

Reconstruction of the Zagreb Cathedral

Croatia

The cathedral through history

- The Diocese of Zagreb was founded by King Ladislaus in the **11th century**, and thus the construction of the first cathedral began
- From that time we have the Gothic chapel of St. Stephen, which is now part of the Archbishop's Palace
- The cathedral during the Middle Ages from the **14th to the 16th century**. It began to be built several times
- In the **seventeenth and eighteenth** centuries, the construction of the southern bell tower continued
- The exact division of the construction of the cathedral throughout history cannot be precisely determined, but it is dated according to the coats of arms of individual bishops that can be found on the facades of the cathedral.

Najraniji prikazi katedrale



Nacrt Zagreba, 1566. godina



Prikaz katedrale, 1690. godina



Prikaz katedrale iz sredine 19. stoljeća

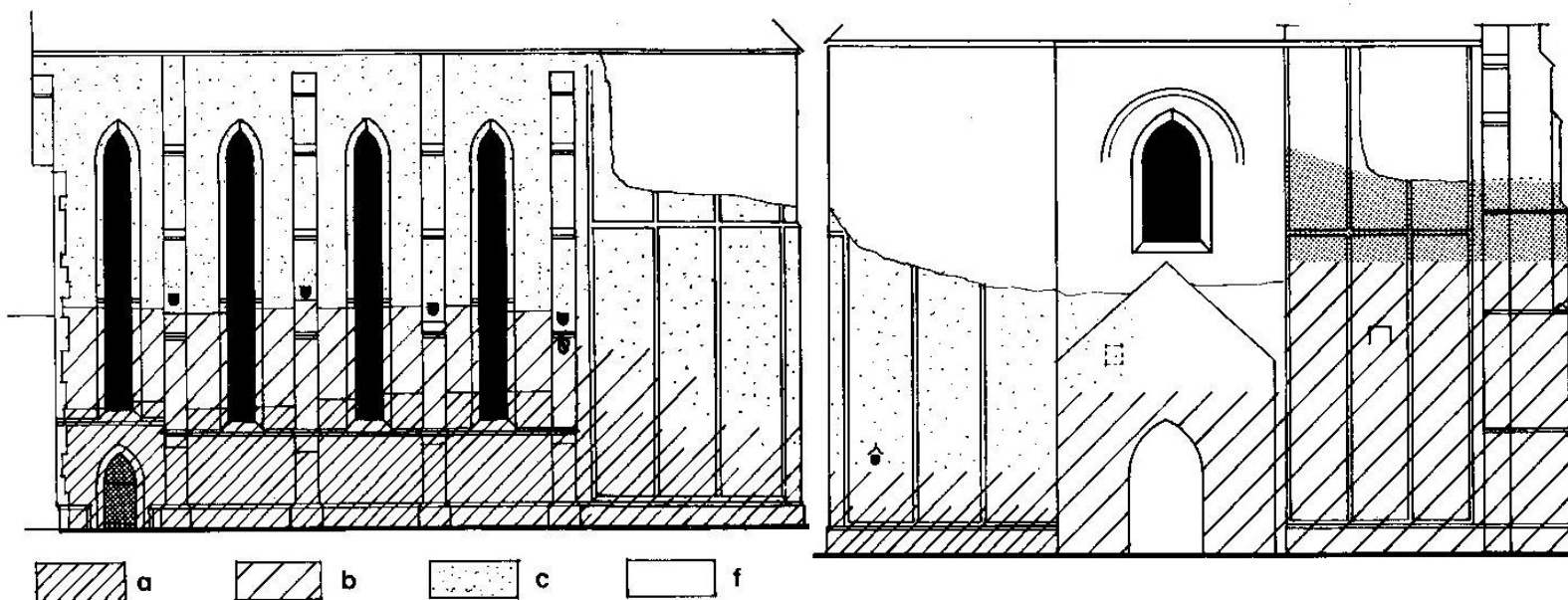


The cathedral through history



Glavno pročelje, Friedrich von Schmidt, 1878.godina

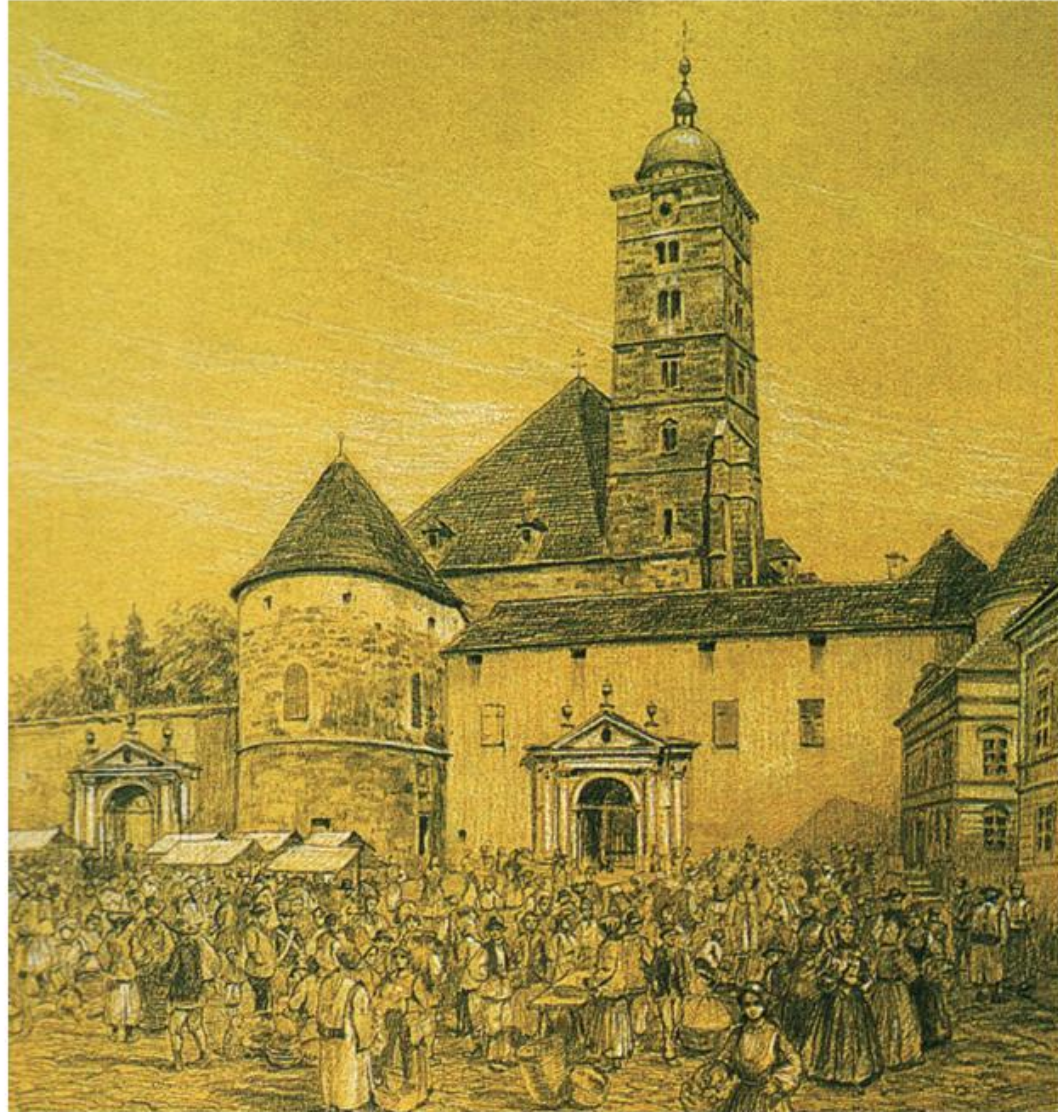
- The cathedral was engulfed by **two great fires** (1624 and 1645) and badly damaged. This was followed by the renovation and construction of the southern Renaissance bell tower, which was also an observation tower. The works are carried out by master Ivan Albertal.
- Throughout history, the building has been **damaged several times** in Tartar attacks – the facades themselves bear witness to the construction phases through the centuries



