls and in the eastern and western recesses of the porch.

A summary of humidity and temperature monitoring for the risk of condensation (presence of dew point) on the surface of the historic material, covering the whole interior of the porch with the portal, is presented in Table 3 below:

Table 3. Listing of humidity and temperature parameters in the porch throughout the year

Measurement date	Relative air humidity (%)	Air temperature (˚C)	Lowest recorded surface temperature (˚C)
Sept 2019	65	19	18.5
early Oct 2019	72	18	16
end of Oct 2019	85	12.5	14.5
Nov 2019	72	12	11
Feb 2020	70	8	6
April 2020	58	15	9.5
May 2020	76	14	13.5
June 2020	75	17	17
early August 2020	62	22	19

As test results (Table 3) show, no risk of condensation (dew point) was recorded on any of the surfaces in the porch (plasters, floor, portal stonework) throughout the year.

The analysis of the results of the dampness of the porch walls obtained, adopted as a reference range of values analogous to those used for measuring wall surface dampness (Table 4) [19].

Table 4. Results of examinations of dampness of wall structure around the portal

Borehole identifier, and its height above the current floor level	Sample identifier	Borehole depth (cm)	Mass humidity (%)
Borehole A1 h = 0.2m	A1/1	10	6.77
	A1/2	35	6.49
	A1/3	60	4.49
	A1/4	85	5.56
Borehole A2 h = 0.9m	A2/1	10	0.81
	A2/2	35	9.18
	A2/3	60	8.74
	A2/4	85	15.33
Borehole B1* h = 0.4m	B1/1	10	7.88
	B1/2	35	7.66
Borehole C1 h = 0.2m	C1/1	10	11.2
	C1/2	35	6.9
	C1/3	60	12.61
	C1/4	85	12.40
Borehole C2 h = 0.9m	C2/1	10	5.93
	C2/2	35	7.4
	C2/3	60	6.67
	C2/4	85	10.18
Borehole D1 h = 0.9m	D1/1	10	8.45
	D1/2	35	9.76
	D1/3	60	9.06
	D1/4	85	8.84
Borehole E1 h = 0.2m	E1/1	10	10.71
	E1/2	35	10.46
	E1/3	60	8.91
	E1/4	85	8.46
Borehole E2** h = 0.9m	E2/1	10	1.26
	E2/4	85	7.86
Borehole F1 h = 0.3m	F1/1	10	3.96
	F1/2	35	8.21
	F1/3	60	10.46
	F1/4	85	8.64

* Approx. wall thickness: 40cm.
** Uniform hard limestone at the depth of 15÷80cm.

In most cases the level of moisture indicated moderate to severe wall dampness. There are no regular moisture trends in the walls, and mass humidity does not decrease with the distance of the measuring site from the floor. In most cases, the samples collected from the deeper sections of the wall had higher concentrations of moisture.

Study of water-soluble salts in the structure of the porch walls, stone surfaces of the portal, and the brick infill

Table 5 summarises the degrees of salt concentration in the samples collected from the wall structure of the porch housing the portal.

The tests indicating the total level of salt concentration (penetration with sulphates, nitrates and chlorides; carbonates being omitted as the object of the test was a pointing mortar) demonstrated a high level of salt concentration in the walls of the porch. Most of the tested samples of mortar with pulverised brick admixture demonstrated the presence of the following ions were: Ca^{+2}, Na^{+}, K^{+}, Mg^{+2} and Fe^{+3} cations and $SO4^{-2}$, NO_3^{-}, and Cl^{-} anions. They belong to calcium, sodium, potassium, magnesium and iron sulphates, nitrates, and chlorides. Discovered in the mortar samples without brick admixtures, marked A2/1, A2/2, and F1/2, were the following ions: Ca^{+2}, Na^{+}, K^{+}, Mg^{+2}, Al^{+3} and Fe^{+3} cations and SO_4^{-2}, NO^{3-} and Cl^{-} anions of calcium, sodium, potassium, magnesium, aluminium and iron sulphates, nitrates and chlorides [34].

Table 5. Results of examination of salt concentration in wall structures around the portal

Borehole identifier, and its height above the current floor level	**Sample identifier**	**Borehole depth (cm)**	**Mass humidity (%)**
Borehole A1	A1/1	10	3.0
h = 0.2 m	A1/2	35	2.8
Borehole A2	A2/1	10	2.7
h = 0.9 m	A2/2	35	2.5
Borehole B1*	B1/1/	10	2.6
h = 0.4 m	B1/2	35	2.5
Borehole C1	C1/1	10	3.1
h = 0.2 m	C1/2	35	3.0
Borehole C2	C2/1	10	2.6
h = 0.9 m	C2/2	35	2.6
Borehole D1	D1/1	10	2.5
h = 0.9 m	D1/2	35	2.3
Borehole E1	E1/1	10	2.9
h = 0.2 m	E1/2	35	2.8
Borehole E2**	E2/1	10	2.4
h = 0.9 m	E2/4	85	2.0
Borehole F1	F1/1	10	2.8
h = 0.3 m	F1/2	35	2.7

* Approx. wall thickness: 40cm.

