Nano-Cathedral

D1.1 – Document on historical /architectural/environmental knowledge of the buildings

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RE	Restricted to a group specified by the consortium (incl. Commission Services)	
CO	Confidential, only for the members of the consortium (incl. Commission Services)	

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D 1.1 – Part A, Background information on the architectural object: San Peter and Mary Cathedral (Cologne, Germany)

1. General information

Cologne Cathedral, officially named “Hohe Domkirche St. Peter”, is the metropolitan church of the ecclesiastical province Cologne and seat of one of the most important Roman Catholic archbishops. Famous for its spectacular size and outstanding High Gothic construction it is probably the best known building of Germany, visited by more than six million people each year. Since 1996, Cologne Cathedral is listed as UNESCO World Heritage site.

Fig. 1: Cologne Cathedral, seen from the south.

Erected on the left high river bank of the Rhine, the enormously sized gothic-neogothic basilica with two high-rising towers is a landmark in the Cologne Lowland, visible from far away. The building material consists of different types of stone, mainly trachyte, sandstone, shell-limestone and basalt. As the cathedral is situated in the heart of the city, surrounded by motorcar and railway traffic, the ancient stone surfaces – depending on their individual durability – are more or less heavily deteriorated by air pollution. This does also apply for the large amount of stained glass windows, dating from various periods, the major part being created around 1300.

Fig. 2: Cologne Cathedral, with the central station.

Housing the famous relics of the Three Magi since the Middle Ages, Cologne Cathedral is an important pilgrim site, where innumerous of prayer-candles are burnt and masses of visitors bring about dust, soil and humidity day for day. The disadvantageous indoor climate causes manifold serious problems for the wealth of important works of art within the cathedral. Affected are e.g. the interior surfaces of stained glass windows, the altar pieces, painted sculptures of stone and wood and the medieval wooden choir stalls including the famous choir screen paintings dating from 1330/40.

Fig. 3: Cologne Cathedral, interior, view from west to east.

Measurements:

External length: 144.58 m
Length of the nave inside: 119.00 m
Width of the nave inside: 45.19m
Height of the nave inside: 43.35 m
Height of the side aisles: 19.80 m
Entire width of the transept: 61.54 m
Width of the transept façades: 39.95 m
Height of the transept façades: 69.95 m
Height of the roof ridge: 61.10 m
Height of the south tower: 157.31 m
Height of the north tower: 157.38 m
Covered area: 7.914 sq. m.
Usable floor space: 6.166 sq. m.
Enclosed area without buttressing: *c*.407.000 m^3

Responsible for the maintenance of the building is the Cathedral Works Department ("Dombauhütte"), established in 1823 and conducted by the Cathedral architect.

2. History of construction

The area of the present gothic church is a place of Christian worship since the Roman times. Christians had a modest a place of worship in the northeast corner of the walled-in Roman city “Colonia Claudia Ara Agrippinensium”, founded in 50 AD. From the fourth century onwards, the small building was enlarged and expanded to a church complex. Around the middle of the 9th century a completely new building was erected, a large basilica of nearly 100 meters length, with two choirs, two crossing towers and two bell towers, the so-called “Old Cathedral”. With the translation of the relics of the Three Magi, taking place in 1164, Cologne Cathedral became one of the most important pilgrim sites north of the Alps. The desire for a new and larger building was already expressed at the beginning of the 13th century, but it was not until August 15, 1248 that the foundation stone was laid by Archbishop Konrad von Hochstaden. In the first stage of construction, the seven ambulatory chapels were erected. Already in 1261 Konrad von Hochstaden could be buried in the axial chapel which was completed and probably glazed by then. In the following decades, the chevet was completed, the inner choir was raised up and around 1300 the architecture of the upper choir with its rich buttressing must have been finished. When in 1322 the ceremonious consecration of the chevet took place, a provisional separating wall closed this area towards the west. The work was continued on the south side, constructing the fundaments for the side aisles and the south tower. Around 1410 the two side aisles were completed. The south tower was erected up to the second story at a height of 56 meters. In the 15th century, the building activity was concentrated on the north side aisles and the east wall of the north tower. Due to decreasing financial means, the building activities considerably slowed down in the 1520 and were finally stopped. Between the 16th and 19th century the cathedral remained unfinished, only works of repair, embellishment and modernization took place. When in 1794 French revolutionary troops besieged Cologne, the cathedral was closed and served as storehouse for the French army. Only in 1801 mess was held again. In 1815 Cologne became Prussian. The government in Berlin initiated first measurements of consolidation and restoration. Under the aegis of cathedral architect Ernst Friedrich Zwirner, who took up his office in 1833, plans for the completion of the cathedral were developed, decidedly according to existing architectural drawings of the 13th century. The continuation of the construction was officially resumed in 1842, starting with the erection of the transept arms, the transept façades and the clerestory of the nave. In 1863 vault and transepts were vaulted, the roof-scape above the newly erected parts was completed and the medieval separating wall to the choir was torn down. In 1880 both towers had reached their full eight of 157 meters. After 632 years of construction time, the completion of Cologne Cathedral was celebrated on October 15th, 1880.

During the long history of construction, a multitude of different stone types were used. In the Middle Ages, the only building material was trachyte from Mount Drachenfels, situated in the

“Siebengebirge” (Seven Hills) at the riverside of the Rhine, 25 km upstream of Cologne. When construction work was resumed in the 19^{th} century, Drachenfels trachyte was not available any more. First repairs were carried out with andesites from Mount Stenzelberg and Mount Wolkenburg, also in the Seven Hill area. But the main stone material for continuing the construction in the 19^{th} century became sandstone. A first choice fell on the rough-grained sandstone from Schlaitdorf in Southern Germany, in use from 1842 until 1862. The second important lithotype was the fine-grained sandstone from Obernkirchen, 15 km east of Minden, today Lower Saxonia, in use from 1847 until 1880. Both varieties were the main building materials of the completion campaign, extensively used for structure-bearing parts such as buttressing, walls and the towers. Further types of Sandstone were also in use, but of minor importance. For sculptures and richly decorated pieces like balconies, various types of especially French limestone were taken. A third period of construction work started already in 1905, only 25 years after the completion was ceremoniously celebrated. At the choir clerestory, substantial parts of the deteriorated medieval trachyte were exchanged against shell limestone, a campaign that lasted for decades until World War II. After the war, basaltic lava from the Eifel region and from Hesse became a preferred stone material for replacements of areas exposed to heavy weathering such as bases, window sills or gargoyles. Today, trachyte from Montemerlo (Italy) is in use to replace deteriorated medieval trachyte. The same is true for the sandstone from Božanov (Czech Republic), a material for exchanging deteriorated sandstone from Schlaitdorf.

3. Architecture and art

Cologne Cathedral is a purely high gothic construction, standing in a row with the large royal cathedrals in northern France as Chartres, Paris and Reims. The immediate model is the cathedral of Amiens. Being one of the latest links in the chain of high gothic cathedrals, Cologne Cathedral incorporates the climax in the development of this ambitious architectural language.

The cathedral is constructed as a basilica with five naves, ambulatory, radial chapels, wide projecting transept and a huge façade with two towers.

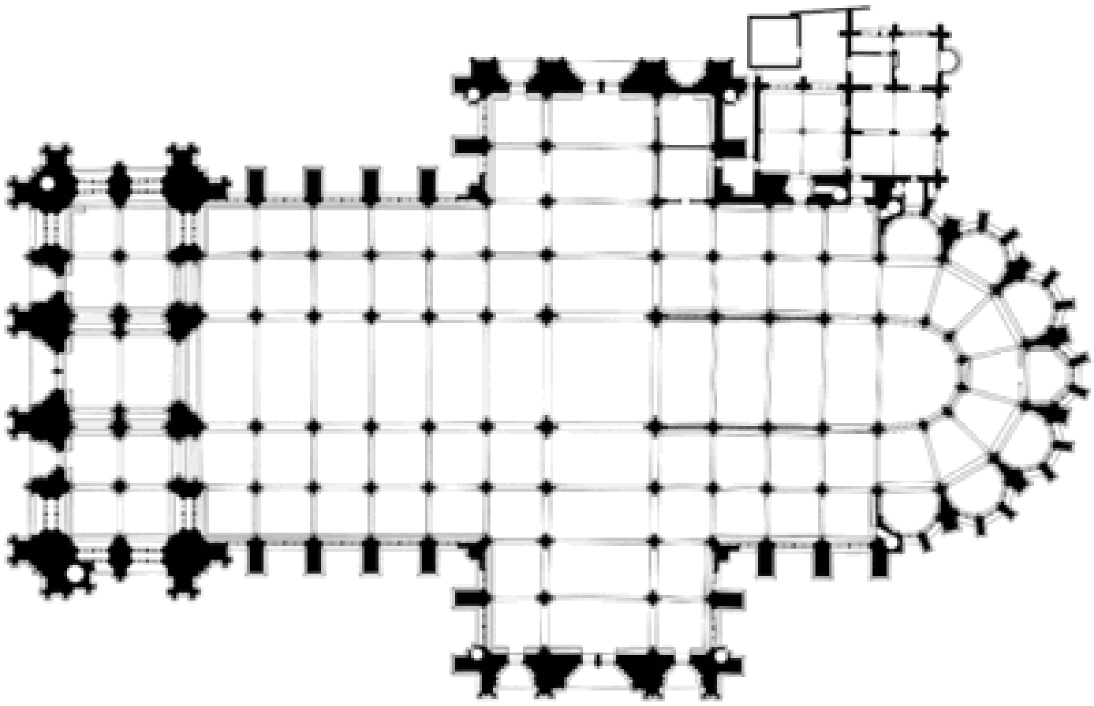

Fig. 4: Cologne Cathedral, ground plan.

<u>Exterior</u>

The ambulatory has seven radial chapels with two respectively three tracery windows, each window with two lancets and three trefoils. The ground floor is without any decoration. The chapels have pointed tent roofs. The slender pier buttresses between the chapels, twice interrupted by water offsets, are crowned with figured arcades. Above pier buttresses are arising, richly decorated with blind tracery. From each pier buttress of the choir-round ascend two flying buttresses to the nave walls, arranged one about the other. At the longitudinal sides of choir and nave, the buttressing has to bridge two side-aisles. Here, above the pier buttresses between both side aisles, again pier buttresses are ascending; thus at these points there are four flying buttresses for each nave pier. The huge clerestory windows are crowned by steep triangular gables. Behind arises the high, lead-covered roof of the nave.

Fig. 5: Choir of Cologne Cathedral, view from the east.

Fig. 6: Cologne Cathedral, buttressing of the south side.

Both transept façades were designed in neo-gothic style by the cathedral architect Ernst Friedrich Zwirner based on the medieval parchment plan of the west façade. Medieval drawings for the transept parts are not preserved.

The west façade ─ erected from 1863 to 1880 ─ with almost 7.000 square meters is the largest church façade ever built. It faithfully follows the still extant medieval parchment plan, drawn up around 1290, probably by the first cathedral architect named Arnold. Despite the abundance of decorative forms, the architectural structure is clear and comprehensive. Each story consists of a lower wall and a window. The two lower stories correspond to the side aisles and the central nave of the interior. The central aisle extends into the vertex of the large central window between the towers. As the interior, the façade has five axes. Above the two lower floors, the towers gradually become octagonal, fully developed in the fourth floor. The transition is covered by enormous free-standing pinnacles of over 33 meters height, rising up over the main pier buttresses at the fourth floor corners of each tower. The towers end in open tracery spires, decorated by crockets and crowned by two finials, each 8.65 meters high. The three portals of are relatively small. Only the south one with its sculpture dates from the Middle Ages, circa 1370-80.

Fig. 7: Cologne Cathedral, west façade.

Interior

The interior of Cologne Cathedral is characterized by its impressive vertical emphasis. Although the construction time covers more than 600 years and various building periods, the originally intended aesthetic aim has been achieved: a harmoniously unified visual appearance of high gothic architecture. The central isles of nave, transept and chevet are almost identical in measurements and vertical structure, with a clear width of 12.20 meter and a height of 43.35 meters. The distance between the pillars is 7.50 meters. The walls are divided into arcades, the triforium and the clerestory. The lower part of the arcades consists of clustered pillars with 13.20 meters height. Their round core is encircled by twelve round responds, corresponding in thickness to the width of the supported vault. The three responds facing the central aisle rise up to the vault capitals, interrupted only by pillar statues. At a height of 19.75 meters, the arcade zone is concluded by the lower ledge of the triforium, a gallery of 1 meter width and 5.80 meters height, glazed towards the outside and with open stonework tracery toward the interior. The clerestory consists almost entirely of large windows. The windows, 5.85 meters wide and 17.80 meters high are divided into four lights. Windows and triforium correspond in their arrangement and appear as a single entity. Thus, the clerestory seems even higher.

Fig. 8: Cologne Cathedral, nave from west to east.

The architecturally most impressive part of the interior is the high or inner choir. It is divided into three areas: the first bays from the west form the choir of the Chapter with choir stalls. Then follow the entrance area and the sanctuary in the polygonal apse with the medieval high altar. The arrangement of the wall decoration is as in the nave, it only turns around in a polygon. Therefore, the pillars now stand closer together. Instead of four lights, the windows in the central five arcades only have two lights. The joint between the long-side part of the choir and the polygonal part of the apse is made more subtle through the fact that that the two first turning-round bays are only a little narrower than the normal ones but having identical window forms.

Fig. 9: Cologne Cathedral, view into the inner choir.

The inner choir is encircled by the ambulatory with seven radiating chapels. After the consecration of the choir in 1322 all chapels were closed-off by grills and stone balustrades with open tracery. This was due to the circumstance that the golden shrine that houses the relics of the Three Magi from now on was exposed in the axe chapel, which became their place of worship for more than 700 years.

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4. Orthophotography and /or 3D laser scanning survey of the building

Please note: 3D laser scanning of Cologne Cathedral has been performed in spring 2015, but the data are not released yet. As soon as the data are available they will submitted

5. List of historic building materials
6. Provenance and use

Classification / Lithotypes	Provenance	Time of use	Extent and Place of Use	Weathering Stability
Igneous rocks				
Trachyte from mount Drachenfels	Germany, North Rhine-Westphalia, Siebengebirge	1248–1560	Often used; flying buttresses of the choir, nave up to 20 m, south tower up to 56 m	Moderately-good, loss of the sanidines, scaling, sanding
Trachyte from Berkum	Germany, North Rhine-Westphalia, near Bonn	1833–1870	Rarely used; flying buttresses of the transepts, balustrades, capitals	Moderate, loss of the sanidines, scaling, sanding
Andesite from mount Stenzelberg	Germany, North Rhine-Westphalia, Siebengebirge	1840–1865	Rarely used; maintenance of the north side aisle, flying buttresses, tracery, cornices	Moderate, loss of the sanidines, scaling, sanding
Andesite from mount Wolkenburg	Germany, North Rhine-Westphalia, Siebengebirge	1829–1875 ?	Rarely used; transverse archs	Moderate, loss of the sanidines, scaling, sanding
Basaltic Lava from Mayen	Germany, northern Rhineland-Palatinate, Eifel	Since 1829	Non-visible parts of the triforium, complete fundament of the portals	Very good
Basaltic Lava from Londorf	Germany, Hesse	Since 1952	Reconstructions after WW II; north transept, central west façade window, sculptures of the northern west portal, angel on top of the gable of the central west-portal	Very good
Basaltic Lava from the quarry “Hannebacher Ley”	Germany, northern Rhineland-Palatinate, Eifel	Since 1829	Base-covering of the south tower, walls of the terraces	Very good
Basaltic Lava from mount “Perler Kopf”	Germany, northern Rhineland-Palatinate, Eifel	Since 1829	Base-covering of the south tower, walls of the terraces	Very good
Basalt from Unkel (columnar basalt)	Germany, northern Rhineland-Palatinate, Bad Honnef	1249–1522, after 1842	Fundaments	Very good
Basalt from Oberkassel	Germany, North Rhine-Westphalia, near Bonn	1842–1880	Interior filling material of the tower walls	Very good
Tuff from Ettringen, Weibern, Plaidt and Kruft	Germany, northern Rhineland-Palatinate, Eifel	Since 1248	Vaulted ceilings, interior filling material of the walls; in higher quality used for sculptures in the interior	Moderate, mainly used in the interior
Sedimentary rocks				

Sandstone from Schlaitdorf	Germany, Baden-Wuerttemberg, near Tübingen	1842–1863 for the exterior, until 1880 for the interior	Facades of the transepts, clerestory and buttresses of nave and transepts, inner walls of the 1^{st}–3^{rd} story of the towers	Mainly very problematic
Sandstone from Obernkirchen	Germany, Lower Saxony, near Minden	1845–1880, again since 1990	External facades of the north tower, south tower from 2^{nd} story up to the spire and the finial	Mainly good
Sandstone from Heilbronn	Germany, Baden-Wuerttemberg	1842–1843	Tracery of the windows in the southern transept, windows of the southern transept, sculptures of the southern transept façade, the music-making angels of the choir	Moderate
Sandstone from Flonheim	Germany, Rhineland-Palatine, near Mainz	1842–1845	Parts of the transept façades	Moderate
Sandstone from Staudernheim	Germany, Rhineland-Palatinate, near Bingen	1867–1877	Sacristy and inner parts of the towers	Good
White Sandstone	Germany, North Rhine-Westphalia, Detmold	1870–1880	Crockets of the spires	Mainly good

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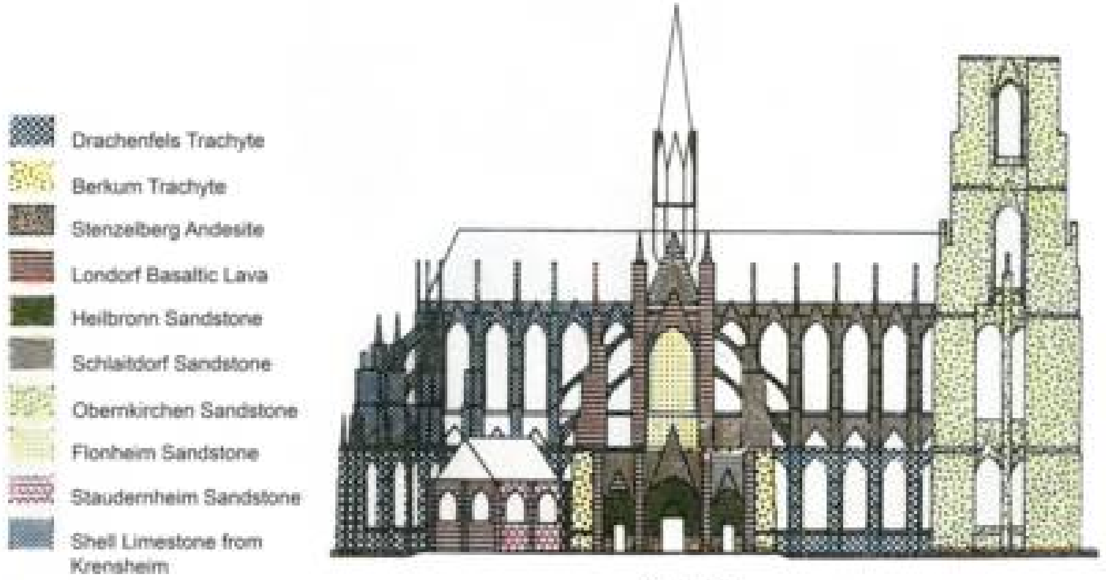
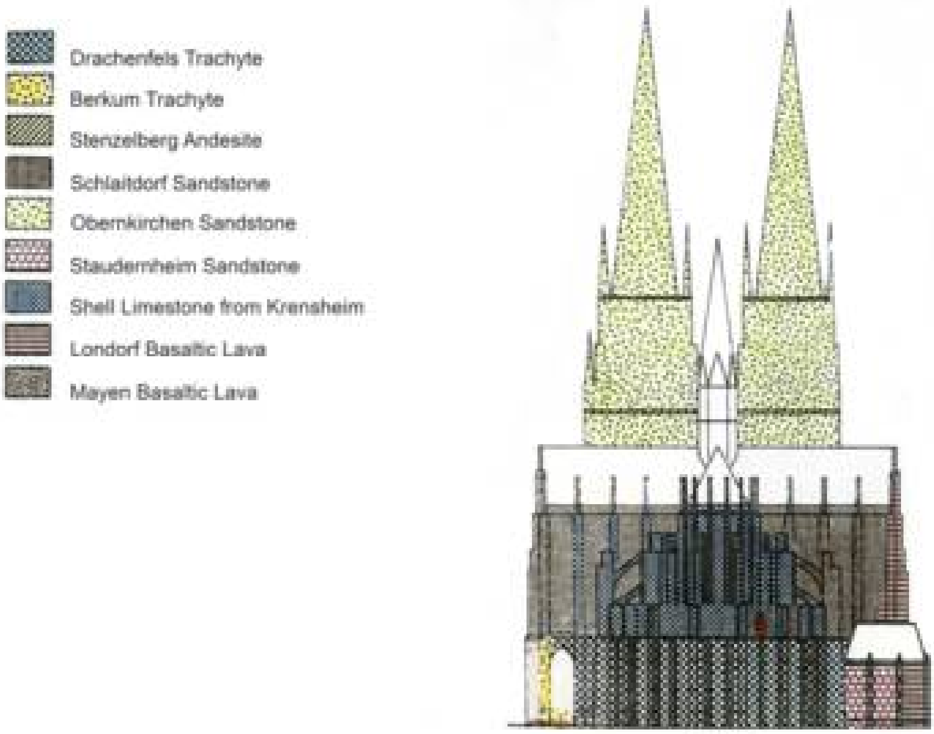
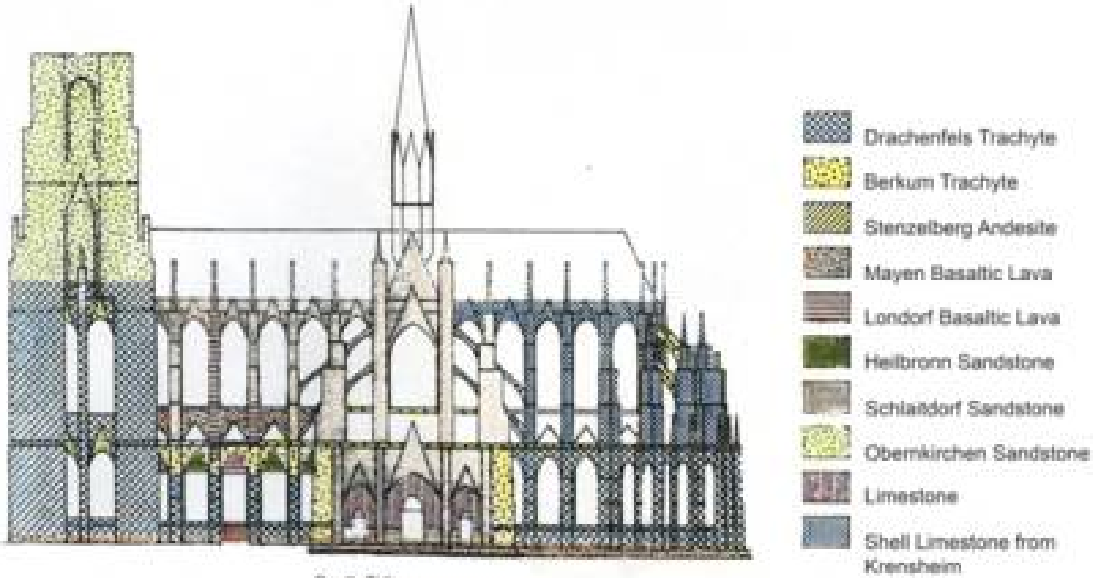
7. Mapping of historical building material
(Middle Ages, 19thcentury, first half of the early 20th century)



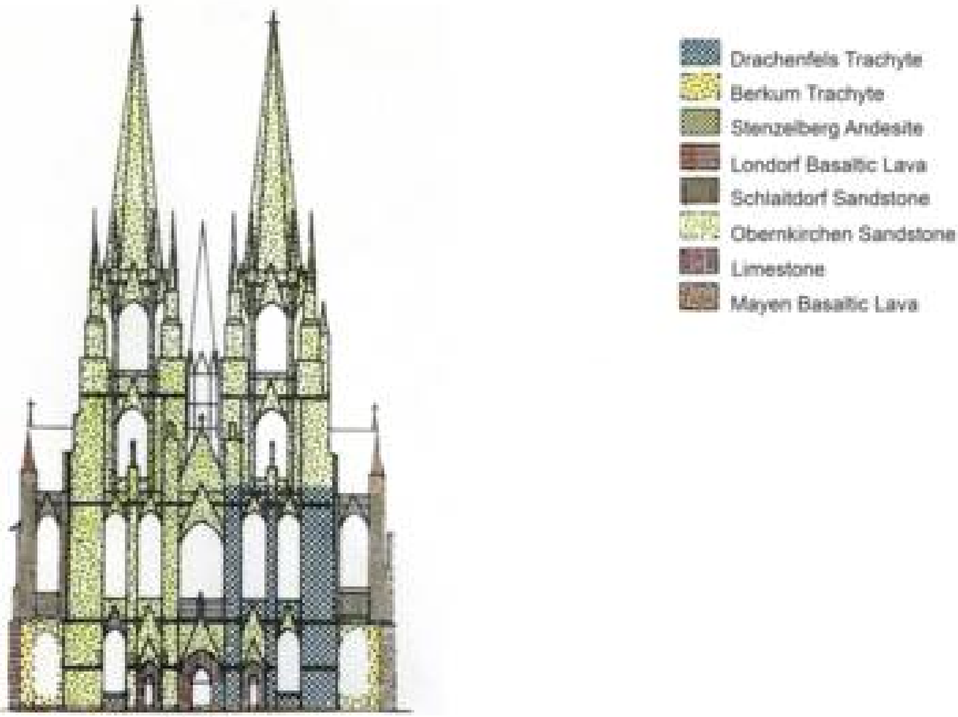
North Side



East Side



South Side



West Side

9. Preliminary evaluation of the conservation state of stone surfaces

In general, all the various lithotypes formerly used for the construction of Cologne Cathedral suffer decay. The most seriously endangered lithotypes are Trachyte and Schlaitdorf sandstone, followed by limestone and the Krensheim shell-limestone. But also the surfaces of the more solid Obernkirchen sandstone are by pollution affected. Three lithotypes were chosen for the investigations in Nano-Cathedral.

1. Lithotype: Tercé limestone

Deterioration phenomena: microkarst, sanding, black crusts, soiling, biological growth (green algae), exfoliation (fig. 10, 11).

Fig. 10: Tercè limestone, portal of the Three Magi Portal, socles on the right side.

Fig. 11: Tercè limestone (details), various specific damages like microkarst, sanding, black crusts, exfoliation and soiling.

2. Lithotype: Schlaitdorf sandstone

Deterioration phenomena: strongly sanding, delamination, scale formation (Fe III-oxide and hydroxides), crumbling, granular disintegration, black crusts, deep alveolization, subflorescence, efflorescence (fig. 12, 13).

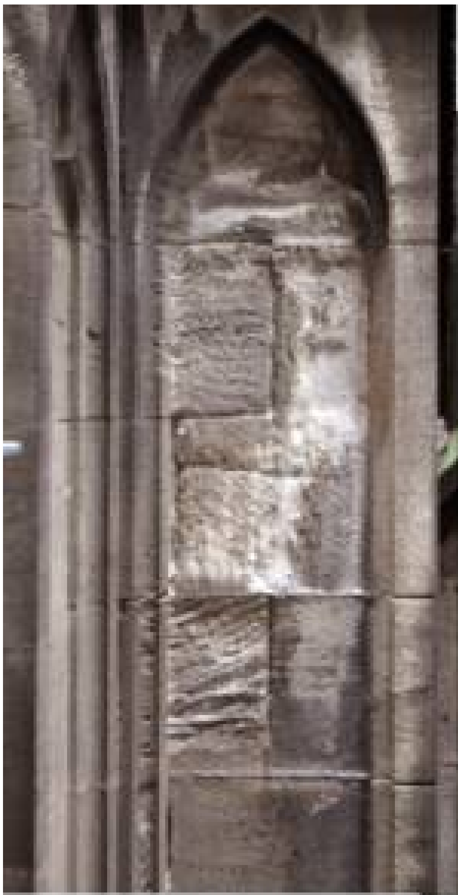


Fig. 12: Schlaitdorf sandstone, buttress B8, south nave / south transept.

Fig. 13: Schlaitdorf Sandstone, detail, various specific damages like strongly sanding, delamination, crumbling, granular disintegration, black crusts.

3. Lithotype: Obernkirchen sandstone

Deterioration phenomena: scaling, powdering, black crusts, exfoliation, flaking, soiling and powdering (fig. 14, 15).

Fig. 14: Obernkirchen sandstone, north tower eastern wall.

Fig. 15: Obernkirchen sandstone, detail, various specific damages like scaling, powdering, black crusts, exfoliation, flaking, soiling and powdering.

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9. Evaluation of environmental aggressiveness

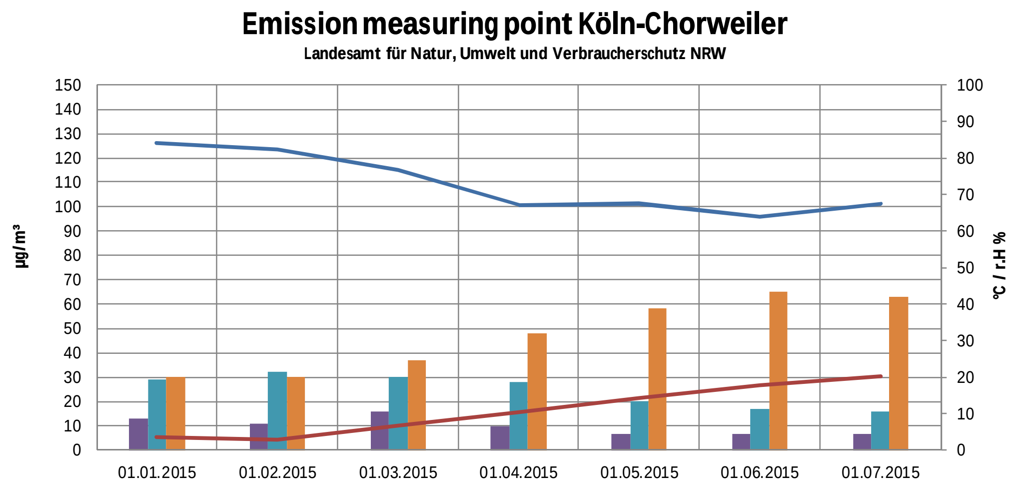
Cologne Cathedral is erected on the left high river bank of the Rhine, 53 m above NN. Situated in the heart of the city, surrounded by motor, ship and railway traffic – Cologne's main station is directly neighboring – the building is exposed to manifold polluting emissions. While the concentration ratio of SO_2 considerably decreased over the last 30 years, NOx and particulate matter stay relatively high, with intermittent increase. Cologne lies at the eastern edge of the Rhenish brown coal basin with opencast mining areas. Within a radius of 30 km are two large coal-firing power plants.

Emission measuring points Cologne

The following charts are based on data from: Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen (http://www.lanuv.nrw.de/umwelt/luft/immissionen/stationen-und-messwerte).

Landesamt für Natur, Umwelt und Verbraucherschutz NRW

	Köln-Chorweiler r.H %	Köln-Chorweiler °C	Köln-Chorweiler SO2 µg/m³	Köln-Chorweiler NO µg/m³	Köln-Chorweiler NO2 µg/m³	Köln-Chorweiler O3 µg/m³	Köln-Chorweiler Partikel PM10 µg/m³
01.01.2015	84,0	3,7		13	29	30	Ref.
01.02.2015	82,2	3,1		11	32	30	Ref.
01.03.2015	76,7	6,8		16	30	37	Ref.
01.04.2015	67,1	10,5		10	28	48	Ref.
01.05.2015	67,5	14,1		7	20	58	Ref.
01.06.2015	64,1	17,6		7	17	65	Ref.
01.07.2015	67,4	20,2		7	16	63	Ref.



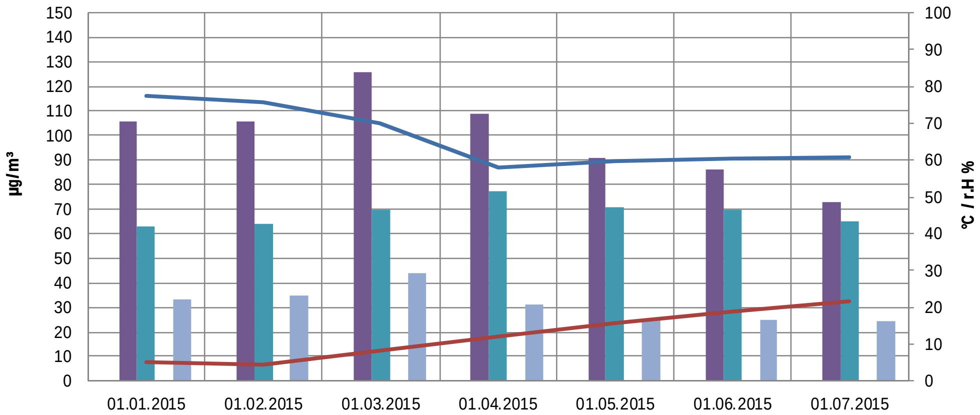
	01.01.2015	01.02.2015	01.03.2015	01.04.2015	01.05.2015	01.06.2015	01.07.2015
Köln-Chorweiler SO2 µg/m³	0	0	0	0	0	0	0
Köln-Chorweiler NO µg/m³	13	11	16	10	7	7	7
Köln-Chorweiler NO2 µg/m³	29	32	30	28	20	17	16
Köln-Chorweiler O3 µg/m³	30	30	37	48	58	65	63
Köln-Chorweiler Partikel PM10 µg/m³	0	0	0	0	0	0	0
Köln-Chorweiler r.H %	84,0	82,2	76,7	67,1	67,5	64,1	67,4
Köln-Chorweiler °C	3,7	3,1	6,8	10,5	14,1	17,6	20,2

Landesamt für Natur, Umwelt und Verbraucherschutz NRW

	Köln Clevischer Ring r.H %	Köln Clevischer Ring °C	Köln Clevischer Ring SO2 µg/m³	Köln Clevischer Ring NO µg/m³	Köln Clevischer Ring NO2 µg/m³	Köln Clevischer Ring O3 µg/m³	Köln Clevischer Ring Partikel PM10 µg/m³
01.01.2015	77,5	5,1		106	63		33
01.02.2015	75,7	4,5		106	64		35
01.03.2015	69,9	8,2		126	70		44
01.04.2015	57,9	12,1		109	77		31
01.05.2015	59,8	15,6		91	71		25
01.06.2015	60,3	18,9		86	70		25
01.07.2015	60,8	21,8		73	65		24

Emission measuring point Köln Clevischer Ring

Landesamt für Natur, Umwelt und Verbraucherschutz NRW



	01.01.2015	01.02.2015	01.03.2015	01.04.2015	01.05.2015	01.06.2015	01.07.2015
Köln Clevischer Ring SO2 µg/m³	0	0	0	0	0	0	0
Köln Clevischer Ring NO µg/m³	106	106	126	109	91	86	73
Köln Clevischer Ring NO2 µg/m³	63	64	70	77	71	70	65
Köln Clevischer Ring O3 µg/m³	0	0	0	0	0	0	0
Köln Clevischer Ring Partikel PM10 µg/m³	33	35	44	31	25	25	24
Köln Clevischer Ring r.H %	77,5	75,7	69,9	57,9	59,8	60,3	60,8
Köln Clevischer Ring °C	5,1	4,5	8,2	12,1	15,6	18,9	21,8

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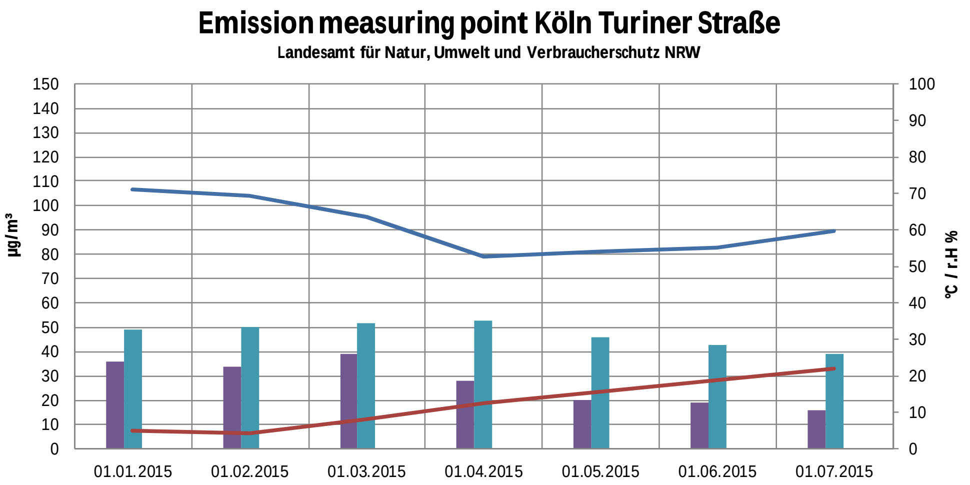
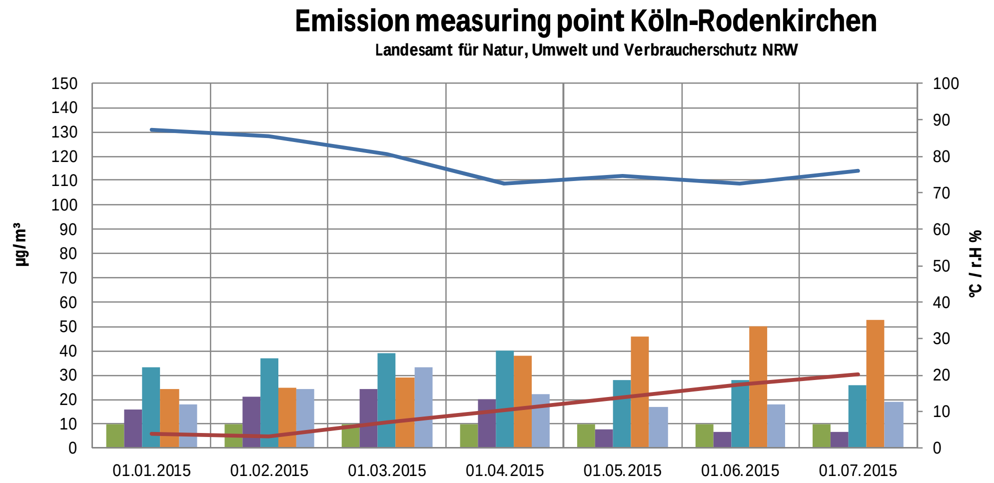
	Köln Turiner Straße r.H %	Köln Turiner Straße °C	Köln Turiner Straße SO2 µg/m³	Köln Turiner Straße NO µg/m³	Köln Turiner Straße NO2 µg/m³	Köln Turiner Straße O3 µg/m³	Köln Turiner Straße Partikel PM10 µg/m³
01.01.2015	70,9	5,1		36	49		Ref.
01.02.2015	69,2	4,5		34	50		Ref.
01.03.2015	63,5	8,3		39	52		Ref.
01.04.2015	52,7	12,3		28	53		Ref.
01.05.2015	54,1	15,7		20	46		Ref.
01.06.2015	55,3	18,9		19	43		Ref.
01.07.2015	59,7	21,9		16	39		Ref.



	01.01.2015	01.02.2015	01.03.2015	01.04.2015	01.05.2015	01.06.2015	01.07.2015
Köln Turiner Straße SO2 µg/m³	0	0	0	0	0	0	0
Köln Turiner Straße NO µg/m³	36	34	39	28	20	19	16
Köln Turiner Straße NO2 µg/m³	49	50	52	53	46	43	39
Köln Turiner Straße O3 µg/m³	0	0	0	0	0	0	0
Köln Turiner Straße Partikel PM10 µg/m³	0	0	0	0	0	0	0
Köln Turiner Straße r.H %	70,9	69,2	63,5	52,7	54,1	55,3	59,7
Köln Turiner Straße °C	5,1	4,5	8,3	12,3	15,7	18,9	21,9

Landesamt für Natur, Umwelt und Verbraucherschutz NRW

	Köln-Rodenkirchen r.H %	Köln-Rodenkirchen °C	Köln-Rodenkirchen SO2 µg/m³	Köln-Rodenkirchen NO µg/m³	Köln-Rodenkirchen NO2 µg/m³	Köln-Rodenkirchen O3 µg/m³	Köln-Rodenkirchen Partikel PM10 µg/m³
01.01.2015	87,4	4,0	10	16	33	24	18
01.02.2015	85,5	3,4	10	21	37	25	24
01.03.2015	80,6	7,0	10	24	39	29	33
01.04.2015	72,3	10,5	10	20	40	38	22
01.05.2015	74,4	14,0	10	8	28	46	17
01.06.2015	72,6	17,5	10	7	28	50	18
01.07.2015	75,9	20,4	10	7	26	53	19

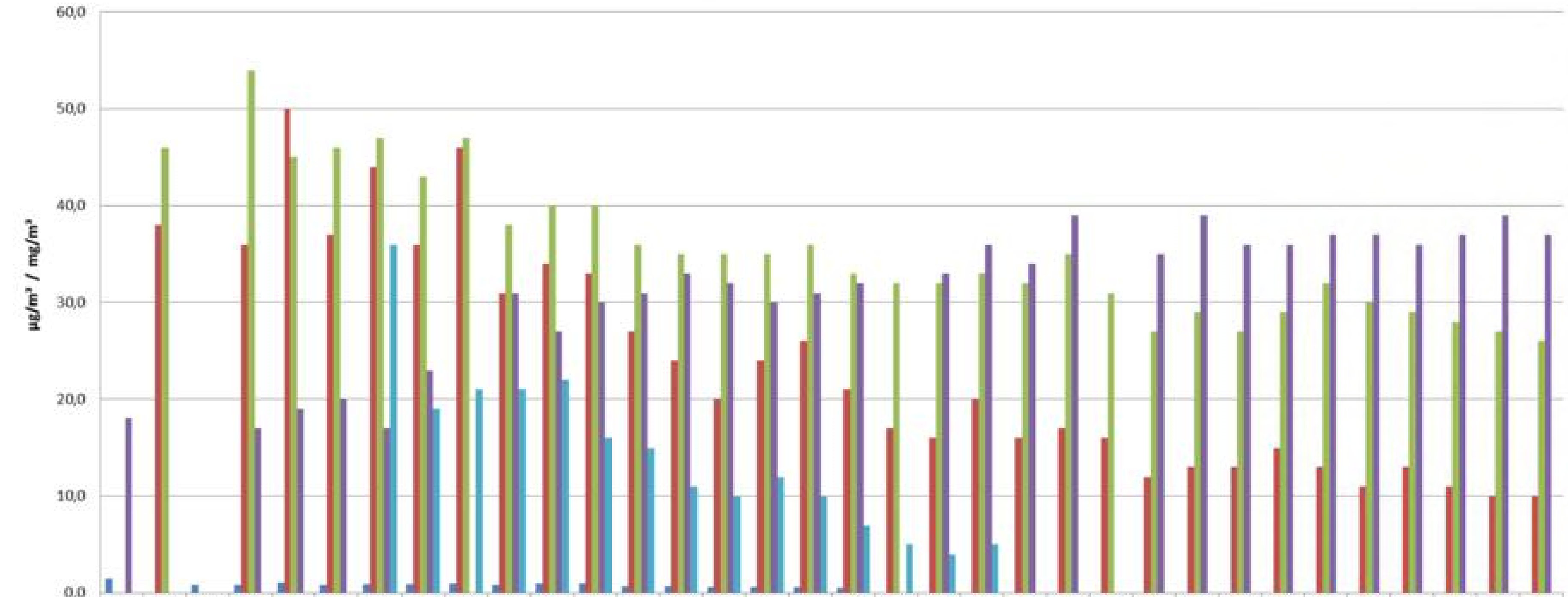


	01.01.2015	01.02.2015	01.03.2015	01.04.2015	01.05.2015	01.06.2015	01.07.2015
Köln-Rodenkirchen SO2 µg/ m³	10	10	10	10	10	10	10
Köln-Rodenkirchen NO µg/m³	16	21	24	20	8	7	7
Köln-Rodenkirchen NO2 µg/m³	33	37	39	40	28	28	26
Köln-Rodenkirchen O3 µg/m³	24	25	29	38	46	50	53
Köln-Rodenkirchen Partikel PM10 µg/m³	18	24	33	22	17	18	19
Köln-Rodenkirchen r.H %	87,4	85,5	80,6	72,3	74,4	72,6	75,9
Köln-Rodenkirchen °C	4,0	3,4	7,0	10,5	14,0	17,5	20,4

Parameters for time domain: 1981 to 2014					
Source: Landesamt für Natur, Umwelt und Verbraucherschutz NRW					
Annual average value					
	Köln-Chorweiler	**Köln-Chorweiler**	**Köln-Chorweiler**	**Köln-Chorweiler**	**Köln-Chorweiler**
Datum	**CO [mg/m³]**	**NO [µg/m³]**	**NO2 [µg/m³]**	**O3 [µg/m³]**	**SO2 µg/m³]**
1981	1,5	0	0	18	0
1982	--	38	46	--	--
1983	0,8	--	--	--	--
1984	0,8	36	54	17	--
1985	1,1	50	45	19	--
1986	0,8	37	46	20	--
1987	0,9	44	47	17	36
1988	0,9	36	43	23	19
1989	1,0	46	47	--	21
1990	0,8	31	38	31	21
1991	1,0	34	40	27	22
1992	1,0	33	40	30	16
1993	0,7	27	36	31	15
1994	0,7	24	35	33	11
1995	0,6	20	35	32	10
1996	0,6	24	35	30	12
1997	0,6	26	36	31	10
1998	0,5	21	33	32	7
1999		17	32	--	5
2000		16	32	33	4
2001		20	33	36	5
2002		16	32	34	--
2003		17	35	39	--
2004		16	31	--	--
2005		12	27	35	--
2006		13	29	39	--
2007		13	27	36	--
2008		15	29	36	--
2009		13	32	37	--
2010		11	30	37	--
2011		13	29	36	--
2012		11	28	37	--
2013		10	27	39	--
2014		10	26	37	--