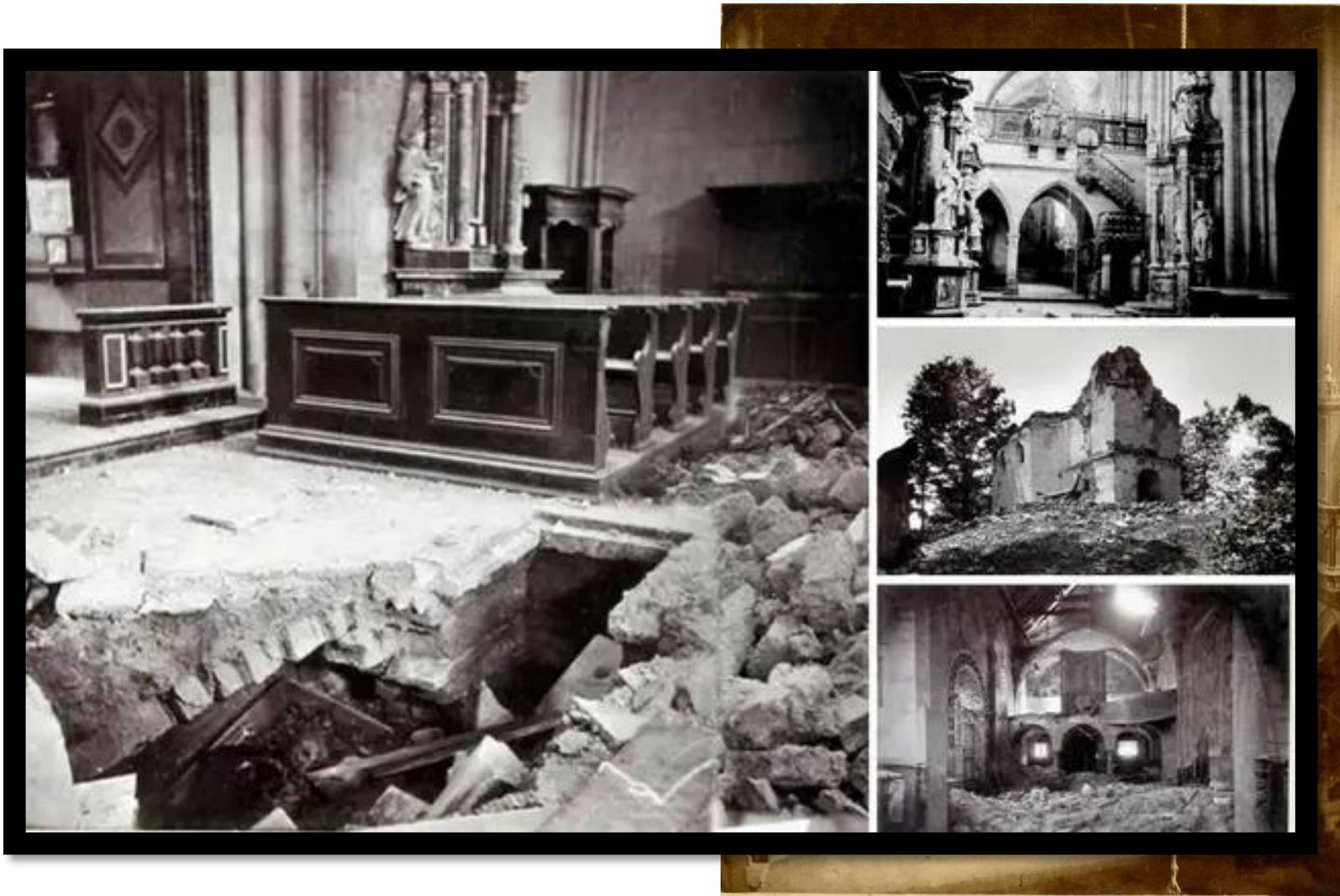
35 Prikaz građevnih faza sjevernog pročelja lade katedrale: a) početak XIV. st.; b) druga polovina XIV. st.; c) početak XV. st. (starija faza).