** Uniform hard limestone at the depth of 15÷80 cm; samples from the depth of 35cm could not have been collected

A qualitative study of the salt concentration in the samples taken from the portal surface revealed that stone sample No. 1 features clearly largest concentrations of calcium sulphate, with sodium nitrates and chlorides, and potassium nitrate present in slightly smaller concentration. Calcium sulphate is also the dominant salt in the stone sample No. 2, which features smaller concentrations of sodium chloride, and least of potassium nitrate and calcium chloride. The salt present in the greatest concentration in sample No. 3, i.e. brick, is sodium chloride, with calcium sulphates, chlorides and nitrates, and potassium nitrate present in significantly lower concentrations. Calcium sulphate is also the salt present in the highest concentration in stone sample No. 4, where a certain concentration of sodium sulphate was also discovered (Table 6) [35].

Salt concentration inside the later brick infill was examined at a specified depth. The salt concentration in the depth profile of the examined sample follows the typical pattern [36, 37]. It is highest in the first four centimetres of the profile depth (Fig. 11a and d), while the values for the last four centimetres show levels that are generally constant (Fig. 11a, b, and c). The electric conductivity ranged from 448 to 332μS/cm. Salt is present at the levels ranging from close to 5 to 3.5% (Fig. 11a). The same observation applies to moisture loss of the sample after drying, where salt content ranges from 2.5 to 3% (Fig. 11b).

Table 6. Salts identified in the samples collected from the surface of the portal

Sample	Soluble salt	Share* (% by mass)
No. 1	calcium sulphate	49÷53%
	sodium nitrate	22÷26%
	sodium chloride	11÷14%
	potassium nitrate	<10%
No. 2	calcium sulphate	68÷72%
	sodium chloride	12÷16%
	potassium nitrate	<10%
	calcium chloride	<5%
No. 3	sodium chloride	63÷67%
	calcium sulphate	12÷16%
	calcium chloride	<10%
	calcium nitrate	<10%
	potassium nitrate	<5%
No. 4	calcium sulphate	51÷55%
	sodium chloride	32÷36%
	sodium sulphate	<10%

Share* is the estimated percentage (share) of the given salt in its anhydrous form in the total mass of the components discovered in the solution after sample elution

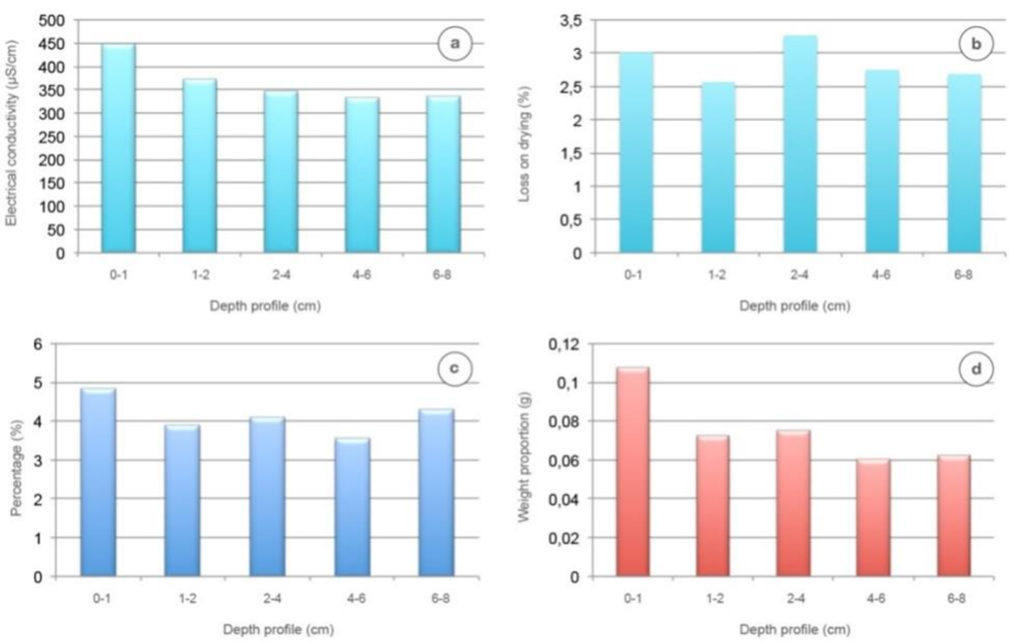

Fig. 11. a) Electric conductivity, b) The loss on drying of the samples, c) % share of salt in the drilling dust from the samples d) Soluble matter in the samples by weight

Figure 12 shows the architectural design system of how the portal will be exposed using a walkway leading to the church and the state of the portal after the first stage of conservation works and the construction of the walkway.