Emission measuring point Köln-Chorweiler

Landesamt für Natur, Umwelt und Verbraucherschutz NRW



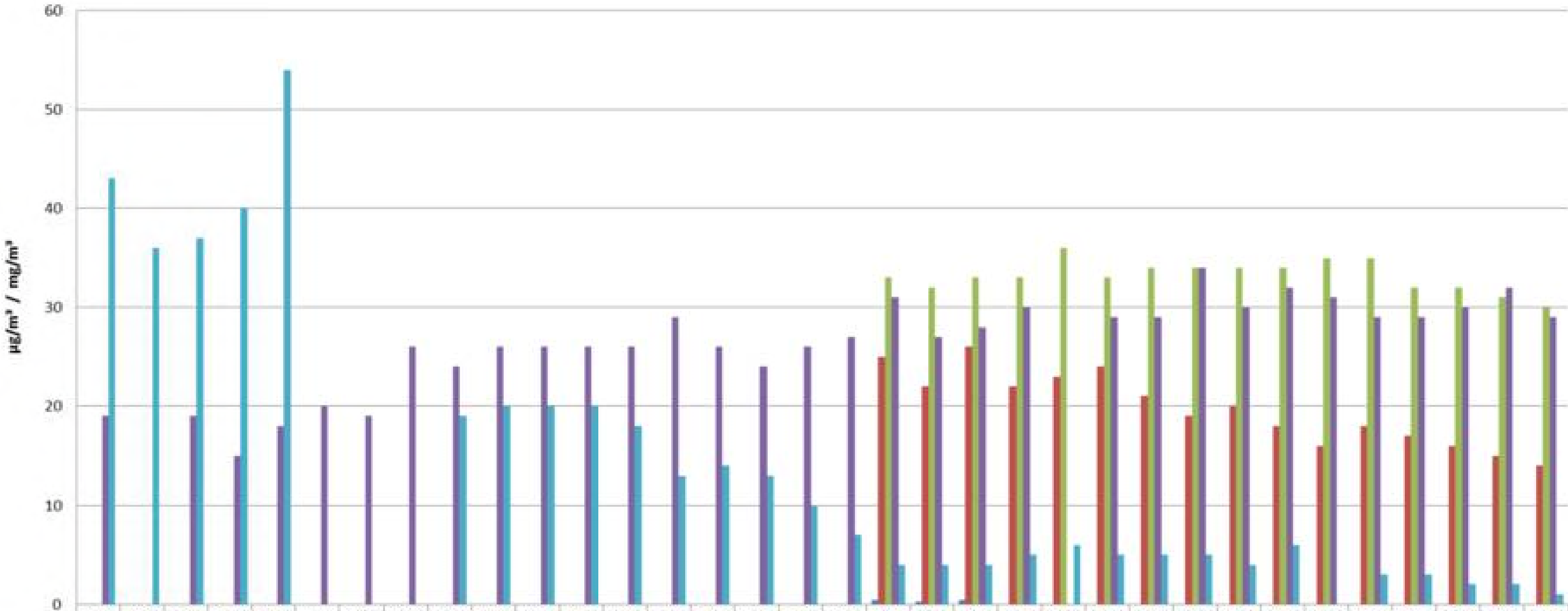
	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
CO [mg/m³]	1,5	0,0	0,8	0,8	1,1	0,8	0,9	0,9	1,0	0,8	1,0	1,0	0,7	0,7	0,6	0,6	0,6	0,5
NO [µg/m³]	0	38	0	36	50	37	44	36	46	31	34	33	27	24	20	24	26	21
NO2 [µg/m³]	0	46	0	54	45	46	47	43	47	38	40	40	36	35	35	35	36	33
O3 [µg/m³]	18	0	0	17	19	20	17	23	0	31	27	30	31	33	32	30	31	32
SO2 µg/m³]	0	0	0	0	0	0	36	19	21	21	22	16	15	11	10	12	10	7

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CO [mg/m³]																
NO [µg/m³]	17	16	20	16	17	16	12	13	13	15	13	11	13	11	10	10
NO2 [µg/m³]	32	32	33	32	35	31	27	29	27	29	32	30	29	28	27	26
O3 [µg/m³]	0	33	36	34	39	0	35	39	36	36	37	37	36	37	39	37
SO2 µg/m³]	5	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0

Parameters for time domain: 1981 to 2014					
Source: Landesamt für Natur, Umwelt und Verbraucherschutz NRW					
Annual average value					
	Köln-Rodenkirchen	**Köln-Rodenkirchen**	**Köln-Rodenkirchen**	**Köln-Rodenkirchen**	**Köln-Rodenkirchen**
Datum	**CO [mg/m³]**	**NO [µg/m³]**	**NO2 [µg/m³]**	**O3 [µg/m³]**	**SO2 µg/m³]**
1981	--	--	--	19	43
1982	--	--	--	--	36
1983	--	--	--	19	37
1984	--	--	--	15	40
1985	--	--	--	18	54
1986	--	--	--	20	--
1987	--	--	--	19	--
1988	--	--	--	26	--
1989	--	--	--	24	19
1990	--	--	--	26	20
1991	--	--	--	26	20
1992	--	--	--	26	20
1993	--	--	--	26	18
1994	--	--	--	29	13
1995	--	--	--	26	14
1996	--	--	--	24	13
1997	--	--	--	26	10
1998	--	--	--	27	7
1999	0,4	25	33	31	4
2000	0,3	22	32	27	4
2001	0,4	26	33	28	4
2002	--	22	33	30	5
2003	--	23	36	--	6
2004	--	24	33	29	5
2005	--	21	34	29	5
2006	--	19	34	34	5
2007	--	20	34	30	4
2008	--	18	34	32	6
2009	--	16	35	31	--
2010	--	18	35	29	3
2011	--	17	32	29	3
2012	--	16	32	30	2
2013	--	15	31	32	2
2014	--	14	30	29	1

Emission measuring point Köln-Rodenkirchen

Landesamt für Natur, Umwelt und Verbraucherschutz NRW



	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
CO [mg/m³]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO [µg/m³]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2 [µg/m³]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O3 [µg/m³]	19	0	19	15	18	20	19	26	24	26	26	26	26	29	26	24	26
SO2 µg/m³]	43	36	37	40	54	0	0	0	19	20	20	20	18	13	14	13	10

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CO [mg/m³]	0	0,4	0,3	0,4	0	0	0	0	0	0	0	0	0	0	0	0	0
NO [µg/m³]	0	25	22	26	22	23	24	21	19	20	18	16	18	17	16	15	14
NO2 [µg/m³]	0	33	32	33	33	36	33	34	34	34	34	35	35	32	32	31	30
O3 [µg/m³]	27	31	27	28	30	0	29	29	34	30	32	31	29	29	30	32	29
SO2 µg/m³]	7	4	4	4	5	6	5	5	5	4	6	0	3	3	2	2	1

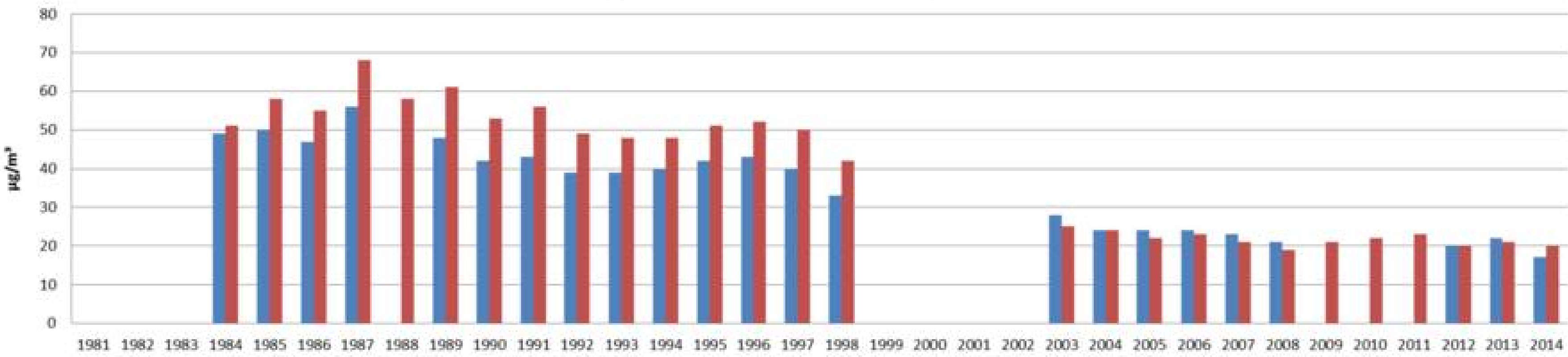
Parameters for time domain: 1981 to 2014

Source: Landesamt für Natur, Umwelt und Verbraucherschutz NRW

Annual average value of particulate air pollution

	Köln-Rodenkirchen	Köln-Chorweiler
Datum	Partikel PM10 / µg/m³	Partikel PM10 / µg/m³
1981	0	--
1982	0	--
1983	0	--
1984	49	51
1985	50	58
1986	47	55
1987	56	68
1988	0	58
1989	48	61
1990	42	53
1991	43	56
1992	39	49
1993	39	48
1994	40	48
1995	42	51
1996	43	52
1997	40	50
1998	33	42
1999	0	0
2000	0	0
2001	0	0
2002	0	0
2003	28	25
2004	24	24
2005	24	22
2006	24	23
2007	23	21
2008	21	19
2009	0	21
2010	0	22
2011	0	23
2012	20	20
2013	22	21
2014	17	20

Annual average value of particulate air pollution



	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Köln-Rodenkirchen	0	0	0	49	50	47	56	0	48	42	43	39	39	40	42	43	40
Köln-Chorweiler	0	0	0	51	58	55	68	58	61	53	56	49	48	48	51	52	50

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Köln-Rodenkirchen	33	0	0	0	0	28	24	24	24	23	21	0	0	0	20	22	17
Köln-Chorweiler	42	0	0	0	0	25	24	22	23	21	19	21	22	23	20	21	20

10. Information on historic and treatments of conservation

I. General information

Coatings with boiled linseed ─ this was for centuries a common way to impregnate and protect stone surfaces against decay. Cologne Cathedral was no exception. Reported treatments with linseed oil date from 1824 and were carried out up to the 1930ies. Additionally, in the 1830ies, tar products like bitumen and asphalts were used as barrier layers against humidity. First methodical tests with various materials for stone conservation started under cathedral architect Bernhard Hertel at the beginning of the 20th century. Comprehensive investigations on the topic of stone decay and stone conservation under the survey of scientists were initiated by cathedral architect Arnold Wolff,, when he took up office in 1972. The ─ at that time ─ most convincing results respectively agents were put into practice over 25 years as large-scaled test-treatment campaigns in such parts of the building where the stones suffered exceedingly serious deterioration.

In spite of all efforts to find acceptable means for chemical conservation treatments, the predominant procedure to meet the gradual decay is still to renew deteriorated stones with lithotypes of more robust and better resistant properties.

II. Silicon-organic conservation test-treatments between 1973 and 1978

An elaborated, large-scaled conservation campaign started in 1973, decidedly declared as test-treatments, distinctly planned as long-termed trials. The applied agents were recommended by the chemist Dr. Siegbert Luckat, Office for Immission-Protection North Rhine-Westfalia in Essen, based on his assessment of stone conservation materials applied on the “Luckat cubes” (see below, section II., “Luckat Cubes”). Used were agents that should only possess a light consolidating and water-repellent effect and were not to produce a vapor barrier. The hydrophobic effect was estimated at around 20 years.

In a first campaign, the sandstone gable of the northern façade was treated with two different agents. The east part was treated with the stone-consolidant “Steinverfestiger und Oberflächenschutz GS 447 c”, produced by Goldschmidt AG, Essen, trade name TEGOVAKON. The agents were applied by hand. The western half of the gable was treated with two products of Wacker Chemie, München. With a high-pressure spray facility either a combination of the stone consolidant W 1301 and the hydrophobaton Wacker 190 was applied or Wacker 190 solely. In 1974, the test-treatments were extended on larger areas of the two transept piers. The eastern pier was treated with the two-component consolidant TEGOVAKON H (Goldschmidt AG), applied by hand, with a subsequent treatment with the Hydrophobaton SIKOVIN (Goldschmidt AG). The western pier got the treatment with agents of Wacker Chemie, Wacker 1301 and Wacker 190, by spraying with high-pressure.

In 1976, consolidation tests were continued at this site with treatments of the east part of the north transept. Treated were surfaces of Schlaitdorf sandstone, Berkum trachyte and limestone ("Savonnières"). Used was the one-component stone-consolidant TEGOVAKON GS 374/10 (Goldschmidt AG). The one-component property was claimed by the cathedral architect, as the previous treatment with the two-component version of TEGOVAKON (see above) had turned out to be not satisfying. The agent was applied depressurized with a Wagner-Airless-spraying device. The same was true for a subsequent hydrophobation (after a break) with SIKOVIN (Goldschmidt AG).
From autumn 1975 until 1977, conservation treatments took place at the south transept façade, whose sandstone surfaces were heavily deteriorated. Start was made with the conservation of the lateral parts. At first, off-scaling and deteriorated crusts were taken off. Afterwards, strongly sanding areas that were to be preserved got a thoroughly strengthening pre-treatment with the conditioner Wacker OH (previously Wacker 1301 OH). After hardening, a-surface cleaning with to 90 °C heated water, sprayed with 40 atü, was performed. Then, after a two weeks drying time, the impregnation of the sandstone started with the hydrophbaton DYNASILAN BSM 40 S (Dynamit Nobel AG, Troisdorf), carried out twice with a Wagner-Airless-spraying device, each application up to saturation. Subsequently, the strong sanding areas were again consolidated with Wacker OH.
In 1977, the treatment was continued at the central part of the south transept façade. The procedure was more or less the same, except that the hydrophobation with DYNASILAN BSM 40 S (Dynamit Nobel AG) was forwarded. The subsequent consolidation of fragile areas was carried out with FUNCOSIL OH (Remmes Chemie, at that time trade name of Wacker OH).
The limestone areas, including the finial over the central porch, were treated differently. Tests performed by Siegbert Luckat had revealed that common hydrophobating agents were not effective on limestone. According to Luckat's results (see below, section II., "Luckat Cubes"), the limestone finial was coated with a mineral paint by Keim (Keim'sche Mineralfarbe, Keimfarben AG).
In 1978, consolidation and protection treatments were started on parts of the buttressing at the south side of the choir and the east side of the south transept. TEGOVAKON V (Goldschmidt AG) was used for consolidation, followed by a hydrophobing with DYNASILAN BSM 40 S (Dynamit Nobel AG).
From now on hydrophobing treatments with DYNASILAN BSM 40 S (Dynamit Nobel AG) were carried out only on sandstone areas of single structural elements, such as pier J 11 in 1981/82 or pier J 8 in 1985.
For years, but in vain, cathedral architect Arnold Wolff requested a follow-up examination of the impregnated areas. It was only in 1986 that the efficiency of the hydophobing treatment was scientifically controlled. Hundreds of penetration tests with "Karsten-Tubes" were performed by the Zollern-Institut, Dortmund. The results were classified by Arnold Wolff as "extremely

disappointing". From his point of view, the test method with Karsten-Tubes turned out as insufficient, because the results of the penetration tests were divergent and partly contradicting. They were never published.

In 1994, hydrobation treatments were stopped at Cologne cathedral. "**It is irresponsible to impregnate the building with agents whose efficiency cannot be verified**", was Arnold Wolff's statement. He often complained in public, that producers of stone protecting agents were selling their products without giving proof of the long-termed effect and were even not helpful in developing appropriate assessment methods.

At least, after an observation period of 15 years, the durability and efficiency of the treatments carried out at the northern and southern transept façades was again investigated by scientists. The documented sample areas were tested on their water-repellent behavior again with "Karsten Tubes". As evaluation criterion the water-absorption coefficient was used (w-value). Additionally a water-transport value was introduced (ω-value).

Evaluated were test treatments of Schlaitdorfer sandstone with:

- KSE OH ─ Consolidation agent, Wacker Chemie
- W 190 ─ Hydrophobing agent, Wacker Chemie
- TEGOVAKON 447 c ─ Hydrophobing agent, (meanwhile) Evonik Industries
- DYNASILAN BSM 40 S ─ Hydrophobing agent, Dynamit Nobel AG

The results of the measurements are depicted in table 1-3:

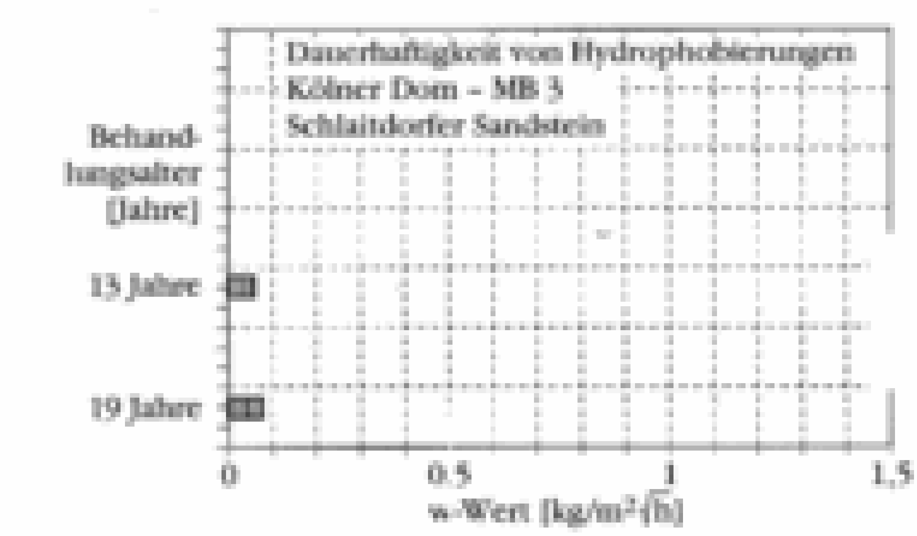


Table 1: Cologne Cathedral, northern transept (gable), Schlaitdorfer sandstone, in 1973 consolidated with KSE OH, then hydrophobated with W 190; w-value < 0,1 kg/m^{2}h^{0,5} (depending on the age of the treatment). [Source: Wendler et al., p. 200, Abb. 3]

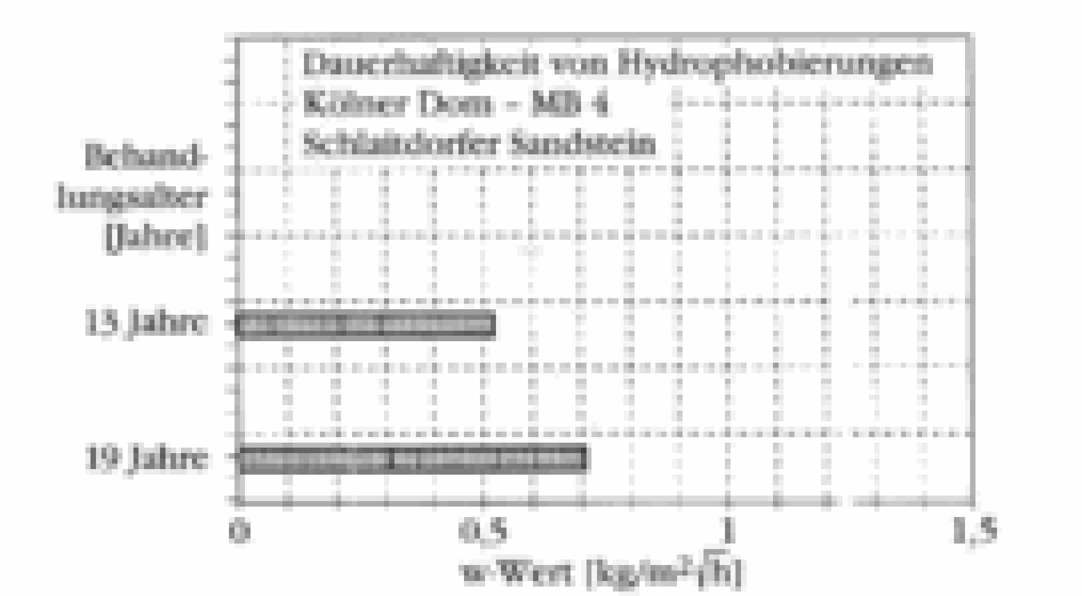


Table 2: Cologne Cathedral, northern transept (gable), Schlaitdorfer sandstone, in 1973 consolidated and hydrophobated with MB 4 Tegovakon 447 c (1973); w-value > 0,5 $kg/m^2h^{0,5}$ (limit of the water-repellent behavior is achieved) [Source: Wendler et al., p. 200, Abb. 4]

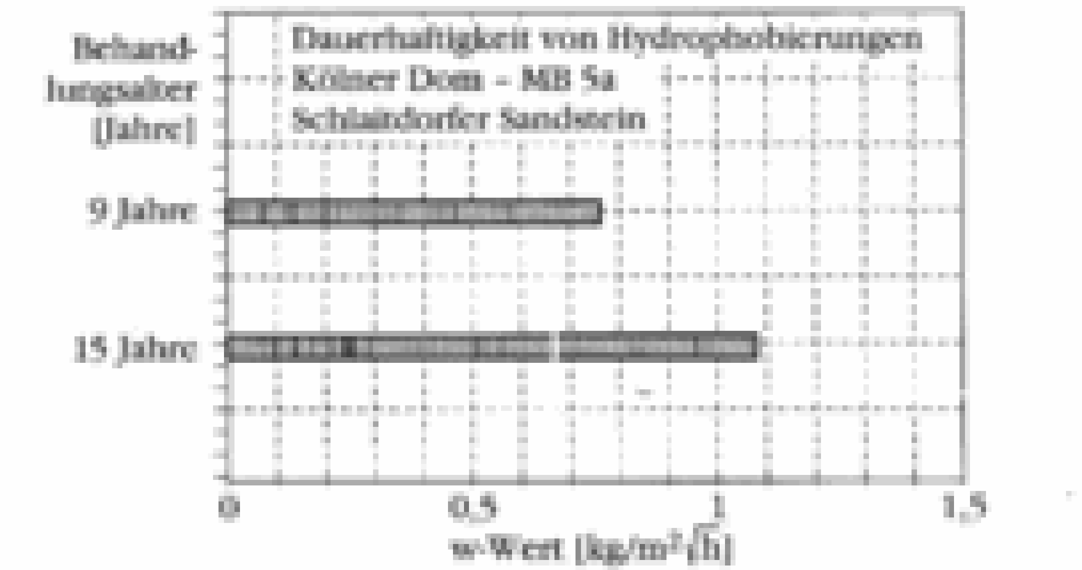


Table 3: Cologne Cathedral, southern transept (gable), Schlaitdorfer sandstone, in 1977 partly consolidated with KSE OH, then hydrophobated with Dynasilan BSM 40 S;
w-value > 0,5 $kg/m^2h^{0.5}$ (progressive degradation of the hydrophobation, depending on the age of the treatment) [Source: Wendler et al., p. 200, Abb. 5]

According to the scientists, the results confirmed results of earlier investigations: The efficiency of Si-organic hydrophobata decreases considerably after 10 to 15 years. Remarkable differences were observed with respect to the exposition and the applied hydrophobating agents.

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II. Long-termed durability tests with various conservation agents in 1975─1978 (“Luckat Cubes”)

In 1973, parallel to the conservation activities described above, started a long-lasting comprehensive investigation regarding the air quality of Cologne and the influence of pollutants on building stones of Cologne Cathedral, of the Minster of Ulm and of some places in Duisburg (in those days one of the highest polluted area in the Federal Republic of Germany). The study was developed and performed by Dr. Siegbert Luckat. Based on these investigations Luckat extended his work with systematic investigations of various conservation agents on lithotypes from Cologne Cathedral, including agents, that had already been applied on sandstone surfaces at the North and South transept façade (see above: II: Silicon-organic conservation test-treatments between 1973 and 1978).

Between 1975 and 1977, an amount of 840 cubes of 4 cm edge length, cut from 8 different stone types were prepared for comparative test-treatments with 40 conservation agents.

Included were the following lithotypes:

1. Schlaitdorf sandstone rough grained,
2. Schlaitdorf sandstone fine grained,
3. Obernkirchen sandstone,
4. Shell limestone from Krensheim,
5. Drachenfels trachyte,
6. Londorf basaltic lava,
7. Baumberg sandstone,
8. Stenzelberg trachyte (in 1977 only).

First, the cubes were subjected to various destructive tests, e.g. crystallization tests with sodium sulfate or treatments combining sulphuric and hydrochloric acid in change with drying cycles. From each stone type, one untreated cube and 40 treated cubes underwent no laboratory tests, but were exposed at the cathedral, on grills mounted on the western slope roof of the south transept. Luckat's evaluation system was simple: the results were either "acceptable" or "not acceptable". According to that, Luckat gave for each lithotype a "recommendation" which of the applied agents seemed to be the most appropriate (consolididator or hydrophobaton, separately or in combination).

In 1975, Luckat's treatment recommendations for the various lithotypes were as follows:

Schlaitdorf sandstone, rough, deteriorated:	TEGOVAKON H, Goldschmidt AG (needs subsequent hydrophobating with SIKOVIN, Goldschmidt AG) Sandsteinfestiger H, Wacker-Chemie
Schlaitdorf sandstone, rough, sound	Bautenschutzmittel LP-C 3631/2, Dynamit Nobel AG
Schlaitdorf sandstone, fine, deteriorated	TEGOVAKON H, Goldschmidt AG (needs subsequent hydrophobating with SIKOVIN, Goldschmidt AG) Sandsteinfestiger H, Wacker-Chemie
Schlaitdorf sandstone, fine, sound	Bautenschutzmittel LP-C 3631/2, Dynamit Nobel AG Bautenschutzmittel LP-C 3631/3, Dynamit Nobel AG
Shell-limestone from Krensheim, low damaged	Bautenschutzmittel LP-C 3631/2, Dynamit Nobel AG Bautenschutzmittel LP-C 3631/3, Dynamit Nobel AG (preferred)

Obernkirchen sandstone	Bautenschutzmittel LP-C 3631/2, Dynamit Nobel AG Bautenschutzmittel LP-C 3631/3, Dynamit Nobel AG (preferred)
Londorf basaltic lava	No treatmend required
Baumberg sandstone	TEGOVAKON H, Goldschmidt AG (needs subsequent hydrophobating with SIKOVIN, Goldschmidt AG)

Two years later, in 1977, Luckat's positive assessment concerning a treatment of the various lithotypes (partly a combined treatment of two agents, one for consolidation and one for hydrophobation with a 3-weeks break between both treatments) were as follows:

Schlaitdorf sandstone rough, Shell-limestone from Krensheim, Baumberg sandstone	TEGOVAKON H, Goldschmidt AG
Schlaitdorf sandstone rough and fine, Shell-limestone from Krensheim, Baumberg sandstone, Stenzelberg trachyte	TEGOVAKON T, Goldschmidt AG combined with TEGOSIVIN HL 20 , Goldschmidt AG (additionally applied after 3 weeks)
Schlaitdorf sandstone rough, Shell-limestone from Krensheim, Stenzelberg trachyte	TEGOVAKON T, Goldschmidt AG combined with TEGOSIVIN HL 20 , Goldschmidt AG (additionally applied after 3 weeks)
Schlaitdorf sandstone rough and fine, Shell-limestone from Krensheim, Stenzelberg trachyte	TEGOVAKON V, Goldschmidt AG
Schlaitdorf sandstone rough, Shell-limestone from Krensheim, Stenzelberg trachyte	Sandsteinverfestiger OH, Wacker Chemie, combined with Wacker 190, Wacker Chemie (additionally applied after 3 weeks)
Schlaitdorf sandstone fine, Shell-limestone from Krensheim, Stenzelberg trachyte	Funcosil Steinfestiger OH, Remmers Chemie, combined with Funcosil SP, Remmers Chemie (additionally applied after 3 weeks)
Drachenfels trachyte, Schlaitdorf sandstone rough and fine, Obernkirchen sandstone Shell-limestone from Krensheim, Stenzelberg trachyte,	Keim-Purkristalat-Farbe, Industriewerke Lohwald, Keimfarben GmbH, combined with Bautenschutzmittel LP-C 3631/2, Dynamit Nobel AG (trade name: DYNASILAN BSM 40 S)

Luckat summarized the insights of his investigation as follows: **An ideal stone conservation material would penetrate endlessly deep, would effect a consolidating without scaling, would not change porosity and water vapor permeability, would have an unlimited water-repelling effect and would not change the visual appearance of the surface**. Such a remedy does not exist. But Luckat stated an increasing trend towards Si-organic products, such as silicic acid, silicone resins or silicons. From his point of view, these compounds were comparatively close to what could be called an ideal stone conservation product.

Twenty years later, the condition of the exposed cubes were again examined by the scientists Esther von Plehwe-Leisen, Hans Leisen and Thomas Warscheid. The pilot program was concentrated on treated cubes of Schlaitdorf sandstone. The strictly non-destructive testing program covered all exposure conditions and included investigations of water-transport properties, mechanical behavior and microbiological contamination. The samples were classified according to the chemical character of the applied agents. In course of the examination, distinct variations between the different groups became evident regarding the degree of hydrophobing efficiency, microbiological contamination and visual spoiling. The published results focused on Si-organic treatments.

The results can be summarized as follows: After 20 years of exposure capillarity remains still reduced for many types of treatments. Best values were determined for samples that were consolidated with Silicic-Acid Ester OH and SAE H [see list above] and got a subsequent hydrophobing with Si-organic water-repellents. The same is true for Polymethylmethacrylat (PMMA) total impregnated cubes. The general assessment of expert says that degradation of water repellency is distinctly dependent on exposure situation; impact of water and pollutants obviously accelerates the degradation of the agents. But the surface absorbency measurements performed in the actual tests presented opposite behavior. Regarding the samples, the range of surface absorbency is much smaller on rain-exposed than on sheltered surfaces. Apart from surfaces covered by silicate paint or coatings all sample groups disposed of surfaces less water-conductive than the untreated cubes. A comparison of the results determined at the cubes and at test areas almost simultaneously treated with comparable agents demonstrated a good conformity of water-uptake measurements. Increase velocities of ultrasonic waves reflected the influence of the treatments on the mechanical properties, which was highest for SAE OH and SAE H and for PMMA total impregnation. Concerning microbiological contamination, which depends on the presence of moisture, high microbial activities on cubes combined with low capillarity and surface absorbency hint on additionally important parameters like nutritive effect of agents used. Combinations of agents altered the properties of the single treatment. Thus, subsequent hydrophobing impeded the extreme spoiling of rain-exposed surfaces of SAE OH consolidated cubes. Additional water-repellent impregnation of silicate paints altered the adhesion to the stone and reduced the velocity of paint degradation.

Further results of this investigation were not published.

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III. Stone conservation treatments at the south choir buttressing in 1978–1999

Between 1978 and 1999, parts of the buttressing at the choir underwent long-termed conservation test-treatments with various consolidating and hydrophobing agents. Although erected between 1248 and 1300, today the exterior structure of the choir is only in parts medieval. As the deterioration of the medieval trachyte was alarming already in the 19th century, first exchanges against sandstone took place already in the 1850ies. Since the beginning of the 20th century, especially between 1926 and 1939, substantial parts of the trachyte stonework, including the flying butresses were by and by replaced by shell limestone from Krensheim. To protect the shell limestone against future decay, surfaces were coated by the oleaginous scale inhibitor TEKAOL.

Unfortunately, the Krensheim shell limestone did not keep what cathedral architect Bernhard Hertel and his successor Hans Güldenpfennig had expected. Already in the 1950ies first damages were visible, since then deterioration is noticeably increasing.

As the silicon-organic conservation test-treatments carried out between 1973 and 1978 at the south transept façade had turned out to be more than insufficient within ten years only, Arnold Wolff considered a traditional protection-method, in use already in the Middle Ages: coatings with lime. A first treatment underwent the pinnacle above pier buttress C 12. An expert group with scientists and experienced conservators prepared four calcareous mixtures with inorganic pigments. The treatment did not produce the desired effect. Only two years after application, the protection coatings had lost adhesion and were powdering.

Therefore, in 1996, Arnold Wolff architect extended the experiments to protective coatings based on silicone resin. Two pinnacles, the pinnacle C3 on the roof gallery balustrade and the pinnacle above the intermediate buttress B2, were coated with stone consolidant Funcosil 100 and Funcosil VM 857 resp. Funcosil VM 860. To match the visual appearance of the surrounding stonework, the material was produced in a special modification, that combined a certain transparency and a pigmentation with light ochre. The compound was termed as “Funcosil Silicon Streichputz Sonderrep. 110 KNK-A”. It consists primarily of Wacker-Silicone and a mixture of various calcite dusts, additives and pigments. The test-treatment with silicone resin was finished in 1999. Apart from the fact, that the applied coating did not fully match the desired visual effect – it was too homogeneous and too light – the impression was positive. Up to now, no negative alteration has been detected by visual controls. Further investigations have not been performed as yet.

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D1.1 – Part B, Background information on the architectural object: Sint Baasf Cathedral (Ghent, Belgium)

Colophon

- All drawings by Architectenbureau Bressers, unless stated otherwise.
- All pictures by Ignace Roelens for Architectenbureau Bressers, unless stated otherwise.
- The text for the chapter *Construction History* is a slightly modified version of the Visitors Guide of the Cathedral, published by Openbaar Kunstbezit Vlaanderen vzw (DE RYNCK, P., *St Bavo's Cathedral. Visitors Guide*, Openbaar Kunstbezit Vlaanderen vzw, Ghent, 2014).
- The text for the chapter *Architecture and art* was obtained from a publication that was published on behalf of the Deputation of the Province of East Flanders and developed in partnership with vzw *Monumentale Kerken Gent*, a non-profit umbrella organisation that aims to promote cooperation between the five parish churches in Ghent city centre and make the city's cultural heritage more accessible to the general public. It was written by Sophie Anseeuw and Liesbet Kusters.

Main figures

Length:	119 m
Width:	47 m
Height of West Tower:	89 m
Ridge height central Nave:	41 m
Height of the central Nave cornice:	33 m
Height of the Nave-aisles cornice:	15 m
Ridge height Choir:	41 m
Height of the Choir cornice:	33 m
Height of Choir-aisles cornice:	19 m

1. General information

St Baafs Cathedral is the most monumental church in Ghent. It is the primary church of the diocese of Ghent and the headquarters of St Bavo's Chapter. The cathedral is situated in the city centre, and has been classified as a monument by law from 1936 onwards.

Management

The cathedral is owned and managed by the church council (the so-called 'kerkfabriek'), a public institution that manages all material means necessary for the performance of the religious service. Among other things, they are responsible for the maintenance of the church building.

Maintenance and restoration of the cathedral

Maintenance and restoration of the Cathedral involves different partners. The Cathedral of Ghent has no workshop of its own. For construction and restoration works on the inside and outside of the cathedral, the church council contracted Architectenbureau Bressers. They act as counsellor for the church council and manage the elaboration, coordination and follow-up of different restoration and maintenance works.

As mentioned above, the Cathedral is classified as a monument by law (dd. 28/12/1936), which means that all works on the building have to be approved and monitored by the Heritage department of the Flemish Government. This government can grant subsidies up to 80%. Finally, as the church council is a public institution, works have to be executed by independent contactors that are assigned following the federal procedure of a public tender.

2. Construction History

The church as we see it today was built and restored in various phases. Hence the variations in style and lithotypes. The general construction history of the cathedral can be roughly classified into five extensive building campaigns, as illustrated on the image below.

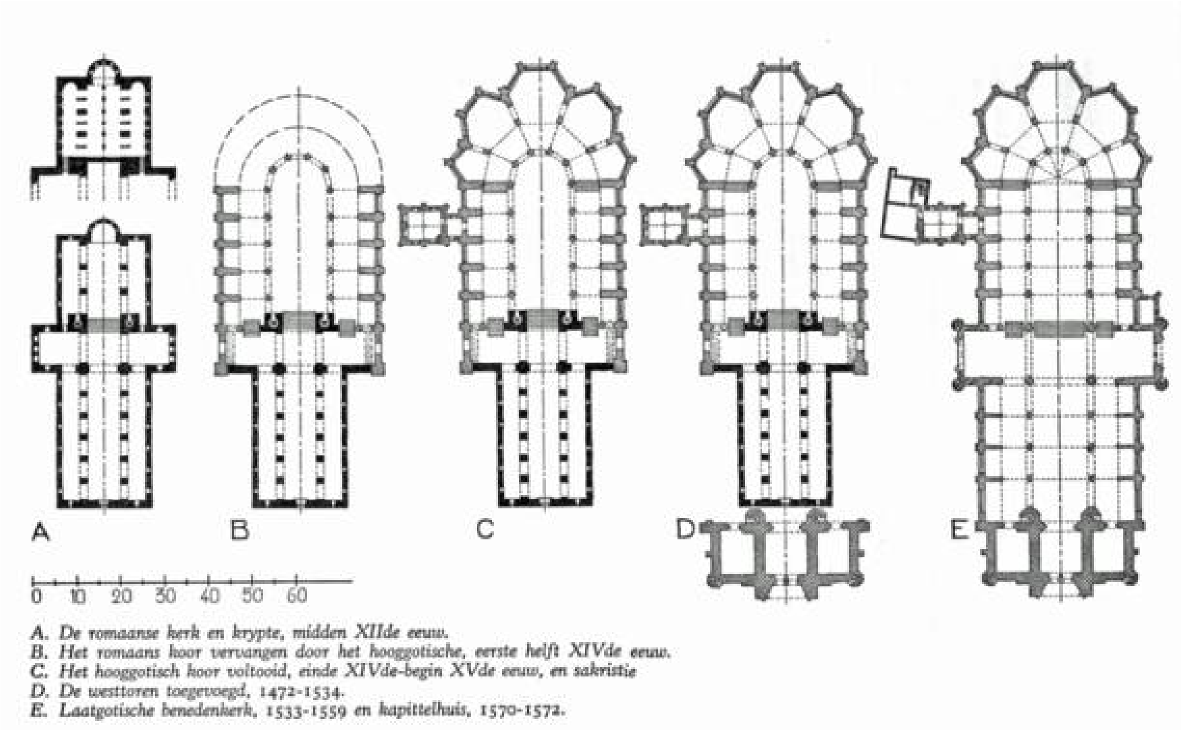

Image 1. **General construction history**

Source: DHANENS, E., *Sint-Baafskathedraal Gent, Inventaris van het kunstpatrimonium, Provincie Oost-Vlaanderen*, deel V, Ghent, 1965, p. 32

A	Roman church and crypt	middle of the 12th century
B	Replacement of the Roman choir with the Gothic choir	first half of the 14th century
C	Completion of the Gothic choir and addition of the sacristy	end of the 14th - start of the 15th century
D	Addition of the west tower	1472 - 1534
E	Replacement of the lower part of the nave	1533 - 1559
	Addition of the chapter house	1570 - 1572

<u>The oldest church: ca. 942</u>

St. Bavo's Cathedral dates back to Ghent's oldest parish church. The earliest mentions of this church date back to the mid-10th century, when the cathedral was still known as St John's Church. Bishop Transmarus of Tournai and Noyon is said to have consecrated this church building that was dedicated to St John the Baptist, the principal patron saint of the *Portus Gandavensis* or 'trading post at the mouth of the river'. This was the ninth-century settlement at the confluence of the rivers Lys (Leie) and Scheldt (Schelde), which later became the city of Ghent. At the core of that settlement were two abbeys: St Bavo's and St Peter's. According to some sources, the church was repaired in 1030 and possibly enlarged. There is no longer any material evidence of this place op prayer mentioned in the second half of the ninth century.

The Romanesque church: 12th century (A)

The earliest church was gradually replaced by a Romanesque-style place of prayer. Under the Gothic chancel, vestiges of it's crypt are still to be seen. These elements date back to the 12th century. This romanesque church was a triple-aisled cruciform church with a lantern tower and a triple-aisled choir above an equally large crypt.

Image 2. Remains of the Romanesque crypt.

The growth of Ghent's population in this period resulted in the establishment of two new parishes – St Nicholas and St James – in addition of the parish of St John. The chancel of St John's Church was too small to accommodate all the families and organisations keen to have a chapel there and it was not 'modern' enough for Ghent, that was undergoing such explosive growth.

The Gothic Choir: 14th and 15th century (B+C)

As the city of Ghent continued to grow, St John's Church was converted into a Gothic church in the 13th century. The first part to be tackled was the high choir. At the end of the 13th century the old side choirs were demolished and in the 14th century the ambulatory and side chapels were extended in the local variant of the Gothic style, the so-called 'Scheldt Gothic'. It was not completed until the beginning of the fifteenth century, when the radiating chapels and the choir aisle were built in a Brabant-inspired High Gothic style. At that time, the Romanesque nave still existed. Political, economic and social problems may explain why it took so long to build. At the start of the fifteenth century the sacristy was built to the north of the church.

A new tower: 1472 - 1534 (D)

From 1472 onwards, a Brabant Gothic tower was built in front of the Romanesque nave. The building works dragged on for more than seventy years, until approximately 1534.

From St John's to St Bavo's: 1533 - 1559 (E)

Once the chancel and tower were built, the Romanesque nave and transept were replaced in a new High Gothic style. These works were completed in 1559. In the meanwhile, Charles V had St. Bavo's Abbey converted into a secular chapter in 1536. Following the Revolt of Ghent in 1539, the abbey closed its doors for good and the various abbey buildings were demolished. The canons moved to St John's Church, which was then renamed St. Bavo's Church. On 12 May 1559, when the papal bull 'Super Universas' was signed by Pope Paul IV, Ghent became the seat of the diocese and St. Bavo's Church was renamed St. Bavo's Cathedral.

Finally, the wooden chancel vaults were replaced by brick vaulting in the seventeenth century, and the general view of the cathedral, as we know it today, was established.

3. Architecture and art

Saint Bavo

Bavo, originally called Allowin, was born in about 600 in Hesbaye and hailed from a noble Merovingian family. His youth and married life were characterised by frivolous court life and the horrors of life on the battlefield. This far from pious lifestyle ended with the death of his wife. Allowin repented, distributed his wealth and joined St Amand in Ghent, where he was given the name Bavo. He chose the lonely life of a hermit until his death around 650. Bavo is depicted as a knight holding a sword and accompanied by a falcon. He is the patron saint of the diocese of Ghent and the falconers, and is invoked to cure whooping cough, throat and lung infections.

Historic overview

St Baafs Cathedral is Ghent's oldest parish church. The earliest mentions of this church date back to the mid-10th century, when the cathedral was still known as St John's Church. It is said that Bishop Transmarus of Tournai and Noyon wanted a small church dedicated to John the Baptist, the main patron saint of Ghent, built in this exact location in the thriving trade settlement. Trading activities were concentrated behind the church, in the city's first port, at the confluence of the rivers Scheldt and Lys.

Centuries earlier, in about 630, St Amand had founded St Bavo's Abbey on the other side of the rivers. He had also founded another abbey at about the same time, dedicated to St Peter. The first inhabitants who lived there were secular priests under the authority of the bishop, but later became Benedictines. St Bavo's Abbey gradually developed into one of the main religious institutions in the Low Countries. That changed when Charles V had St Bavo's Abbey converted into a secular chapter in 1536. Following the Revolt of Ghent in 1539, the abbey closed its doors for good and the various abbey buildings were demolished. The canons moved to St John's Church, which was then renamed St Bavo's Church. On 12 May 1559, when the papal bull Super Universas was signed by Pope Paul IV, Ghent became the seat of the diocese and St Baafs Church was renamed St Baafs Cathedral.

Architectural history

No material traces have been found of the original 10^{th} century parish church. The oldest visible architectural elements date back to the 12^{th} century Romanesque church, a triple-aisled cruciform church with a lantern tower and a triple-aisled choir above an equally large crypt. Only the central part of the Romanesque crypt has survived.

As the city of Ghent continued to grow, St John's Church was converted into a Gothic church in the 13^{th} century. The first part to be tackled was the high choir. At the end of the 13^{th} century the old side choirs were demolished and in the 14^{th} century the ambulatory and side chapels were extended in early Gothic style. Later, five apse chapels were also extended in a Brabant-inspired High Gothic style. A Brabant Gothic tower was built in front of the Romanesque nave and later the old nave and transept were converted into a new, uniform High Gothic structure. The works were completed around the mid-16th century. The result is a perfect sample of the ever-evolving Gothic architectural style.

With the rise of Protestantism, religious turmoil and the resulting Iconoclastic Fury of 1566 and 1578, many church interiors were destroyed, including St Bavo's Cathedral's. Only *The Adoration of the Mystic Lamb*, which had promptly been moved to the tower, was saved. It was only when Antoon Triest was appointed Bishop of Ghent that the interior of the cathedral was restored to its former glory, albeit in the style of the Counter-Reformation, Baroque. To this day, the church's appearance is dominated by the striking opulence of its furnishings with their dramatic, contrasting and lively decorations.

A key figure in the evolution of the church is Bishop Antoon Triest (1576-1657). Following a period of office in Bruges, he was appointed the seventh Bishop of Ghent in 1620. His official inauguration in 1622 marked the start of a 35-year term. As part of his resolute approach, Triest made great efforts to help the poor. He also regularly visited the parishes and accurately described the state of each church, the maintenance required and the artworks it housed. Triest was an art collector and enjoyed redecorating the cathedral. In his will he left a large sum for the continuation of these works.

Following the annexation of the region to France (in the late 18th century), all church property was confiscated. St Bavo's Cathedral suffered the same fate. Its most valuable paintings were all taken to Paris. Church life was restored after the Concordat of 1801 between Napoleon and the Vatican. Ghent once again had a bishop, who ensured the cathedral was used for its intended purpose and the chapter became operational again. It was only after Belgium became independent that the necessary restoration works finally started, this time in the Gothic revival style. There was a very fine line between restoration and renovation. Inside the church, plaster was removed, the high choir was equipped with new stained-glass windows and the triforium in the nave was decorated with tracery.

Art and interior

Apart from the Gothic exterior, the interior of the church also has a lot to offer. The cathedral is one of the most frequently visited monuments in Ghent, as it is home to not only the world-famous altarpiece *The Adoration of the Mystic Lamb*, but also to over ten centuries of history and art history.

The western entrance

A Renaissance porch dating back to 1572 welcomes visitors inside. The design speaks for itself: it is a temple structure with semi-columns resting on heavy plinths. The cornice is inscribed with the motto of Viglius Aytta, the church's priest at the time, who donated the structure. The pediment features his coat of arms, flanked by that of the chapter and the *Sint-Baafsheerlijkheid* manor.

The Ghent Altarpiece: The Adoration of the Mystic Lamb

St Baafs Cathedral is home to one of the greatest masterpieces of Flemish painting, *The Adoration of the Mystic Lamb*, also known as the *Mystic Lamb*. After Hubert Van Eyck (c.1366-1426) died, the retable was completed by 1432 by his brother Jan (c.1390-1441). The piece was commissioned by Joos Vijdt, Alderman of Ghent and church warden of the then St John's Church, and his wife Elisabeth Borluut. Initially the altarpiece was displayed in their private chapel in the ambulatory. The iconography on the middle panel is inspired by the Book of Revelation. The central scene is the redemption of mankind through the sacrifice of Christ on the cross, represented in the form of the Lamb. The surrounding panels show figures on their way to worship the Lamb, from the Just Judges to the Knights of Christ, hermits and pilgrims. Above we see Christ on his throne, flanked by Mary and John. The side panels show Adam and Eve, as well as angels singing and making music.

The restoration process of *The Adoration of the Mystic Lamb* started in 2012. The panels are being restored in various phases at the Museum of Fine Arts in Ghent, where visitors can follow the restoration. During this process the Caermersklooster Provincial Cultural Centre is hosting an exhibition on the history of the altarpiece.

Image 3. Replica of *The Adoration of the Mystic Lamb* by Jan and Hubert Van Eyck (1432), positioned in the Vijd Chapel.

The pulpit

The pulpit is a sculptural masterpiece in Rococo style, which was created in 1741-1745 by the renowned sculptor Laurent Delvaux (Ghent, 1696-Nijvel, 1778). The central group shows two allegorical figures. The woman holding an open book represents Truth, while the winged man symbolises Time. Time throws off his veil and looks at Truth – simply put, in time the truth will always emerge. The woman is seen leaning against the tree trunk that supports the enclosure. The staircase is flanked, left and right, by an angel with Antoon Triest's coat of arms. Three marble reliefs adorn the enclosure: the birth of Jesus, the conversion of Paul and the conversion of Bavo. The draped abat-voix is supported by an apple tree, a reference to the Garden of Eden, and above, the angels are seen carrying a cross.