36 Prikaz građevnih faza zapadnog pročelja katedrale: a) početak XIV. st.; b) druga polovina XIV. st.; c) početak XV. st. (starija faza); d) dio razrušen poč. XVI. st. za napada J. Thurna na Kaptol.

The cathedral through history

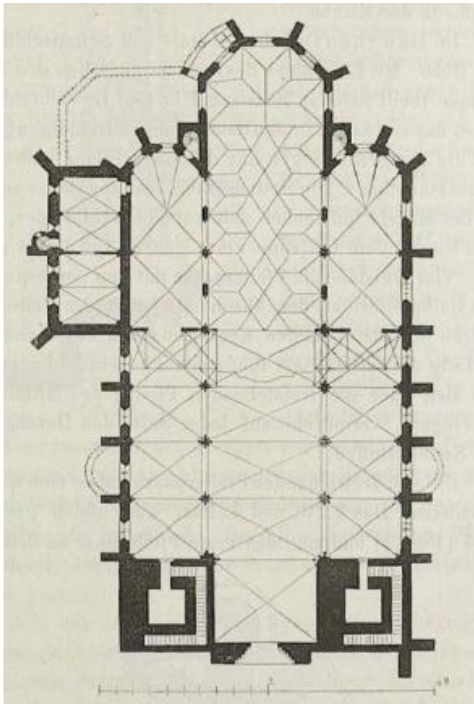


The Great Zagreb Earthquake of 1880

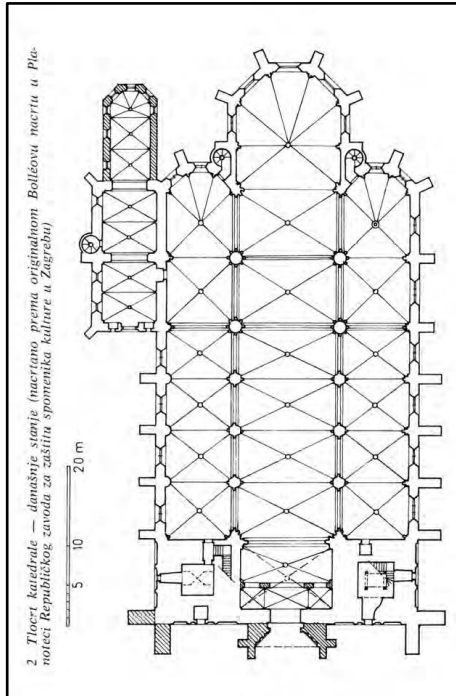


The Great Zagreb Earthquake of 1880

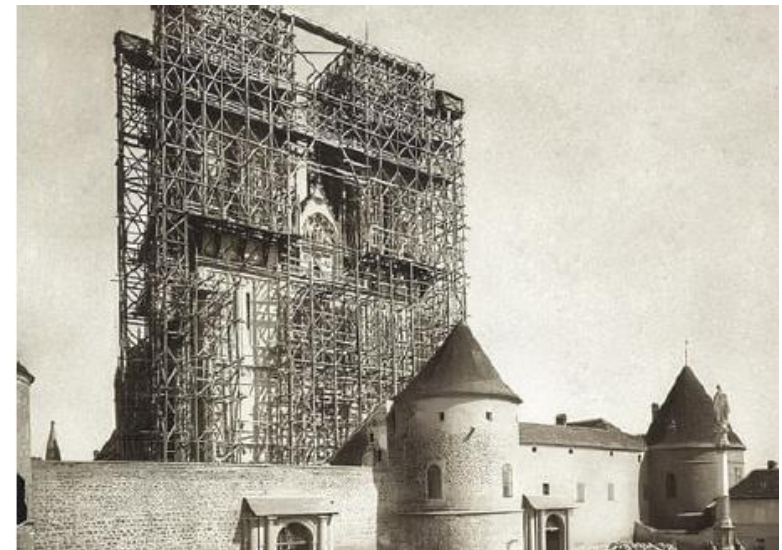
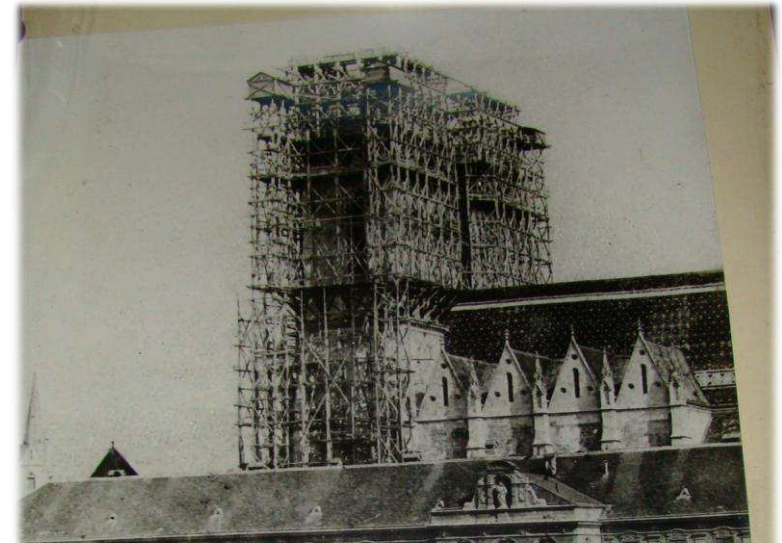
- The restoration/reconstruction of the cathedral in the **neo-Gothic style** was led by Hermann Bolle
- The reconstruction was **completed in 1902**, as part of this renovation, two towers 108 m high were erected on the west side of the façade