Fig. 12. Architectural design of how the portal is to be exposed with the use of a footbridge leading to the church

Conclusions

The specialist tests of the portal and the porch made it possible to establish the basic facts about the reasons of the damage, and have had a bearing on the strategy of conservation actions:

1. The study of the petrographic composition of the sandstones used for the portal indicated their Carpathian origin, while the clear differences in the proportions and types of the cement and rock clasts indicate acquisition of stone from different sources. The sandstones with low levels of clay cement were probably obtained from the outcrops of the Istebna strata, from the late Cretaceous and early Tertiary, while the varieties with abundant carbonate cement from the Gez, Grodzisko or Lgota strata from the Lower Cretaceous [38, 39]. Outcrops of such sandstones closest to Kraków are located within the range of 10÷20 kilometres from the city centre, south of Wieliczka. Among early medieval structures in Kraków, Carpathian sandstones of varieties similar of to the ones described above were found in the two-apsed rotunda (referred to as the “B” church inside Wawel Castle) [40] and in the Church of the Benedictine Monastery in Tyniec [41].
2. The results proving differences in the grain, its packing, and the quantity and quality of the cement explain why the damage has been uneven [18] and demonstrate that the decay also resulted from the different endurance of the stone, resulting from different inner structures. This fact prompted adapting conservation methods depending on the section of the portal [42].
3. The research on the dampness of the portal and porch made it possible to eliminate surface condensation as the cause of damage. Examination of the surface of the portal indicated that its lower parts were damper due to the capillary action of ground water. At the same time, the lack of a clear boundary in the degree of dampness below and above the floor level from

before 2020 confirmed that the actual damage had been caused by the drying of the wet material accompanied by the simultaneous crystallisation of water-soluble salts. The high moisture content in the samples collected from the deeper parts of the porch walls revealed the problem of moisture being present throughout the wall. (The high moisture results deep within the walls simultaneously confirmed the sealing nature of the cement plaster used in the interior of the porch.) This proved the risk of moisture evaporation through the porous sandstone of the portal, which has resulted in its accelerated decay [23, 24].

4. Testing for the presence of water-soluble salts in the wall structure and in the disintegrating elements of the stonework demonstrated dangerously high level of such salts. The identified salts are typical of the architectural heritage of Kraków. Tests of the salt concentration in the porch walls and of the portal followed slightly different methods, yet the qualitative results indicated similar proportions in the walls and portal. From the point of view of conservation, this is an important conclusion as it indicates the absence of unsuccessful conservation treatments during the past interventions [31, 32]. It should be emphasised that salt concentration is linked to a process of decay that depends on the type and amount of salt, and encompasses physical decay through crystallisation pressure, chemical decay through hydrolysis or increasing the hygroscopicity of the surface, which in turn greatly facilitates the proliferation of microorganisms. For this reason, the urgent undertaking of works eliminating moisture and salt concentration has become a priority [43].

The results of the research were used to develop guidelines for conservation, accounting for the specific nature of the building material and the diagnosed causes of its damage:

1. Due to the high level of moisture in the porch and portal, and the use of clay cement in the portal (and the reactivity of clay minerals with moisture), damp-proofing became a priority stage. A comprehensive damp-proofing project involving guidelines for maintaining appropriate moisture and temperature conditions in the closest vicinity of the Romanesque structure was developed.

2. With respect to the planned damp-proofing and to prevent the rapid desiccation of the stone, application of a desalination compress was envisaged for the portal. In the first stage, it will serve pushing the zone of moisture evaporation and salt crystallisation. The treatment will make it possible to protect the sections of the stones near the surface. After a period of stabilising the wall moisture, desalination will continue to migrate the water-soluble salts present in the stone to the compress. The treatment will be repeated several times.

3. Once the desalination process is over, the stone structure will be reinforced locally. The preparations used will be adapted to the type of cement and the structure of the individual blocks [18, 29, 30].

4. The next stage will comprise the necessary conservation measures carried out in line with the principle of conservative conservation, i.e. removal of secondary layers the surface, topical filling in of the pointing mortar and stonework, introduction of mineral mortar bands supporting the detached or cracked fragments, and reconnection of flaked stone.

5. In parallel, the brick infill added later to the portal will be replaced. A study of the distribution of salt concentration in the samples collected from the brick infill in the portal confirmed the typical feature of salt accumulation in the parts close to the surface. This indicates the ongoing process of migration of moisture to the surface of the materials, and the need to replace the brick infill due to the concentration of salt within it [33]. The infill ideally fulfils the role of a “compress”, which should be repeated by installing a new one, on principle with greater capacity of absorption by weight and porosity higher than that of the original

sandstone. Thus, once the process of salt removal has been completed, the brick infill will be replaced by stone with the abovementioned properties.

6. In parallel with the works on the portal, the sealing plaster of the porch must be removed urgently and replaced with specialist vapour-permeable plasters that accumulate water-soluble salts.

7. As the whole portal will be displayed to the view, a balustraded footbridge over the archaeological excavation will be constructed to allow access to the church and a view of the portal (Fig. 12) [37].

Although the research that has been carried out does not exhaust all the issues related to the protection of the portal, it has made it possible to start an important stage of saving the unique piece of Romanesque stonework. Conservation works on the portal and monitoring of its condition will continue for at least another two years.

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