The nave chapels

The nave has four side chapels on the northern side and four on the southern side. In the 19th century, in line with the neo-Gothic style, the gates were replaced and the chapels were entirely redecorated. The dignified set-up in the new concept illustrates the respect for older artworks. A perfect example is the St. Macarius chapel, a neo-Gothic *Gesamtkunstwerk* designed by the renowned Jean-Baptiste Bethune (1821-1894). The polychrome interior, the stained-glass window, the sculptures and the gate form one harmonious whole.

The statues of Peter and Paul

The choir gate is flanked by statues of St Peter and St Paul, which were created by Karel van Poucke (1740-1809) around 1780. This Diksmuide-born sculptor settled in Ghent following a stay in Italy and became Director of the Ghent Conservatory. St Peter is depicted in the traditional counter-pose holding two crossed keys. St Paul is seen throwing the adder that had bitten his hand in the fire. This representation of the saint, in a pose based on a Bible story, is rather uncommon.

Image 4. View on the interior of the Cathedral.

The painting The Conversion of Saint Bavo

The Conversion of Saint Bavo (1624) is a masterpiece by Peter Paul Rubens (1577-1640), who was asked to create a painting to adorn the main altar in 1612. When the then bishop died, Rubens remained unpaid, but after countless disputes, he completed the work following the appointment of Triest as bishop, who was a great admirer of the painter's work. The painting depicts two important events: the conversion of Bavo and his entry into the monastery. At the centre of the panel, the steward is seen distributing Bavo's possessions while Bavo's daughter Gertrude, on the left, is watching the scene above. We see Bavo kneeling in full armour beneath an arch, while Amand and Floribert, wearing mitres, welcome the convert. The staircase running diagonally across the painting links the two scenes.

The organ

In 1650 Bishop Triest ordered this Baroque organ from Bis and Destré in Lille. At the same time, Ghent-born carpenter Boudewijn van Dickele built the case. The instrument is still where it originally stood, but it was renovated in 1767 by Ghent-born organ maker Lambertus Van Peteghem (1742-1807) and in 1935 it was coupled to the organ for the Brussels World Expo built by Johannes Klais (1890-1965) from Bonn.

The high choir

The high choir stands ten steps above the nave and is one of the most beautiful examples of the Baroque refurbishment. It is enclosed by Italian marble, decorated with 13 grisaille reliefs by Ghent-born painter Pieter Norbert van Reysschoot (late 18th century). They represent scenes from the Old and New Testament related to the Eucharist. The mahogany choir stalls lead visitors to the high altar. There is a dramatic representation of Bavo right above the temple-shaped tabernacle, in a central position. He is looking up to heaven, flanked by Amand and Livinus.

Image 5. View on the high choir with its Baroque refurbishment in Italian marble.

The choir chapels

The ambulatory has ten side chapels and five apse chapels with exuberantly decorated Baroque gates. These chapels were financed by guilds, clergymen or private individuals whose coats of arms are visible on the gates. An image of the saint to whom the chapel is dedicated is given pride of place. The chapels are richly decorated with artworks from the 16th to the 21st century, reflecting harmony in diversity. The stained-glass windows by Hendrik Blondeel (1956-1997) in the Vijdt Chapel and by Michel Martens (1921-2006) in the Priest's Chapel illustrate the perfect integration of contemporary art in a historical setting.

Image 6. View on the central choir chapel.

The mausoleum of Bishop Antoon Triest

Triest's mausoleum was created in 1652-1653 by Jerôme Duquesnoy the Younger (1602-1654), a sculptor who had learned the craft from his father and went on to forge a brilliant career in Brussels. The Bishop is represented reclining and looking at the choir. Below, two angels hold a scroll with an inscription. They are flanked by two seated angels holding an hourglass and an inverted torch, the symbols of transience. The mausoleum and the statues of Mary and Christ beside it are placed in an architectural setting, forming part of a group of works in honour of four Bishops of Ghent.

The coats of arms

The 51 coats of arms of the Knights of the Order of the Golden Fleece commemorate the 23rd and last Ghent Chapter of 1559.The coats of arms of the first Ghent Chapter, from 1445, are visible on the choir gate. From 1430 onwards, its members, who all belonged to the highest noble ranks, formed an advisory board for the House of Burgundy and later the House of Habsburg. Its members included Charles V, Philip II and the Count of Egmont. The family coats of arms of the Knights of the Golden Fleece can be recognised by the golden chain from which a ram's fleece is suspended.

The crypt

An underground crypt was the ideal place to worship martyrs, saints and their relics. The crypt at St Baafs Cathedral is the largest in Flanders and was used both for the regular veneration of the saints and the veneration of the Holy Sepulchre. All this can be seen in the iconography of the crypt's frescoes. The quality and technique of the late mediaeval frescoes is highly varied, which makes it likely that they were created by various painters.

Image 7. View on the central part of the crypt with its late mediaeval frescoes (15th-16th century).

The Gospel Book of Livinus

This valuable parchment manuscript dates back to the 8th century and is part of the collection that was transferred to the former St John's Church from St Bavo's Abbey in 1540. It includes a letter written by Abbot Othelbold (1019-1030) to Countess Otgiva concerning the relics at St Bavo's Abbey, with an inventory of the artworks that had survived the Norman invasions. The red velvet band with embossed silver was created in the second half of the 17th century by Jan van Sychen. The engraved medallions depict St Livinus as a bishop, holding a cross staff and his ripped-out tongue in a pair of tongs. The Gospel Book and four other artworks are on the Flemish Government's List of Masterpieces and are part of the Cathedral's large collection of manuscripts.

The Calvary Triptych

This triptych was created by Joos van Wassenhove (c. 1464-1468). The painter combined the style of the Flemish Primitives with that of the Early Italian Renaissance. The painting represents Calvary, with Jesus on the cross in the centre, high above the crowd in a mountainous landscape. On the left, Mary is seen fainting, supported by John and Mary Magdalene, while Longinus appears on horseback on the right. The side panels show predictions from the Old Testament of Jesus' redemptive death on the cross. The left panel shows Moses throwing a log into the water of Marah to make it sweet, and on the right he is seen placing the Copper Snake on a pole.

Image 8. Calvary Triptych by Joos van Wassenhove (ca. 1464-1468).

4. Orthophotography

Since 1983 Architectenbureau Bressers has been appointed by the church council for restoration and maintenance works on the cathedral. Since then, several orthogonal plans, sections and elevations were (hand) drafted, varying in scale and detail according to the specific building components or entities that needed maintenance or restoration.

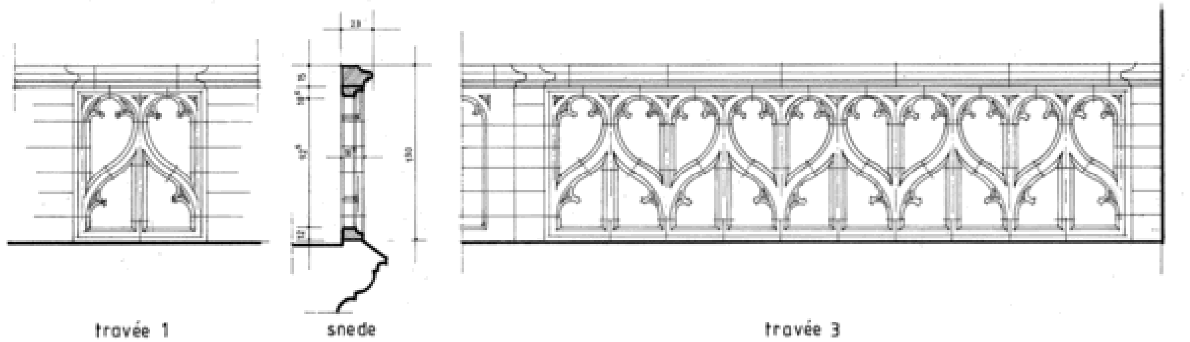

Image 9. Hand drafted survey of the parapet at the northwest and southwest of the tower (1990).

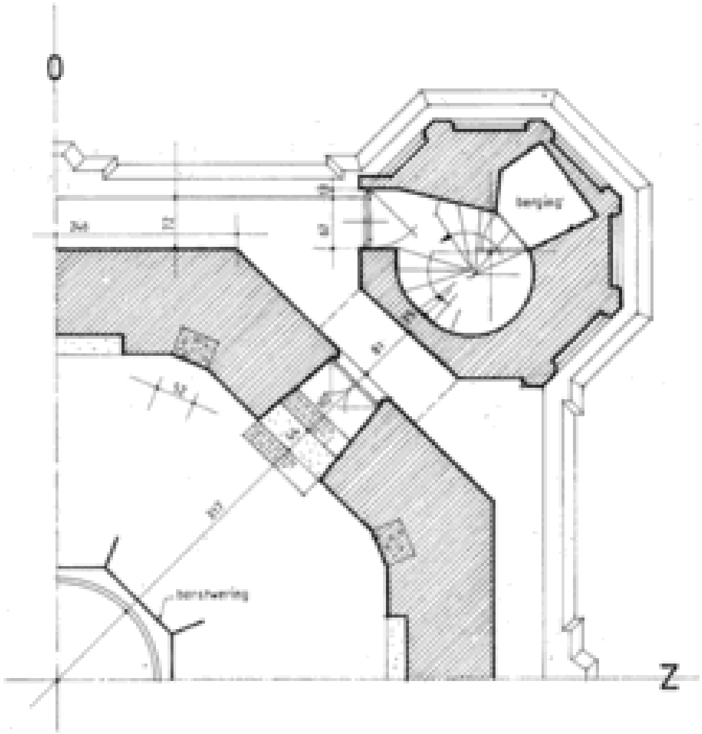

Image 10. Hand drafted detail plan of the stairway tower at a height of 61 m (1991).

Since 1999, step by step, some of these plans were digitalised or redrawn using the Vectorworks software, which allows to quickly add and remove different layers (pathology, materials, ...) on top of these plans. Again, due to the vast scale of the building, the scope, size and detail of the drawings is based upon the needs during works.

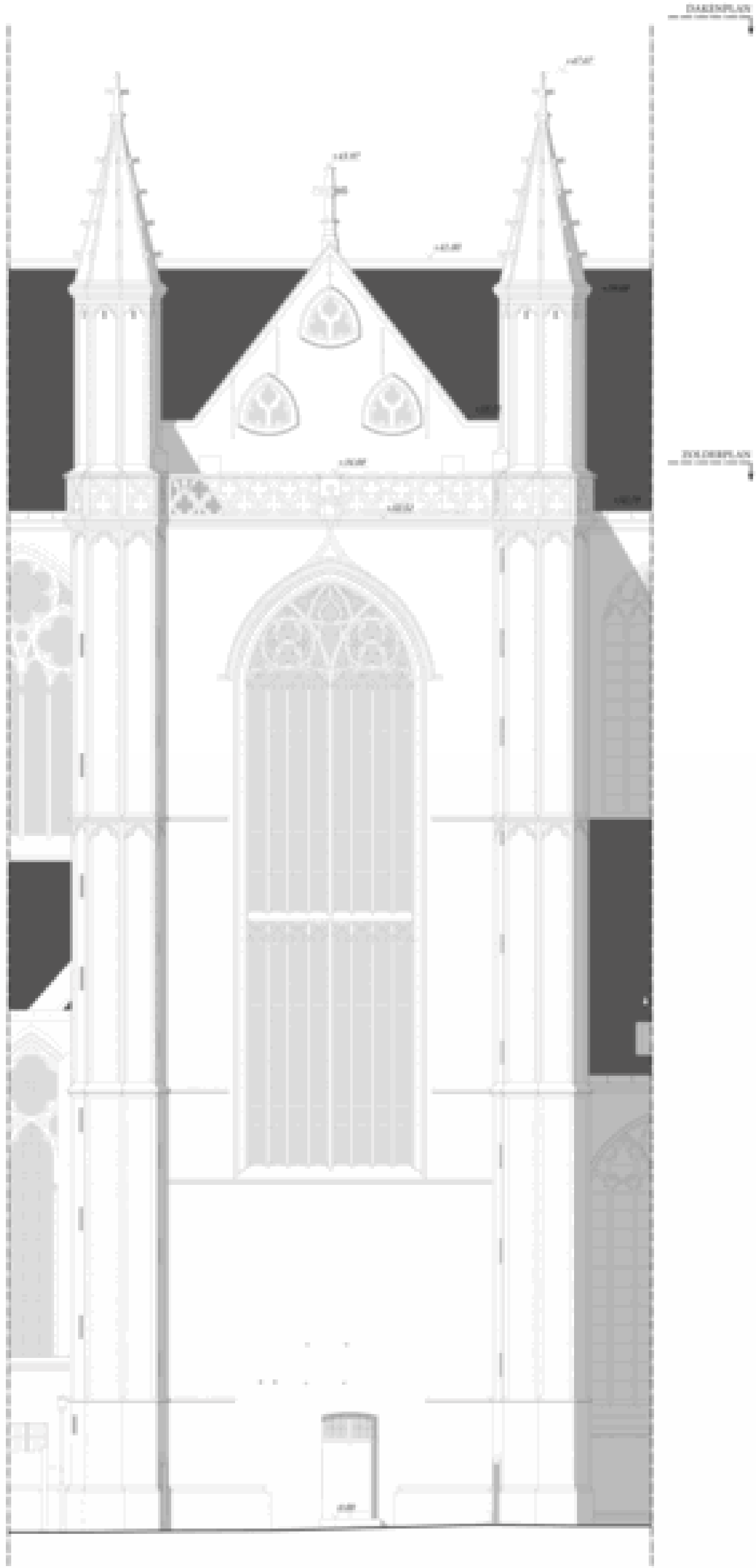

Image 11. Detail of the northern elevation of the transept, prepared for the stability works on the tops of the flanking towers (2015).

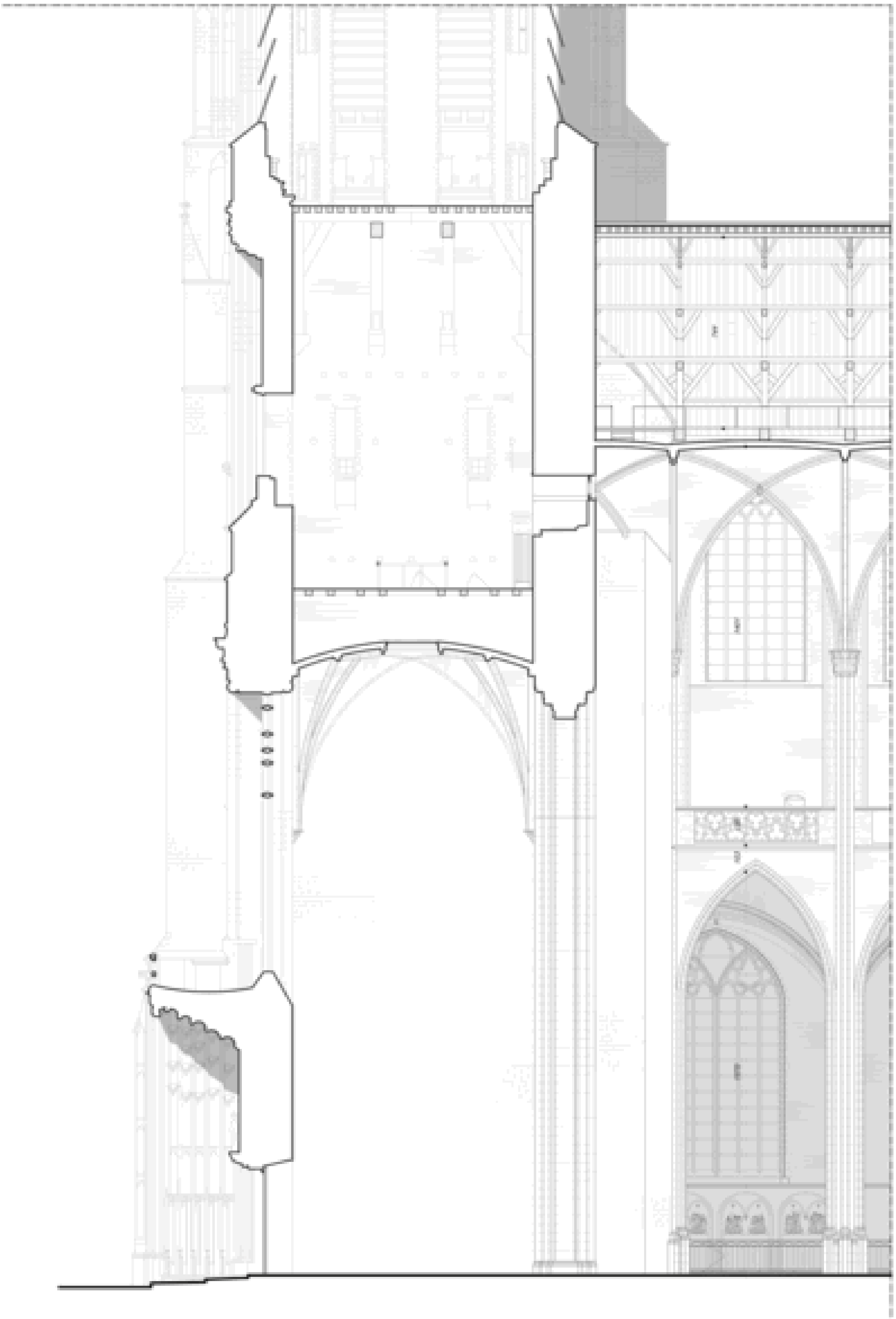

Image 12. Longitudinal section of the West entrance, prepared for the restoration of the nave (2015).

Subsequently, as the different restoration and maintenance works will continue, these digital plans, sections and elevations will be further supplemented and elaborated.

5. Background information on the architectural object with regard to the used stones

The Cathedral was originally built with stones originating from various Belgian quarries. In the nineteenth and twentieth century, many restoration campaigns took place, most of which are poorly documented. Although information concerning these campaigns is often difficult to find in church and state archives, the works are visible on site, owing to the use of foreign lithotypes, originating from France (Massangis, Reffroy, …). The information below has been collected through observations on site and archive research.

Original construction materials

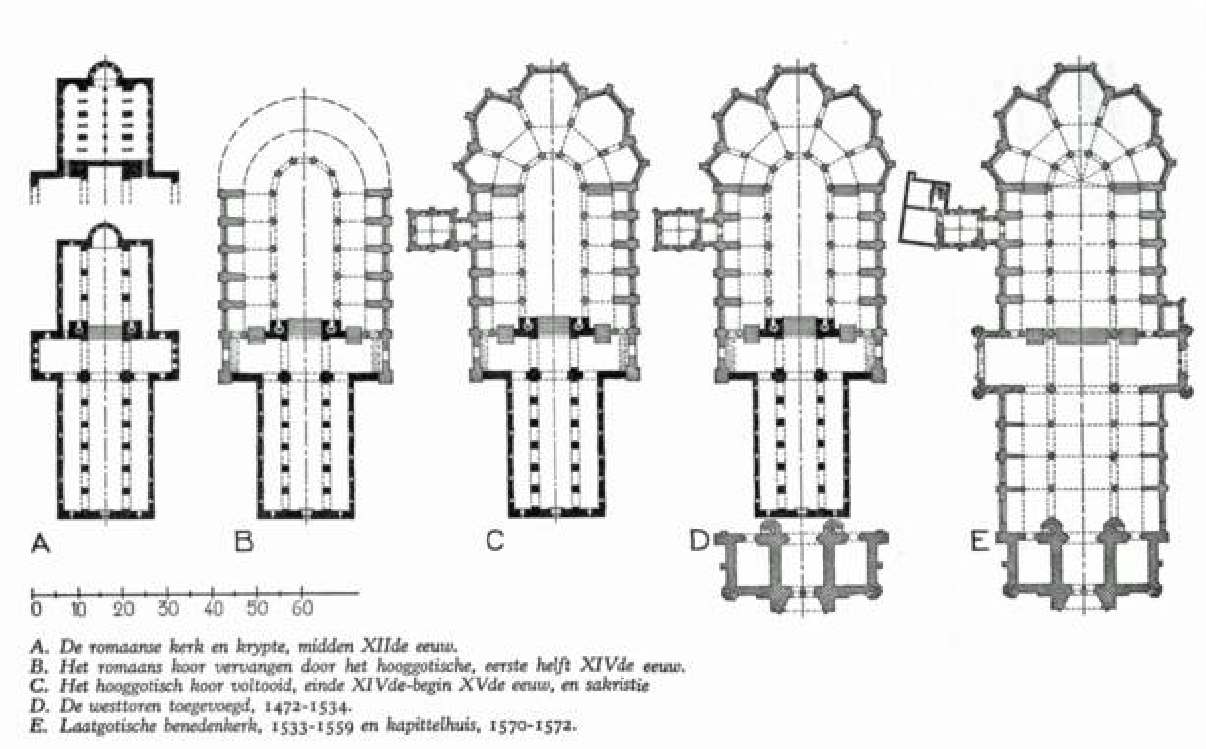

Image 13. General construction history

Source: DHANENS, E., *Sint-Baafskathedraal Gent, Inventaris van het kunstpatrimonium, Provincie Oost-Vlaanderen*, deel V, Ghent, 1965, p. 32

A	Roman church and crypt	middle of the 12th century
B	Replacement of the Roman choir with the Gothic choir	first half of the 14th century
C	Completion of the Gothic choir and addition of the sacristy	end of the 14th - start of the 15th century
D	Addition of the west tower	1472 - 1534
E	Replacement of the lower part of the nave	1533 - 1559
	Addition of the chapter house	1570 - 1572

Throughout the construction of the cathedral stones originating from different quarries in Belgium were used. The choir was built using ***Tournai stone*** (first half of the 14th century - start of the 15th century). The nave, the tower and the chapter house (1472-1572) were built using ***Balegem stone*** (facings, sculptured ornaments, moulding, …) and ***Gobertange stone*** (facings).

Repairs and restoration campaigns throughout the nineteenth and twentieth century

Throughout the nineteenth and twentieth century, the cathedral was subjected to various restoration and repairing works. Unfortunately, the exact extent of these works are, until today, difficult to determine, due to the lack of historical documentation. The first known restoration dates from 1811. Earlier repairs may have occurred, but none of them are documented. From what we know, we can presume that in the 1850s and 1860s, works were mainly focused on the tower. These works comprised, among other things, the reconstruction of the pinnacles of the flanking towers using **Savonnières stone** (1860-1866) and (probably) extensive works on the west portal. From that moment onwards, several restoration works on the tower were executed. These works consisted of the replacement of degraded stone using different (mainly foreign) types of stone, such as ***Reffroy***, ***Euville***, ***Savonières*** (France) and ***Belgian Blue stone*** (Belgium). In 1875 some works have been executed, but again these are poorly documented.

Between 1886 and 1887 the west portal was heavily restored (stone to be determined) and the northern portal was removed. Information about these works is rare. The last extensive restoration campaign of the twentieth century took place between 1957 and 1961, and included the renewal of a great amount of original white stone with ***Massangis***.

6. Description and data of the used stones

Original building materials

Throughout the construction of the cathedral stones originating from different quarries in Belgium were used. The chancel was built using ***Tournai stone*** (first half of the 14th century - start of the 15th century). The nave, the tower and the chapter house (1472-1572) were built using ***Balegem stone*** (facings, sculptured ornaments, moulding, …) and ***Gobertange stone*** (facings).

a) Tournai limestone (BE)

Tournai is a calcareous stone mined in the region around the city of Tournai in the Province of Hainault (Belgium). It’s has a very dark appearance and was used particularly in the Romanesque period in Belgium for sculpted items. Sometimes it is mistakenly called *Tournai marble*, although this is inaccurate from a geological point of view.

Tournai limestone has mainly been used during the construction of the chancel (phases B+C), from the end of the 13th century until the start of the 15th century. Locally, it can be found in the plinth of the nave (built between 1533 and 1559) (see the plans in *Annex G02*).

Image 14. Provenance of the “Tournai limestone”

The authentic Tournai stone used on the exterior parts of the choir and the nave is heavily degraded and soiled. During the restoration campaign of 2006-2010 a lot of stones of the clerestory of the choir had to be replaced by new pieces of Tournai stone.
Technical and physical properties can be found in the datasheets in *Annex G01*.

b) Balegem limestone (BE)

Balegem is a sandy limestone with a light gray appearance, that quickly takes a light yellow-beige to orange patina. It was a widely used building material in buildings throughout Flanders during the 14^{th} 15^{th} and 16^{th} century. Until the nineteenth century, Balegem stone was mined in various places in the provinces East-Flanders, Flemish Brabant and the Brussels-Capital Region (see the image below, n°1). Currently, only the quarry in Balegem (East Flanders, see the image below, n°2) is still being used, although mostly for the winning of sand. Only small amounts of rather small blocks are appropriate for restoration.

Image 15. Provenance of the “Balegem limestone”. Image based on DE CLERCQ, M., *Herstelmortels voor de Ledesteen: receptontwikkelingen en eigenschappen* (Theses, University of Ghent, Department of Geology and Soil Sciences), Ghent, 2014, p. 13.

Balegem limestone has been used during the construction of the tower and the nave, from 1472 until 1572 (phases D+E). It was mainly used for sculptured ornamentation and structural elements. Locally, parts of the facings are executed in Balegem (see the plans in *Annex G02*).

Balegem stone is mainly subjected to sanding, crust formation and coving. Moreover, the Balegem stone seems to be very sensitive to climatic differences between the south and north oriented faces of the building.

Technical and physical properties can be found in the datasheets in *Annex G01*.

c) Gobertange limestone (BE)

Gobertange is a sandy limestone, with a rather white appearance, and has been quarried from 12th century onwards. In the cathedral several variations of this lithotype are found. A first type originates form quarries in the Brussels region (1). The other type was mined in the region around the village of Gobertange in the Province of Walloon Brabant (2).

Image 16. Provenance of the “Gobertange limestone”

Gobertange limestone has been used during the construction of the tower and the nave, from 1472 until 1572 (phases D+E). It was mainly used for facings (see the plans in *Annex G02*).
The deterioration of the Gobertange stone in the Cathedral is characterised by the rounding of the edges.
Technical and physical properties can be found in the datasheets in *Annex G01*.

Replacement stones

Throughout the nineteenth and twentieth century, the cathedral was subjected to various restoration and repairing works. Unfortunately, the exact extent of these works are, until today, difficult to determine, due to the lack of historical documentation. The first known restoration dates from 1811. Earlier repairs may have occurred, but none of them are documented. From what we know, we can presume that in the 1850s and 1860s, works were mainly focused on the tower. These works comprised, among other things, the reconstruction of the pinnacles of the flanking towers using Savonnières stone (1860-1866) and (probably) extensive works on the west portal. From that moment onwards, several restoration works on the tower were executed. These works consisted of the replacement of degraded stone using different (mainly foreign) types of stone, such as ***Reffroy***, ***Euville***, ***Savonières*** (France) and ***Belgian Blue stone*** (Belgium). In 1875 some works have been executed, but again these are poorly documented.

Between 1886 and 1887 the west portal was heavily restored (stone to be determined) and the northern portal was removed. Information about these works is rare.

The last extensive restoration campaign of the twentieth century took place between 1957 and 1961, and included the renewal of a great amount of original white stone with ***Massangis***.

d) Reffroy (FR)

Reffroy is a French limestone that was mined in the region around the villages of Reffroy and St. Joire in the département de la Meuse, Région Lorraine. These villages are situated nearby the Euville quarries.

Image 17. Provenance of the “Reffroy stone”

Because of their young age, the Reffroy stone found in the Cathedral is in relatively good shape. The detailing of the moulding is still legible.

Reffroy stone was used during the restoration campaigns in the early twentieth century as a replacement for degraded white stones. It can mainly be found in the moulding of the plinths of the nave (see the plans in *Annex G02*).

e) Euville (FR)

Euville is a French limestone that was mined in the region around the cities of Euville, Géville et Commercy in the département de la Meuse, Région Lorraine, nearby the Reffroy-quarries.

Image 18. Provenance of the “Euville stone”

Euville stone was used during the restoration campaigns in the early twentieth century as a replacement for degraded white stones. It can mainly be found in sculptures and ornamentation (see the plans in *Annex G02*).

Long term effects of deterioration are still unknown, due to the young age of the stones. Throughout the building a variety of different qualities is used, but, in general, the Euville stone used for the cathedral is in rather bad condition.

Technical and physical properties can be found in the datasheets in *Annex G01*.

f) Savonnières (FR)

Savonnières is a French limestone that was mined in the region around the city of Savonnières in the d'Indre-et-Loire, Région Centre-Val de Loire, nearby the Reffroy and Euville quarries.

Image 19. Provenance of the “Savonnières stone”

Savonnières stone was used for the reconstruction of the pinnacles of the four flanking towers between 1860 and 1866 (see the plans in *Annex G02*).

In general, Savonnières stone is in a bad condition, despite its young age. Apart from the sanding of the surface, the stones show several fractures. The lines of fractures suggests anomalies in the constitution of the stone.

Technical and physical properties can be found in the datasheets in *Annex G01*.

g) Belgian Blue stone (BE)

Belgian Blue Stone is a Belgian lithotype that is mined around the cities of Soignies, Écaussinnes, … (1) and around the Condroz region (Barvaux, Clavier,…) (2).

Image 20. Provenance of the “Belgian Blue stone”

The Belgian Blue stone was used for replacement of cornerstones, window framing and moulding during the last quarter of the nineteenth century (see the plans in *Annex G02*).

The conservation state of the elements in Blue stone varies throughout the different locations and elements where the stone is used. This due to the use of various qualities of stone. Moreover, the integration of metal bars in the window frames (used to stabilise the stained glass) has resulted in substantial damage.

Technical and physical properties can be found in the datasheets in *Annex G01*.

g) Massangis (FR)

Massangis limestone is a lithotype that was mined in the region around the city of Massangis in the département Yonne, région Bourgogne.

Image 21. Provenance of the "Massangis stone"

From the 1950s onwards, Massangis became the most used white stone for the restoration of monuments in Belgium. In St. Bavo's Cathedral it was used for the restoration of window frames, parapets and sculptured ornaments, during the 1950s and 1980s (see the plans in *Annex G02*).

In general, Massangis stone is in a good condition, which seems logical keeping in mind that this stone is only used from the second half of the 20th century onwards. Some ornaments are in bad shape because of the use of a bad quality of stone.

Technical and physical properties can be found in the datasheets in *Annex G01*.

7. Mapping

The state of the building (materials, pathology) as well as the used restoration techniques are recorded during the restoration campaigns, and indicated on the plans. Some examples are added in *Annex G02*.

8. Environmental data

The charts below shows several environmental parameters measured by the Belgian Royal Meteorological Institute (KMI) in their weather station in Ukkel. This site is situated in the central part of Belgium and the values can be considered to represent the temperate climate of the region. The climatic normals are provided in the form of mean values calculated over a period of thirty years (1981-2010).

All charts below have been collected from the website of the Belgian Royal Meteorological Institute (*http://www.meteo.be/*).

Climatic Normals

Paramater	Climatic normal	Unit
air pressure (at sea level)	1016,00	hPa
average wind speed	3,40	m/s
sunshine hours	1545	h/year
average temperature	10,50	°C
average maximum temperature	14,20	°C
average minimum temperature	6,90	°C
absolute maximum temperature	32,40	°C
absolute minimum temperature	-8,40	°C
number of frost days (min. < 0°C)	46	days/year
number of winter days (max. < 0°C)	7	days/year
number of summer days (max. ≥ 25°C)	28	days/year
number of heat days (max. ≥ 30°C)	4	days/year
average relative humidity	80	%
average vapor pressure	10,60	hPa
average yearly precipitation	852,40	mm/year
number of days with precipitation equal to or above 0,1 mm	199	days/year
average for rainfall plus snowfall	19	days/year

Table 1. Climate normals (1981-2010), as measured in Ukkel (Belgium)
Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

Climatic Averages

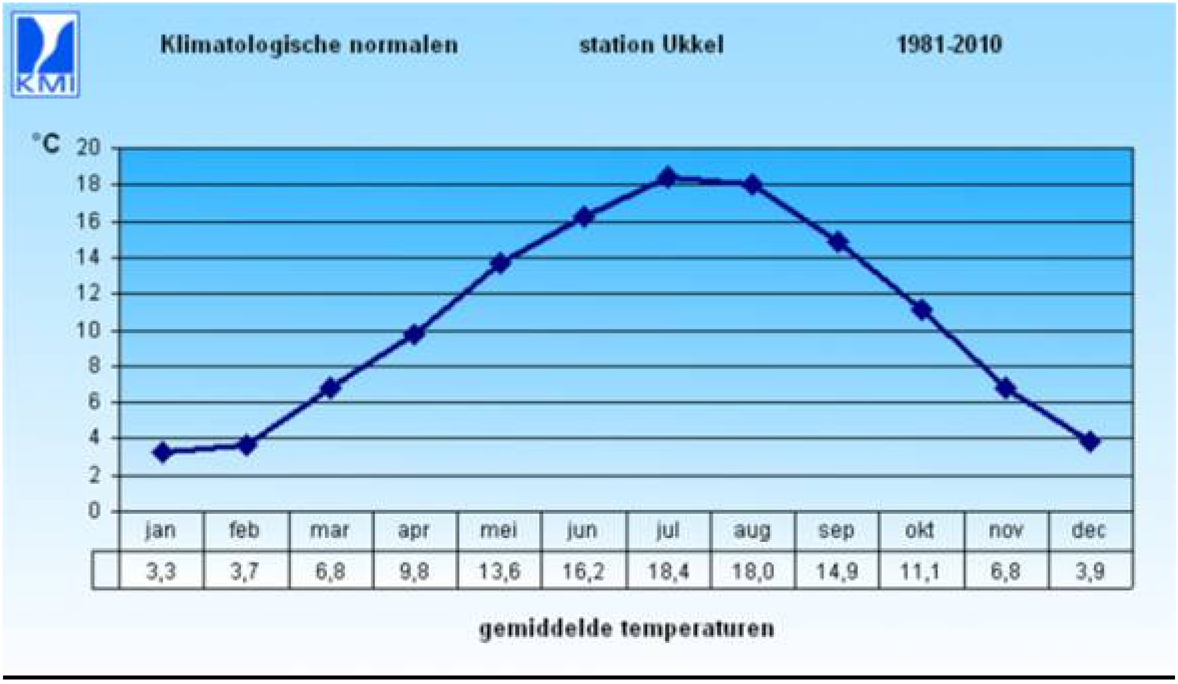

Table 2. Average temperature (°C).

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

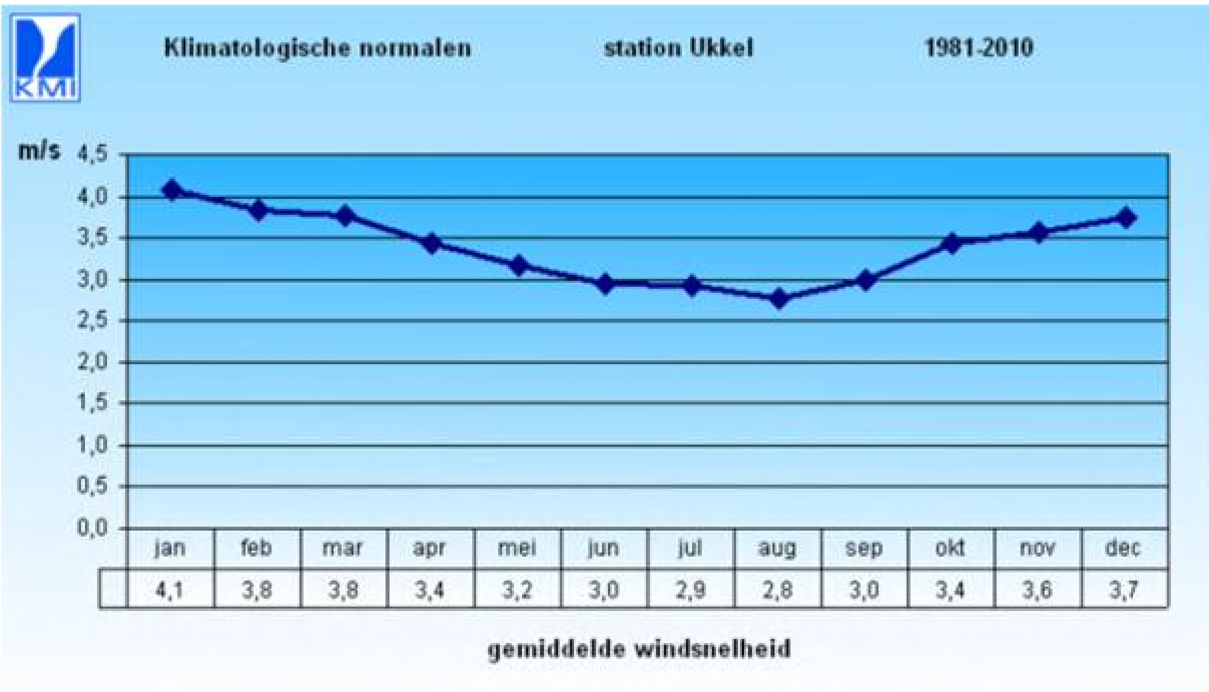

Table 3. Average wind speed (m/s).

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

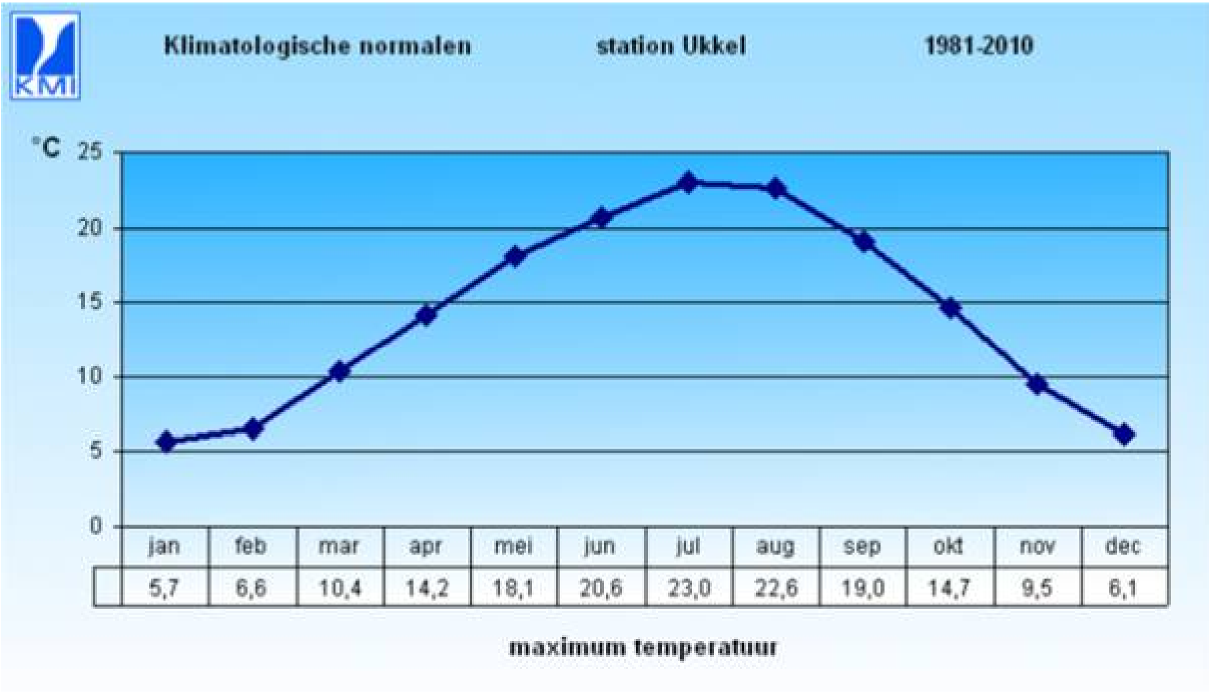

Table 4. Maximum temperature (°C)

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

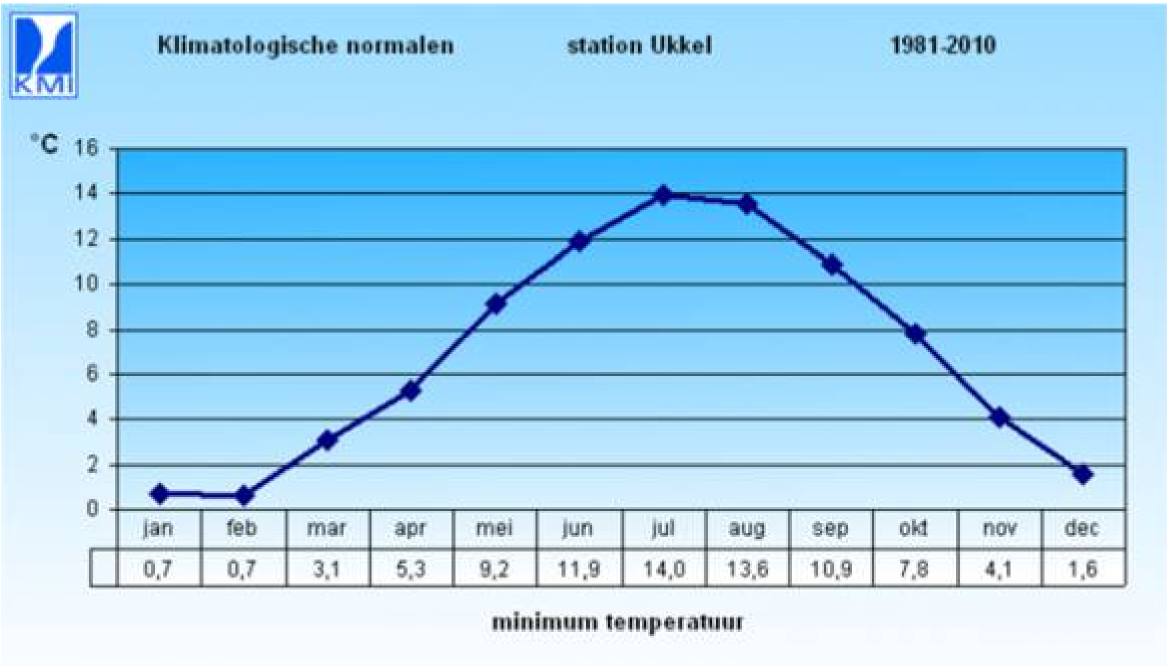

Table 5. Minimum temperature (°C).

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

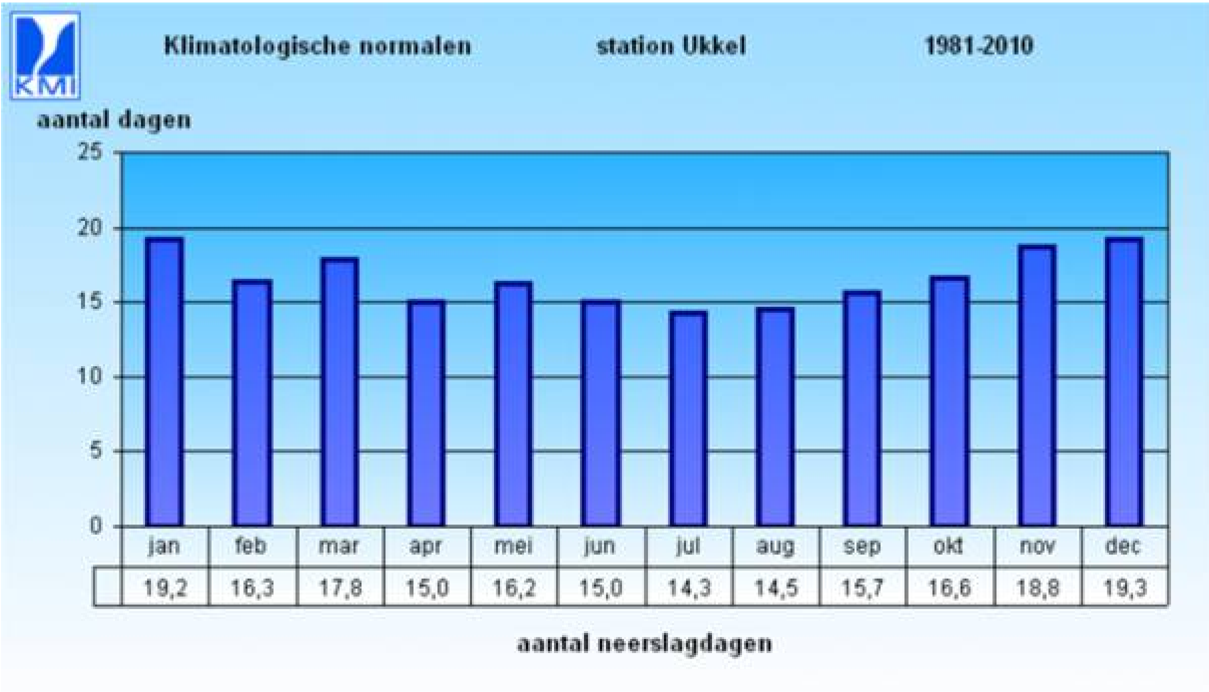

Table 6. Days of precipitation.

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

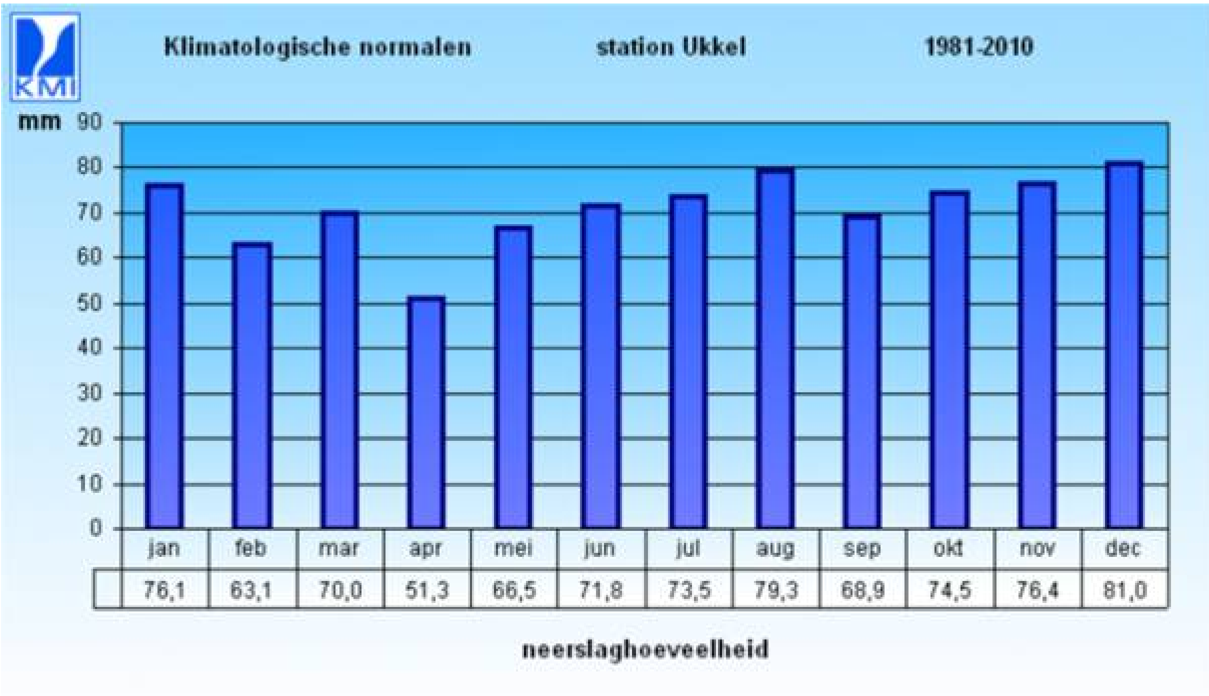

Table 7. Precipitation quantity (°C).