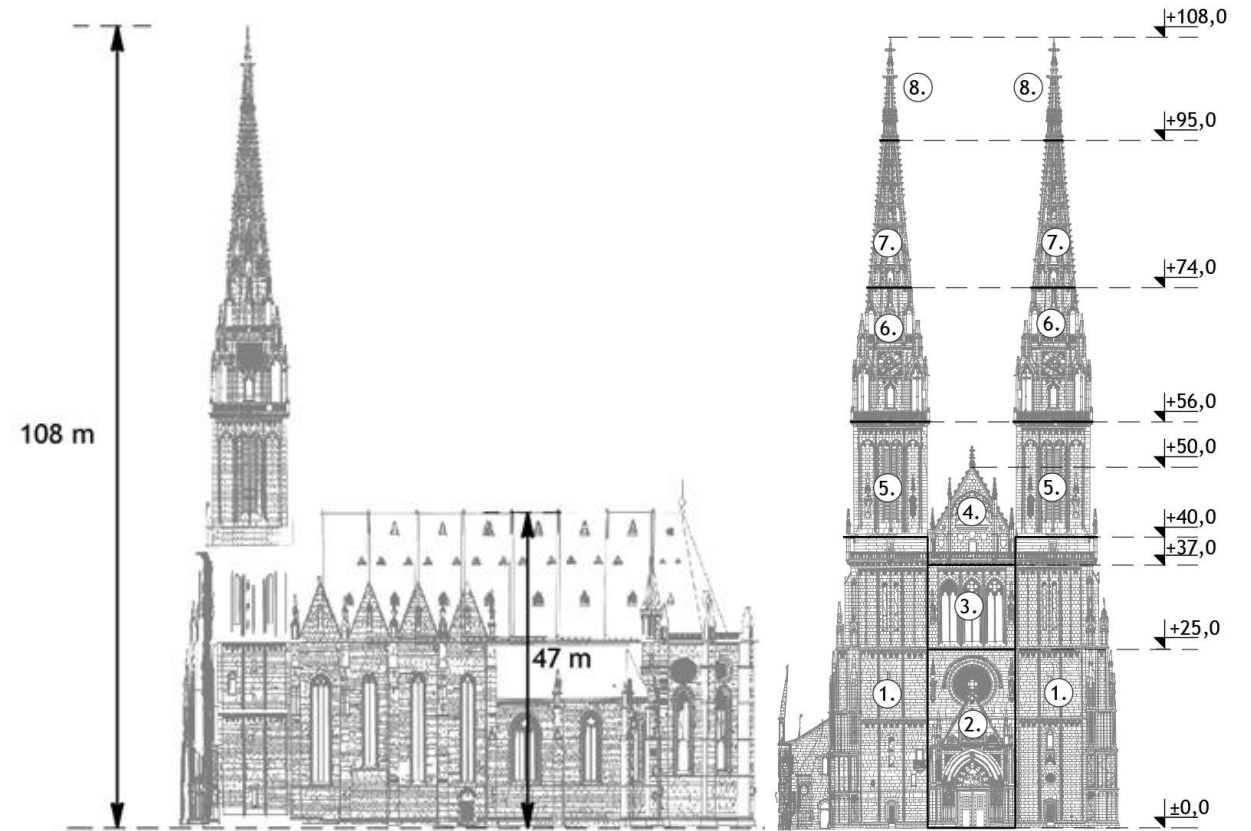
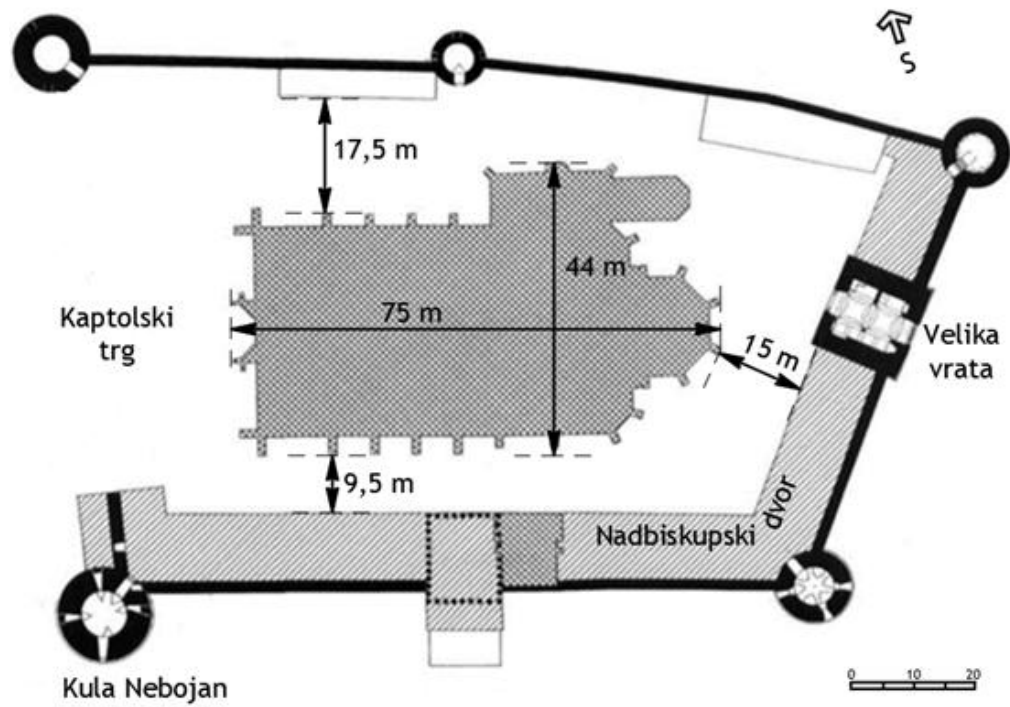
*Tlocrt Katedrale, K. Weis,
1859. godina*