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

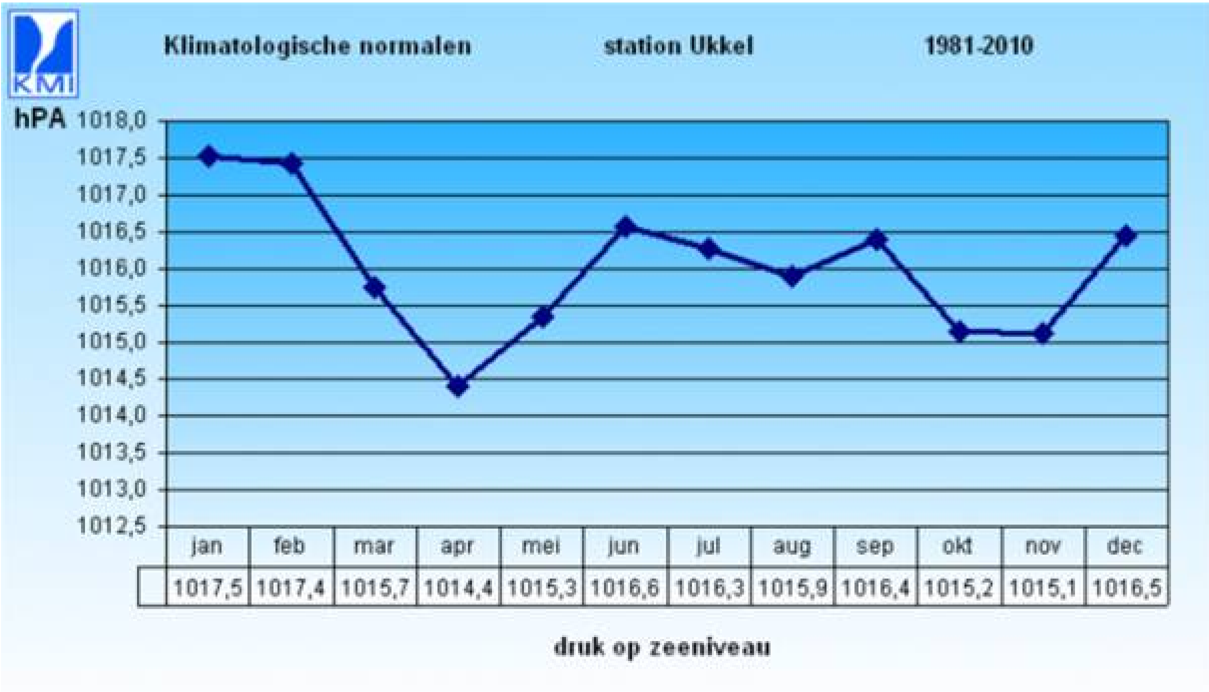

Table 8. Air pressure at sea-level (hPa).

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

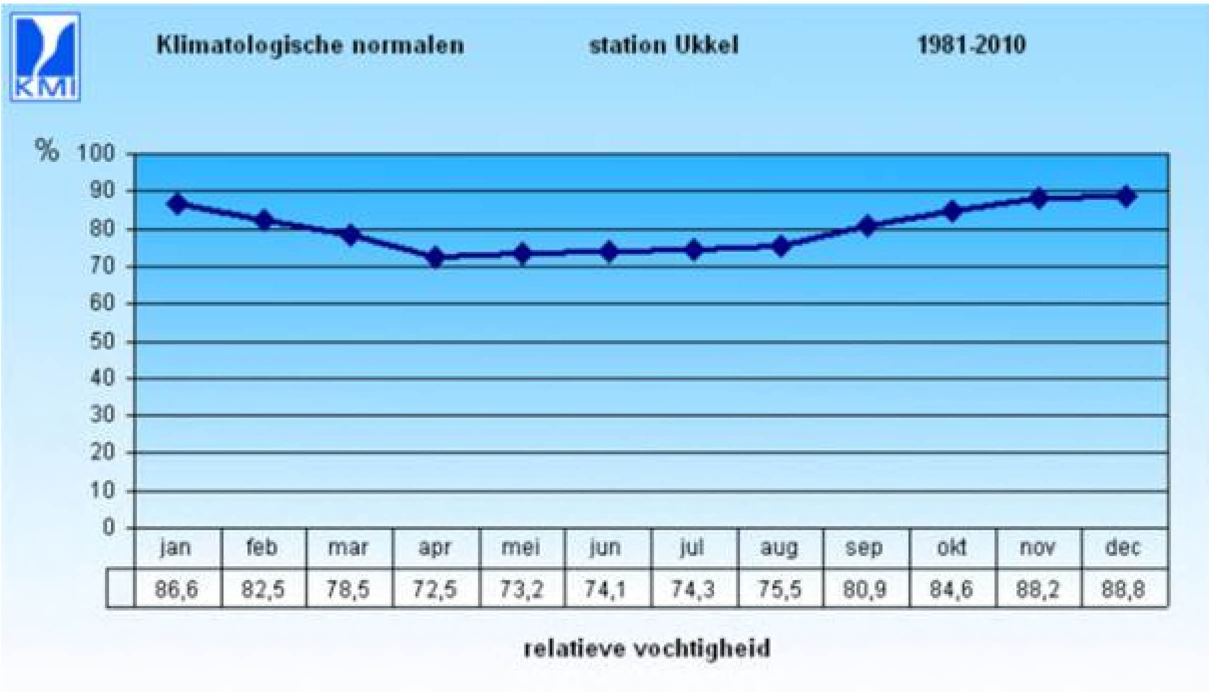

Table 9. Relative humidity (%).

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/*

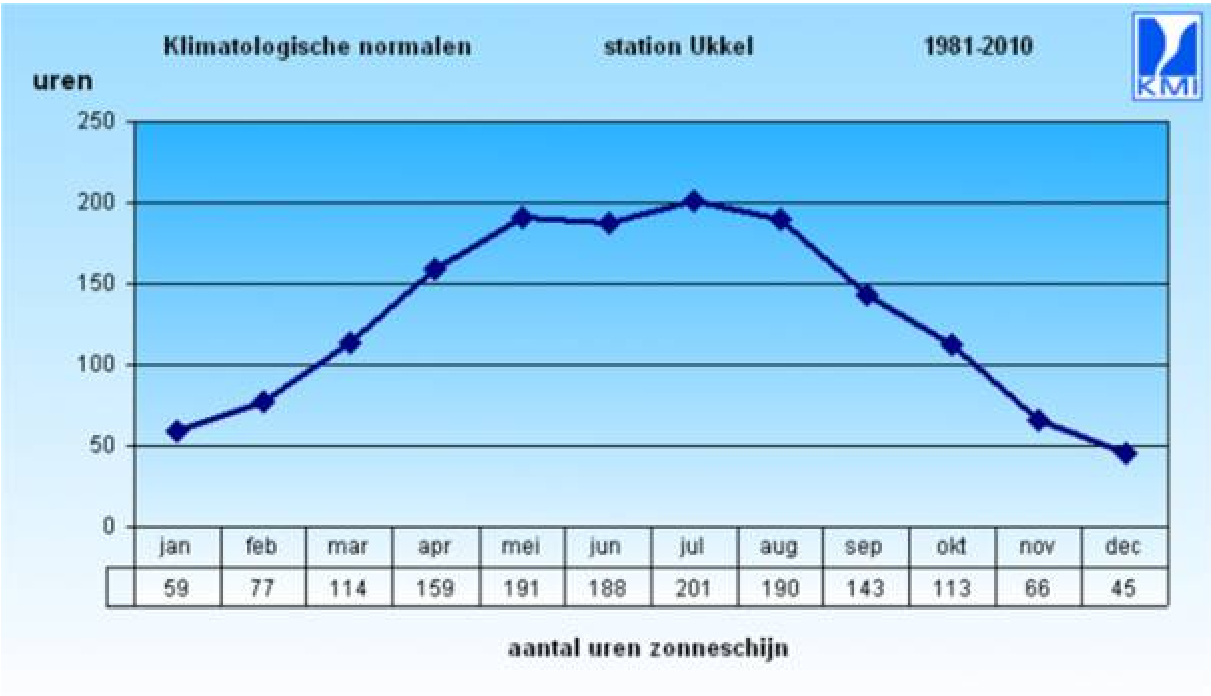

Table 10. Hours of sunshine.

Source: *Royal Meteorological Institute of Belgium (http://www.meteo.be/)*

9. Historic Treatments

During recent works on the tower and the choir no clear traces of historical treatments of the stones have been discovered. It seems that, during the historical restoration campaigns throughout the nineteenth and twentieth century, deteriorated stones were just simply replaced by new stones of different, mostly French, origins (Massangis, Reffroy, Euville, Savonières, …).

On the other hand, al joints were replaced a first time probably at the end of the 19° century and for sure in the campaign of 1957 - 1961. Cementitious materials were used. As result the decay of the natural limestone was accelerated with the result that historical treatments of the stones are even more difficult to recognise.

10. Recent Treatments

The treatments or techniques described below were used during the most recent restoration campaigns of the clerestory of the choir (2006-2010) and the tower (2013-2016). The decisions on which methods to use depends on the different lithotypes and their specific deterioration patterns. It is discussed in advance between the church council, the architect, the Heritage department of the Flemish Government and specialised institutions as the university of Ghent, KIKIRPA, ... During the restoration works the methods are discussed on site with the contractor. The goal is always to preserve the maximum amount of original material.

Cleaning

First of all, loosened crusts are removed and sanded surfaces are softly scrubbed. Afterwards, the healthy parts of the stones are cleaned using low pressure wet abrasive blasting with rotating nozzle. Blasting pressure (0,01-0,03 MPa), blasting agents and distance to the surface are determined on site, according to the results of preliminary cleaning test. They can vary according to the type of stone, the type and degree of deterioration or soiling and orientation of the stone surfaces of ornaments.

Full or partial replacement

Elements that are severely deteriorated are replaced by new pieces in the same material (Balegem is replaced by Balegem, Gobertange by Gobertange, …) with the same form. If certain stones are only partially damaged, the deteriorated parts are removed and new pieces of stone are glued into the original stone. Stones which are loose or areas with stability issues are disassembled and reinstalled using the original disassembled stone blocks.

Image 22. Disassembled pieces of white stone.

Image 23. New pieces of stone, glued into the original stone.

Image 24. Low pressure wet abrasive blasting with rotating nozzle.

Image 25. Cleaned Gobertange (A) and Balegem (B) after the removal of the pointing.

Repointing

Joints based on cementitious mortar are always removed and repointed with mortars based on chalk. Joints with bad consistency are removed and replaced to prevent water infiltration.

Protection and consolidation

Only if the deterioration is limited and superficial, the stone might be treated with products based on ethyl-esters to consolidate the upper layers of the stone, although this technique is used rarely. The Heritage Department of the Flemish Government is rather reluctant in the use of chemical agents, both for protection and consolidation of natural stone. Nevertheless, in some cases it is useful and necessary. During the most recent restoration campaigns the following chemical agents were used locally:

Trade name	Company	Main properties
KSE300	*Remmers*	*Consolidant*
RC Stone Hardner	*Reynchemie nv*	*Consolidant*

Table 11. Chemical agents used during recent restoration campaigns.

The datasheets of these products are added in *Annex G01*.

Image 26. Area's after restoration with (A) new pieces of Balegem stone, (B) cleaned and repointed Balegem stone, (C) new pieces of stone glued into the original Balegem stone, (D) cleaned and repointed Gobertange stone. The parapet is built in Massangis (E).

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D1.1 – Part C, Background information on the architectural object: Oslo Opera House (Oslo, Norway)

1 General information

The Oslo Opera House is the home of The Norwegian National Opera and Ballet and the National Opera theatre in Norway. The building is located in the Oslo city center, at the head of the Oslofjord. The structure contains 1100 rooms, a total area of 50.030 m^2. The main auditorium seats 1,364 and two other performance spaces can seat 200 and 400. The main stage is 16 m (52 ft) wide and 40 m (130 ft) deep. The angled exterior surfaces of the building are covered with Italian marble and white granite and make it appear to rise from the water. It is the largest cultural building constructed in Norway since Nidarosdommen was completed circa 1300. The roof of the building angles to ground level creating a large plaza inviting pedestrians to walk up and enjoy the panoramic views of Oslo. While much of the building is covered in white granite and *La Facciata*, a white Italian Carrara marble, the stage tower is clad in white aluminium in a design by Løvaas & Wagle evoking old weaving patterns.

Fasade, Operaen

The operahouse is the first element in the planned transformation of this area of the city. The marble clad roofscape forms a large public space in the landscape of the city and the fjord. The public face of the operahouse faces west and north - while at the same time, the building's profile is clear from a great distance from the fjord to the south. Viewed from the Akershus castle and from the grid city the building creates a relationship between the fjord and the Ekeberg hill to the east. Seen from the central station and Chr. Fredriks sq. The opera catches the attention with a falling, which frames the eastern edge of the view of the fjord and its islands. The building connects city and fjord, urbanity and landscape. To the East, the ‘factory' is articulated and varied. The activities within the building are visible: Ballet rooms at the upper levels, workshops at street level. The future connection to a living and animated new part of town will give a greater sense of urbanity.

1.1 Landscape and general arrangements

The opera's landscape comprises of the marble roof, additional marble clad areas, and the areas between the building and the surrounding streets. Access to the plaza and the main entrance is over a marble clad footbridge over the opera canal. The plaza forms a part of a public promenade and cycle lane which continues around the west and south sides of the building, and eventually coming to a planned bridge over the Aker river to the east.

As early as the competition entry, Snøhetta proposed that the roofscape should be openly accessible to the general public and that it should be clad with white stone. Today the building's defining feature is the characteristic geometry of the roof as it rises from the fjord and is laid out like a carpet over the public areas. An important move has been to introduce channels along the roof edges with ramps and steps. This met the height regulations for balustrades by raising the line of the roof itself.

The surface treatment of the stone, its pattern, cuts and lifts which create a shadow play, have been designed in close collaboration with the artists. The white marble ‘La Facciata' is from the Carrara quaries in Italy. The north side and all the stone cladding which is in contact with water is a norwegian granite called 'Ice Green'. Prototypes and tests at full scale were studied at the contractor's facilities before the final choices were made for colour nuance and surface texture. A consecutive quality control regime has been implemented throughout the production process.

Operaen om kvelden

During the building period it became clear that rapid and considerable settling of the ground level around the building would need to be addressed. Large areas of gravel, which is designed to take local vehicular traffic has been laid around the building footprint. Trees are planted in the gravel areas, and a zone of street furniture is located along the pavement line with cycle parking, benches and specially designed streetlamps in stainless steel. The asphalt pavements has black granite edges while granite paving on larger areas highlights the entrances to the restaurant, opera street, and stage entrance. The dark grey colour palette is a clear contrast to the light stone and aluminium of the building itself within a cool monochrome language.

Landscaping of the surrounding areas has been designed in collaboration between Snøhetta and Bjørvika infrastructure who have been responsible for the planning of the street around the operahouse.

Courtyard

The courtyard is a garden in the middle of the production area of the building. It is surrounded by facades of black glass, aluminium and timber and open to the sky. There is direct access to the courtyard from ground and basement levels while the upper levels experience it as a green lung deep inside the building. In front of the sound insulated rehearsal rooms at basement level, vegetation has been planted to form a screen. The floor of the courtyard is a composition of timber dekking, white marble, and green areas. A marble stair connects the two levels. Grasses, climbing plants and perennials are planted around clusters of cables reaching up to the upper levels and providing shade to the facades.

Lysgård, Operaen

The building is split in two by a corridor running north-south, the ‘opera street'. All the public areas and stage areas are located in the western part of this line.. The eastern part of the building houses the production areas which are simpler in form and finish. Comprising of 3 to 4 storeys above ground.

There is also a basement level - U1 - below this part of the building. The sub stage area is a further 3 storeys deep.

The building's western part

A marble clad plaza leads the visitors to the foyer and other public areas. A secondary entrance on the north facade gives direct access to the restaurant and foyer. To the south, the foyer opens up to the inner Oslo fjord and views of Hovedøya island. There is a dominant view of the city to the west and the north , while the auditoria is located to the east. The building can accommodate about 1900 audience. 1400 in the main auditorium, 400 in stage 2 and 150 in rehearsal room 1, which doubles as a black box theatre.

There is a brasserie to the south of the foyer, a restaurant to the north and several bars which can operate separately during performances. Service functions such as educational tour areas, cloakrooms, toilets, information/ticketing desk and diverse smaller rooms are located around the foyer. Access to the two main auditoria is provided from the foyer, at ground level, and from the public galleries.

The large stage area occupies a significant part of the building footprint. Here is the main stage (16m x 16m) with an 11.8m deep substage, two side stages and two rear stages, as well as a scenery hall and store. There is a free height of minimum 9m throughout these areas. Storage for the backdrops is located above the rear side stage. Finished scenery for several performances and acts can stand ready on the rear and side stages as well as below stage. In addition, the large rehearsal room is located in direct connection to the stage areas and can provide further scenery storage should this be necessary.

The orchestra rehearsal room - an acoustically sensitive space - is also located in the western part of the building - at basement level. This hall is the orchestra's most important rehearsal space and can also be used for recording purposes. The requirement for variable acoustics is achieved by the use of adjustable panelling and drapes. The room can achieve similar acoustics to the main auditorium. A passage from the foyer, along the southern facade, leads to rehearsal room 1 allowing it to be used as a public performance space.

The production and administration areas are all located to the east of the ‘opera street' with approx 1000 rooms of varying sizes and functions. The opera street is the main communication artery for all the employees - almost 600 persons of more than 50 different professions.

A large loading dock running east west splits the back of house area in two. Here also, the dimensions of the space are given by the size of scenery elements, up to 9 meters high.

The ‘hard workshops' where the scenery is made, is located to the north. . Several professions, carpenters, metalworkers, painters and decorators. have their workspaces here. The finished scenery is moved through the loading dock and directly into the rear stage area.

All the other functions necessary to serve the needs of the dancers and singers ‘Soft workshops' with costume production, wigs, hats, gloves and make up areas is located to the south including the administration and changing rooms. A spacious green courtyard is at the heart of this area on levels U1 and groundfloor. Most of the changing rooms houses 4 performers with all the necessary costume and make up for each show. The rooms are also intended as a place for relaxation and concentration which is therefore equipped with a day bed.

The opera and ballet departments have several large rehearsal rooms in this zone on levels 3 and 4. and it is possible to transport scenery from the loading dock to the rehearsal spaces on level 3 via an elevator with a clear height of 6m. The largest of the rehearsal rooms has a clear height of 9m and is as large as the main stage. This allows the dancers to practice a complete performance. All these spaces have walls with acoustic attenuation. There are also a number of small rehearsal rooms at plan 2. The wig makers, make-up artists, and dressers are located closer to the stage at level 1 (ground). From here the artists can access the stage areas at ground level or from the basement.

At level 2 there are music archives, offices, and support functions for the orchestra as well as a health center and gym. Level 3 houses the administration department with a large canteen to the south with a terrace overlooking the fjord.

The main auditorium

The main auditorium is a classic horseshoe theatre built for opera and ballet. It houses around 1370 visitors divided between stalls, perterre, and three balconies.

Hovedscenen, Operaen

Technical spaces occupy the area above balcony 3. The orchestra pit is highly flexible and can be adjusted in height and area with the use of three separate lifts.

On each side of the stage are mobile towers, which allow for adjustments in the proscenium width for ballet or opera without damaging the acoustics of the hall. Reverberation time is fine tuned using drapes along the rear walls and control rooms for sound and light are located to the back of the hall.

The form of the auditorium is based on several relationships: short distance between the audience and the performers, good sight lines, and, above all, excellent acoustics. The architectural intentions for a modern auditorium with traditional, acoustic musical performance have been developed in parallel with requirements for visual intimacy and acoustic excellence. In older opera halls acoustic attenuation was often achieved by using rich decorative, sculptural elements on most surfaces. In this case the requirements have been met with a clean, carved aesthetic using a modern formalistic language.

The requirement for a long reverberation time results in a room with a large volume. In this case the volume is increased by the use of a technical gallery, which cantilevers out over the walls below, giving the hall a T-shaped section. The main structure of the stone clad roof above is included in the volume of the hall rather than being hidden behind a false ceiling. Optimum acoustics have been achieved by using the following methods:

The oval ceiling reflector visually finishes the hall and also reflects sounds in very specific ways. The same principle is used as with the balcony fronts. The rear walls at each level are made up of convex panels to avoid focussing and to spread sound evenly through the room. The geometry of the interlying walls, main orchestra reflector, and the mobile towers are modulated to scatter sound around the space. Using timber staves of varying dimensions to modulate sound of different wavelengths. All the surfaces are of relatively dense materials to avoid high frequency vibrations. Balcony fronts are 50mm solid oak where the rear wall panels are 100mm MDF with oak veneer.

The stage curtain

The stage curtain is also an important element in the auditorium. Together with the chandelier and seat fabric it is a contrast to the dark timber. It was made by the American artist Pae White, following an international competition. She has worked with digital images of aluminium foil which reflects and adopts the colours of the auditorium. These images are then transferred to a computer driven loom

Stage 2

Stage 2 can, depending on the chosen seating configuration, house an audience of up to 400. It will be used by both opera and ballet, as well as for banquet functions, rock concerts, experimental performances and children's theatre. It is a multi use hall where the seats, which are on large wagons, can be repositioned in a number of different configurations. There are 2 large elevators which form an amphitheatre, orchestra pit and transport seating wagons for storage in the basement. The area which is normally the stage is made up of removable floor elements. The auditorium has no fly-tower but rather an extensive motorised pulling system to hang and transport scenery, backdrops and acoustic reflectors when necessary. A 9m high sliding gate connects the stage area with the back stage zones and scenery stores. The reverberation time in the hall can be damped down for amplified performances.

The client required an auditorium with the flexibility of a black box but with an amount of architectural quality and identity. These to requirements are generally considered to be mutually exclusive, but after close discussions with the end user, a solution was found where of a black box has a high quality contrasting, freestanding structure placed inside it. This ‘object' has rounded, high gloss, red paneling on the outside and a cooler metallic silver finish in towards the stage. Four technical bridges span across the space at high level housing lighting and ventilation and forming an important visual and acoustic ceiling. Between the columns, large, black painted doors and removable panels are used to adjust to different configurations. These panels have also been given acoustic consideration.

Interiors

The exterior of the opera house becomes diffuse as night falls. The large timber ‘wave wall' in the foyer is illuminated and the building takes on a completely different character.

Foajeen, Operaen

[illegible]

The interior becomes the façade. It shows how interdependent the interior and exterior of the building are.
The building's architectonic ideas and concepts have also been used in the buildings interiors. The task has included considerable interior planning based on the schedule of rooms, functions, colours, materials, and surface treatments, coordinating lighting schemes, technical installations, built in furniture, wet rooms, kitchen solutions, elevator cars, fittings and fixtures.
It has also encompassed design and coordination of the end user equipment and loose furnishings. Cooperation between the various architectural disciplines has been vital.

Furnishings and equipment in the public areas

The interior, from cloakroom to auditorium can be described as a formalistic journey, which takes the visitor from the open unknown to the enclosed and secure. The level of abstraction to be seen in the outer spaces has made it natural to minimise the number of recognisable building elements and details.At the same time it has been a clear aim that the furniture elements use the same design language as the building as a whole.
Larger elements such as bar counters, shop fittings, ticket desk, and cafè interiors are either integrated in larger building forms or designed as free standing sculptural forms in white corian. These can be completely closed down when not in use.

Publikumsgarderobe, Operaen. Utsmykning: "The Other Wall" av Olafur Eliasson
Foto: [illegible] / Statsbygg

The cloakroom and foyer are further furnished using simple seating forms and high tables made of steel plate coated with industrial rubberized black lacquer. Upholstery is with flat sheets of felt and sheep skin. Signage is made of the same black steel and white glass surfaces complete a number of the interior elements.

Furnishing of the production areas

These zones are designed with ergonomics, functionality, and experience. The workshops are rational rooms where the logistics of mechanisation dominate the design. Wig and make-up workshops have been provided with specially designs workstation modules specific to the user's requirements. The costume department, which is a hectic space full of activity has been given solution specific to its complex logistics. The three artforms; Ballet, opera, and orchestra have all their requirements for changing rooms fulfilled with standardised but purpose built furniture. However, the orchestra has a larger, 10 man changing rooms with areas for unpacking instruments, rest, and changing prior to a performance, and with shared access to toilets and showers. The Ballet, choir and soloists have smaller 4 or 6 man rooms with person specific places and showers shared with the neighbouring room.

For the ballet these rooms function as a home base in a day filled with training and rehearsals. All the changing rooms are specially design with fitted, standardised furniture, make up tables, day beds and cupboards.A great deal of work has gone into designing the rehearsal spaces for the different groups. These are important working spaces, with optimised acoustics, ventilation, and lighting. The intention has been to provide a great deal of spacial quality and the acoustic wall panelling in particular contributes to this.

2 Choice of materials

2.1 <u>Stone, timber, glass</u>

Panoramabilde av Operaen

The materials, with their specific weight, colour, texture and temperature, have been vital to the design of the building. Snøhettas architecture is narrative. It is the materials which form the defining elements of the spaces. It is the meeting of the materials which articulates the architecture through varied detail and precision.

In the operahouse, three main materials were specified as early as the competition entry: White stone for the ‘carpet', timber for the ‘wave wall', and metal for the ‘factory'. During the continued work on the project, a fourth material, glass, which allows for the exposure of the underside of the ‘carpet', has been given specific attention.

After an international tender competition, the italian marble, “La Facciata”, was chosen. This is a stone which, in common with other marbles, retains its brilliance and colour even when wet. It has the necessary technical quality in terms of stability, density, and longevity. The producer, Campolonghi, has had the professional ability, capacity, and experience necessary for such a large and complex project.

The accessible area of the ‘carpet' is approx. 18,000 m^2. Its detailed design has been important: the architect desired that it should not interfere with the general dorm of the building but that it simultaneously was articulated enough to be interesting at close quarters. Together with the artists several alternatives were proposed before a particular non repetitive pattern with integrated raised areas, special cuts, various surface textures, and specific details were designed to articulate the main geometry.

Trapp i foajeen, Operaen

Oak has been chosen as the dominating material for both the 'wave wall' and the main auditorium. For the wave wall it has a light and varied surface. Oak is used throughout for the floors, walls and ceilings. The wave wall has a complex organic geometry made up of joined cone shapes. It is also an important acoustic attenuator within the foyer space. To achieve these goals it is made up of smaller elements which can deal with the changing geometry and provide acoustic absorption.

Inside the auditorium oak has been chosen for a number of reasons: It is dense, easily formed, stable and tactile. The oak has been treated with amonia to give a dark tone. Here too oak is used for floors, walls, and ceilings, as well as balcony fronts, and acoustic reflectors. The high glass facade over the foyer has a dominant role in the views of the building from the south, west, and north. Early in the project it was realised that this glass faced was more important than previously assumed, both during the day and night when it would act as a lamp illuminating the external surfaces.

The glass façade is up to 15 meters high. It was the architects intention to design a glass construction with an absolute minimum of columns, framing, and stiffening in steel. The solution was to use glass fins where minimised steel fixings are sandwiched inside the laminates. The requirements for the glass's stiffness increased due to the desire for large panels and slim joints where the panels meet. Thick glass of this sort tends to be quite green rather than transparent. It was therefore decided that the façade of the operahouse would use low iron glass.

2.2 Materials used in the production areas.

The brief for productions area specifies that they should be simple and inexpensive. This means that they are of general office quality with painted walls and linoleum flooring. This works well as a neutral background to the opera's colourful costumes and stage elements which enliven the spaces.The colour palette is therefor quite simple and neutral.The open courtyard forms a central reference point to the production areas and the corridors which encircle it are given a dark colour to make orientation easier. The rehearsal rooms have different characters for ballet, opera and choir. The ballet spaces are light and airy with views over the fjord to the south. On the other side, the choir space is more introvert with daylight from a high clerestory window facing east. Enclosing the musical experience. Colours and materials have a warmer, darker hue.

D1.1 – Part D: Background information on the architectural object: Santa Maria Cathedral (Pisa, Italy)

Main features:

Length:	101.5 m
Width	69 m
Height of the dome**:**	54 m
Height of the façade:	35.4 m
Width of the façade:	34.2 m

1. General information, present state

Pisa is located in the Central Italy, 12 km from the Ligurian Sea, 20 km from Livorno, 15 km from Lucca and 80 km from Florence. Pisa is located in a fertile plain, and it is divided in two part by the Arno River.

Pisa was the birthplace of Gailileo Galilei and hosts the University of Pisa, one of the oldest universities in Italy, that was formally founded on September 3, 1343 by an edict of Pope Clement VI. The University of Pisa has an academic botanical garden i.e. Orto botanico di Pisa founded in 1544. In Pisa, there are two other important academic institutions: the Scuola Normale Superiore di Pisa i.e. Scuola Normale, founded in 1810 by Napoleonic decree as a branch of the École Normale Supérieure of Paris, and Sant'Anna School of Advanced Studies or Scuola Superiore Sant'Anna, established in 1987 and operating in the field of applied sciences.

Opinions about its origin are discordant, but probably Pisa rose between the 5th and the 7th century BC. At first, Pisa was a Greek and an Etruscan settlement, and later a Roman town. During Middle Ages, Pisa was part of the Longobardo Kingdom, and then of the Carolingio Empire. The medieval period (XI-XIII centuries) coincided with the peak of Pisa's economic and political power. Pisa was one of the four Italian coastal republics (Amalfi, Genova and Venezia) until it was annexed to the Ducato of Tuscany in 1406. Pisa became part of Italy in 1861.

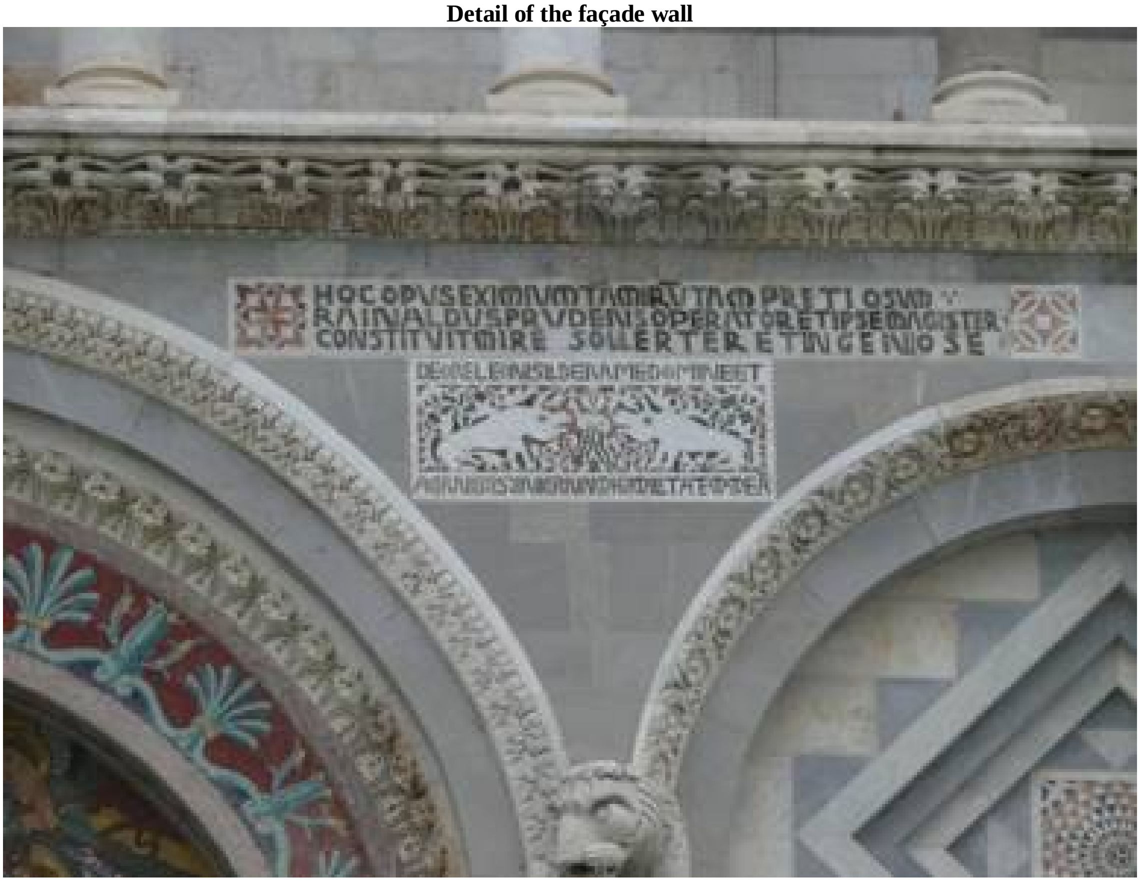
Pisa's climate is Mediterranean, characterised by hot summers with plenty of sunshine. July and August usually are the hottest months, with an average temperature of around 23ºC. Spring and autumn are generally very mild with pleasant temperatures. In winter, Pisa sees its coldest, wettest weather. Temperatures drop to around 6.5ºC in January, while November sees the most rainfall with an average of 122 mm falling throughout the month.

Brief chronology
Founding of the new church of Pisa: 1063
First consecration: 1118
End of construction: last quarter of the XII century
Partial destruction (fire) and restoration: 1595

The following pictures show the present state (the morning of December 4, 2015) of the Pisa's Cathedral:

Sepulchre of the architect Buscheto (façade)

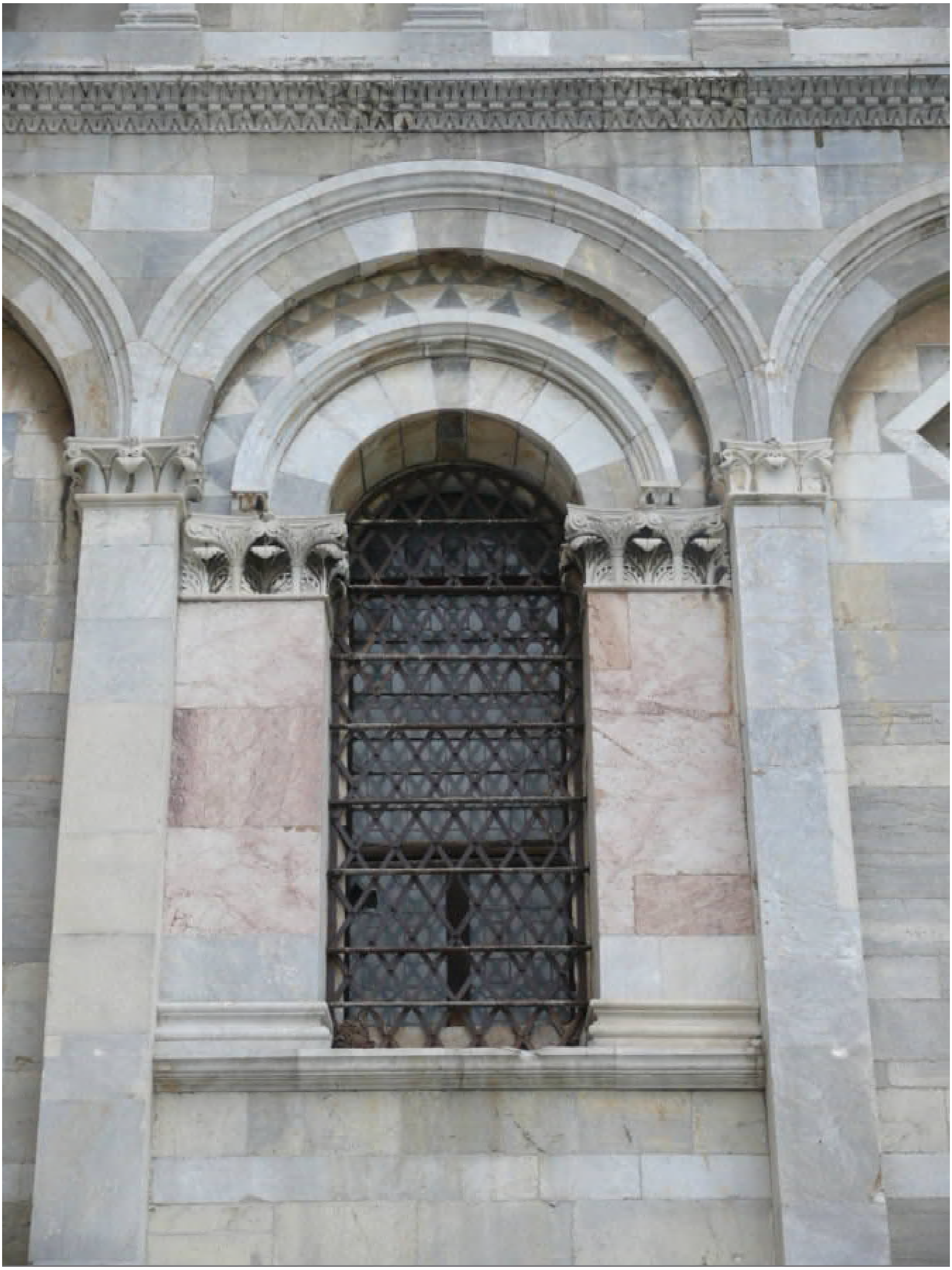
Detail of the façade wall



Epigraph dedicated to the architect Rainaldus

Detail of the façade

Capital (façade)



The dome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2. Construction History

The Unesco World Heritage site “Piazza del Duomo di Pisa”, the Cathedral Square, is a unique exhibition path which spreads out over a green lawn grass, in the place which has always been consecrated to worship.

All the monumental buildings are closely related, and narrate A MILLENNIUM CULTURE we have inherited. They represent A SINGLE DESIGN concept, a symbol of Christian allegory, of a dialogue between heaven and earth, and they outline A STYLE developed in maritime Pisa, resulting from the encounter of different peoples, cultures and languages.

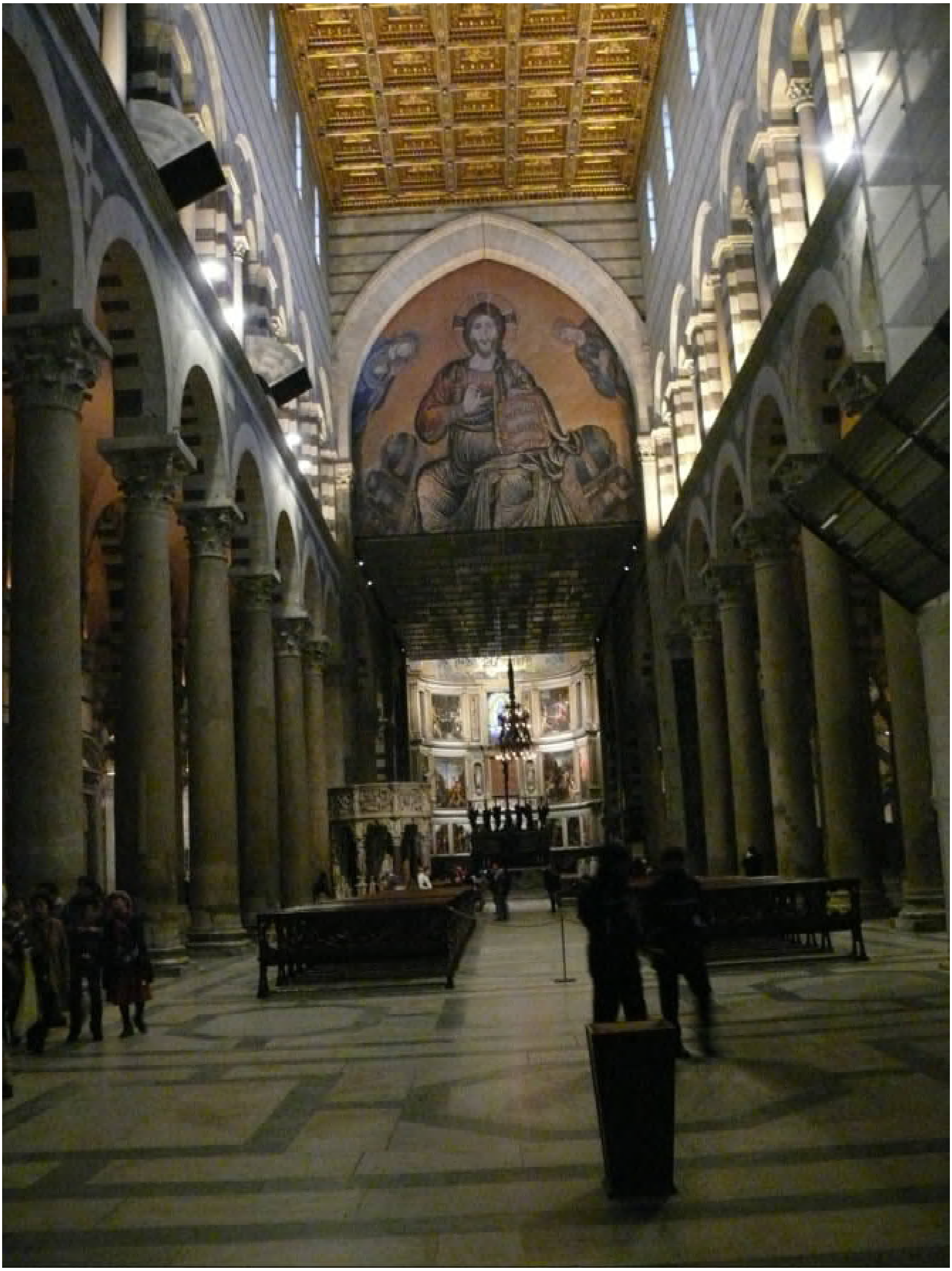
One is also amazed by the unique isolation of this group of monuments: the large area where the sacred buildings rise is actually on the edges of town, in the north-western corner, looking almost proud and distant from the daily bustle of the town. But a careful historical interpretation and the contribution of some recent archaeological findings give back to the Cathedral all its centrality, based on the original choice of the site and preserved through the centuries as the heart of the religious and civil life of Pisa.

This was the place chosen for the Church of Pisa since its origins, which are unanimously considered to date from before Constantine's peace pact of 313. But the oldest sacred buildings were pulled down with time and the monuments we can admire today date back to the mid-centuries of the Middle Ages, when at the peak of its glory after its triumphs at sea Pisa asserted its supremacy over the region and all over the world, going so far as to claim for itself the role of a 'new Rome'. Such boundless pride and awareness gave birth to the plan to rebuild, near an earlier cathedral that has been rediscovered during recent archaeological excavations, the new church of Saint Mary founded in 1064, the year of the triumph of Pisa against the Saracens in Palermo, whose spoils were partly invested in building the church. The «temple of snow-white marble» this is how it was called by the author of the funereal inscription for its architect, Buschetto represented the whole civil and religious community; and it had to reflect its fame and power to the eyes of the world: epigraphs were placed on the façade to celebrate the main maritime victories; reused pieces of Roman monuments were fitted on the sides to highlight the greatness of Pisa as the 'other Rome'; the façade was richly decorated with ornamental features, such as the outstanding Arab-inspired polychrome lozenges; finally, the rooftop was adorned with the magnificent Islam-made bronze griffon which is now on display at the Museo dell'Opera (the original one has been replaced by a copy), coming perhaps from Spain and most likely arrived in Pisa with the spoils of some military expedition.

The Baptistery, founded in 1152 on a design by Diotisalvi, was built in front of the **Cathedral**, lined up with its façade: a building that according to the latest studies is deeply imbued with the memories of the Holy Sepulchre of Jerusalem, a fact that goes back to the issue of the influences and relations

between the architecture of Pisa and the East. The round plan of the Baptistery was taken up again in 1173 by the anonymous designer of the Bell Tower (Bonanno Pisano? or still yet once again magister Diotisalvi?). A unique work in its roundness which recalls the curves of the nearby apses of the Cathedral, sharing with the other monuments of the Square the recurring motif of the pillars and small arches. Just after its completion the most famous monument in town was affected by that 'mysterious disease', which has made it famous all over the world and at the same time gave it the serious static problems that have been solved after over eight hundred years of trepidation by the strengthening work carried out in the 1990s.
With the Bell Tower, the group of monuments of the **Cathedral** seemed to be complete; but in the thirteenth century, while the works went on and the buildings were enriched with wonderful works of art, two new buildings were added to the site of the Square as it looks today, both born on the decision of the great archbishop of Pisa, Federico Visconti. The New Hospital, was built south, imposed on the township in 1257 by Pope Alexander IV as a token of the reconciliation with the Apostolic See after over fifteen years of a crisis, designed to help pilgrims, the poor and the sick: it is the big building that today hosts the Museo delle Sinopie, where we are now. In front of this building, in 1277, a new cemetery began to be built for grouping the tombs which until then had been left scattered all around the Cathedral. This plan led to the building of the Cemetery, an extraordinary four-sided cloister which with its marble façade closes, on the north side, the «**Piazza dei Miracoli**» (Miracle Square) which had been conceived for the burial of the dead and instruction of the living, who were asked to ponder on life on earth and the eternal one through the magnificent series of frescos whose preparatory sketches the so called “sinopie” are now kept in this Museum.

In 1595, a fire seriously damaged the cathedral, which was affected by restoration works and by the reconstruction of the roof and of the frontal doors.
The nave is covered by a wooden coffered ceiling that in the XVII century replaced the original exposed trusses.
The decorations in the Cathedral of Pisa are rich and sumptuous, the development of which is related to an often-troubled history marked by often-calamitous events that culminated in the fire of 1595. The only remains of the important commissions that completed the decoration of the Cathedral in the early 14th century are the mosaics on the apsidal conch - where Cimabue painted the figure of Saint John the Evangelist (1302 ca.) – the new pulpit (1302-1310) by Giovanni Pisano, and the disjoined sepulchral monument to Emperor Henry VII (1315), which used to be at the centre of the apse, and about whose construction the project *Un monumento per l'Imperatore* tried to shed light.



The central nave

The pulpit of Giovanni Pisano

The so-called "*Lampada di Galileo*"

3. **Cathedral's Workshop**

The administration responsible of the maintenance of the cathedral is the Opera della Primaziale Pisana (OPAE), that was established at the time of the first works for the erection of the monuments of Piazza del Duomo, which took up and distinguished the whole period of the mediaeval city-republic of Pisa.

Opera della Primaziale Pisana employs over 100 staff: engineers, architects, accountants and secretary, restorers, gardeners, masons, a carpenter and a locksmith and surveillance staff. The workshop is working permanently and its members are well familiar with the building, its state and problems, so most of damages can be quickly detected and repaired.

Our daily commitment is to ensure that the future generations are transmitted these masterpieces of medieval architecture housed in the Piazza del Duomo and their rich collection of sculptures and paintings.

The Historical Photo Archives

The archives consist of approximately 2,000 prints, approximately 1,000 plates and several films. These figures only concern the photographic materials developed from 1860 to the Second World War. Extremely important are the photos of the cycle of Frescos of the Cemetery before the 1945 fire. The collection has always been a scientific point of reference for historians and art historians. In addition, the archives include a large number of footages of events and works at the Cathedral Square. The plan for computerising all of the documents and developing a video library will end in 2005.

Printed iconographic materials

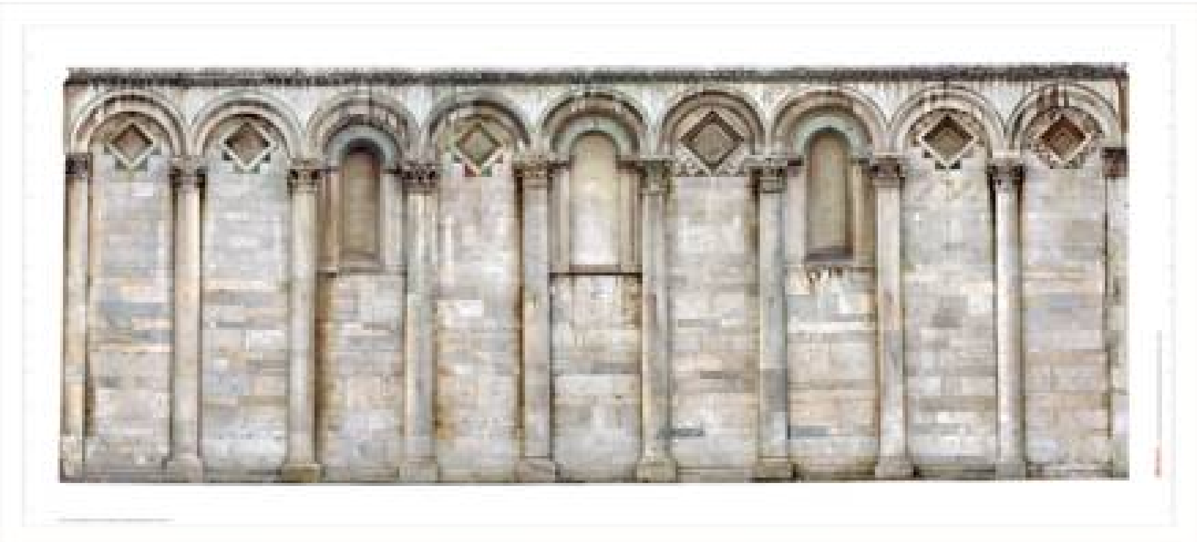
Extremely interesting is the collection of prints including iconographies of the city of Pisa. The oldest ones include two magnificent xylographs of the Liber Chronicarum which was printed in Nuremberg in 1493. The seventeenth-century collection includes some etched maps published in Amsterdam and Northern Italy which take their origin from Soli's engraving dating from 1603-1613. The largest group of iconographies dates back to the XVIII and XIX centuries, and it was engraved by foreign artists who, after coming to Pisa in the wake of the Grand Tour, used to portray the monuments of the Cathedral Square in their views. The iconographies by E. Cresy and G. Taylor, works of a high historical and scientific value, are instead the fruit of studies and accurate measurements. Some Tuscan artists are the authors of some precious engravings of the Square dating from the late eighteenth century. These include the Lucca-born artist Ferdinando Fambrini, the author of a set of fourteen views of Pisa, probably executed with the assistance of painter G. Tempesti and A. Da Morrona, from 1786-87. In addition, the collection includes a set of prints by Ranieri Grassi, a pre-eminent cultural figure in Pisa as well as a very prolific writer and illustrator of the early nineteenth century. Lastly, Lasinio's original drawings and famous engravings of a large part of the Cemetery's frescoes also deserve special attention.

Leaning Tower restoration photo archive

It consists of a wide database of photographic data shouted during the restoration works. For each stone, decorative element, capital, arcades, columns, a set of photos has been taken in order to record iconographic information related to the three phases: before/during/after restoration.

4. Ortophotography and/or 3D laser scanning survey of the building

The ortophotography was realized by Dedalo S.a.s. for the main apse restoration.



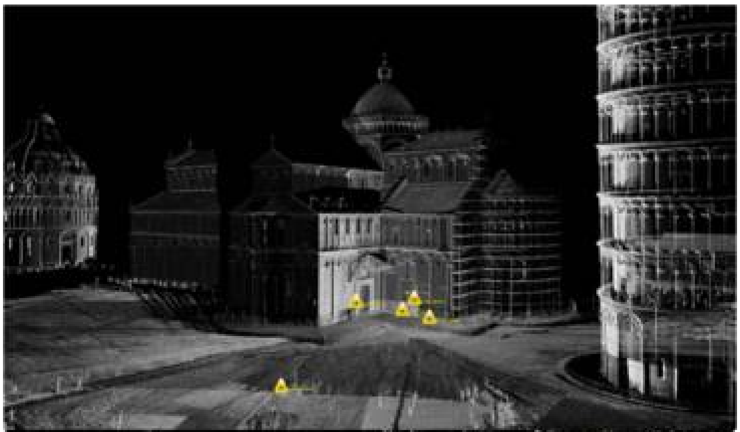
First storey

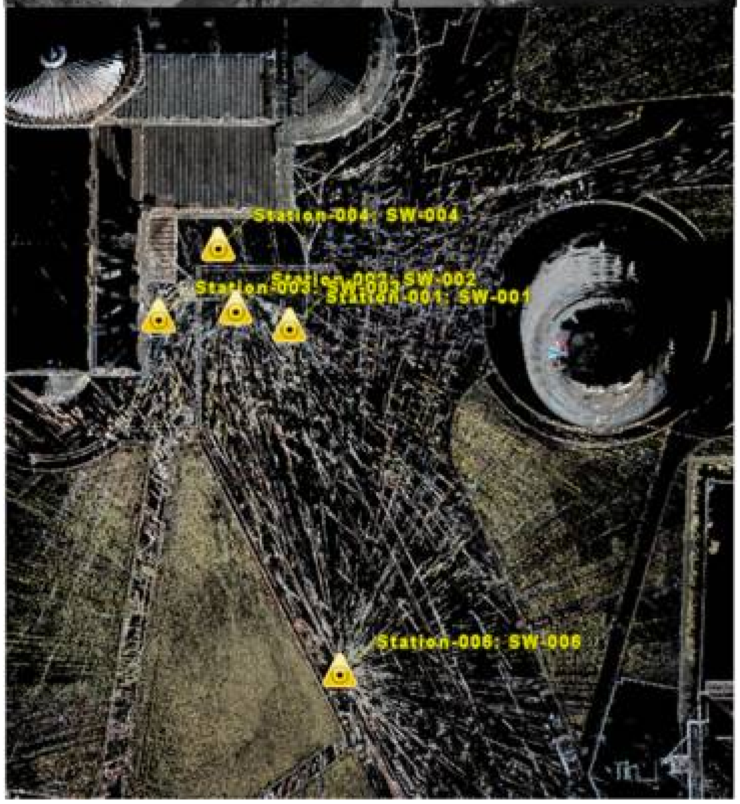
Second storey loggia (top: colonnade, bottom: wall)

Third storey loggia (top: colonnade, bottom: wall)

In 2015, a survey 3D Laser Scanner method was usef for the representation of architectural structures of N and S transects. The survey of the outer wall of the Cathedral, was performed by 3D Laser Scanner, using the latest generation Leica Scan station P40, ideal for measurements with high resolution, high accuracy and speed of acquisition, the P40 captures the pictures for detail (HDR).
To obtain a good resolution, and detect even the most difficult parts, they have been performed n. 5 scans (using a tripod and a particular column with elevation which allowed to perform the scans by at least 2 meters in height from the ground), a scans at a distance of about 4 meters from the wall, three to distance of about 12 meters and one to about 50 meters for a general overview and to be able to detect as far as possible the lower parts of tall windows.

The main features of the used instrument are:
1. a wide field of acquisition in single scan of 360 ° horizontally and 270 ° vertically, acquisition speed for up to 1,000,000 points / sec., A high precision 3D (3mm to 50 meters) and very reduced presence of noise (uncertainty) in the individual scans (0.5mm to 50 meters).
2. The system is controlled by a software integrated in the device, flow rate of about 200 meters radius
3. The ability to view, share, quote, describe the point cloud (file three-dimensional 3D) in Internet / intranet web browser directly into the operating system, through a plug-in TrueView.

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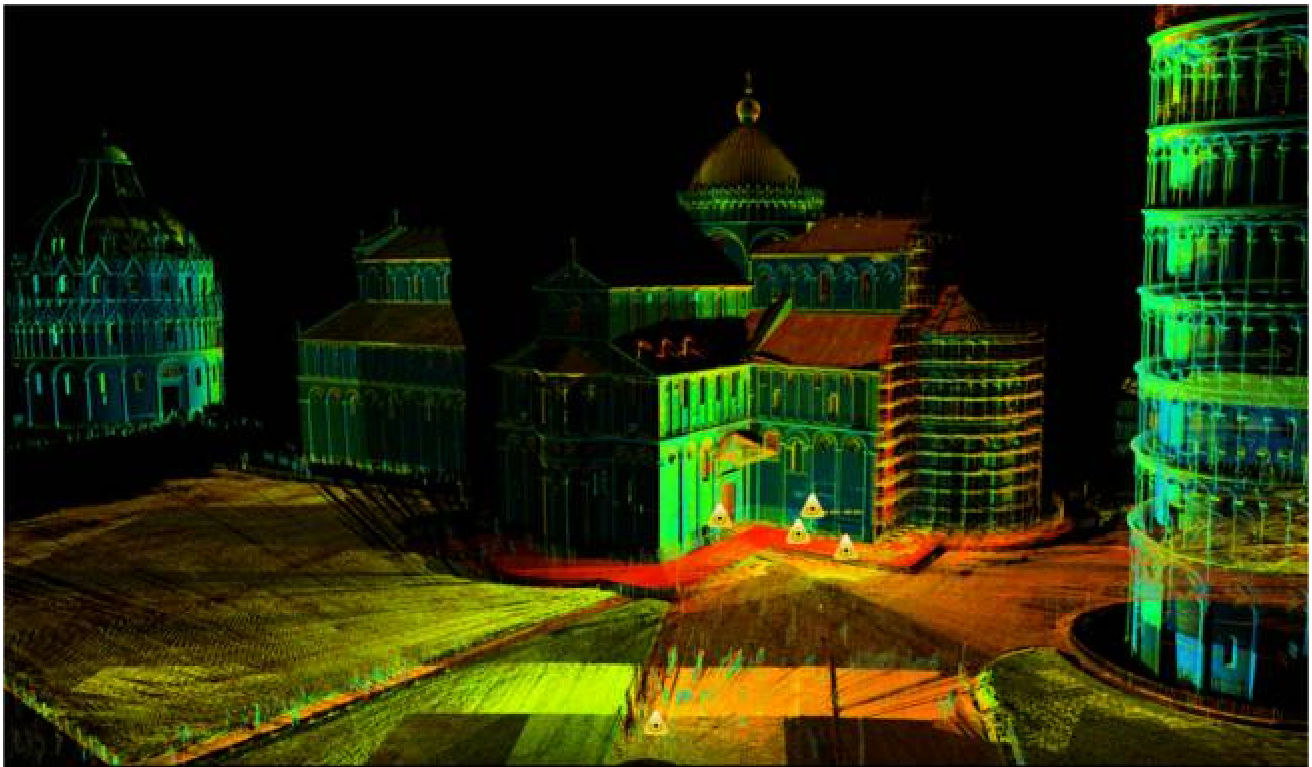
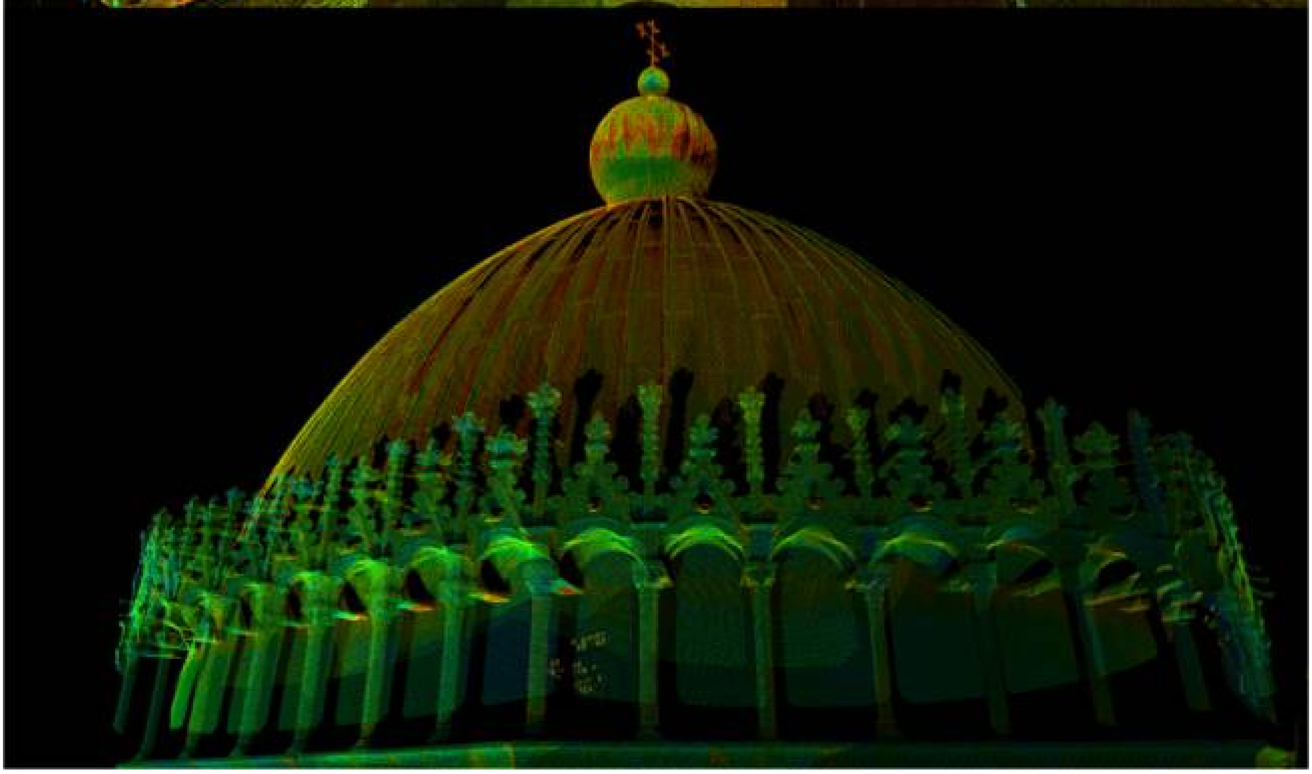




5. List of the building materials including stones used in the construction of the building

Stone materials in construction:

Monte Pisano marble
Apuan Alps marbles
Black limestones
Calcarenite “Panchina” of Livorno
Monzogranite/granodiorite from Elba Island
Eastern Mediterranean white marbles
Other coloured marbles and stones (Red porphyry, Breccia di Seravezza, red limestones, serpentinite)

Original jointing and bedding mortars: slaked lime with marble dust, sand and brick dust.
Roof construction: wood, lead sheets.

6. Information of the stones on the building, and their provenance and use

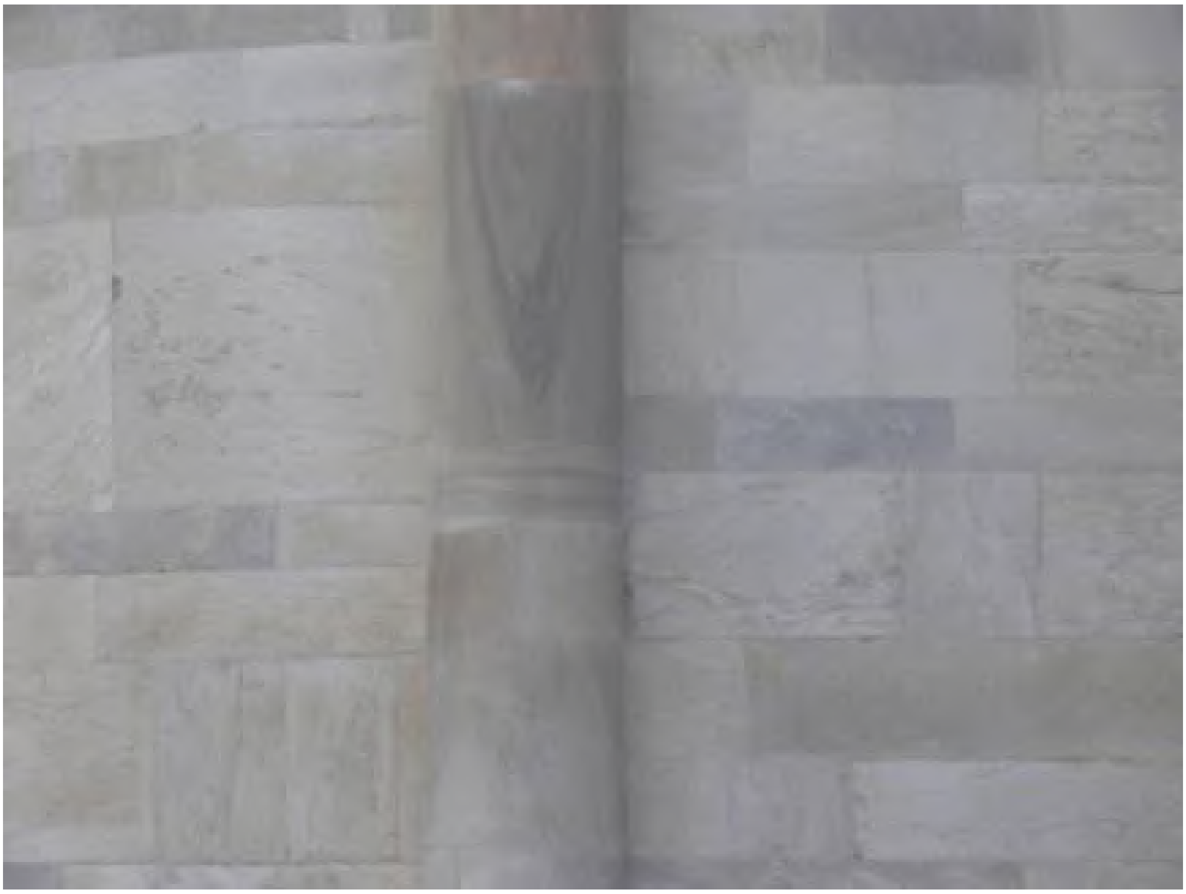
Preliminary data about the building stones used in the Cathedral of Pisa comes from the analyses carried out during the pilot restoration site and a paper is going to be published. The main lithotypes are the marbles from the *Monte Pisano* Marble (MPM) and White Apuan Marble (WAM). The MPM were quarried in elevations near to Pisa, in the locality of San Giuliano, and it is characterized by very fine grain size (50 to 110 µm) and microgranular texture. The ashlars are whitish to light grey, and their surfaces frequently show in relief the presence of dolomite-rich veins. This rock was used in the medieval buildings of Pisa, such as the other monuments of Piazza del Duomo, and in many historical edifices of Lucca. The WAM is characterized by a grain size that ranges from 150 to 400 µm. Its varieties, recognized through their macroscopic features (white, greyish and greyish-veined), suggest the provenance from different quarries of the Carrara basin; WAM was widely used since the Roman Age both for architecture and sculpture. The dimension of some blocks of MPM and WAM and the irregularity of the irregular courses of the lower part of the first storey wall, suggest the presence of reused materials.

There are also numerous ashlars of Proconnesian marble, a Turkish rock coming from the island of Marmara, characterized by white to greyish colour, mortar texture and maximum grain size over 2 mm; one capital of Pentelic marble, the white marble of the famous Parthenon, which was quarried on the Mount Pentelikon and is characterized by fine grain size and greenish streaks due to the presence of presence of oriented muscovite/sericite crystals; and one capital of Paros white marble, quarried in the Cycladic island of Paros (Greece) and characterized by fine to medium grain size. These three stones that comes from the Eastern Mediterranean, were frequently used in the Roman Era too.

The wall of the loggia of the third storey is mainly made up of quite regular blocks of the calcarenite "*Panchina*", a stone that comes from the coastal area South of Livorno. It consists of a calcareous matrix and by fossils and clasts up to few centimeters. This rock was commonly used in Pisa until the half of the 12th century.

A black limestone, a red marly limeston and a serpentinite were used prevalently in the ornamentations of the apse walls. Two black limestones outcrop in the area around Pisa, the presence of black flint suggests a provenance from the Monti d'Oltre Serchio rather that from the Monte Pisano. This rock was originally black, but its surface was altered to light grey because of the atmospheric phenomena. The red limestone belongs to the Scaglia Formation of the Tuscan Nap Sequence. Its main Tuscan historical quarries were located in San Giusto at Monterantoli and Monsummano (Florence) but the provenance of Pisa's Cathedral elements is uncertain. This rock was used also in some of the most important churches of Florence, such as Santa Maria Novella and Santa Maria del Fiore. The serpentinite is characterized by dark green to black colour and it is also known as Green Prato's Marble. It is associated with black and red limestones in the ornamentation of several medieval buildings of Pisa and of other Tuscan cities. This rock outcrops in several areas of the Northern Appennines but the most important Tuscan historical quarries were in Figline di Prato (Prato) and in Impruneta (Florence).

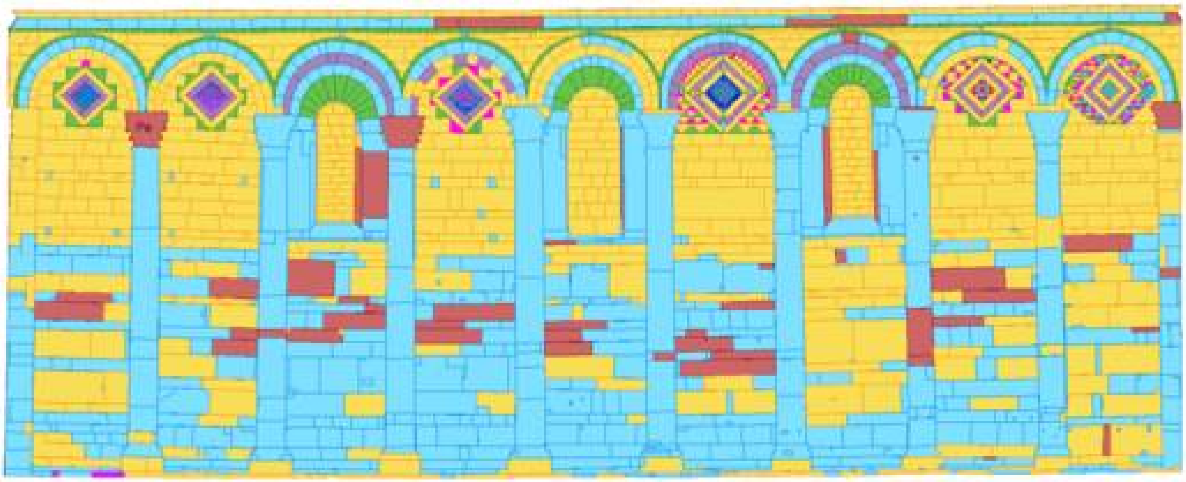
Detail of the first storey ornamentation of the apse

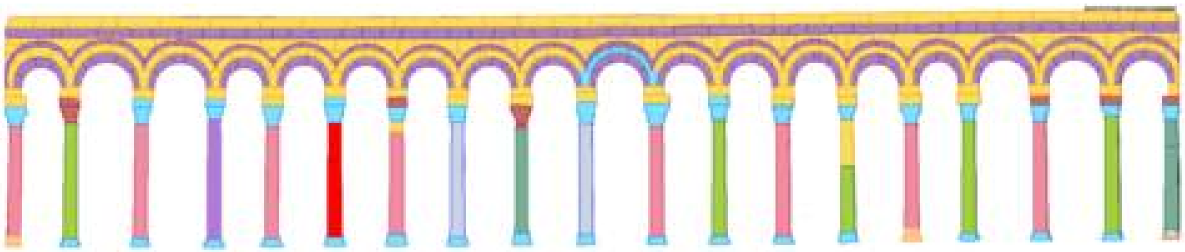


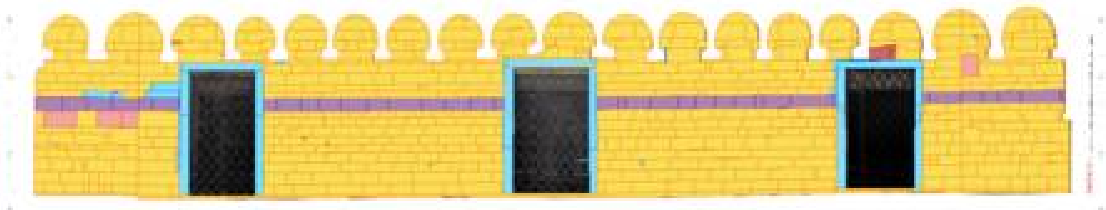
Detail of the first storey of the apse

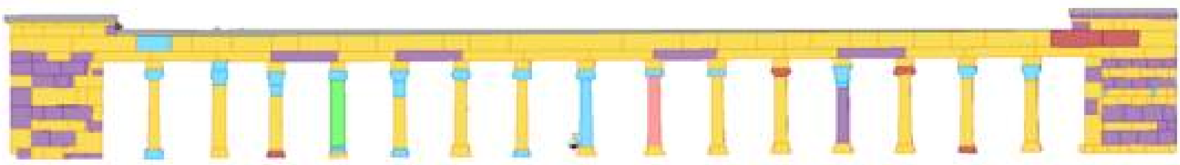
Third storey wall made up with Panchina calcarenite

7. Mapping of the stones









8. Evaluation of environmental aggressiveness

The cathedral of Pisa undergoes various environmental phenomena that contribute to the deterioration of stone and marble. The problem of "acid rain" certainly contributes to the corrosion of the surfaces, but the most important alterations are caused by daily and seasonal fluctuations of temperature ("baked" marble phenomenon) and by the crystallization of soluble salts, with the resulting formation of surface efflorescence, most of which is sodium chloride. The latter process should be correlated to the action of marine aerosols, transported by the winds that blow prevailingly from the South.

Black crusts cover a large part of the surface in protected parts (arches, capitals, arcades). Added to these deposits are the lime encrustations caused by the flow of rainwater and by seepage migration from inside the walls.

Another phenomenon linked to the presence and movement of water in various forms is the growth of weeds and biological film. The sectors most affected by biological attack are the North and East.

As shown in a study for the restoration of the Leaning Tower, the study of water in its various meteorological manifestations and its impact on the surfaces has revealed the principal directions of provenance of the wet weather and the areas most greatly affected, supporting the data on deposits of polluting particles. Statistically, rain, drizzle, fog and snow come prevailingly from the East; drizzles and fog primarily wet the North and South sectors, whereas with rain and snow the surface most affected is the East side. The dynamic of the phenomena is further complicated by the direction of the wind, which noticeably affects the slant and penetration of the rain, evaporation times in relation to height, and cycles of salt dissolution and crystallization.

Another important element, carefully studied for the restoration of the Leaning Tower, is the amount of direct solar radiation. Temperature readings and monitoring of the daily exposure time enabled us to evaluate especially the gradients of thermal expansion of the various materials in the various architectural parts. From was has been ascertained, it would appear that the columns and capitals are the weakest structures: they are thin elements – thus easily heated – and are exposed to direct radiation for a very long time. They thus tend to expand much more than the wall structure of the body of the hole construction. On the columns, the repeated cycles of expansion of the stone and its compression in the storeys of the galleries easily leads to situations of physical collapse and aggravation of decay.

With regard to sectors of exposure, the side subjected to the greatest direct solar radiation is certainly the South, where on registers the highest temperatures and the longest hours of exposure in every season except summer; in this season the greatest gradients move to the East and West sector.

9. Preliminary evaluation of the conservation state of stone surfaces

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The following forms of alteration were observed in the central apse of the cathedral (2012-13 observation time). The terms of alteration forms are defined according to the ICOMOS Glossary:

Crack:
- Fracture
- hair crack
- splitting

Detachment:
- exfoliation
- granular disintegration (powdering, sanding, sugaring)
- scaling

Features induced by material loss:
- alveolization
- erosion

Mechanical damage:
- impact damage

Discoloration and deposit:
- black crust
- deposit
- discolouration
- efflorescence
- encrustation
- graffiti
- patina (iron rich patina, oxalate patina)

Biological colonization:
- alga
- lichen
- moss
- mould
- plant

10. Information on historic and recent treatments of conservation

The old preventive and remedial treatments are as follows:

For consolidation:

- ethyl silicate Estel 1000 (*CTS*) used on the Cathedral façade
- acrylic polymer Primal AC 33 (*Rohm and Haas*) used on the Cathedral façade
- Barium Hydroxide
- Acryl resin and silicone resin in organic solvents Acrisil 201 (*CTS*)
- Fluorinated copolymer Akeogard CO
- Methacrylate-Ethyl Metacrylate resin Paraloid B 72 (*Rohm and Haas*) used on the Cathedral façade

For protective coating:

- perfluoropolyether Fomblin Y Met
- microcrystalline wax

The present preventive and remedial treatments are as follows:

For consolidation:

- ethyl silicate Rhodorsil RC70 (*Rohm and Haas*)
- nano-silica Zargun 260012 (*Colorobbia*)
- micro-emulsion acrylic, acrylic polymer Primal WS-24 (*Rohm and Haas*)

For protective coating:

- no product

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D1.1 – Part E, Background information on the architectural object: St. Stephen's Cathedral (Vienna, Austria)

Main figures:

Length:	107,2 m
Width:	34,2 m
Height of Choir:	22,4 m
Height of Central Nave:	28 m
Height of South Steeple:	137 m
Height of North Steeple:	68 m
Height of Facade-Steeples:	66 m
Roof: height:	60 m
Foundation of the steeples:	4 m deep.

1 General Information, present state

St. Stephen's Cathedral is seat of a roman catholic Archbishop. The cathedral is situated in the center of the city of Vienna, an UNESCO world heritage site since 2001. The most impressive part of the church is its south steeple, which is not only remarkable for its tall shape, but for the fact, that it was at the time of its completion the highest stone building in Europe, reaching 137 m.

Originally a parish church, since 1365 it is seat of a chapter, consisting of 12 capitulars, since 1469, seat of a bishop, 1726 an archbishop.

The cathedral is a foundation asset, managed by the chapter. For operating the affairs two organizations exists: the Kirchenmeisteramt for ordinary service, as custody, sacristans, cleaning etc., the Dombauhütte, the cathedral's workshop, for building affairs, preservation and masonry.

After being severely damaged in 1945 the cathedral's restoration lasted into the 1970s.

Since then restoration work concentrates in cleaning, restoring damages caused by environmental pollution, frost-crackling, humidity in the stones and morter-joints. Although recently exhaust gases have decreased, still the remove of sulphuric, black crusts is an important step at the beginning of restoration. Vienna has got a rather continental climate with cold winters and warm, dry summers, especially in winter there are numerous freeze/thaw cycles (approx. 200 per year) stressing the structure of the building.

Cathedral's Workshop

Responsible for the maintenance of the cathedral is the cathedral's workshop, employing approx. 20 people: masons, sculptors, a carpenter, a locksmith, architect, archive, accountant and secretary.

The workshop is working permanently,its members are well familiar with the building, its state and problems, so damages can be detected generally at an early time.

There is a scheduled plan of restoration, which takes about 35-40 years, in cases of emergency, however, it has to be changed and adapted to prevent stronger damages.

Brief chronology

Founding of the new Parish church of Vienna:	1137
First consecration:	1147
West-facade:	~1235
Choir:	1304-1340
West chapels:	1360-1400
Nave:	1360-1450
South steeple:	1359-1433
North steeple:	1450-1513
St.Stephen's becoming cathedral:	1469
Annexes: sacristies	~1700
Building for the workshop	1960

2 Construction History

<u>Foundation of St.Stephen's, early times</u>

The oldest documents connected to St. Stephen's date from 1137: When the mediaeval city expanded beyond the roman walls, the Bishop of Passau gave land to the margrave of Austria, to vuild the city, but retained a piece of land to build the New Parish Church of Vienna, dedicated to St. Stephen. Already ten years late, 1147, the first parts of the new church could be consecrated.

It must have been a church with three isles (approx. 50 m long) with two western steeples and a porch between them.

<u>Existing parts, traces:</u>

Only the lower parts of the western steeples are still existing. Their name "pagan steeples" probably refers to their antiqueness.

<u>Romanesque church:</u>

This early church was replaced between 1200 and 1240 by a lateromanesque church.

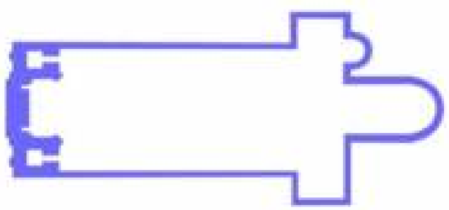
Parts of the westwork were preserved, but behind the facade there was built a new nave with three aisles, a transept – broader than the nave – and an apse.

The westwork had a new gallery, the porch was expanded to the west, projecting between the steeples. This porch is called "Riesentor", the fundaments of which and its predecessors were excavated in 1996, the fundaments of the nave and parts of the apse during post-war reconstruction-works and in 2000.

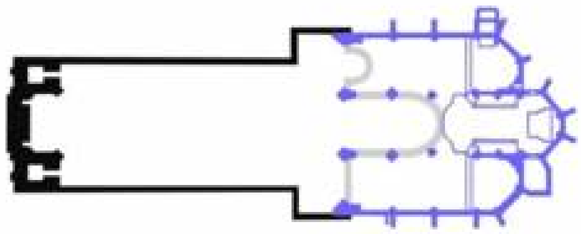
<u>Existing parts, traces:</u>

A remarkable part of this romanesque church still exists: the westwork with the steeples, the facade, Riesentor, and parts of the gallery, which was altered in the 15th century.

A part highly important for the present shape of the cathedral was the transept, which defined the broadness of both the existing choir and the nave as well as the position of the two gothic steeples.



St. Stephens, approx. 1240



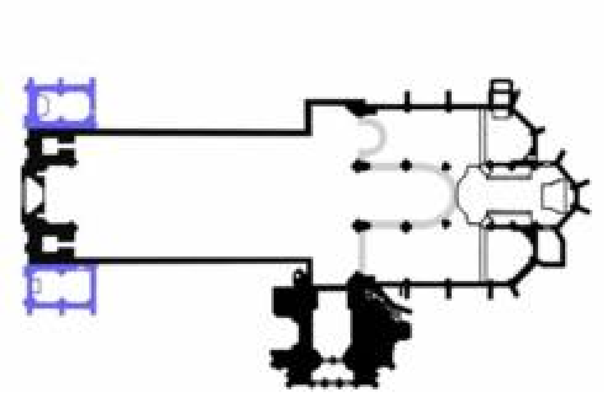
Gothic Choir, 1304-1340

Early gothic: 1304-1340

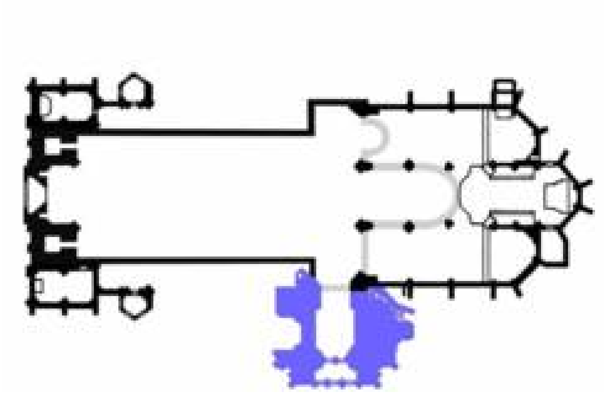
In 1304 a building, situated east of the old church was bought in order to expand the choir of St. Stephen's. The new choir became a three naved hall with cross-ribbed vaults, the middle aisle with 5 bays, the side aisles with 4 bays, all of them with polygonal apses.

Existing parts, traces:

The choir is still existing, restorations had to be made after several wars (1683 , 1809 and 1945), and to repair the damages caused by the fact, that the huge steeple was attached to the choir. Being much heavier it caused more intense subsidings of the basements. These tensions in the fundaments caused crackles in the walls and deformations of the walls.



After 1359: Western chapels added, South steeple begun,



1433, South steeple finished side portals

Late 14th century

1359 Duke Rudolf IV. laid a fundament for the "Augmentation of the Church". Although the document recording that fact doesn't assign exactly the place of this event and the first part to be built, we can see, what his plans were. Anyway, his great plans were not finished in his lifetime. For he died at the age of 26 in 1365, not much can be accomplished at that time.

The Plan consisted in a new nave, now as broad as the choir (and the former transept), probably new was the concept of two portals in the north- and south- walls of the naves. They show a rich instrumentation with sculptures, both show the duke and his wife as statues in the jambs.

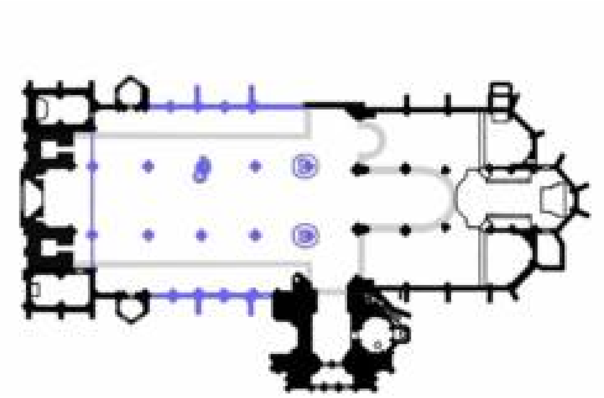
Since the nave was now broader than the old facade, on both sides of the western steeples two chappels were added, the lower ones with regular cross-ribbed vaults, the upper ones with five-parts-ribvaults. These vaults can cover a big, single arch on one side and two smaller arches on the other. So each bay has two windows. This system was planned for the side aisles of the main nave as well, but when the ceiling was evntually vaulted in the 1440es, style had changed and now the ribs form a rich and comparably complicated net of rhomboids, circles and other forms.

The plan Rudolf's to make St.Stephens a church with four steeples – similar to the romanesque imperial cathedrals of the rhine. Of course he wanted to lay emphasis on the nobility of his family – His great-grandfather Rudolf I was German King 1273-91 and was buried in the cathedral of Speyer. St.Stephen's should become the new Pantheon of his family with imperial claim.

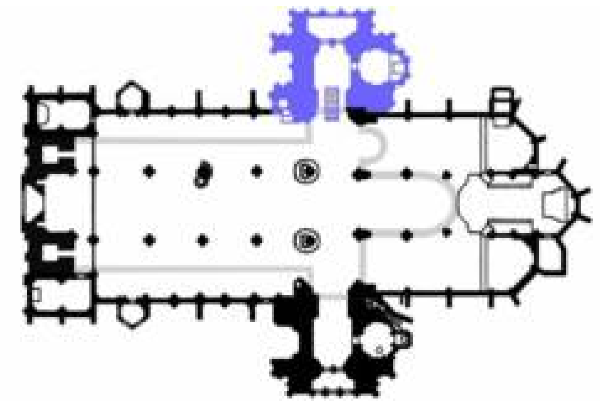
In the 1360s the chapels, the side portals and the westernmost parts of the new nave were finished or in execution.

Late gothic phase, 1400-1440: nave, south steeple

Around 1400 the south steeple had reached the height of about 20 meters, then plans were changed, the steeple should get much higher. For that reason the structure of the steeple was changed totally. But it was a phase of very intense building activity: The steeple was finished 1433 and around 1440 the walls of the nave must have been completed, because the timberwork of the roof was mad in that time.



approx. 1450: Walls of the nave finished



1513, Nave vaulted, north steeple added

1450-1513. Nave vaults, north steeple

During the time, when the south steeple became an extraordinary high structure, nobody planned to give it a pendant any more.

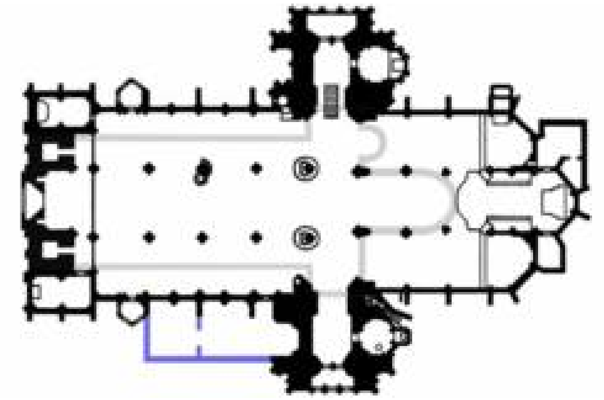
Emperor Frederic III, who had his grand uncle Rudolf IV as a model in many aspects: He revived the original plan of a second steeple next to the choir.

So in 1450 the fundaments for the steeple were laid, 1467 the walls were begun, and already 1476 the chapel of St.Barbara was finished and consecrated.

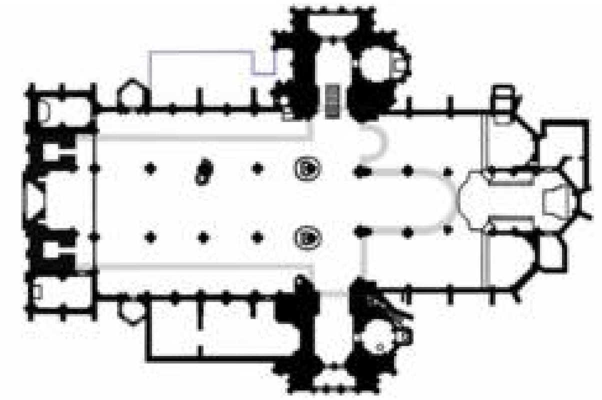
But a few years later the impetus tired, and 1513 the building activities were stopped.

Baroque and modern annexes

In baroque times the two sacristies were rebuilt in the 1720s, using medieval walls, in 1857 on the north side the workshop was built in framework with bricks. Unfortunately this part was destroyed 1945, for the restoration in post-war-period temporary barracks were used, only in 1960 a new workshop was built in brickwork covered with sandstone.



1730: Sacristies added



1857: Workshop on the north side

3 St Stephen's, Architecture and art.

The cathedral church of Vienna is not only a landmark for the city of Vienna, but also for the whole country of Austria. The city is strongly focused on the steeple of St.Stephen's, many streets of the city and roads in the surroundings give view to the steeple, the roof with its glazed tiles towers the city-center and forms an emblematic view of the city. From 15th century on the cathedral is "portrayed" in many vedutas of the city.

Just to mention the most remarkable paintings: The altarpiece of the Albrechtsmeister (made for a Viennese church in 1440, now in a Museum in Klosterneuburg), the altar of Schottenkirche, Vienna (1470), of St. Margaret in Medias, Rumania, (1480), a fresco in Palazzo Lantieri, Gorizia (I), showing the Turkish Siege of 1529, painted 1550, and in present many logos and the Austrian 10 cent – coin or the signature of the Austrian broadcasting corporation for Eurovision-broadcasts.

However the cathedral shows very different styles, due to its long construction period from 1137 to 1513. Fortunately from every phase there are still some parts conserved.

Albrechtsmeister: Joachim and Anne at the Golden Gate: Detail with skyline of medieval Vienna, ca. 1440

Schottenaltar: Flight to Egypt, Veduta of Vienna, approx. 1460

<u>Historic overview of Vienna:</u>

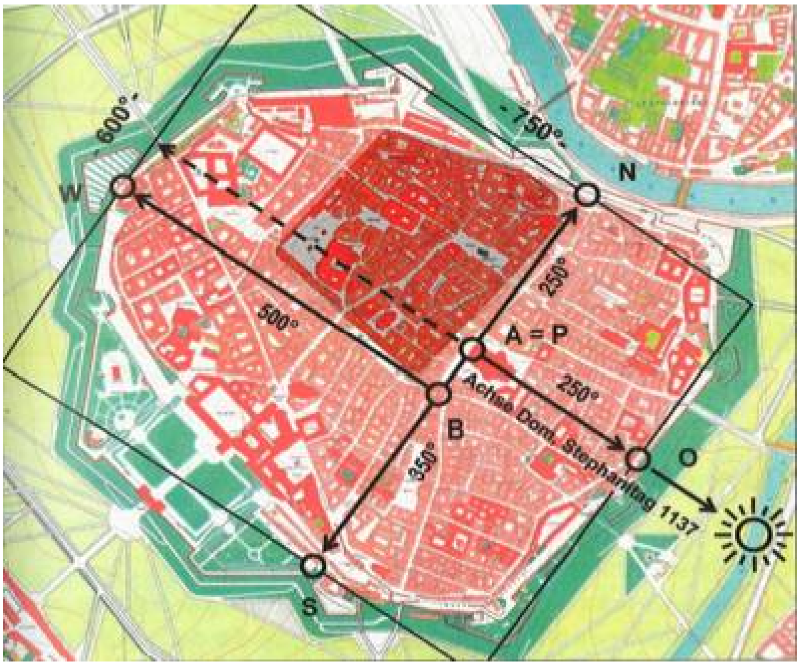
The history of St.Stephen's is tightly connected to the history of the city of Vienna. In roman times Vindobona was just a little "castrum" near the province capital of Carnuntum, 20 km east. Since it lies at the eastern end of the Alps and in an area, where the danube tends to form many little branches, it has however been a very important point of international traffic since prehistoric times.

After the decline of the Roman Empire no solid structures of government were established in that area.

After the battle at the Lechfeld in 955 two factors guaranteed a peaceful development of the Danube area: A margravate could be established in the Austrian heartland, and the Hungarians became resident in the pannonian plains. The margravate expanded slowly to the east, changing its capital, to keep contact with the moving official border.

Within the shelter of the roman walls of the castrum Vienna had been a marketplace even in the early middle ages, but there are no traces of urban live in that times.

The oldest medieval building still preserved, is the church of St.Ruprecht, built in the 1130s.



City expanson after 1137:
dark red: Roman castrum, light red: mediaeval city

In 1137, the city expanded dramatically. The new walls marked the borders of the city for the next 700 years. Only then, in 1859 the walls were torn down and the zone of walls and glacis was redesigned as “Ringstraße” with representative official buildings of the 19th century.

The development must have been extremely stormy: Already in 1145 Vienna became the new capital of Austria, with a representative court and a remarkable church.

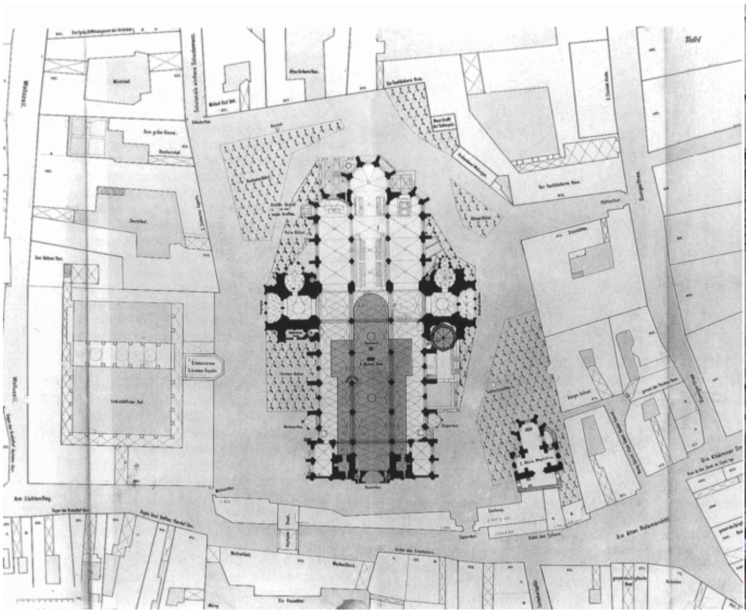
However, the seat of the bishop was still in Passau, only in 1469 St. Stephen's became a cathedral, but the diocese was hardly bigger than the city itself, it became became the seat of an archbishop not until 1722. Since there was no bishop in medieval Vienna, there was no continuous mastermind and principal, The different phases with strong efforts to construct and to enlarge St.Stephen's were carried on by different groups and motivated by different aims:

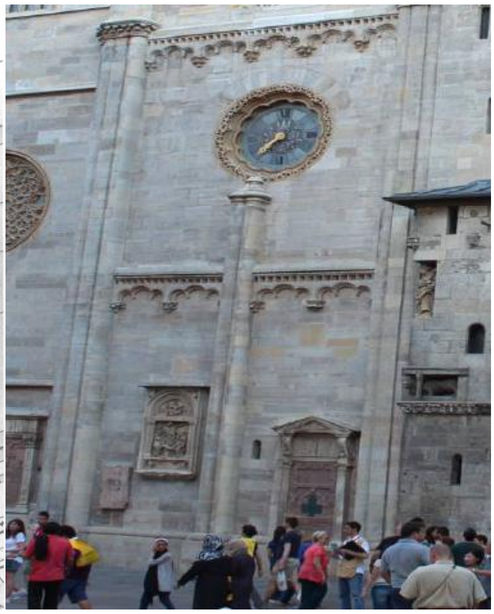
In many cases it were the dukes who wanted to make St.Stephen's more representative, and worthy to be a cathedral: This was the case in the early 13th century, when Leopold VI and Frederick II made proposals to divide the diocese of Passau and become Vienna seat of the new diocese; when Rudolf IV laid the foundations to the “augmentation” of St.Stephen's in 1359; when Frederick III had the nave vaulted and built the north steeple around 1450. Of course to get a bishop was not the only motivation for building activities: for the dukes it was important to show their might and legitimacy, when Otakar Przemysl restored the western facade around 1270 and when Albert II supported the building of the choir until 1340. The most important group to finance the construction however was the people of Vienna and its citizenry. They were interested in having a representative and handsome church, with wide naves both in choir and nave, to have space for public ceremonies as well as for private services and memory. They wanted to have a steeple as high as no other in christendom, or at least in Central Europe. This was the most important reason for changing the plan for the steeple to a very high, tall and “competitive” structure.

First phase, Romanesque, 12th century:

The oldest parts are preserved in the western facade: the groundfloors of the so called “Heidentürme” (pagan towers), were built in the twelfth century and seem to belong to the church that was consecrated on April 23rd 1147. This church must have been quite representative, with approx. 50 m length and elaborate architectural sculpture and figurative paintings.

Some of the stones of this church have been used for the fundaments of the church of the 13th century. These stones, mainly fine elaborated architectural blocks, were found in the post-war excavations and in an archeological campaign 2000.





Scheme of the Development of St. Stephen's churchyard

Oldest parts: ground floor and its of the western steeples

Second phase: Late Romanesque, early 13th century:

This church is still determining the proportions of the existing cathedral, even in the parts not existing any more. It was a three naved basilica with a transept and probably three apses. The width of the transept remained the with of the later built choir and nave and determined the position of the two steeples.

The westwork of this phase is still preserved in the main parts: Two romanesque steeples with square bases and octagonal shape in the higher levels still exist (the so called “Heidentürme”, i.e. “pagan towers”).

They are framing a prominent portal porch, the “Riesentor”, i.e. “giant's gate”. This wide, funnel-shaped portal is round-arched and shows geometric “normannic” patterns in the achivolts and columns. But the porch is closed by a rather narrow pointed arch, the outer side rather plain and shapeless. In some parts of the frieze the reliefs are interrupted, stylistic changes are obvious.

Fortunately several plans to purify the western facade and to reconstruct the “original” status (Ferdinand v. Hohenberg, 1780, Frierich v. Schmidt, 1870 and Julius Hermann, 1900) were not implemented, archeological excavations 1996 proved that there had been an other status of the Riesentor.

Characteristics of art:

The “Riesentor” is characterized by geometric, so called “normannic” ornaments. Originally coming from northern England (Durham, 1066), this style of decoration spread all over Europe, especially to Sicily.

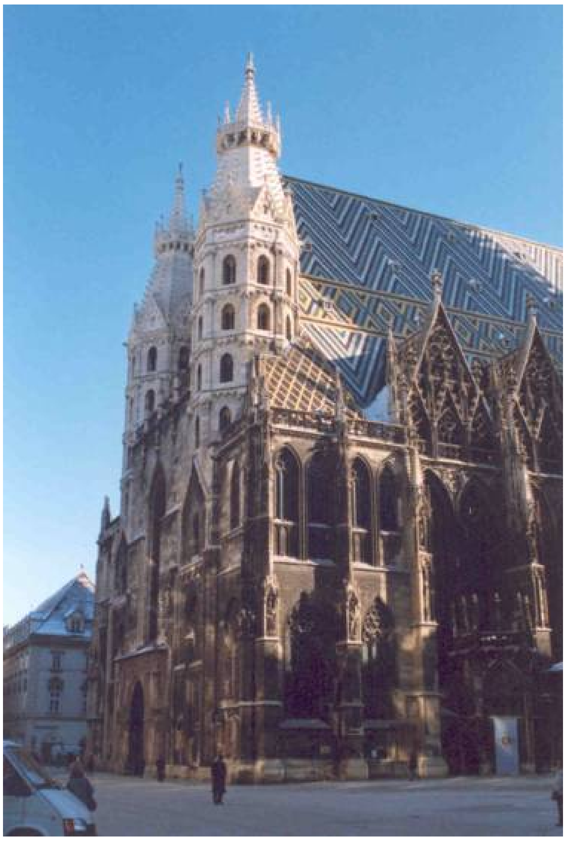
In central Europe it was used in that times as a political statement: It assigned a follower of Emperor Frederic II (1212-1250), who was not only king of Germany, but also of Sicily and tried to find something he could establish as typical for both his reigns.

The style changed during construction time: in the frieze some sculpted blocks with ornamental decoration are set next to ones with narrative reliefs.

On the outer side gothic style became dominant. The porch shows a pointed arch to the exterior, the ornaments become more generalized and abstract.

The portal was originally painted, traces of color were discovered as early as 1830 and 1996 seven layers could be separated.

In 15th century, when the nave was vaulted, even the portal was “modernized”, parts removed and covered with plaster. Characteristic for this part is the coexistence of romanesque, “normannic” and gothic style, signifying a piece of art built in a phase of stylistic transition.



Westwork

westfacade

Porch of the “Riesentor

Frieze and columns in “normannic” style

<u>“Early” Gothic, the Choir:</u>

In 1304 plots were purchased to add a new three aisled hall choir to the transept. The choir could be consecrated in 1340. There are some peculiarities in that part: The shell is not totally covered by windows, there are broad stone walls flanking the buttresses. The central pillars are very massive, because they had to carry a very high roof with a special construction: above the bows there was a brick wall to stabilize the timberwork of the truss made of larch wood.

<u>Artistical significancies:</u>

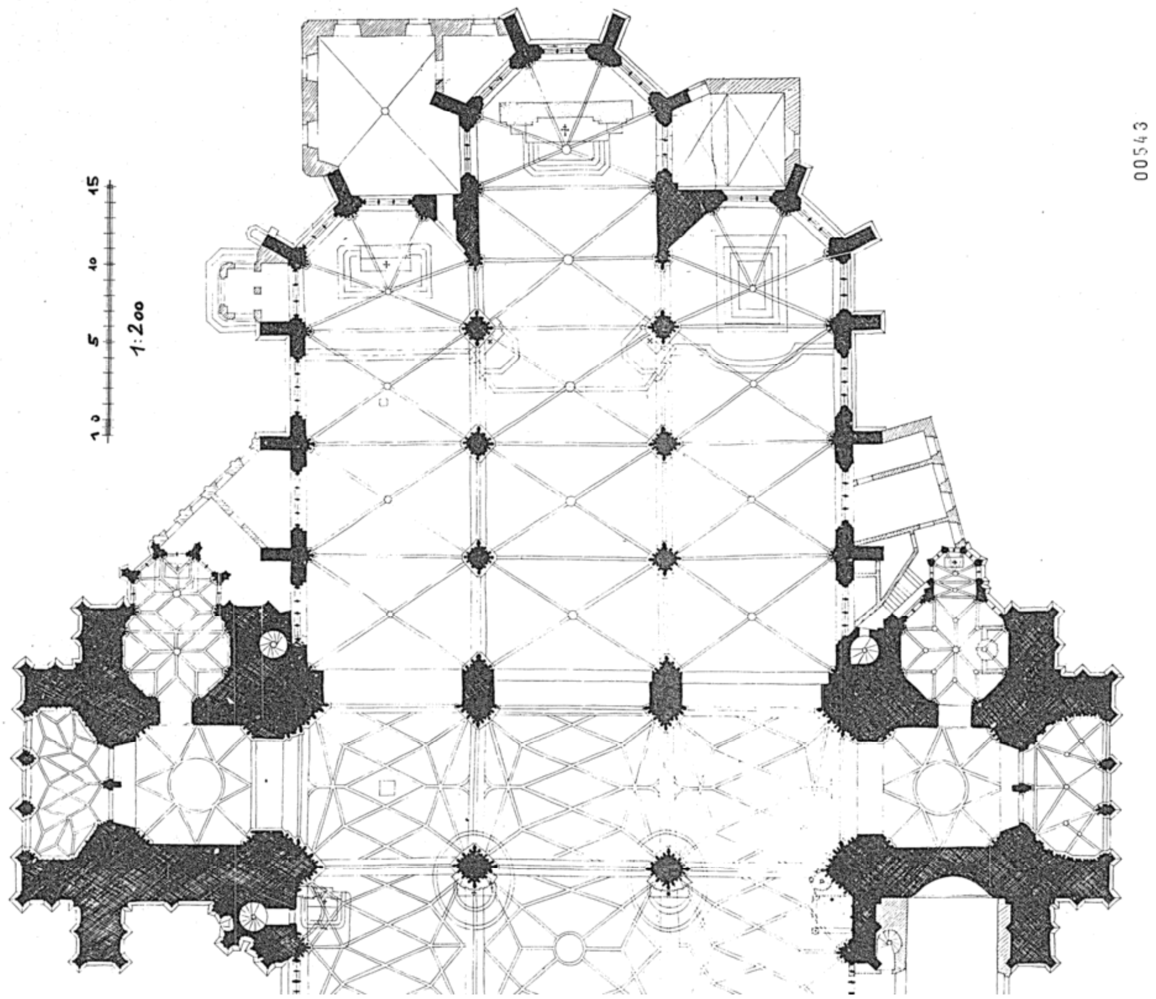
Remarkable is the multitude of sculpted consoles at the exterior, supporting the choir's gargoyles. They show angels, playing music and they are still preserved as originals, not as copies. The most precious piece of art coming from that time is the “Madonna of the servants”, probably made for the apse of the northern nave, still called the “ladies nave”. It is now situated near the pilar supporting both the choir and the south steeple.

Choir, north view, pre-war photo

console on the choir

interior of the choir

“Dienstbotenmadonna”



Ground plan of the choir

<u>Gothic: Rudolf's initiative</u>

In 1359 duke Rudolf IV, later called “the founder”, laid a foundation stone for an augmentation of the church. It seems that in his time not only the western chapels had been built, but also the westernmost parts of the nave and the two side portals, the “Singertor” in the south and the “Bischofstor” in the north. These two remarkable ensembles of sculpture show in the tympana the story of St.Paul (south) and death and Assumption of Mary (north). They are flanked by male (south) and female (north) saints in the archivolts. Both the doors however are flanked by Rudolf and his wive Catherine of Bohemia, accompanied by servants presenting their coats of arms.

To both portals polygonal porches have been added, they were built approx. 1450 (south) and 1510 (north). The western chapels had to be added to fill the difference between the old romanesque westwork and the new, broader nave. On both sides, each north and south, two superimposed chapels were added. This scheme follows in general the pattern of the Sainte Chapelle in Paris, but with a totally new approach: the lower chapel for the public is higher, with sculptures, altars etc., the higher floor is an intimate private chapel for the family. Originally the windows were filled with stain glassed windows, showing the most important representatives of the Habsburg family, up to 1380. Since the 19th century they were preserved in museums.

“Singertor, 1365

Detail: Sculpture of Rudolf IV

Artistical significancies:

By adding the four chapels on the sides of the steeples a very broad facade resulted, structured by pilasters. Originally the facade could not be seen frontally, because there was no street leading to it, only passing tangentially. The Riesentor was not the main entrance to the church until 1945. People entered St.Stephen's through the both side portals, Singertor at the south and Bischofstor at the north side. Both were sheltered by polygonal late gothic porches, and can not be seen from the exterior. For that fact they are well preserved and show delicate ensembles of sculpture made around 1365. Especially the relief of St.Paul in the “Singertor” on the south side is an impressing work of art, showing organic movement of both horses and riders with high emphasis on the spatial disposition.

The south steeple

The most impressing part is the south steeple, begun around 1360, planned to become only 60 m high, it had reached the height of choir and transept around 1400. 1395 the chapel with a hanging vault, situated between the two eastern buttresses of the steeple, was consecrated. At this state, plans were changed, a Master Wenczla, probably Wenzel Parler from Prague was the leading architect, after his death 1404, plans were changed again. Work advanced rapidly, and the two masters of the workshop, Hans and Peter Prachatitz managed to finish the steeple within less than 30 years, adding more than hundred meters to the height achieved before and reaching 137 meters. The masters tried to hide the borders between the different floors of the steeple, achieving an almost continuously narrowing pyramide.

Artistical significancies:

In the lower parts the buttresses are set orthogonally, with sharp corners and in square shape. In about 20 m height their character changes, the corners are smoothed, supported by sculpted beasts. In the upper parts it becomes characteristic for the steeple's architecture, that all corners, alternations etc. are covered by pinnacles, wimpergs and tracery, to show the illusion of a continuously developed structure.

Remarkable is the series of monumental sculptures showing the parents and parents in law of Rudolf IV.

Although they are older than the architecture they are standing in, they seem to belong to the initial concept of Rudolf, being obsessive about representation of his family.

Buttress Steeple Consoles

Nave

Simultaneously with the steeple the nave was constructed, and around 1440 the huge roof was made. Covered with glazed tiles it dominates the view of the cathedral and is an optic counterpart to the steeple, balancing the different shapes of the church with the romanesque steeples in the west and the – compared to the steeple – low choir.

The facades of the nave are crowned by a series of gables, of which only one could be decorated with tracery already in the middle ages. It is now called the “Friedrichsgiebel” (gable of Frederick), because it was built in Emperor Frederick's times, but the name first appeared in the 20th century. The other gables were built but as plain walls, with the tracery just painted on them.

The tracery was completed only in the nineteenth century, which was the only major addition to St.Stephen's in the 19th century.

The vaults, originally planned with four ribs in the middle nave, with five in the side aisles (with two windows for each bay), were executed with a net-ribbed vault.

The peculiar fact, that the middle aisle is about 5 meters higher than the side aisles is rather common for churches under the patronance of Frederick III. Probably this pseudo-basilica was esteemed as more prestigious than a hall, which was typical for “bourgeois” buildings.

Artistical Significancies:

The edges of the nave are marked by late gothic canopies, covering altars. The first was constructed around 1450, the latest around 1510. they show increasingly detailed tracery, getting more delicate. The youngest canopy shows even bent pinnacles and organic, soft forms.

At the northwest corner the pedestal for an organ is situated. In a totally different form its structure is developed out of one point, supported by the self-portrait of the artist, Anton Pilgram.

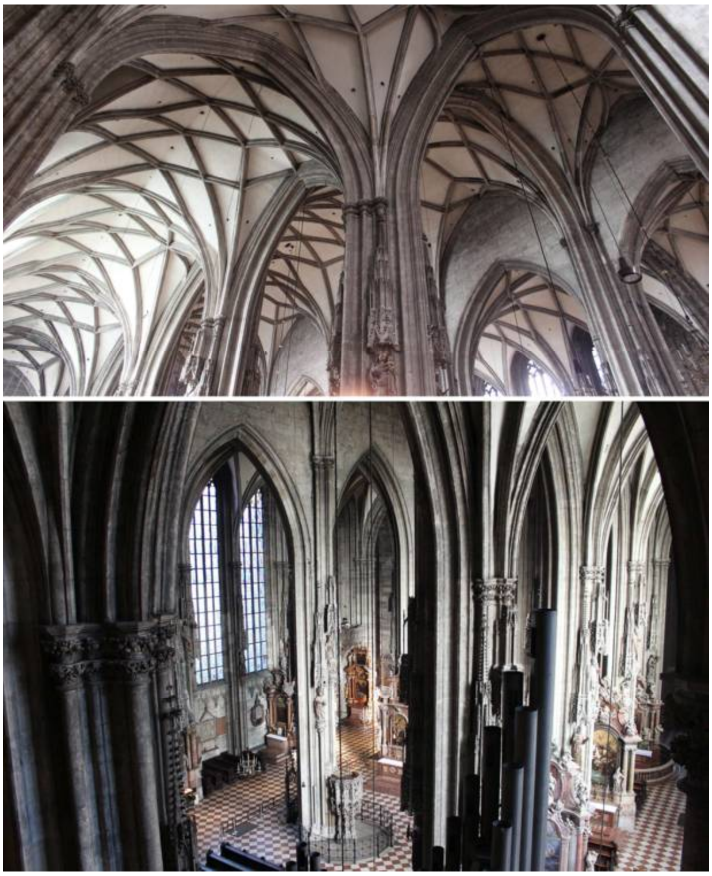
The ribs of the structure form geometric, spatial loops, carrying the gallery, once holding an organ. This new construction marks the end of gothic period in St.Stephen's: it was finished in 1513, the year when the workshop was reduced and construction of the north steeple stopped.

The self portrait as well shows a new type of artist: he is no more a nameless servant to the art, he is now a self-conscious individual, typical for modern times.

Northern steeple

Since the southern steeple had got a totally different shape than originally planned, the second steeple had to be rethought as well. It is probably only due to Frederick, who wanted to accomplish the plans of his great uncle Rudolf, that the plans for the north steeples were revived.

We are in the lucky position that various plans for the completion of the steeple are preserved, so we know that it wouldn't have been an exact copy of the south steeple, although the general shape would have been the same.
But even in the finished parts the north steeple is more massive, the entrance hall is higher than the one in the south steeple and the naves. It has got two staircases, on on the east side (as the south steeple has) and one on the west side.
The tracery covers the walls with a vail of vertical bars and leads to a different optical effect. .
In 1513 constructing activities were stopped for several reasons: At the end of the middle ages the aim to construct a high steeple was not so important any more, especially, if it was only an additional one. Times became more warlike: 16 years later Vienna was besieged, so the building activities



Nave: Vaults: of the central aisle Nave: Vaults with different heights

focussed on the city walls. Maybe there were also aesthetic reasons: a solitaire is sometimes more impressive, then a pair, but we don't know for sure.
The steeple remained as a torso, till in 1583 it was finished with a cuppola, in renaissance forms, but wich gothic ornaments. Since 1957 it hosts the biggest bell of the cathedral, moulded in 1710 from conquered cannons, destroyed 1945, it was remoulded from the fragments and brought to the steeple.

North Steeple, 1467-1513

“Welsh cap”, added 1583

Interior

In the last phase of the mediaeval building activity representation in the interior became more important: the delicate pulpit, the organ pedestal by Anton Pilgram (finished 1513) the tomb of Frederick, begun in 1467 by Niclas Gerhaert van Leyden, finished in 1517 are very ambitious pieces of sculpture of their time.

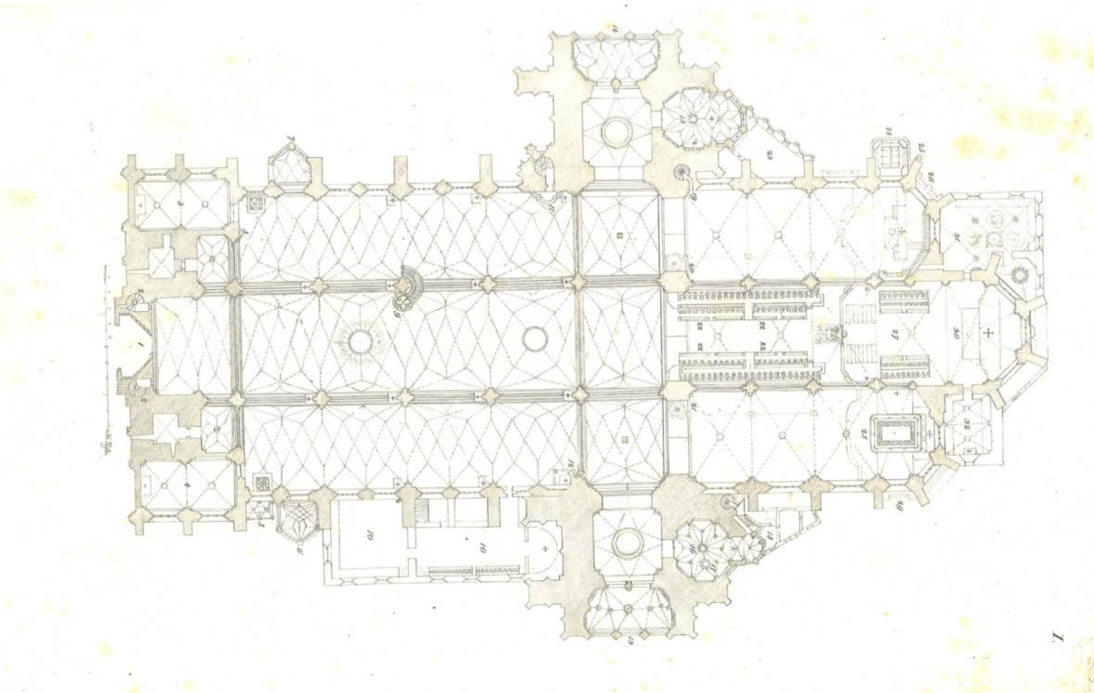
Tomb of Frederick III, 1463-1517 Organ Pedestal, Pilgram, 1513

Choir with the main altar (1647) and two side altars (approx. 1715)

A severe change of the appearance occurred in the 17th and 18th century.

The high altar and the altar was the first to show baroque richness. It was finished and consecrated in 1647, in the same time the altar of St. Peter, St. Paul and the the quattro coronati, donated by the guild of the stonemasons was built in the northern nave.

A more intense phase of baroque decoration was made beginning in 1715, when the damages of 1683 had been repaired and the glorious time of expanding Austria allowed donations for precious altars, sculptures, oratorios, stoups and many other pieces of decoration and liturgical use.

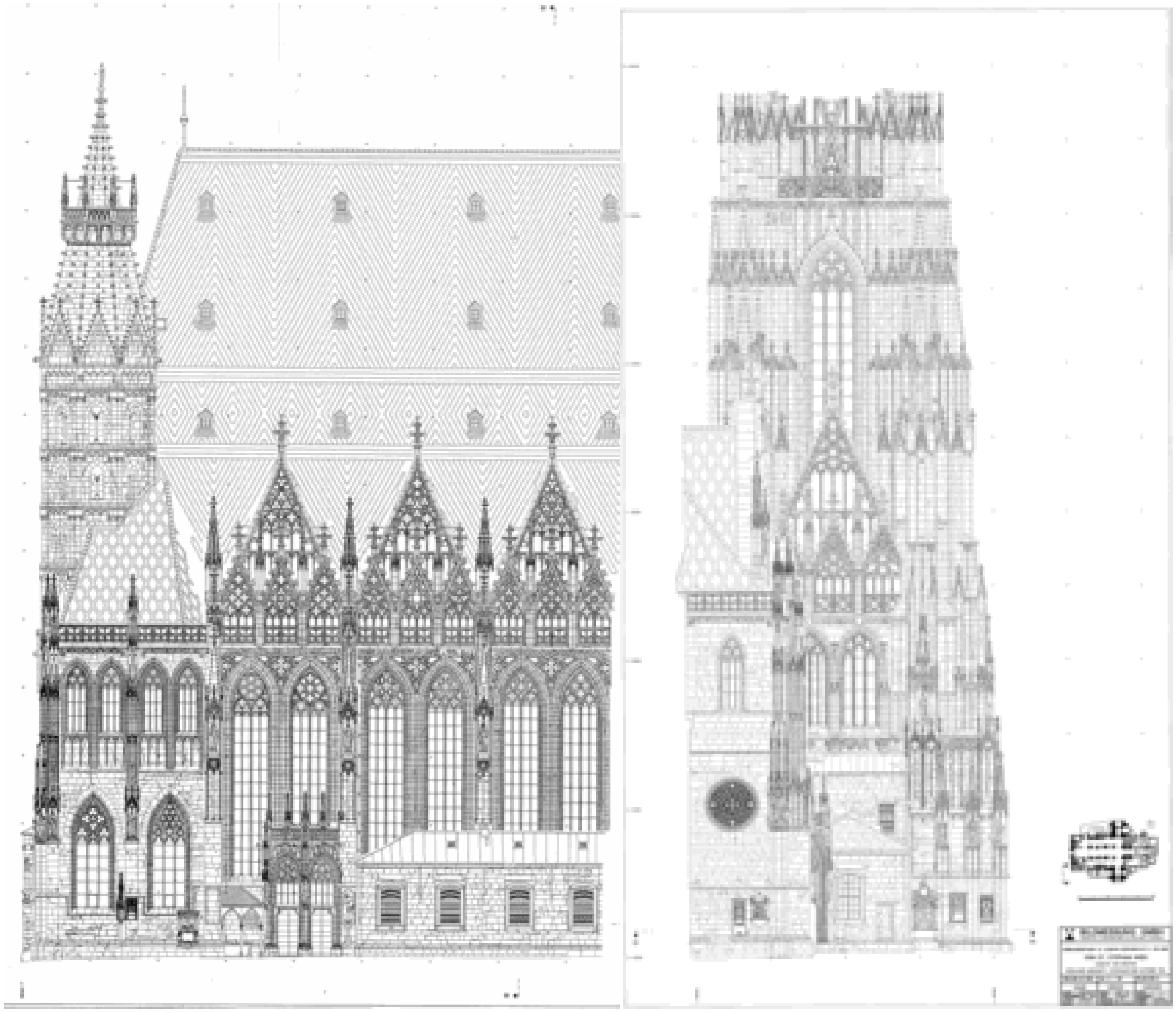


Floor plan from 1828, showing the stables

South view of St.Stephen's, 1828, before the historistic additions in the gables

4 Orthophotography

In 1991 the cathedral was photogrammetrically surveyed, plans were printed at a scale of 1:50. For digital processing of the data, the plans were scanned, vectorized and divided into manageable parts, following the building structure. (see annex V040: Vienna_Photogrammetric_Plans.zip).



5 Background information on the architectural object with regard to the used stones

From the earliest prevailed constructions of the 13th century, over the gothic and baroque building activities and the large-scaled interventions of the late 19th century, up to the recent works of restoration, the vast majority of stones used in the construction of St. Stephens Cathedral in Vienna have always been limestones from the so-called *Leithakalk Formation* in the vicinity of Vienna. Deposited along the coast lines of the neogene *Parathetys Ocean* and extracted in numerous quarries from Roman times until the 20th century, these *Leithakalk* rocks are of a biogenetic calcareous nature. Local lithological variations are due to the differing fineness of fossil shells, varying amounts of terrigenous silicate components, and alternating degrees of recrystallization and cementation, resulting in a variation of fine and highly porous to coarse and relatively compact lithotypes. When observed in the building they can frequently be traced back to the quarry of origin, most of them serving as an excellent time marker. Today, however, most of these stones are not available any more since the vast majority of quarries have been closed at some stages during the 20th century.

Soft and porous calcareous arenites from the *Leithakalk Formation* were mainly used for fine sculptural works, while coarser and more compact stones were predominantly taken for the constructive elements, for example most of the ashlars of the Cathedral. Although their weathering resistance varies according to the lithological properties, all of them are generally prone to the action of water and acidic air pollutants. As a rule, the stone surfaces protected from the impact of rain or running-off water are covered by back crusts composed of gypsum, while in the exposed areas they are affected by dissolution and erosion and thus appear clean. Thus, small-scaled carved elements are in particular due to sharp contrast of both conditions on either side. Chemical weathering of the calcite minerals lead to significant losses of grain cement and hence cohesion in the interior fabric of the stones, while dense crusts form in areas of precipitation in protected areas. According to lithological as well as external factors of each element, this general pattern varies phenomenologically and in respect to its intensity.

(1) Late Romanesque building structure

(west façade, main entrance named "*Riesentor*", Romanesque towers named "*Heidentürme*"): Algal *Leithakalk* limestone from the Western margin of the Viennese Basin south of Vienna, for its Badenian age also called "*Badenium Wien-Süd*". Originates from the former quarries between Maria Enzersdorf and Mödling. Very similar lithotypes can be observed in the northwest of Vienna, in the abandoned quarries from Nussdorf along the Eichelhofstraße.

(2) Gothic building structure

(a) Gothic Albertine Choir (1304-1340): composed of four lithotypes namely the recycled or reused "*Badenium Wien-Süd*", Sarmatian "*Atzgersdorfer calcareous arenite*", calcareous arenite from Au at the Leitha Mountains, and a quartz-rich sandstone from an village called Velm-Götzendorf in the northern region of Lower Austria. The last application of natural stone arose during the restoration phase in the 19th century, mainly using calcareous arenite from St. Margarethen in the Burgenland.

(b) The Gothic west façade: three dominantly used lithotypes have been observed on the west façade: the "*Badenium Wien-Süd*" (re-used from removed older parts of the building), algal limestone from Mannersdorf and the porous detrital limestone from St. Margarethen. Moreover repair in the base area was made with different arenites, rudites and conglomerates located at the western margin of the Viennese Basin, as well as a calcareous arenite from Zogelsdorf.

(c) The northern tower the so-called *"Adlerturm"*: here various lithotypes can be observed e.g. algal limestone from Mannersdorf, calcareous arenite from Au or Stotzing from the Leitha Mountains, as well as the arenites of Sarmatian age from Atzgersdorf, Hietzing or the so-called Türkenschanze (Wien XVIII). Moreover conglomerates from the region of Ternitz and Bad Fischau were used during the restoration works. Rarely calcareous arenites from Steyregg in Upper Austria is visible. Calcareous arenite from Zogelsdorf is also present; especially the porch of the Northern tower ("*Adlerturm"*) and its architectural arrangement was constructed with this lithotype.

(3) Use of natural stone for ornamental elements and sculptures

Already in the 12th/13th century the lithotype "*Badenium Wien-Süd*" was obtained for ornamental elements. In the 14th century the homogenous limestone from Au-Loretto-Stotzing was in use, while in the 15th and 16th century the most important lithotype for sculptural artworks was the very fine-grained soft calcareous arenite from Breitenbrunn. All ornamental parts of architectural relevance like tracery, pinnacles and gargoyles were also commonly carved out of stones from Au, Mannersdorf and Hietzing.

(4) Mid-19th century period

A variety of Neogene lithotypes were used since the middle of the 19th century for restoration work: conglomerates from Bad Fischau and Lindabrunn, Leithakalk limestone from Aflenz, Stotzing, Wöllersdorf, Mannersdorf, Hundsheim, Oslip, etc. The most important stone for the reconstruction work is the St. Margarethen limestone from Burgenland.

(5) Decoration stone

Most of the side altars are carved out of a red-coloured Liassic limestone from Adnet, “Untersberger Marble”, various types of marble, grey Ybbsitzer limestone, limestones with applied coatings, Solnhofener limestone and serpentinites.

6 Description and data of the used stones

Badenium Wien-Süd

This *Leitha Limestone* (Corallinaceencalcarenite to –rudite) was one of the most important natural stones in Vienna from the 12th and the 13th century. It originates from a quarry that does not exist anymore but was formerly located between Maria Enzersdorf and Mödling. The fossils that are dominating are Corallinaceae (calcareous red algae), several seashells and bryozoans. The size of the Corallinaceae varies from 2 to 4 millimetres. In thin sections the fragments of Corallinaceae, bryozoans and sea urchins can be observed. Those components are cemented with fine- to coarse grained calcite. Minor traces of fine-grained quartz can also be seen.

Table 1. Technical and physical properties of “Badenium Wien-Süd”

Examination	Units	Average	Values
Uniaxial compressive strength	N/mm^2	26,9	19,2-34,3
Bending tensile strength	N/mm^2	6,6	4,9-7,6
Indirect tensile strength (Brazilian Test)	N/mm^2	2,8	2,3-3,8
Bulk density	g/cm^3	2,12	2,09-2,16
Water absorption	M. %	6,8	5,9-7,4
Ultrasonic velocity	km/s	3,5	3,4-3,7

St. Margarethen

The so-called “Roman quarry” in St. Margarethen in Burgenland is a significant factory quarry in eastern Austria. St. Margarethen is one of the most important natural stones from the group of limestone’s known as “*Leithakalk*” that has been used in historical buildings, monuments and their restoration. It is yellowish-brown to light grey, varies remarkably in quality and is porous (grainstone, biosparite). It has a fine to coarse-grained structure in which also rhodolite and different bivalves (such as: *Ostrea sp., Pecten sp., Chamys sp.*) are present. In thin sections it occurs very porous and is composed mainly of small fragments of coralline algae and foraminifera. Additionally echinoderms, fragments of serpulides and ostracods can be seen. The components are cemented with fine-grained calcite.

Table 2. Technical and physical properties of St. Margarethen

Examination	Units	Homogenous variety	Coarse grained variety
Bulk density	g/cm^3	2,03	2,06
Open porosity	Vol. %	15,2	11,2
Water absorption	M. %	7,5	5,4
Ultrasonic velocity	km/s	3,37-3,52	3,55-4,20
Examination	**Units**	**Average values**	
Compressive strength	N/mm^2	25,4 (19,3-30,9)	
Bending tensile strength	N/mm^2	5,25 (3,03-8,08)	

Zogelsdorf

The use of the Zogelsdorf natural stone (historically known as the "Eggenburger natural stone") goes back to the 12th century. The large numbers of small quarries between Eggenburg, Kühnring, Reinprechtspölla, Matzeldorf und Zogeldorf were unified in the course of time to one quarry, the so called "Waldbruch". This stone had the biggest importance in the 17th and 18th century. The primary rock forming organisms are a mass of bryozoans. Moreover pectinidae and singular appearance of sea urchins and barnacles can be observed. Siliciclastic components are represented by mono- and polycrystalline quartz, muscovite, potassium feldspars and plagioclase. The components are cemented by fine- to medium grained calcite (Biosparite after Folk 1974).

Table 3. Technical and physical properties of Zogelsdorf

Examination	Units	Average	Values
Compressive strength			
Dry:	N/mm^2	16	4-38
Water saturated:	N/mm^2	16	7-24
Bulk density	g/cm^3	1,91	1,65-2,08
True density	g/cm^3	2,70-2,71	-
Effective porosity	R. %	30	27-33
Water absorption	M. %	9,3	6,2-14,3
Ultrasonic velocity	km/s	3,3	2,9-3,8

Au

In the region of Au, Loretto and Stotzing in the Leitha Mountains in numerous quarries of Sarmantian calcareous arenites, ashlars and stone for sculptures were extracted. The first time in Vienna this limestone was used about 1330/40. Due to his homogeneity this stone was quarried in large blocks and by the 14th century it was the most famous stone of Vienna and its surroundings. The second major application period was during the second half of the 19th century. The lithological composition of this lithotype shows algal foraminifera dominance. The grainsize ranges between 1 and 2 mm. The single particles are beeing sourranded by fine-grained calcite-cement. Other components are fragments of bivalven, bryozoans colonies, serpulids and ostracods. Siliciclastic detritus can be observed in form of quartz, muscovite and plagioclase.

Table 4. Technical and physical properties of Au

Examination	Units	Average values
Compressive strength		
Dry:	N/mm^2	11
Water saturated:	N/mm^2	10
Bulk density	g/cm^3	1,83
Water absorption	M. %	17
Ultrasonic velocity	km/s	2,6 (2,3-2,8)

Mannersdorf

The limestones from the Leitha Mountains were commonly used in Vienna from the end of the 14th and especially in the 15th century, particularly for carved elements and the built heritage.

From the beginning of the 15th century the Mannersdorfer limestone was delivered to Vienna for the constrcution of the St. Stephans Cathedral.

During that time a medium-dense lithotype variety was used. For the construction of the Viennese Ringstraße during the second half of the 19th century, a highly-dense Mannersdorf limestone was used.

This variety was not comparable with the medieval stone in terms of its technical characteristics. Very often its been observed that unbroken red coralline algae colonies are present. Moreover oysters and casts of ox-heart bivalves (*Glycimeris sp.*) are common.

This limestone is widely used for Portland cement production. In addition to the currently used quarries there are numerous abandoned quarries.

Historically it was also very important for the production of quicklime. Occasionally Mannersdorf stone blocks are still quarried for floor panels. Fresh out of the quarry and still wet Mannersdorf algal limestone is sensitive to frost.

Table 5a. Technical and physical properties of Mannersdorf
(compact variety used in the 19th century)

Examination	Units	Dense, compact algal calcitic
Compressive cube strength	N/mm^2	83, 4 (70-102)
Bending tensile strength	N/mm^2	11,1 (8-14)
Bulk density	g/cm^3	2,43-2,69
Void volume	Vol. %	7,1-9,8
Water absorption	M. %	2,9 (1-4)
Ultrasonic velocity	km/s	5,3 (4,6-5,6)

Table 5b. Technical and physical properties of Mannersdorf (medieval variety)

Examination	Units	Medium dense, porous variety
Compressive cube strength		
Dry:	N/mm^2	26,4 (19,4-37,8)
Water saturated:	N/mm^2	19,3 (13,7-25,5)
Bulk density	g/cm^3	2,06 (1,98-2,13)
Water absorption	M. %	6,8 (5,8-7,6)
Insoluble remains in hydrochloric acid	M. %	1,73

Breitenbrunn

The Sarmatian calcareous arenite from Breitenbrunn originates from seven quarries and was mined in three different qualities. Macroscopically it presents itself as a fine-grained, often dazzling white, porous and soft limestone with small black and rust-coloured inclusions. In thin section the dominance of foraminifers and ooids is observable. Breitenbrunn arenite is known as a perfect stone for carving because it is easy to shape. Nowadays all quarries are closed and partially not even accessible.

Table 6. Technical and physical properties of Breitenbrunn

Examination	Units	Average values
Average compressive strength		
Dry:	N/mm^2	13
Water saturated:	N/mm^2	8
Bulk density	g/cm^3	1,77
True density	g/cm^3	2,70 – 2,71
Pore volume	Vol. %	40 - 42
Water absorption	M. %	21,0
Ultrasonic velocity	km/s	2,6 (2,5-2,7)

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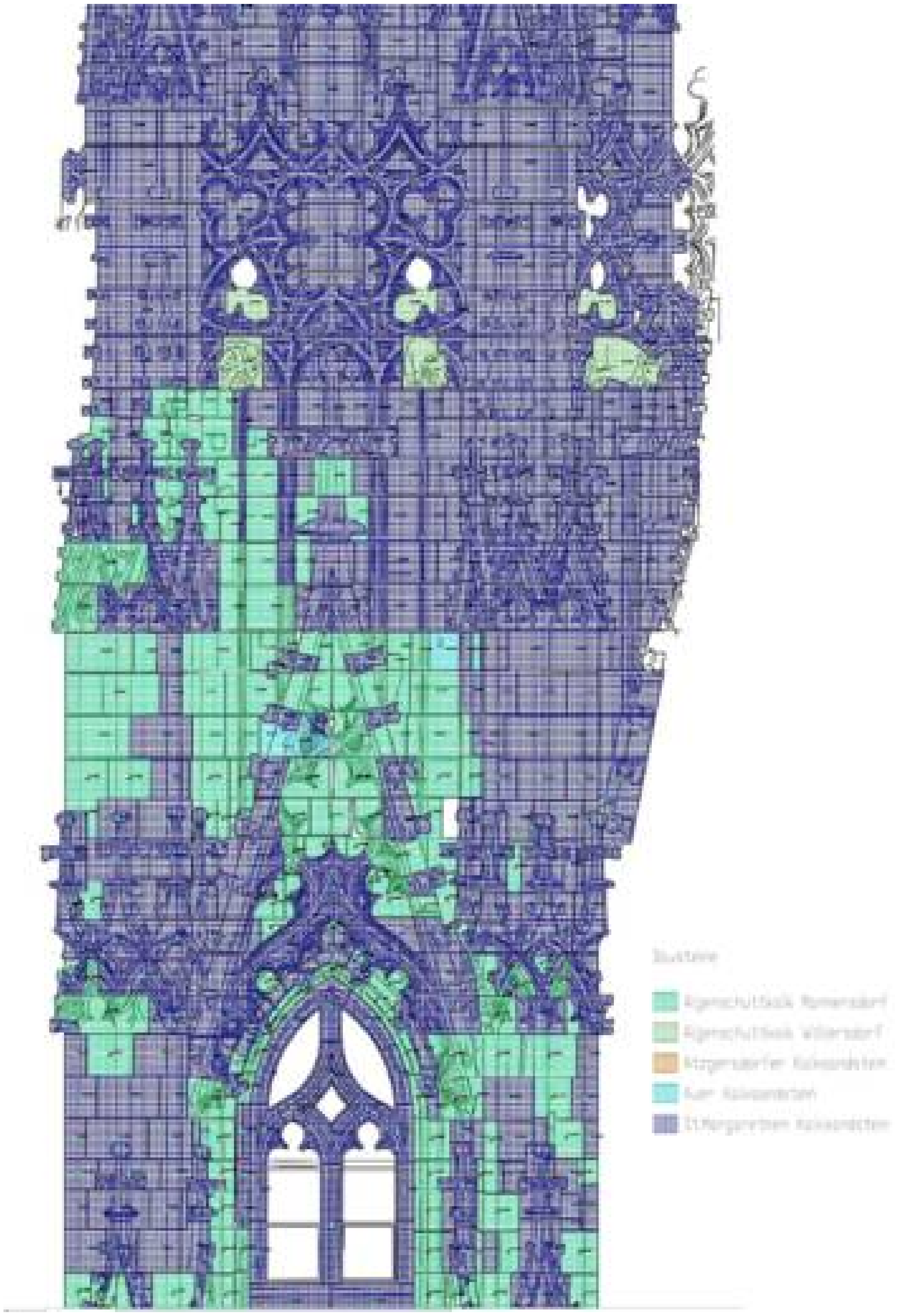
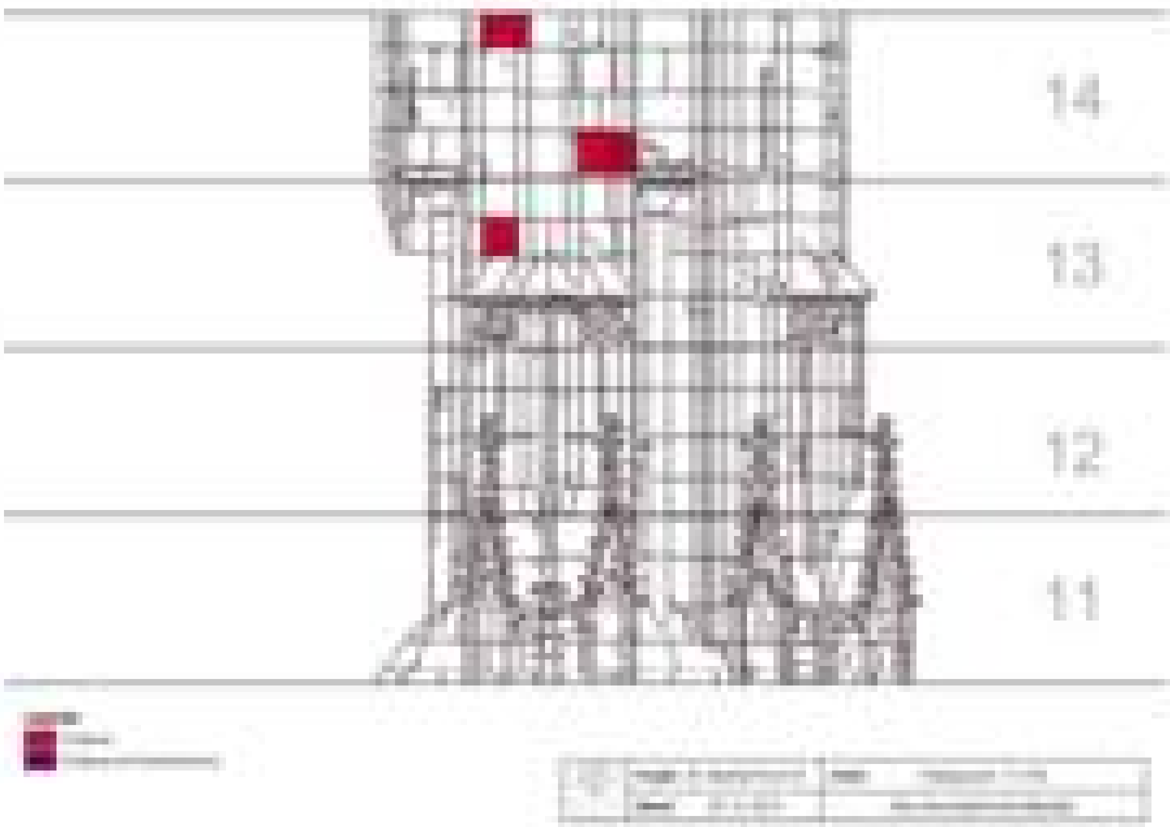
7 Mapping

The state of the building is recorded during restoration campaigns. The mapping is made on the photogrammetric plans and shall be transformed to a CAD-based system connected to a database.



Mapping of Petrography, south steeple

Mapping of Cleaning, south steeple



Mapping of Strengthening, south steeple

8 Environmental Data

Weather:

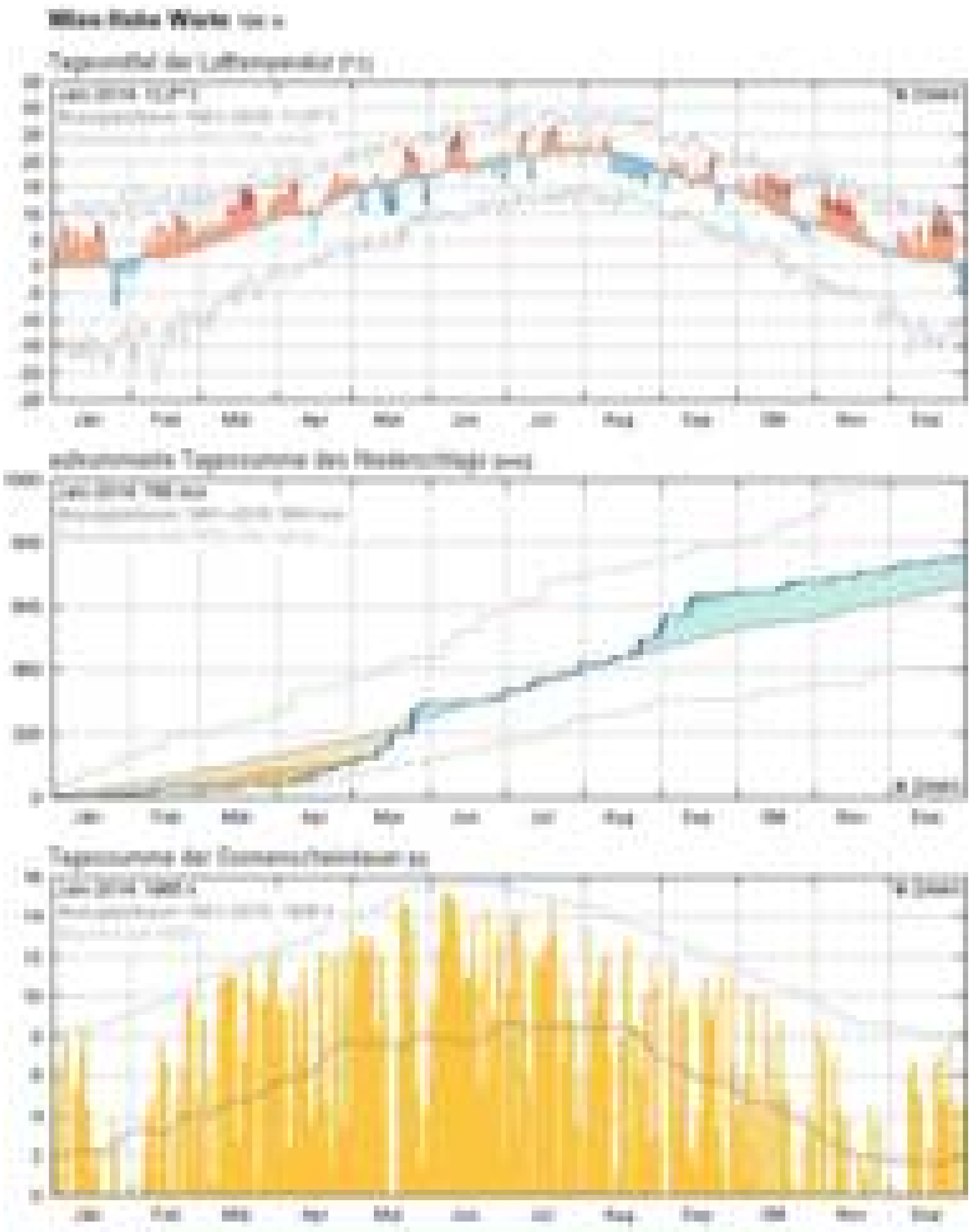
Weather data of the city center are recorded at an exact base since 1872.

Since 1872 average temperature of every day is recorded as well as the amount of precipitation.

Since 1880 also the duration of sunshine is recorded.

Most significant for crucial weather events is the diagramm for precipitation, clearly indicating a period of bad weather in summer, and the diagramm for temperature

(See Annex V081_Vienna_Air_ClimateData_1872-2015)



Climate Data, Vienna, City, 2014 (ZAMG)

Pollution Data:

Since 1970 a measuring point for environmental pollution is installed directly at the cathedral.

Since 1970 SO_2 concentration is measured, from 1987 on even O_3 and TSP (*Total Suspended Particles). The station is run by the city of Vienna – Department 22 – Environmental Protection.*

http://www.umweltschutz.wien.at

Significant is the decrease of SO_2 since the early 1970s, one factor was of course the establishing of a pedestrian zone on St.Stephen's square and adjacent streets, and the reduction of acid exhaust gases.

See also Annex V082_Vienna_Air_Pollution_diagramms.

Measured Values SO2, Stephansplatz, 1971

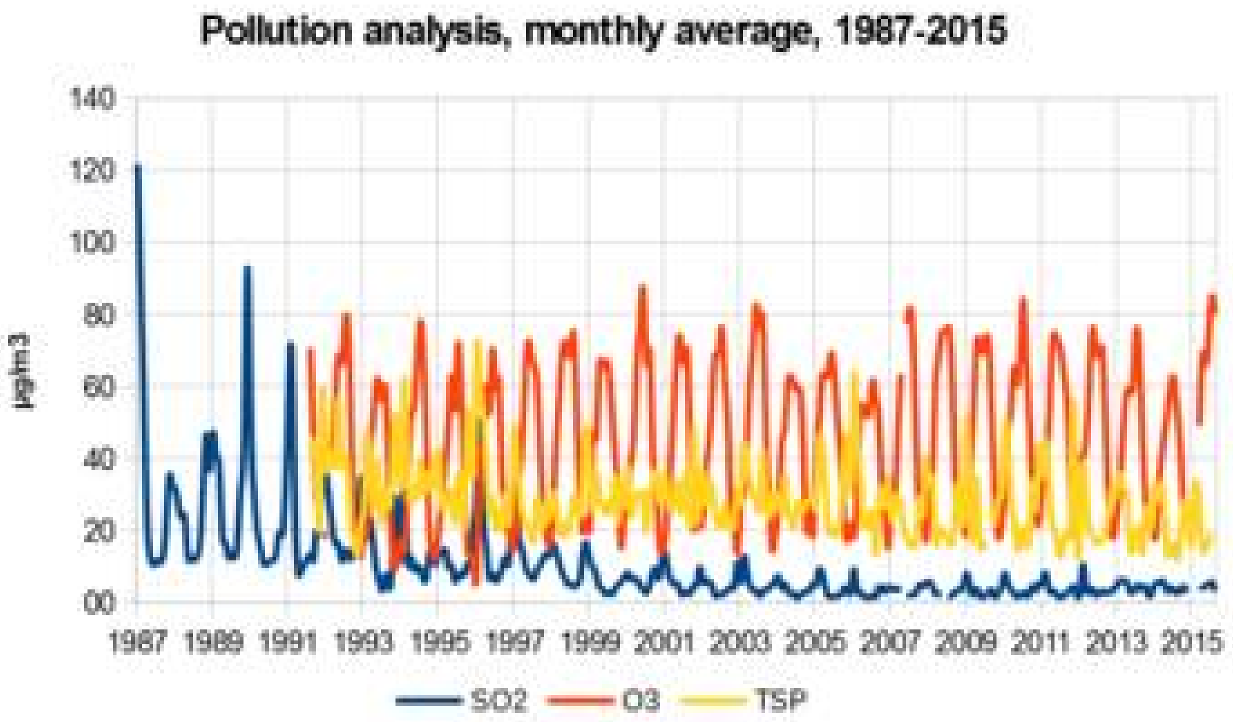
Average per month	µg/m³	month
Maximum	400,0	1.1971
Minimum	30,0	8.1971
Median	180,0	
Average	171,4	
Standard deviation	114,7	

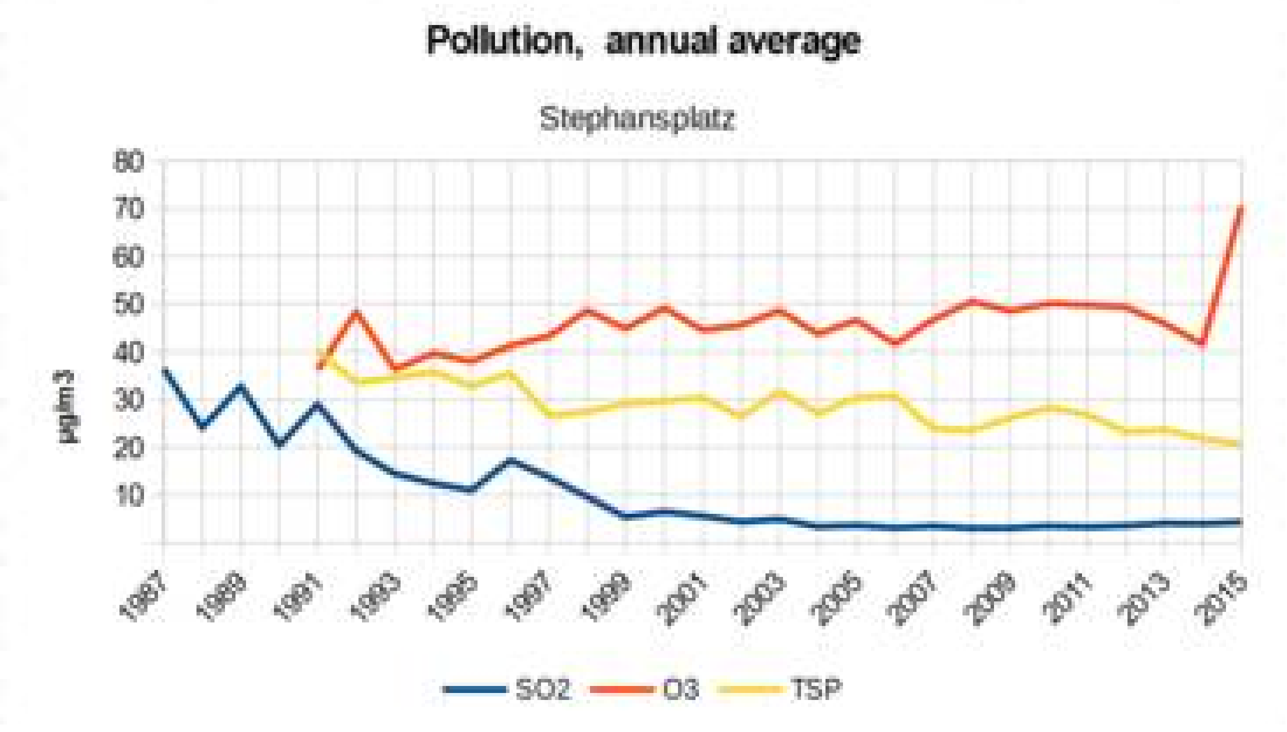
Measured Values SO2, Stephansplatz, 1975-2014

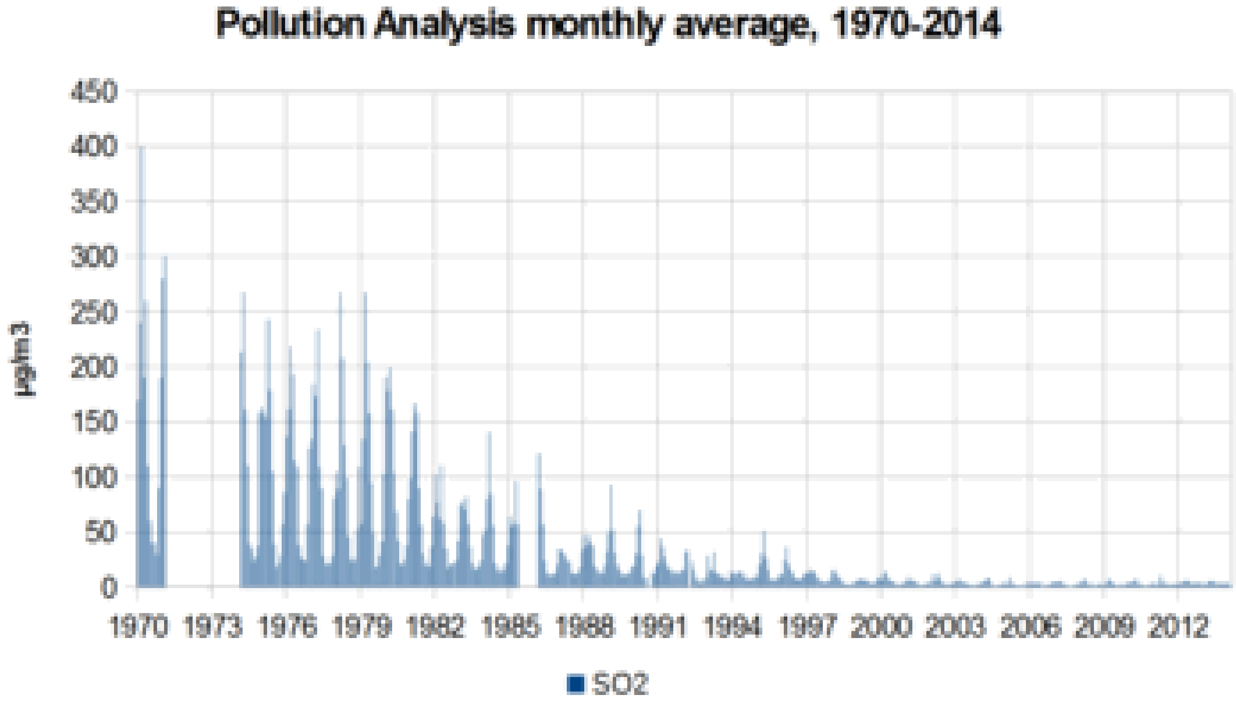
Monatsmittelwert	µg/m³	month
Maximum	267,5	2.1975
Minimum	1,2	6.2006
Median	11,6	
Average	31,5	
Standard deviation	49,2	

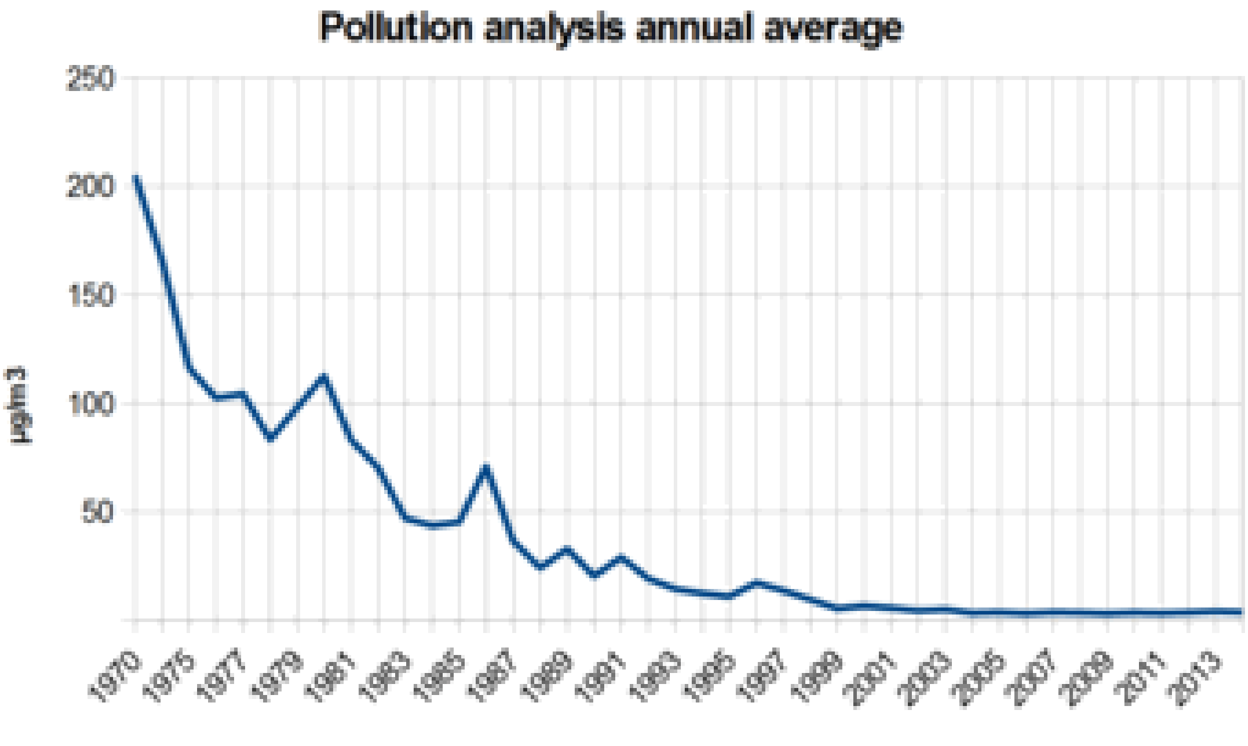
Measured Values O3 and TSP, Stephansplatz, 1991-20

	O3		TSP	
Monatsmittelwert	µg/m³	month	µg/m³	month
Maximum	86,8	6.2000	70,8	1.1996
Minimum	8,1	1.1996	13,4	11.1992
Median	46,6		29,3	
Average	45,8		31,2	
Standard deviation	20,7		9,4	


Pollution analysis, monthly average, 1987-2015
140
120
100
80
60
40
20
00
µg/m3
1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
SO2 O3 TSP


Pollution, annual average
Stephansplatz
80
70
60
50
40
30
20
10
µg/m3
1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
SO2 O3 TSP


Pollution Analysis monthly average, 1970-2014
µg/m3
450
400
350
300
250
200
150
100
50
0
1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012
SO2


Pollution analysis annual average
µg/m3
250
200
150
100
50
1970 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013

9 Historic Treatment

The viennese workshop has for a long time refused to use chemical agents and still is rather reluctant in their use. Nevertheless it is sometimes useful necessary and appreciated.

In historic context treatment with boiled linseed oil can be noticed, especially in parts particularly exposed to humidity as ledges, friezes, tracery in the higher parts and finials on the steeple, especially the main finial of the spire.

Tracery with linseed oil on the “Friedrichsgiebel”

Frieze with foliage, soaked with linseed oil

10 Recent Treatment

In the last years the following chemical agents were used:

	Choir I	Choir II	Choir III	Choir IV	Lackner- niche	sacristy	Prim-portal	South steeple I	South steeple II	South steeple III	South steeple IV	Westwork I	Westwork II	Nave I
Remmers Funcosil 100			x	x		x	x	x	x	x	x	x	x	x
Wacker 100 OH	x	x	x		x			x						
Remmers Funcosil 300												x		
Remmers Festiger 500E											x	x	x	x
Motema FX 10					x		x							
Funcosil Hydr. + 20% Wacker OH	x	x	x	x		x	x	x		x				
StoPrim Fungal										x				
Conipox resin and hardener			x				x	x	x					
Akepox 2030	x	x	x	x	x	x	x	x						
Harz Fa. Fischer FIS EM 1100S								x	x	x				
Trassflex Cimtec CM42											x			x
Ledan D2					x									x
Nirosta rods div. DM	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sprialanker div. DM											x	x	x	x
Ripinox rods div. DM								x	x	x	x	x	x	x
carbonfibre rods div. DM				x			x	x	x			x		
glassfibre rods div. DM			x	x	x	x	x	x	x	x	x	x	x	x
Remmers Mortar RM 1014 and 1063			x	x										
Primal	x	x	x	x	x	x	x	x	x	x	x	x	x	x
div. Colours, powder and Pintasol	x	x	x	x	x	x	x	x	x	x	x	x	x	x
repair mortar - hydraulic lime mortar	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Grout – hydraulic lime mortar	x	x	x	x	x	x	x	x	x	x	x	x	x	x

For detailed information see Annexes V070 (including data sheets) ond V071-V075.

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D1.1 – Part F: Background information on the architectural object: Santa Maria Cathedral (Vitoria-Gasteiz, Spain)

Main features:

Length:	72 m
Width	66 m
Height of the vaults**:**	24 m
Height of the tower:	60 m
Width of the naves:	20 m

1. General information, present state

Vitoria-Gasteiz is the capital city of the Basque Autonomous Community and of the province of Araba/Álava in northern Spain.

The municipality — which comprises not only the city but also the mainly agricultural lands of 63 villages around — is the largest in the Basque Autonomous Community, with a total area of 276.81 km2 (106.88 sq mi), and it has a population of 242,082 people (2014).

Vitoria-Gasteiz is a multicultural city with strengths in the arts, commerce, education, healthcare, architectural conservation, aeronautics, vehicle industry, oenology and gastronomy. It is the first Spanish municipality to be awarded the title of European Green Capital (in 2012) and it is consistently ranked as one of the 5 best places to live in Spain.

The old town holds some of the best preserved medieval streets and plazas in the region and it is one of very few cities to hold two Cathedrals.

From an urban point of view, Vitoria-Gasteiz is a mid-sized city, the line of which is adapted to the traditions of each historical moment.

The medieval town is set in almond-shape around the hill foundation, which by its privileged position as the only elevation in the plain of Álava, became a defensive stronghold coveted by the kingdoms of Navarre and Castilla during the 11th and 12th centuries.

The defensive walls of the old Gasteiz were built between the years 1050 and 1100. Because of that first defensive role, its narrow streets surrounding the oval resulted in compact rows of houses parallel to each other and with respect to the medieval walls (of which only some sections are preserved and gates).

Between the years 1854 and 1856 was an event that changed the face of the city.

In the 19th century, in recognition that the city was small, an expansion was planned in neoclassical style, and little by little planning for the city has given Vitoria-Gasteiz its current form.

The Old Quarter has many architectural jewels such as Bendaña Palace, the Fournier Museum of cards, the Ezkoriatza-Eskibel Palace, the Villa Suso and the greatest historical treasure of Vitoria-Gasteiz: the Cathedral of Santa Maria (Old Cathedral).

Catedral de Santa Maria:Aereal view from north east

Catedral de Santa Maria: Aereal view from the south

The history of the Cathedral of Santa María (commonly known as Old Cathedral), is itself a synthesis of the history of Vitoria-Gasteiz. Built on the cemetery of the primitive village of Gasteiz, the romanic church of Santa María collapsed with the fire of 1202, and Alfonso VIII of Castile (who had conquered the ville just 2 years earlier), ordered the city be rebuilt and raised at the site of a former church that was to serve two very different purposes: regular religious services and weapon storage. Thus was born the Cathedral of Santa Maria, both church and temple-like fortress that served as entry to the city. The project changed with the centuries, so that each modification was made without taking into account the above. This was the case in the 15th century (when the church became collegiate), and finally in the 1960s, when it was decided to reverse the previous works of strengthening of the external walls and widen the windows, made purely for aesthetic reasons, which had severely damaged the stability of the building. Today, the cathedral is open again, and offers visitors guided trips exposing the recent archaeological findings and explaining current restoration. It has become one of the main attractions of Vitoria-Gasteiz.

From the Middle Ages to the 18th century, the population of Vitoria-Gasteiz and the layout of its streets remained almost unchanged. And it was not until the late 18th century when growth required the expansion of the city outside. To solve the problem of the difference in height between the original kernel on the hill, and the plain below, the arches are erected and the Plaza De España or Plaza Nueva, which soften the transition to a much needed neoclassical expansion (s. XIX) of wide streets and gardens, whose greatest exponent is in the street detail, the Park of La Florida, and the Andre Maria Zuriaren Enparantza/Plaza de la Virgen Blanca, with its façade pulled viewpoints.

Finally, the new quarters of Vitoria-Gasteiz are built in accordance with a development plan that favors parks, recreation areas and the quality of life, reconciling keeping the identity of the city with the need to accommodate the growing population. Drawing on the district of San Martin, first planned new neighborhood in this way, the city has increased its outreach to a fast growth in recent years concentrated in the neighborhoods of Lakua, Salburua and Zabalgana. The city of Vitoria-Gasteiz has received several international awards for its urban development. Special mention for the so-called 'green ring', a network of parks and green spaces around the city destined to be the lung of the future Vitoria-Gasteiz, and to link the city with the countryside. This ring is formed by the parks Salburua, Zabalgana, Armentia, Alegria river, Gamarra, Abetxuko, and Atxa-Landaberde, although still lacking in areas integrated into this ring

In spite of the relative distance to the Bay of Biscay, the maritime influence is strong enough to ensure that Vitoria-Gasteiz has an oceanic climate under the Köppen climate classification, typical of the Basque country. Winters are much cooler than in lowland coastal areas, whilst summers are similar in terms of high temperatures, with cool nights due to the elevation. Summers show a significant influence of mediterranean precipitation patterns, but enough precipitation usually occurs to remain marine in nature. Sunshine levels are low by Spanish standards and the climate is humid year-round.

Santa Maria Cathedral Foundation

The Santa María Cathedral Foundation is an institution that was created to manage and develop the proposals included in the Master Plan for the Integral Restoration of the most well-known and historically significant temple of the city of Vitoria-Gasteiz. It was formally constituted at the end of 1999 by the Diputación Foral of Alava (the provincial governing body) and the Diocese of Vitoria-Gasteiz.

The research carried out during these years has generated great in-depth knowledge of the building traits of the temple and its history, defining the interventions needed to solve the problems that have been detected along the way. Also, this rigorous methodological process has resulted in hugely valuable information about the origins of Vitoria-Gasteiz. The model of management that the Foundation operates by has been exported to other institutions, as a work method.

The Santa María Cathedral Foundation not only manages the architectural restoration of the Cathedral; it also develops cultural, educational and tourist activities to bring value to the temple as an instrument to stimulate public participation and bring life back to the historical centre of the city. Some of the most outstanding amongst these activities, as well as the guided tours to the restoration works, are specialized congresses, meetings and seminars; encounters and conferences with prestigious writers; the production of musical concerts, theatre plays, exhibitions and publications; or the organization of workshops and courses on traditional trades and crafts.

This multiplicity of angles is what defines the integral character of the project. Their combination allows the Santa María Cathedral Foundation and its project to generate a wealth of benefits that extend into all areas: monument restoration, urban regeneration, promoting culture and tourism, scientific development and research, educational incentives, historic recovery, while boosting citizens' self-esteem and stimulating economic and social action.

The whole process aims to consolidate the activities generated around the Cathedral, turning the building into an active and stable element within city life. By developing all of its potential uses, some of which have already been successfully initiated, we intend to also stimulate an attitude of permanent care and maintenance towards the Cathedral, which is necessary to guarantee its future conservation.

Catedral de Santa Maria: Aereal view from south east, with the transept and Santiago chapel

2. Construction History

<u>A) Pre-existing structures</u>

Before work began on the construction of Santa María Church (the modern-day cathedral), the northern end of the hill was already the site of several dwellings that once formed part of the old town of Gasteiz. Remains of these pre-existing structures have been uncovered during the excavation work carried out at the foot of the cathedral itself and in Santa María Square, as well as during the cleaning work carried out at the north-western end of the building. It is fascinating to note that several of the remains seem to be aligned in the same direction, a direction that does not, however, correspond to the axis of the modern-day cathedral, thus suggesting a completely different planning criteria. The remains of all these pre-existing structures are of undeniable historical interest, but some have an additional value in that they help us chart the evolution of the cathedral over the following centuries.

Some of the most interesting remains are also the oldest walls still standing within the structure of the cathedral itself.

They are not what 19th and 20th scholars imagined when they pointed to the tower that can still be seen from Cuchillería Street and which is, as we will see, a later addition. The oldest walls still standing in the building have gone almost unnoticed until today, and are those that run along the northern end of the current portico.

These walls contain the remains of the first great entrance gate leading into the city. This gate is the oldest of all surviving entranceways and can be seen from Santa María Street. Until not long ago, it had remained partially hidden by a contemporary annex which was pulled down recently, enabling us to see for the first time its right-hand reveal, which shows signs of various alterations. From the surviving structure, we can calculate the size of the original gateway, which measured almost 7 metres in height and 4 and a half metres in width.

This entrance gate (which predates both the mod1ern-day cathedral and Alfonso VIII's building) was pulled down during the construction of the new church. The rest of the wall (i.e. that which encloses the modern-day portico) was preserved, thus giving the portico its strange geometrical shape, which can only be explained by the fact that the structure was added on to a pre-existing construction. Having pulled down the old access, the townsfolk now needed to build a new one. They therefore opened up another large archway in the same wall, slightly to the west of the old entrance, reusing the materials saved from its demolition. This second entranceway remained functional for over two centuries, until it was blocked up during the second half of the 15th century, when the portico that shelters the cathedral's main entranceway was built.

From historical documents we know that in 1536, a third gate was built in what is now Fray Zacarías Street. The entrance gate remained in use from 1536 to the middle of the 19th century, as is evident in the maps that have survived from this period. We know that the gate existed in 1825. By 1860, however, it had disappeared.
Finally, and although it bears no direct relation to the structure of the current building, we feel we should mention the discovery of the remains of two previous churches (facing in a completely different direction) in the cathedral's substructure. These churches, along with various related constructions, are evidence of a completely different, pre-existing settlement and indicate that the hill was inhabited long before historians had first thought.

B) The project initiated by Alfonso VIII

After the conquest of Vitoria by the king of Castile, Alfonso VIII in 1200 and the fire which destroyed the city two years later, the Castilian monarch initiated an ambitious building project which radically changed the city's urban layout. Until recently, the extension of the city boundaries to the west with the construction of three new streets, had for many years between the only known evidence of this project.
Recent research into the history of Santa María Cathedral, however, has considerably widened our knowledge of the work carried out during this period of mass reconstruction. Having extended the city westwards, Alfonso VIII then proceeded to improve its defensive boundaries to the north, initiating a project that is surprising for both its ambitiousness and scope: the construction of a great church that would fulfil a twofold objective: improve the city's defences and give the city a church in keeping with the ambitious urban reconstruction project currently underway.
This new building, characterised by its extremely thick walls, formed an integral part of the city's defences, serving as a great barricade protecting the city's northern flank. Perhaps the most incredible thing about this building, however, is that its external walls have survived almost entirely in tact down the centuries, in some cases even up to the height of 20 metres. This is especially important for the following reasons:
a) From the perspective of heritage and history, it gives us the original remains of an extremely old and highly significant monument
b) From a structural point of view, it is important because it tells us of the existence of a previous building, never before considered, which had a direct influence on the shape and structure of the subsequent cathedral.

c) From the perspective of the history of architecture, it offers an explanation for a contradiction that has puzzled art historians for many years. We refer to the presumed archaism of the lower level and its difference from the upper building. Although the building as a whole was generally considered by historiographers to coincide with the aesthetic canons of the classical gothic style, its large crossing remained a puzzle, being closer in style to Cistercian principles.

This contradiction was usually resolved (although the explanation fell somewhat short) by references to the 'archaic' nature of the floor design. Fortunately, today we know the real reason for this presumed archaism - the existence of a large pre-existing building which had hitherto gone unnoticed.

According to the university lecturer Lucía Lahoz, 'on the basis of this argument, it seems logical to attribute the rebuilding of Vitoria's church to the revitalisation of the Santiago Pilgrim Trail, which passed through the city after leaving Bayonne.

During the period in which Vitoria was annexed by Castile, the Pilgrim Trail underwent a resurgence, and Santa María must have been the first church encountered by pilgrims upon entering the city ... (This serves to) reinforce the link between the old Santa María Cathedral and the cult of Saint James, so staunchly defended by Apraiz.'

C) Alfonso X. A change of project.

The gothic church The building work began by Alfonso VIII underwent a drastic change during the reign of Alfonso X (1252-1284). This second construction, basically gothic in style, was built in two main phases on the site of the pre-existing structure, over a long period of time stretching from the second half of the twelve-hundreds to the end of the 14th century. It was during these two construction phases that the inside of the church took on the appearance it still retains today. Alfonso X. A change of project. 1st gothic phase. The first of these two construction periods (referred to from hereon as the first gothic phase) was initiated by Alfonso X, who began by adding a layer of ashlar stone to the inside walls, with the aim of ennobling the building constructed by Alfonso VIII. This was not the only modification carried out in this phase, however. Windows were added to the chapels in the apse and the rectangular chapels located next to them, the ceiling over the three apse chapels and the ambulatory was vaulted and work began on closing off the areas left unfinished by Alfonso VIII's project, namely the western wall of the south crossing and the left nave. The columns separating the naves were also partially raised to the second level. Santa María Church gradually grew larger. We know the order of the activities listed above thanks to data uncovered by the archaeological excavations. The discovery of a number of similar coins, ten of which date from the time of

Alfonso X, indicate that it was during his reign that much of the work carried out during the first gothic phase was completed.

Alfonso X. A change of project. 2nd gothic phase. At one point, all construction work on the church ceased for a number of years. Although we do not know exactly how long this period of inactivity lasted, all indications suggest that it was not long. What is clear from the analysis of the building is the presence of new architects and new master builders, whose incorporation into the project resulted in a radical change in construction techniques during the period we have called the 2nd gothic phase. During this phase, different types of bonds appear, and the marks left by the stone-working instruments also change. This period saw the first mason’s marks (hitherto non-existent in the church building), as well as the development of iconographic features with different decorative carvings from those favoured during the previous period.

The architects that participated in this second gothic phase were responsible (in general terms) for the cathedral’s current appearance. They defined the perimeter of the building more or less as we see it today. They added the Santa Ana entranceway in the west wall of the southern crossing; extended the foot of the church to its current position by incorporating two new sections; built a magnificent main entranceway that is now sheltered by a portico; constructed the Santiago Chapel against the outer walls of the old church built by Alfonso VIII; and finally, raised the ceiling by building the triforium.

However, it is important to note that they did not build the triforium all the way around the perimeter of the cathedral, but rather focused on the central area, building the vaults in this section from timber. This is extremely important, since it played an important role in the church’s subsequent structural development. The church remained unfinished, although open for worship, and the high vaulted ceiling was made from wood. The vaults at either end of the crossing had yet to be built, and these areas were covered instead with a simple, two-sided sloping roof.

D) 15th-16th century . Replacement of wooden vaults with stone vaults and completion of the church building.

On 7th October 1496, a bull was granted for the transfer of the Armentia Collegiate Church to Vitoria, although this move did not actually take place until 14th February 1498. Santa María, until this time just a simple parish church, now became a Collegiate Church, as part of the oligarchy’s plan to, in the opinion of J.R. Díaz de Durana, ‘bring prestige to the city and make it the ecclesiastical centre of the region’.

As this lecturer at the University of the Basque Country says, the transfer of the Collegiate Church to Santa María aimed ‘in the first place, to distinguish Vitoria as an urban centre, a political subject and an ecclesiastical focus point (...) something which ... would further reinforce the grandeur of the city itself, bestowing on it, from an ecclesiastical point of view, a status similar to that of an episcopal see’.

This historical event serves to explain and justify the process of expansion and beautification to which Santa María was subjected towards the end of the 15th century and most of the fifteen hundreds - a process which is largely responsible for many of the problems which still beset the building to this very day.

Building work, especially during the 16th century, was frenetic. It was during this period that the tower, choir stalls and San Juan, la Inmaculada Concepción, Altar del Cristo, San Roque, San Marcos, de los Reyes, San Bartolomé, San José, San Prudencio and de la Piedad Chapels were built, along with a series of magnificent tombs such as those of the Ortiz de Caicedo family, Don Cristóbal Martínez de Alegría and Don Martín Sáez de Salinas, among others.

A number of other structural projects were also carried out during this period, which, also less immediately apparent from an artistic or aesthetic point of view, nevertheless proved infinitely more important to the future of the cathedral building. During the 15th and 16th centuries, the upper levels left unfinished during the previous phase were completed, with the construction of stone vaults in the new sections and the replacement of the wooden ones in the old sections.

This process was to a large extent responsible for the building’s subsequent structural problems, against which later generations have fought an ongoing battle. The replacement of the wooden vaults with stone ones forced the building to withstand a load for which it had not been designed and initiated the long chain of distortions and structural damages that are still so evident today.

E) 17th - 19th century. First general alarm and fight against ruin.

During the mid sixteen-hundreds, the first general alarm was sounded.

A number of documents from 1647 have survived which offer a fascinating insight into the problems of the period, when the threat of total ruin was glimpsed for the first time. The documents describe a desperate situation: ‘what is currently required for the repair of the Santa María Church is to remove all the roofs covering the principal nave and the crossings ... for these rest on vaults and this the reason for the toral arches and crossing having split and the main walls having fallen down ...’

Despite the general repair work carried out at this point, during which the vaults were rebuilt, freeing them from strain, and a new wooden roof added, the problem remained far from solved.

In this sense, the 18th and 19th centuries were characterised by the city's inhabitants' dramatic struggle to prevent the total collapse of the church building.

The two enormous buttresses built by the architect Martín Saracíbar in 1856 and 1870 reflect the deep-seated concern experienced during this period. The construction of the buttresses required the sacrifice of two chapels (Santa Victoria the Chapel of the Kings), as well as the magnificent Santa Ana entranceway.

F) 20th century. M. Lorente's restoration project

The last restoration works prior to the current project were those carried out by the architect Manuel Lorente during the 1960s, which radically changed the cathedral's general appearance but contributed little to solving the building's underlying structural problem. The criteria behind the project were mainly aesthetic, and were an attempt to 'return' the building to its 'pure' gothic state, despite the fact that such a state had never really existed.One indication of the purely stylistic and aesthetic motivations behind the restoration works is the fact that most of the budget was spent on eliminating wall overlays, an intervention which, far from resolving the building's structural problems, aggravated them even further. For example, the elimination of more than half of the buttress in the southern crossing (built one century beforehand) reinitiated the movement of the left-hand crossing towards the west.

The main activities carried out during this period (1960-1967) were:

-Elimination of support arches

-Elimination of historical plasterwork

-Opening up of new windows

-Uncovering of the Santa Ana entranceway.

3 Architecture and art

Old Cathedral of 'Santa Maria de la Asunción' in Vitoria-Gasteiz, Araba, Basque Country, Spain

Religion: Catholic Christian of the Roman Rite

Diocese: Diocese of Vitoria-Gasteiz

Architectural Style: Gothic

Coordinates: latitude 42° 51’03” North
Longitude 2°40’19” West

<u>General structure of the building complex</u>

Santa María Cathedral is a collection of multipurpose buildings constructed during a range of different historical periods. The main building, which is also the oldest in the complex, is Santa María Church, whose principal axis faces west, although it tilts slightly to the north at the eastern end.

Catedral de Santa Maria: Aereal view from the north west, with the portico of the west facade

At the southern end of the building stands Santiago Chapel, today the Santa María Parish Church. Although the chapel is smaller than the main building, it is nevertheless of great architectural and structural interest. At the western end of the building, the foot of the church, so to speak, is a large, apsidal, north-south-facing portico which shelters and forms part of the decorative design of the entranceway. Rising above the southern end of this portico is an enormous belfry, crowned by a magnificent spire which stands sixty metres above the street below. The Cathedral service buildings line the entire eastern wall of Santa María Church and Santiago Chapel. The most important of these buildings is the Sacristy, constructed in the late baroque style. The 19th and 20th centuries saw the construction of numerous other administration, storage and service buildings, mainly as the result of the transfer of the episcopal see to Vitoria and the conversion of the Collegiate Church into a Cathedral in 1861.

Santa María Church

With a pronounced Latin cross-shaped floor plan, three naves, chancel with ambulatory and radial chapels, Santa María Church contains a wealth of elements corresponding to the different periods of the gothic tradition. Later on, we will examine the various construction techniques used, as part of our structural assessment of the building complex as a whole.

Ambulatory

Basically decagonal in shape, the ambulatory consists of five trapezial sections which lead to five apsidal chapels, the three central ones being semidecagonal in shape while the two end ones are trapezial. These chapels give out into the arms of the crossing, forming a very curious structural composition.

The apsidal chapels are illuminated on three of their sides by carved windows which look out over the ramparts walk, between

the buttresses that support their vaulted ceilings. The trapezial chapels have only one window, which also looks out over this walk. These openings provide a source of light for these small spaces nestled between the thick, otherwise windowless stone walls that once formed part of the city’s defences. All the ceilings in the ambulatory are vaulted.

The aisle and end chapels are covered with simple four-part vaults, while the apsidal chapels are crowned with six-part vaults on each side and over the entrance.

Except for the set of buttresses and the windows set into the wall, the outside of the ambulatory is hardly visible at all, being hidden behind a series of service apartments.

It is therefore difficult to comprehend the spatial configuration of this part of the cathedral from the exterior.

Catedral de Santa Maria: Aereal view from south east, with the transept and Santiago chapel

Buttress

Gallery

The Transept

The powerful structure of the transept, on the other hand, can be clearly seen from the exterior. The immense difference in height between the central nave of the transept and the side chapels and ambulatory, make the huge stone structure impossible to miss as it rises over the rooftops of the lower levels. The structure is made mainly from masonry, although some areas are faced with ashlar, and is adorned by the graceful figures of the buttresses. This large nave is impressive from the inside also, although its high, slender design is nowadays somewhat obscured by the series of low support arches described in more detail below.

Interior gallery of the clerestory

Each of the nave's arms (north and south) comprises three sections, which provide access to the chapels and the ambulatory. At either end of this great crossing on the eastern side, the visitor can see the rectangular chapels which form part of two impressive masonry towers. Unlike those in the ambulatory, these chapels contain high, extremely recessed loopholes, which do not provide much light. The southern tower is currently hidden by the Sacristy, which prevents us from appreciating what would otherwise be an impressive composition, with the delicate ambulatory set between two imposing towers. The vaults in the chapels are similar in design and construction technique to those in the ambulatory: four-part ogival vaults built from ashlar. The central nave is also covered by a series of ribbed vaults, although these are both larger and lighter, with more slender transverse and ogival arches and narrower vault stones than the ones in the chapels. The central nave is lit by six windows along the east wall, of which the end ones are recent additions, built by the restorer M. Lorente. Round windows are also set into the north and south walls, the one on the south side being composed of three lower arches, which are also a later addition constructed by M. Lorente.

Buttresses of the transept

Northern facade of the transept

Naves and side chapels

Similar in volume to the transept, the main area of the cathedral consists of three, five-section naves, with the central one being much higher than the two side ones (and therefore clearly visible from the outside).

Southern facade of the nave with belfry

These naves are set at right angles to the transept, forming a Latin cross.
The side naves contain chapels leading back from the base of the abutments of the upper buttresses. Some of these chapels are of quite a significant size, while others are little more than niches between columns.
They are covered by ogival vaults very similar in style to those in the ambulatory: three-part vaults with robust support ribs and thick ashlar vault stones.
The central nave, on the other hand, is covered by a series of more delicate vaults with simple, ogival ribs except in the initial section near the entrance, which is crowned by a vault reconstructed later during the 17th century, featuring intermediate ribs and liernes and resting on narrower, less robust arches.

Northern facade of the nave with the Christ Chapel

As regards illumination, the southern side nave contains a series of lancet windows overlooking the square and set between the walls, thereby protected from the inclemency of the weather. The northern nave has a small round window. The windows in the central nave were also subjected to drastic modification by the architect Lorente.

The north and south walls of the first section have no windows, although there is a great oculus in the western façade.

he second, third and fourth sections are lit by six small round windows (the four westernmost ones added, and the easternmost one re-opened, by Lorente), and the section immediately prior to the crossing contains two high, narrow lancet windows facing north and south.

Interior of the cathedral Northern facade of the nave under scaffold

The crypt

Access to the visit is done by going up a wooden staircase which leads us directly to the Cathedral´s crypt. Here we find the church crypt which the Castilian monarque Alfonso the VIII began to build after the conquest of Vitoria in the year 1200. Excavations carried out in the old cathedral around the year 1997, led to the discovery of this space hidden until then, which has greatly changed the knowledge we had about the construction history of Santa Maria. The construction of this crypt started with the building of three hexagonal floor four meter thick absidioles, which you will see in this visit. Once the three absidioles were built, the crypt was rethought changing to an octagonal floor. These new absidioles approximately four meters in height placed the crypt floor at the level that you see now, opening on its walls various windows for illumination which still can be partially observed.

After removing all the rubble, a moat which defended the Navarre city of Nova Victoria from the 1199 siege by the Castilian king Alfonso the VIII which formed a complex defensive system, was discovered.

From this space you can contemplate the construction solution adopted for the structural consolidation of the cathedral. The original bases have been enclosed by rubblework rings and mortars of lime and sand have been injected to fill in the empty spaces and cracks and thereby create compact bases. Moreover, big ashlar-work arches have been built to connect the bases one to each other and the arches themselves, support the new final wooden floor, at the same height as the previous one. The wooden oak flooring, which we will later see, is supported by this wooden structure, constructed with traditional carpentry techniques.

Next to the pillars you can see the lowest part of the vault a spectacular flat vault, done with big piece of masonry covers the presbytery. It is called “The Millennium Vault” and it is made up of 348 Markina black limestone pieces, around 350 tones which has been assembled in a construction feat without precedent since the 19th century.

The wooden staircase which allow visitors to access directly to the Cathedral´s crypt

Visitors in the crypt, People on the catwalks made, under the transept

Visitors in the crypt, under the “Millenium vault”, on the catwalks

Santiago Chapel

Located at the southern end of the crossing, Santiago Chapel is a later addition, being built during the second half of the 14th century. It contains a single, two-section nave and a semidecagonal apse with a straight ante-apse. Four chapels lead off from the nave, those on the northern side being slightly less recessed than those facing south, giving the ensemble a sense of asymmetry which, until recently, no one had been able to explain, and indeed few had even noticed or included in their plans of the building. Today, thanks to the discovery of the defensive wall of which the cathedral once formed part, we now know that Santiago Chapel was built against the southern section of a large, solid wall which limited the space available for the new construction, thereby giving rise to the lack of symmetry we observe today.

Western facade of Santiago chapel

The chapel was built outside the first walled precinct, taking advantage of this structure along its northern and western sides, where visitors today can still see sections of the old ramparts walk. The construction of the chapel in what was now an area safe from attack, enabled larger windows to be built into its southern and eastern façades. Thus we can appreciate the large stain-glass windows so typical of the late gothic style. The chapel’s ceilings are simple ribbed vaults, although there are some liernes running between the keystones of the transverse arches and ogives. Made from ashlar, its construction is nevertheless based on a series of wide vault stones (as opposed to the slender ones of the cathedral's principal naves), which rest on arches that are neither as slender as those in the cathedral's high vaults nor as robust as those in the lower ones.

The western portico and the tower

A later addition, dating from the 15th century, the portico respects the original building's initial layout, extending the north, central and south naves by the same distance. However, the axis of the composition changed with the addition of an apsidal end on the northern side of the portico during the 16th century, and its extension in an east-westerly direction, which inverted the proportion of the church's own sections.

Aereal view of the cathedral form the northwest

What we see today, is a structure formed by three straight sections, the middle one having a rectangular floor plan while the 'apse' is clearly pentagonal in shape. The upper section of this structure, probably built at the end of the 15th century, continues the line of the archivolts and pilasters in the arches and ribs of the vaults. Similarly, the original decorative design is complemented by a series of statues resting on corbels and covered with baldachins, which are situated on either side of the bases of the columns that support the ceiling vaults. For their part, the vaults are larger and lighter than those in the church's principal nave. They rest on slightly less pointed, slender transverse arches and feature delicate intermediate ribs, liernes and curved ribs running between keystones. The star design of the first and third vaults (opposite the church's side naves) uses only straight ribs, while the central and end vaults feature curved elements for bracing the ribs using medallions. The great belfry that rises over the first section of the portico was built during the 16th and 17th centuries, although the spire was rebuilt in the 19th century after it was destroyed by a fire. The lower part of the tower is robust in appearance with scarce windows. It is faced with ashlar on the southern side, facing the square, although its other walls are plain masonry. The cornice, also of finely-worked stone, is made from different materials and is a later addition. The second section of the tower is an irregular octagonal. In the belfry itself, four of the sides contain open archways, through which we can see the bells. Finally, the spire is made from wood and has an interesting structure - it supports a small lantern crowned by a second mini-spire, also made of wood and covered with slate tiles.

Southern facade with belfry

Monumental staircase inside the tower


Visitors inside the tower


Western portals of the cathedral

Interior of the portico

Inscriptions on the main portal of the portico

Exterior of the portico under scaffold

The Sacristy and other annexes

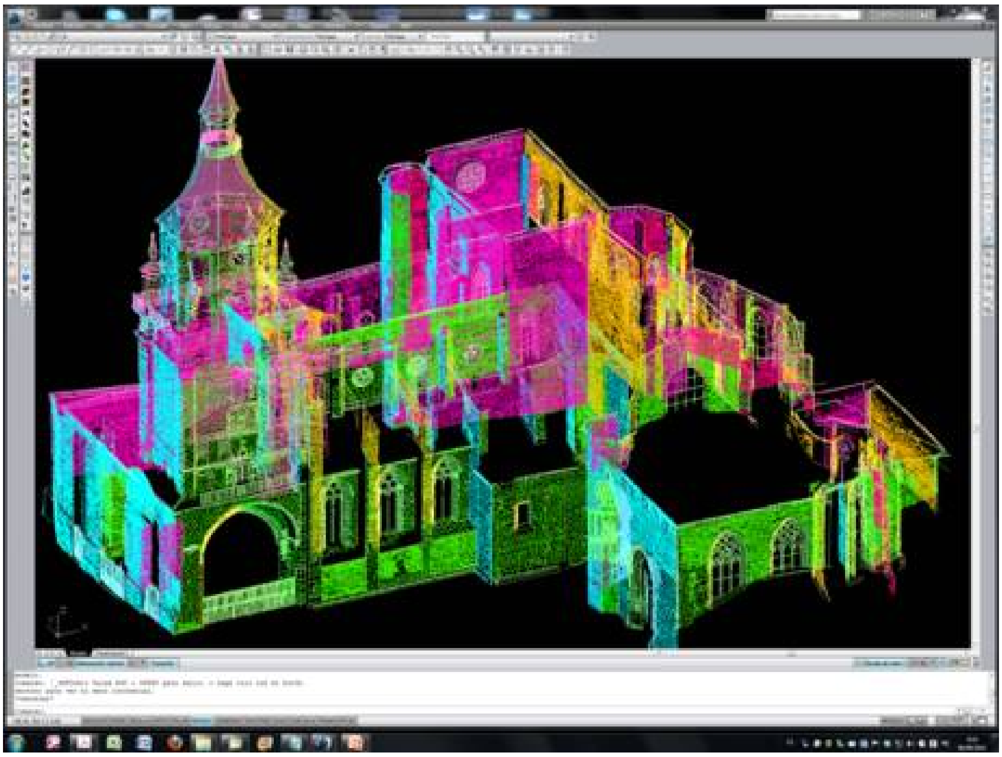
During the 18th century, the imposing Sacristy was built in the south-eastern corner between the transept and the ambulatory. The structure is octagonal in shape and is covered by a vault built from long thin bricks that rests on a series of elements designed to cope with the difference in level between the building and Cuchillería Street. Both during its construction and over the years that followed, the Sacristy was surrounded by a growing number of smaller, multipurpose structures, built in the conventional style with heavy, load-bearing walls and wooden frameworks. All these structures had two entranceways, one from the street and one from the inside of the Sacristy, and were distributed on two or three stories descending from the level of the cathedral floor to the street below. They were mainly used as storerooms, boiler rooms, offices and classrooms, etc.

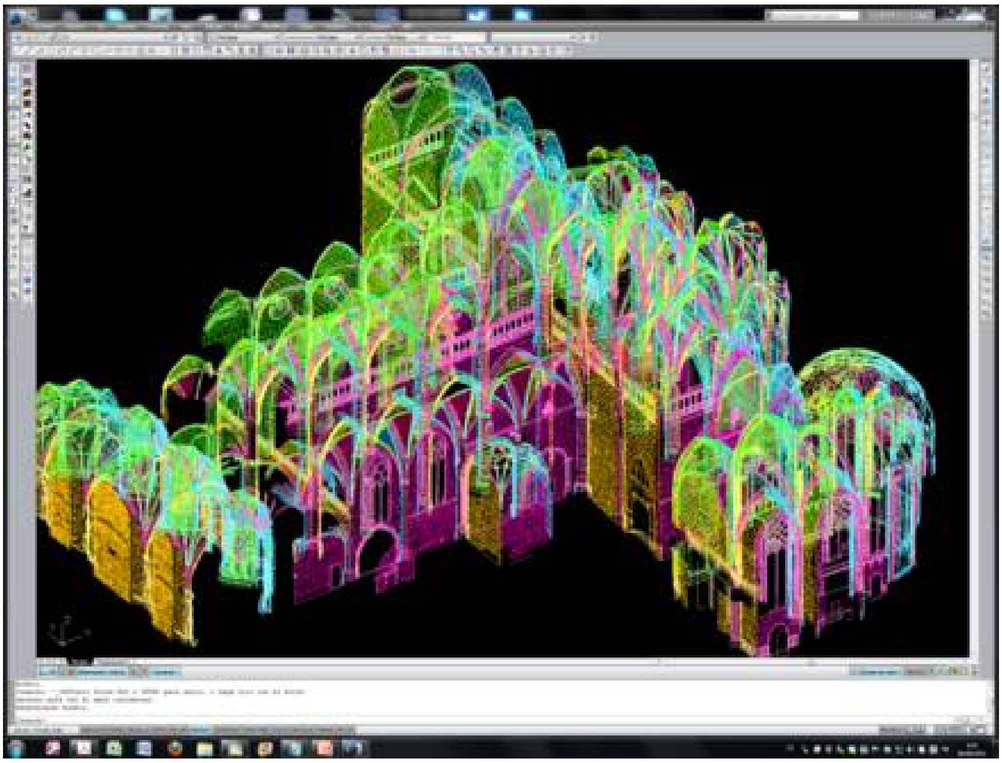
Sacristy: detail of the vault.

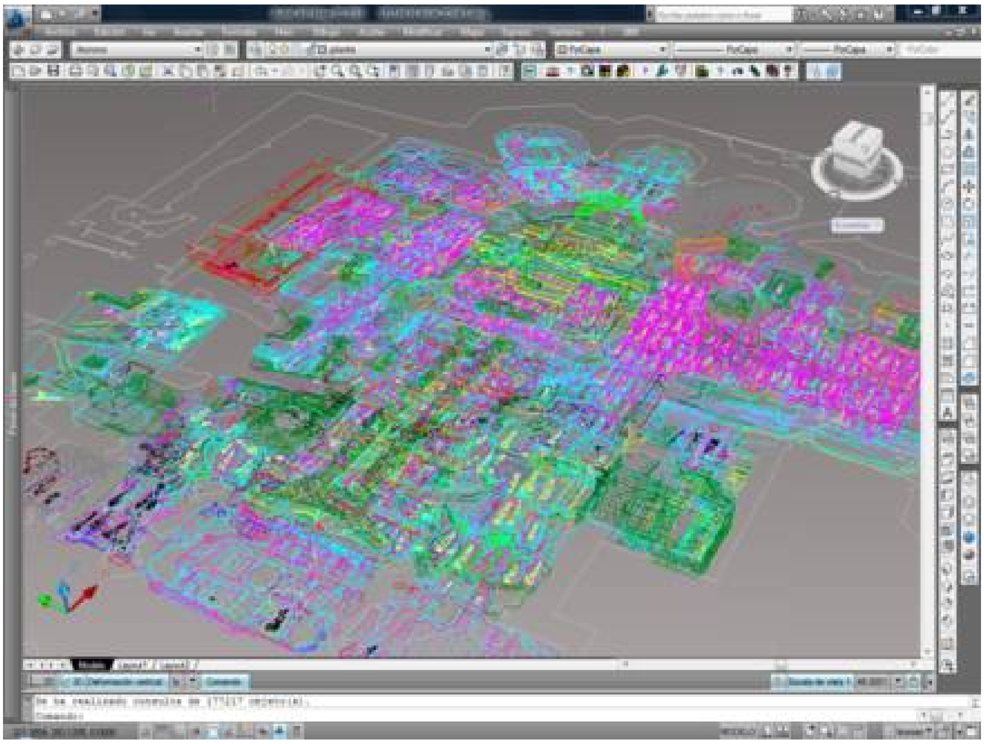
Interior of the Sacristy.

4. Photogrammetric 3D survey of the building.

There is a 3D photogrammetric model of the interior and exterior of the Cathedral and its excavations.







The 3D model is linked to a number of Databases of history, archaeology, architecture, art, conservation and restoration themes. All the stones reppresented in the model have its correlation with items in the databases. Also the archaeological drawings are linked with a complete table of data related to the stratigraphy and tipology of the site.


Catedral de Vitoria - [Relaciones]
tblVariosElementos
tblMateriales
tblAparejos
tblMorteros
tblJuntas
tblRevestimientos
tblVariosDepositos
tblArtefactos
tblHallazgosMatConstructivos
tblEspeciales
tblHallazgosEspeciales
tblNoInventariables
tblHallazgos
tblMateriasOrganicas
tblHallazgosMatOrganicas
tblVariosSoluciones
tblVariosSuperficies
tblElementos
tblZonas
tblDepositos
tblSolucionesDe...
tblSuperficies
tblPeriodo
tblSecuenciasEstratigraficas
tblHallazgosTecnicasTalla
tblHallazgosMuestras
tblRefEsqueletos
tblRefPlanos
tblRefDibujos
tblRefFotos
tblOtrasFichas
tblRefFotogrametria
tblRefDocumentos
tblDatacionHallazgos
tblDatacionEstratigrafica
tblRelaciones
tblMatReutiliz...
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tblMarcasCan...
tblMuestras
tblEsqueletos
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tblDibujos
tblFotos
tblFotogrametria
tblDocumentos

5. List of the building materials including stones used in the construction of the building

Ajarte lumachelle

Lumachelles are limestone rocks mainly consisting of shells. They can be classified as biomicrite rocks. There are two subtypes depending on the diameter of porosity: millimetric porosity and centimetric porosity. Both types constitute a continuous series. It is difficult to distinguish the two subtypes inside the building due to the layers of lime render. On the exterior the two subtypes are easily distinguished by the greater degree of alteration and loss of material than those of centrimetric porosity.

When it is fresh the rock is light grey-cream to light grey-yellow. Weathered rock is light grey-blue. The rock appears to be high density, with characteristic cavities from the break up of fossils, mostly bivalve fragments.

It is mostly composed of calcite, with micrite and calcirudite texture; 5% of the rock is dolomite, present inside the cavities and additional minerals in the form of clay can be seen. The porosity of the cavity, whether it is millimetric or centrimetric, is not communicated and involves 15-20% of the rock. The slight variations in the degree of dolomitisation translate into subtle pink and yellow coloured variations. It belongs in chronological terms to the Danian-Montian (60 myr).

The most important alterations are the fractures affecting the ashlar stones, due to differential forces. Nevertheless, there is no intrinsic alteration in general terms and the only alterations to be observed are due to the action of external forces. On the lower sections, in contact with the substratum, there is usually partial loss of material due to chipping and honeycomb weathering. Occasionally salts crystallise. This is a result of the high percentage of porosity which enables capillarity and the filtration of fluids. In areas exposed to friction, we can see anthropic wear, a result of the rock's low resistance. In areas exposed to the elements, the lumachelle with centrimetric porosity presents clear evidence of honeycomb weathering processes, chipping and significant loss of material. This is a result of the milli-centrimetric size of the cavities made by bivalves, which encourage water retention, and exposure of the interior areas to the air.

All of this results in weathering processes connected to temperature changes, gelifraction, capillarity, wind erosion and so on.

The majority of white rocks present in the cathedral come from Ajarte lumachelles. They are used as ashlar stones and columns, on the web spandrels of the lateral naves as well as in almost all of the sculptures.

In the Treviño area of Ajarte it is difficult to determine the level of extraction of the lumachelle as the subsequent limestone quarries have erased the original quarried surfaces. Although two former surfaces have been clearly distinguished, many other much smaller ones can be made out. The distinguished quarries are located close to Ajarte and along the old road from Ajarte to Vitoria.

The quarried face in Ajarte drops 10º to the south and the side tilts slightly towards the quarry floor, making it possible to move forward on the quarry face with little edaphic cover. Likewise, the gentle relief and drop enables an extensive lateral development of the quarried surface.

Although the layer has a potential of approximately 1 m, a suborthogonal system of diaclasts can be seen, enabling removal using bars and wedges. The organisation of stratification plans and diaclasts makes it simple and easy to quarry.

Sierra de Elguea Sandstone

It is sandstone quartz between ochre (yellow-orange) and purple, which when weathered is ochre-grey to grey-purple. They are Albian sandstones (85 m.d.a.) from the Supraurgonian complex, specifically Valmaseda Formation.

It presents abundant sedimentary structures, mainly crossed beds, burrows and paleocurrents. Lignified plant remains are also common. Sandstone sized quartz accounts for more than 80% of the rock, with a bed of white mica (<7%). Additional minerals are iron oxides (<2%). The cementation is siliceous. The grains of quartz have angular to subangular roundness, with average sphericity. The intergranular contacts are saturated and concave-convex.

Although there is high intergranular porosity (10%), with the subsequent sugaring effect, it is a very resistant rock and not alterable, due to the saturated intergranular contact and siliceous cementation. In the cathedral this is best represented in the Chapel of Christ (Capilla de Santo Cristo). It is also seen on buttresses, the bell tower cornice, tower corners and portico paving and the Plaza de Santa María. From Valmaseda (Vizcaya) to Alsasua (Navarre) several banks of delta sandstone have been recognised as suitable for quarrying. From the documentation it seems that the first sandstones were brought to the Cathedral from the Mugarriluze mountain, in Elguea, and later perhaps from Larrea and then finally from Araia, specifically from the Arrazpi and La Negra quarries.

Quarrying took advantage of the very marked beds, making an initial cut with a point chisel and then using wedges. Once the block was removed, the first cut was made with a point chisel given the hardness of the material. It is an excellent quality rock, although not widely quarried due to its hardness and the consequent wear and tear on tools. The extraction of large blocks was done using thermal quarrying techniques such as fire and water.

Olárizu calcarenite

They mainly correspond to intrasparudites, including biomicrorudites, bioesparites with an appearance of lumachelles, and biomicrites. They present an odulated lamination, occasionally bioturbated. In addition to this continuous series, a subtype of bioclastic calcarenite from Olárizu has been distinguished. In any event, in the original quarries, they all form a complete series at the outcrop level that explains the variations found in the Cathedral. Visually they are mainly dark blue-grey to dark grey-green calcarenites. On occasions, the exterior face coincides with joints filled with calcite recrystallisation, which gives it an intense white colour.

This arrangement is occasional but with a significant visual impact.

The main mineral is calcite. Quartz is 10-25% of the total of the rock, bioclasts 10-25% and feldespars <2%. On the lamella, as accessory minerals, we can see white mica, chert and glauconite. The clasts are very rounded or subangulated, with high sphericity. Porosity is absent on the lamella. Interangular contacts are tangential. The age of the calcarenites of Olárizu is Campanian (70 myr).

The calcarenites and bioclastic calcarenites of Olárizu appear in all the exterior masonry walls and along with the lumachelle of Ajarte are the most abundant in the Cathedral. As for alterations, on the exterior only black crust can be observed, foreign to the rock. On the bioturbated facies with certain porosity there can be phenomena of loss of cementation with the resulting erosion, although it has been observed very occasionally and with little impact.

In general it can be considered to be a rock with very good geotechnical properties and low alterability. There are many quarry recesses where this type of rock has been extracted, widely used in buildings in Vitoria-Gasteiz. We could mention the quarries of Lasarte, Mendiola, Arechavaleta, Gardelegui or Castillo, although the most representative facies are located at the top of Olárizu mountain. The orthogonal system of joints and the

sub-parallel centi-decimetric stratification enables an easy extraction with bars. As the finality is constructive, as rough stone, and the extracted fragments present quite flat joints, they can be used on site directly, without the need for pre-measurements. An observation that is corroborated due to the non-existence of dump heaps at the quarries visited.

Local marl

In this summary there are micrites with intraclasts and dark blue-grey intramicrites from the Campanian period (70 myr). The alteration colour is light blue-grey, with occasional ochre tones. As the predominant sedimentary structure we can observe a thin parallel lamination, although there is also gravel with a massive structure. Echinoderms or inoceramids are frequent. In general it is a very compact rock with small water channels with calcite recrystallisation and ochres due to alteration of sulphurs. The local marls are mainly composed of calcite in the form of micrite and to a lesser extent as calcirudite (2-5%). Additional minerals are iron oxides. Moldic porosity is observed (<2%) with calcite recrystallisation.

It is the substrate of the Cathedral and is always present as gravel in the walls. As for alteration, it should be noted that the local marls contain a small portion of montmorillonite, which along with the lamination, favours the expansive activity of the clay. As a result, it is a rock which easily fragments when subjected to changes in humidity. Likewise, with compressive forces not perpendicular to the lamination it can have low load resistance values.

Undoubtedly, of all the rocks present in the monument it is the most problematic type. Its origin must be located close to the Cathedral, as it is its own substrate. Due to the orientation, morphology and proximity, it may well have been extracted from the nearby Plaza de las Brullerías. As it is fragile, it is easily extracted, though not suitable for carving. Within the series of local marls we have distinguished black limestone, which judging by its facies probably corresponds to a calcareous level interspersed in the marl series of the Cathedral's substrate. It occasionally appears among the masonry of the column pillars and at the bottom of the walls, at the top of the masonry foundation. Characterised by its massive nature and lack of alteration.

6. Information of the stones on the building, and their provenance and use

Ajarte lumachelle limestone (millimetric porosity) IDStone MT-001 (spanish: caliza lumaquela de Ajarte)

Rock: Biomicrite

Identification and classification: Lumachelle (millimetric porosity)

Sediment structures: Massive

Diagenetic structures: Fossil disintegration, essentially fragments of bivalves

Additional minerals: Clay (<2%)

Intergranular contacts:

Alochemicals and Orthochemicals: Calcite

Sediments and lithoclasts: Cavities (15-20%) partially dolomitised (<5%)

Colour of fresh rock: Light grey-cream to light grey-yellow

Colour of weathered rock: Light grey-blue

Clasts:

Matrix:

Cementation:

Formation:

Age: Danian-Montian (60 m.d.a)

Origin: Ajarte (Treviño)

Size: Micrite and calcirudite

Roundness:

Sphericity:

Porosity: Uncommunicated cavity (15-20%) millimetric

Relative presence: Very abundant

Observations:

The recrystallisation of the dolomite in geodes, using the fossil fragment cavities, basically bivalve, presents in different degrees of development, not exceeding the dolomite in 5% of the total. The slight variations in the degree of dolomitisation translate into subtle pink and yellow coloured variations. Type 18 can by distinguished with millimetric to centimetric porosity, although this differentiation can be understood as a complete series with all the intermediate terms.

Distribution:

Almost all of the "white" stones in the cathedral are this type. They are used as ashlar stones in walls and columns as well as in almost all of the sculptures.

Documentation:

Parish records (1571) (Fol. 149v.): "... a maestre Françisco de Aroztegui cantero por la hobra que yço en el altar mayor (to master quarry man Françisco de Aroztegui for the work on the main altar)... ...por beinte y siete carros de piedra blanca de axarte a ciento y setenta el carro (maravedís), los cuales se traxeron para ensanchar el altar maior y pilares" (for twenty six barrows of white Ajarte stone for one hundred and seventy maravedis each barrow, which were brought to dress the main altar and pillars).

Parish records (1571) (Fol. 178r.-180r.): "... por ochoçientos y çincuenta y seis carretadas de piedra negra que para la obra traxeron los vecinos de Lasarte, Mendiola, Arechavaleta, Gardelegui y otras partes...(for eight hundred and six wagon loads of black stone brought for the construction by the residents of Lasarte, Mendiola, Arechavaleta, Gardelegui and other parts) ...que pagaron a Prudencio y Toribio de Alegría, hermanos, vecinos de Ajarte, por dozientos y cinquenta y tres carretadas de piedra franca que traxeron para la dicha obra...(paid to Prudencio and Toribio de Alegría, brothers and residents of Ajarte for two hundred and fifty three wagon loads of French stone brought to the construction) ...a Domingo de Sorillar, vecino de Oçaeta, por beinte y quatro baras de piedra arenaza tablamento...(to Domingo de Sorillar, resident of Oçaeta, for twenty four sandstone slabs) ...y por diez y ocho baras y media desquinas ..." (and for eighteen bars and corners)

Alteration:

The most important alterations are the fractures affecting the ashlar stones, due to differential forces. On the lower sections, which are in contact with the substratum, there is usually some loss of material as a result of chipping and weathering. Occasionally salts crystallise. This is all due to the high percentage of porosity which encourages capillarity and the filtration of fluids. In areas exposed to friction, we can see anthropic wear, a result of the rock's low resistance.

Nevertheless, we do not observe any intrinsic alteration, only alterations due to the action of external agents.

Quarries:

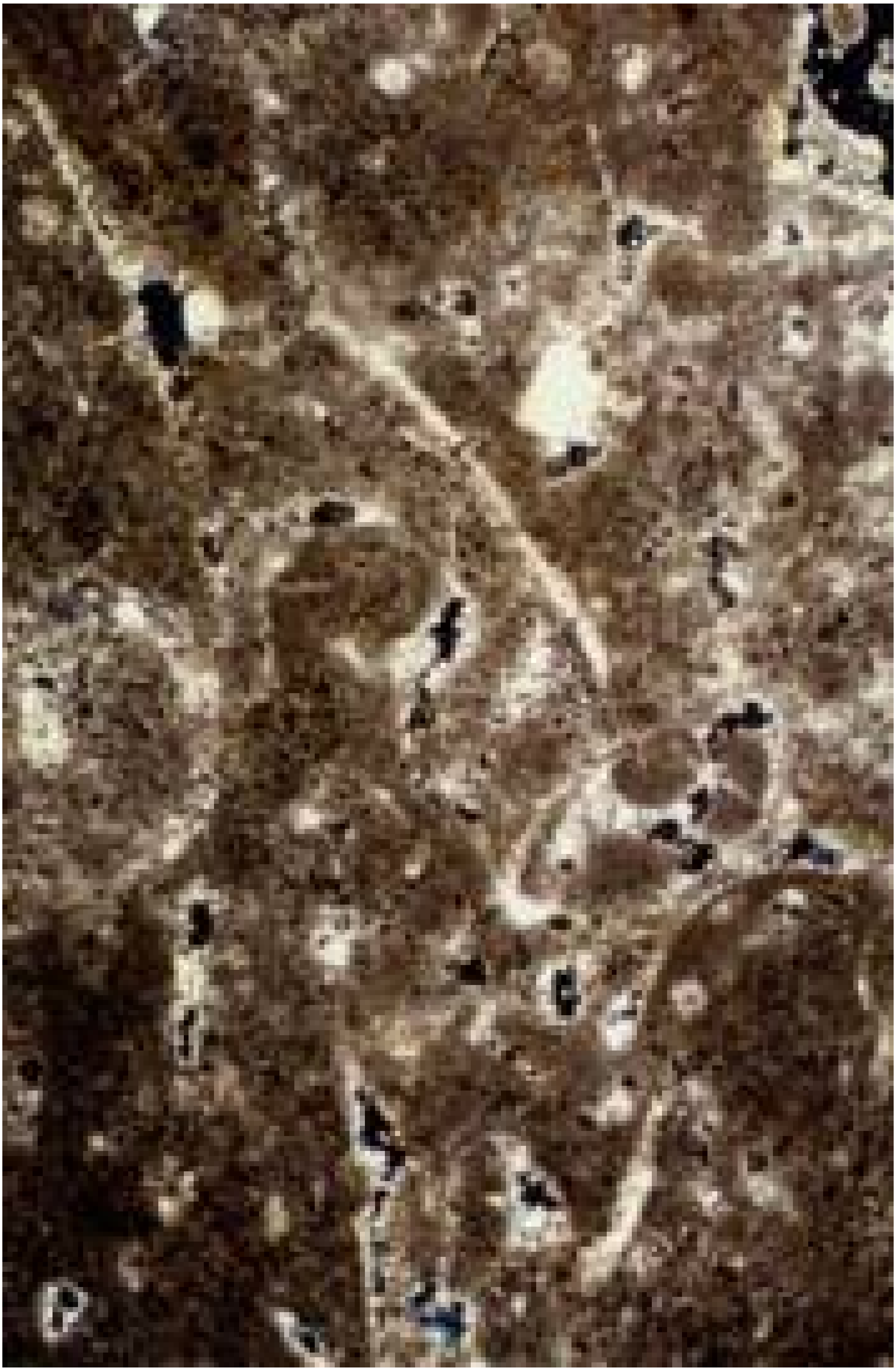
In Treviño area of Ajarte it is difficult to determine the level of extraction of the lumachelle as the relatively recent limestone quarries have erased the original quarried surfaces. Although only two former surfaces are mentioned, many other much smaller ones can be made out. The quarries are located on the old Ajarte to Vitoria road (quarry number 1: X=529850, Y=4734250) and near Ajarte (quarry number 2: X=530200, Y=4734150).

Extraction:

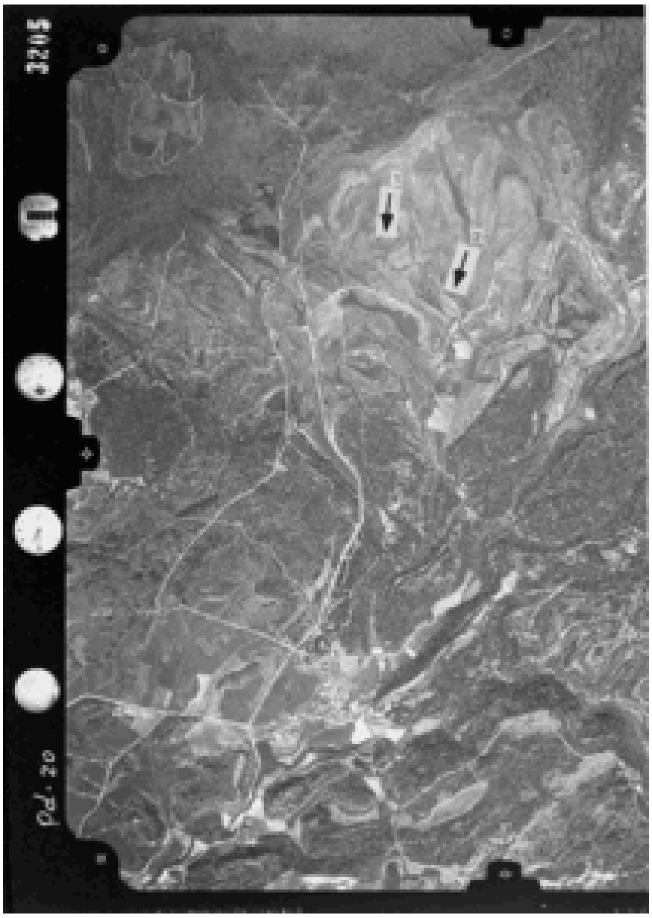
The quarried face drops 10º to the south and the side tilts slightly towards the quarry floor, making it possible to move forward on the quarry face with little edaphic cover. In the same way, the topography allows quarrying of the lumachelle with a wide lateral development, as can be seen on the ground.

Although the layer has a potential of approximately 1 metre, a suborthogonal system of diaclasts can be seen, enabling removal using bars and wedges. The organisation of stratification plans and diaclasts makes it simple and easy to quarry. In addition, it is easy to work with, meaning different tools can be used to sculpt it: axes, carving tools, chisels and/or toothed stone chisels.

Macroscopic photography



Microscopic photography



Aerial photo of the quarry

Terrestrial photo of the quarry

Sierra de Elguea Sandstones. IDStone MT-003 (spanish: arenisca de Elguea)

Rock: Quartz arenite or arenaceous quartz

Identification and classification: Siliceous sandstone

Sediment structures: Stratified and crossed beds; burrows and paleocurrents.

Diagenetic structures: Lignified plant remains.

Additional minerals: Iron oxides (<2%)

Intergranular contacts : Saturated and concave-convex

Alochemicals and Orthochemicals Sediments and lithoclasts:

Colour of fresh rock: Ochre (yellow-orange) to purple

Colour of weathered rock: Grey-ochre to grey-purple

Clasts: Quartz (>80%)

Matrix : White mica (<7%)

Cementation: Siliceous

Formation: Valmaseda

Age: Albian (85 m.d.a.)

Origin: Sierra Elguea-Altzania (Elguea, Larrea and Araia)

Size: Sandstones

Roundness: Angular to subangular

Sphericity: Average

Porosity: (10%)

Relative presence: Very abundant

Observations:

In the same rock two extreme colourations can be observed, between ochre (majority) and purple, including all tones in between.

Distribution:

Best represented in the Chapel of Christ (Capilla de Santo Cristo). It is also seen on buttresses, the bell tower cornice, tower corners and portico paving and the Plaza de Santa María.

Documentation:

Parish records (1577) (Fol. 178r.-180r.): ...a Domingo de Sorillar, vecino de Oçaeta, por beinte y quatro baras de piedra arenaza tablamento...(to Domingo de Sorillar, resident of Oçaeta, for twenty four sandstone slabs) ...y por diez y ocho baras y media desquinas ..." (and for eighteen bars and corners). Parish records (6th September 1649) (Fol. 546-547): Pedro de Yparategui, vecino de Larrea en la Hermandad de Barrundia, se compromete a traer piedra de sillería arenisca para la cornisa de la torre por precio de 2.200 reales (Pedro de Yparategui, resident of Larrea and member of the brotherhood of Barrundia, agrees to bring sandstone ashlars for the tower cornice at a price of 2,200 reals). Accounts of the Canonry of Santa María de Vitoria (1858) (receipt 111): desmonte y empedrado de una porción de la plazuela de frente de la iglesia: (dismount and sculpting of a portion of the square in front of the church) 2,411 reals. Manuel Lorente restoration project (1962-1966) (measurements): "... pavimento de piedra caliza pulida y asperonada ..." (sanded and polished limestone paving)

Alteration:

Although there is high intergranular porosity with the subsequent sugaring effect, it is a very resistant rock and not alterable, due to the saturated intergranular contact and siliceous cementation. Known locally as asperón (sandstone), it is widely used as millstones and whetstones and in smelting furnaces, which demonstrates its strength.

Quarries:

Only three quarries have been referenced. Quarry number 1 (X=539620, Y=4756510) in the area around Mount Mugarriluze, to the north of Elguea. Quarry number 2 (X=557090, Y=4750680) to the north of Araia, known as Arrazpi. And quarry number 3 (X=557290, 4749970) known as La Negra, also to the north of Araia but in an area belonging to Albéniz.

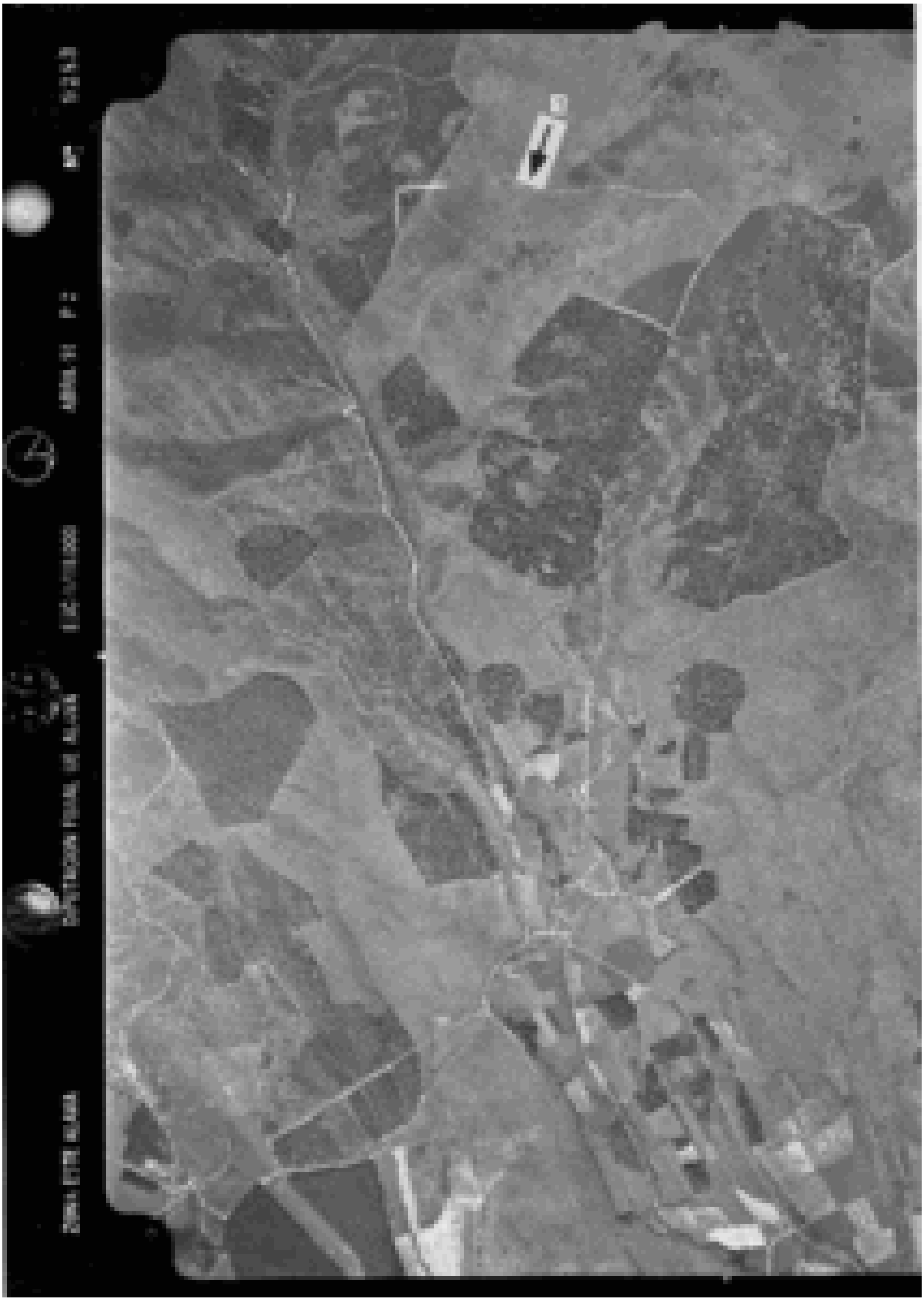
From Valmaseda (Vizcaya) to Alsasua (Navarre) several banks of delta sandstone have been recognised as suitable for quarrying. From the documentation it seems that the first sandstones were brought to the cathedral from Mugarriluze and later perhaps from Larrea and then finally from the aforementioned quarries in Araia.

Extraction:

The crossed beds which are highly marked are used, making a pre-cut with a point chisel and then using wedges. Once the block was removed, the first cut was made with a point chisel given the hardness of the material. It is an excellent quality rock, although not widely quarried due to its hardness and the consequent wear and tear on tools. The extraction of large blocks, for example millstones, was done using thermal quarrying techniques such as fire and water.

Macroscopic photography

Microscopic photography



Olárizu calcarenite. IDStone MT005. (spanish: calcarenita de Olárizu)

Rock: Intrasparrudite

Identification and classification: Calcarenite

Sediment structures: Ondulated lamination and stratification, at some levels very bioturbated

Diagenetic structures:

Additional minerals: White mica, chert and glauconite

Intergranular contacts: Tangential

Alochemicals and Orthochemicals: Calcite and clays and white micas (<1%)

Sediments and Lithoclasts: Quartz (1025%), bioclasts (1025%), calcite (<2%) and feldespars (<2%)

Colour of fresh rock: Dark blue-grey to dark greengrey

Colour of weathered rock: Idem

Clasts:

Matrix:

Cementation:

Education:

Age: Campanian (70 myr)

Origin: Olárizu (Castillo)

Size: Calcarenite, and microsparite and sparite

Roundness: Very round and subangular

Sphericity: High

Porosity:

Relative presence: Very abundant

Observations:

This type varies from intrasparrudites (NI16; NI53; EI415 and WI12), biomicrorrudites (SI111; SI34; WE18bis (1); WE18bis (2), WE18bis (3), EE1, EE12 and NI112), to biosparites with appearance of lumachelles (NI63 and WE53). In addition there are some blue-grey biomicrites (NI69) of the same origin, specifically from the base of the calcarenites. All of them, along with type number 6: Olárizu bioclastic calcarenite, form a complete series at the outcrop level that explains the variations found in the masonry of the Cathedral. On occasions, the exterior face of the masonry coincides with joints filled with calcite recrystallisation, which gives it an intense white colour.

Distribution:
It makes up all the exterior masonry walls, and along with the lumachelle of Ajarte are the most abundant in the Cathedral.

Documentation:
Factory books (year 1577)I (Fol. 178r.180r.): "... por ochoçientos y çincuenta y seis carretadas de piedra negra que para la obra traxeron los vecinos de Lasarte, Mendiola, Arechavaleta, Gardelegui y otras partes... (for eight hundred and six wagon loads of black stone brought for the construction by the residents of Lasarte, Mendiola, Arechavaleta, Gardelegui and other parts) ...que pagaron a Prudencio y Toribio de Alegría, hermanos, vecinos de Ajarte, por dozientos y cinquenta y tres carretadas de piedra franca que traxeron para la dicha obra... (paid to Prudencio and Toribio de Alegría, brothers and residents of Ajarte for two hundred and fifty three wagon loads of French stone brought to the construction).

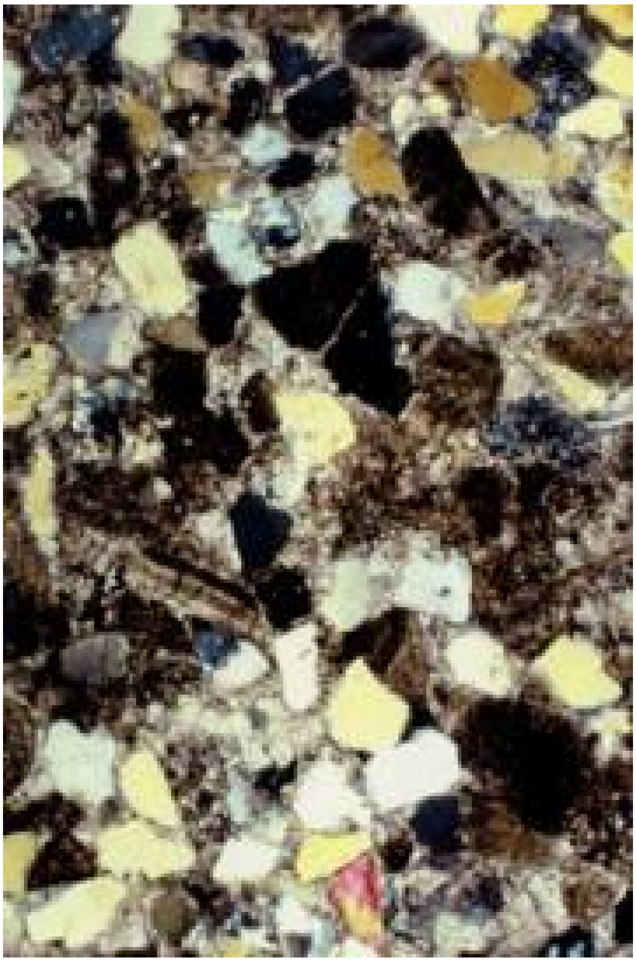
Alteration:
On the exterior only black crust can be observed, foreign to the rock. On the bioturbated facies with certain porosity there can be phenomena of loss of cementation with the resulting erosion, although it has been observed very occasionally and with little impact. In general it can be considered to be a rock with very good geotechnical properties.

Quarries:
There are many quarry recesses where this type of rock has been extracted, widely used in Vitoria. Only five of them have been referenced around Olárizu mountain, beside Castillo and Mendiola: quarry number 1 (X=527650, Y=4740600), quarry number 2 (X=527650, Y=4740110), quarry number 3 (X=526640, Y=4740210), quarry number 4 (X=526680, Y=473980) and quarry number 5 (X=652210, Y=4740850).

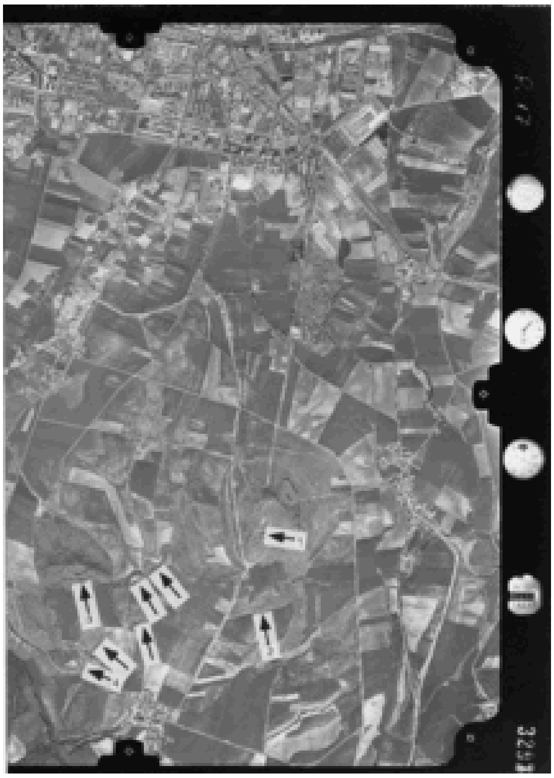
Extraction:
The orthogonal system of joints and the centidecimetric stratification, although not parallel, enable an easy extraction with bars. As the finality is constructive, as rough stone, and the extracted fragments present quite flat joints, they can be used on site directly. This is obvious

due to the non-existence of dump heaps at the visited quarries.

Macroscopic photograph



Microscopic photograph


Aerial photograph of the quarry


Close-up photograph of the quarry

Local marl. IDStone MT007 (spanish: caliza margosa local)

Rock: Micrite with intraclasts or intramicrite

Identification and classification: Marl

Sediment structures: Parallel to massive lamination

Diagenetic structures:

Additional minerals: Iron oxides

Intragranular Alochemical and Orthochemical contacts: Calcite and calcite

Sediments and Lithoclasts: Clays and bioclasts

Colour of fresh rock: Dark grey-blue

Colour of weathered rock: Light grey-blue with ochres

Clasts Matrix:

Cementation Formation:

Age: Campanian (70 myr)

Origin: Plaza de las Brullerías and substrate of the cathedral

Size: Calcirudite (25%) and micrite

Roundness:

Sphericity Porosity: Moldic (<2%) with calcite recrystallisation

Relative presence: Very abundant

Observations:

In general, it is very compact with small water channels with calcite recrystallisation and ochres due to alteration of sulphurs. Echinoderms or inoceramids are frequent.

Distribution:

It is the direct substrate of the Cathedral and is always present as gravel in the masonry.

Alteration:

It probably contains a small portion of montmorillonite, which along with the lamination, favours the expansive activity of the clay. As a result, it is a rock which easily fragments when subjected to changes in humidity.

Likewise, with compressive forces not perpendicular to the lamination it can have low load resistance values. Undoubtedly, of all the rocks present in the monument it is the most problematic type.

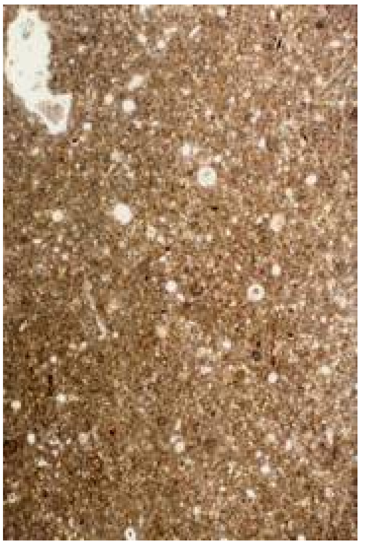
Quarries:

It would be located close to the Cathedral, as it is its own substrate. Due to the orientation, morphology and proximity, it may well have been extracted from the nearby Plaza de las Brullerías.

Extraction:

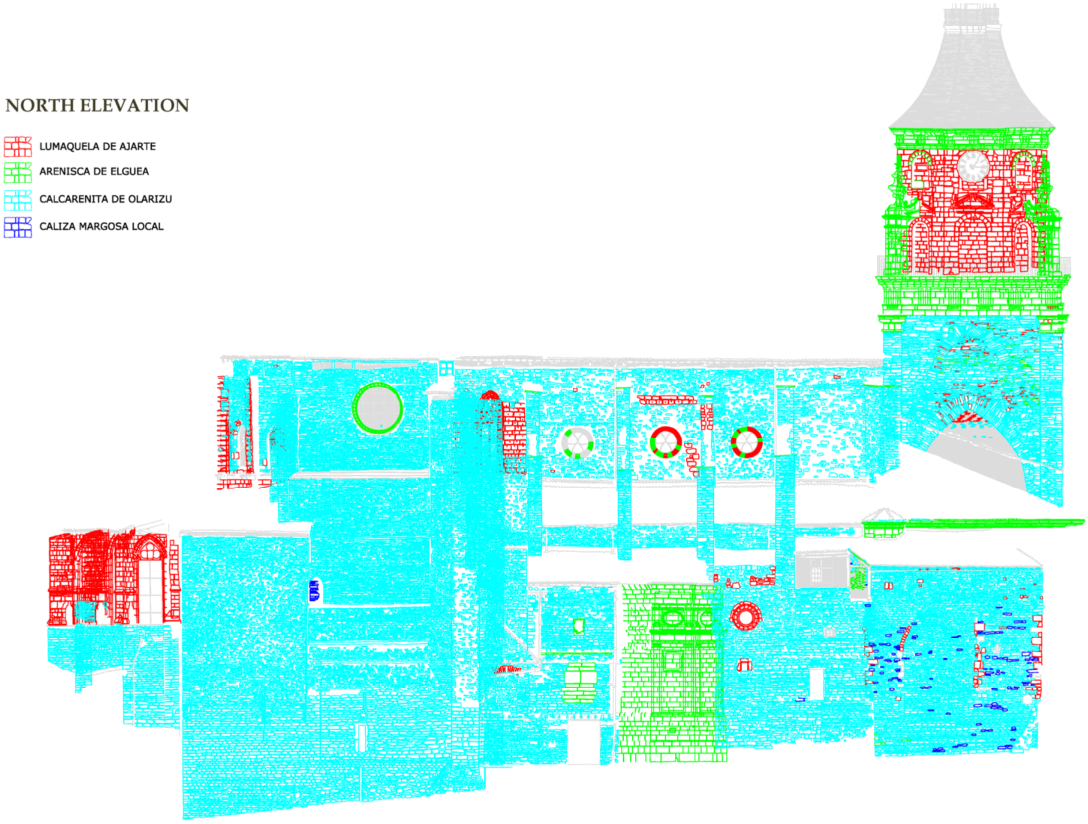
Easily fractured and fragile. Not suitable for carving.

Macroscopic photograph



Microscopic photograph

7. Mapping of the stones



8. Evaluation of environmental aggressiveness

The two factors that most importantly affect the conservation of stone in Vitoria cathedral are the atmospheric contamination and the extremely cold and wet climate present.

First of them, the contamination has been a great problem some years ago, when the deposition of black dust provinent of heat smokes and cars circulation caused a black crust all over the north and east facades, more exposed to the wind that wears those carbonic compositions. Moreover, those facades are mostly made of calcarenite stone, that is very much sensitive to the depositions, due to its high porosity and scarse compacity.

Then, the extreme climate, with frozen nights and hot days during most part of the year (with thermic gaps that can reach occasionally 20 or 25 degrees), and the high relative humidity of the atmosphere (over 85% also during a great part of the year) make an explossive cocktail of water, ice and wind that affects seriously all the stones in the cathedral. The circle of infiltration of water into the porous surface of the stones during day, with the low temperatures of night that get into ice that water, has as result a break of the surfaces components and a progressive erosion of the stones.

9. Preliminary evaluation of the conservation state of stone surfaces

Although the decay problems are very different for each one of the lythotypes present in the Cathedral, we can characterize most of them according to the ICOMOS_ISCS glossary.

For the two lithotypes selected for the Nanocathedral project, the main problems are:

- Crack and deformation
- Detachment
- Material loss
- Discoloration and deposit
- Biological colonization

10. Information on historic and recent treatments of conservation

Old preventive and remedial treatments:

As the latest restoration process of the Cathedral dates of the 1960 decade, there were not chemical consolidation or protection treatments applied. They doesn't exist then (in Spain) by that moment. But a 'traditional' treatment of applying a patina of lime and portland was used to get two objectives: the 'whitening' of the interior of the Cathedral (as for the Le Corbusier thesis of the 'White Cathedrals') and to get an uniformity of the same surfaces, as they were made in different stones and different masonry patterns.

Present preventive and remedial treatments:

To the day, we don't have applied any consolidation or protection treatments in the surface of the stones with any chemical product. The bad experiencies in other buildings and climates has convinced us that is necessary to await for a demonstratedly effective treatment without collateral damages to be developed, before taking the decission of applying it extensively.

Anyway, to protect the stone actually damaged, we have made little applications of lime mortar in the places where the water-ice-erosion process was present. This has been made only in the tower and portico facades, and we are waiting for its results before to extend the solution to other parts of the cathedral.

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