*Tlocrt Katedrale, H. Bolle,
1900. godina*



General info

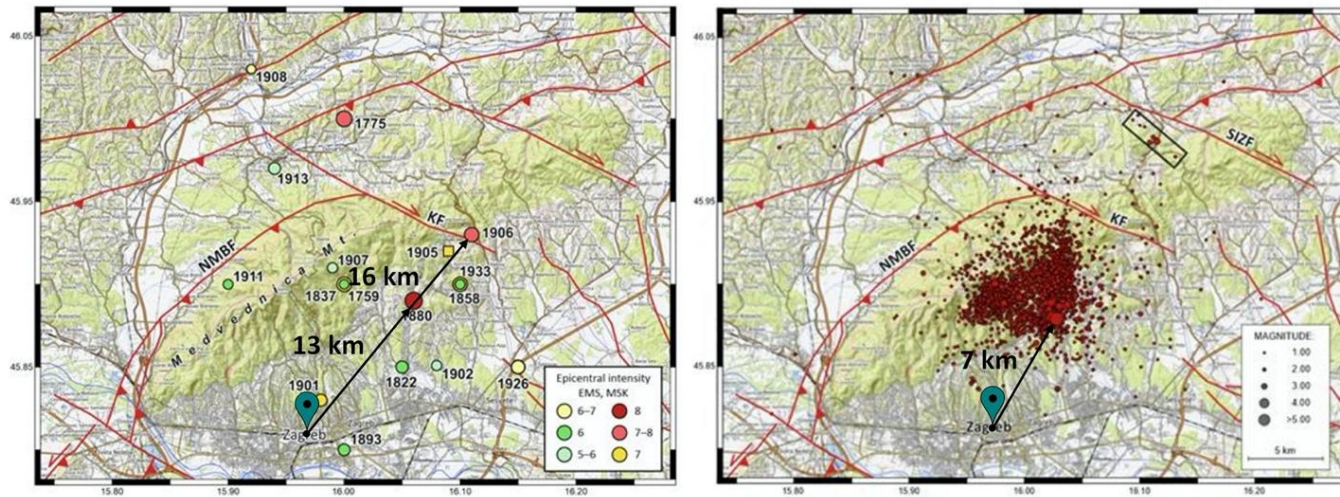


walls
~ 120 cm

walls
> 300 cm

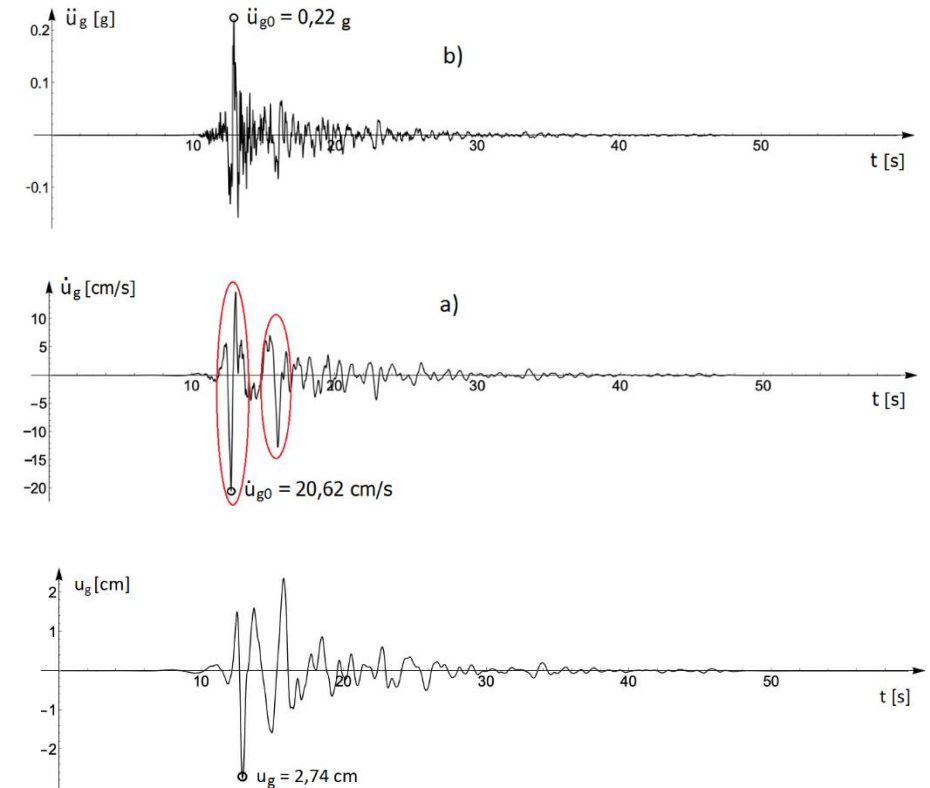
Location and location of the Cathedral

➔ Risky location of the building



Distance of the Cathedral from the epicenters of the three strongest earthquakes from the recent past [research by Prof. Herak]: 1880, 1906 and 2020

7-16 km

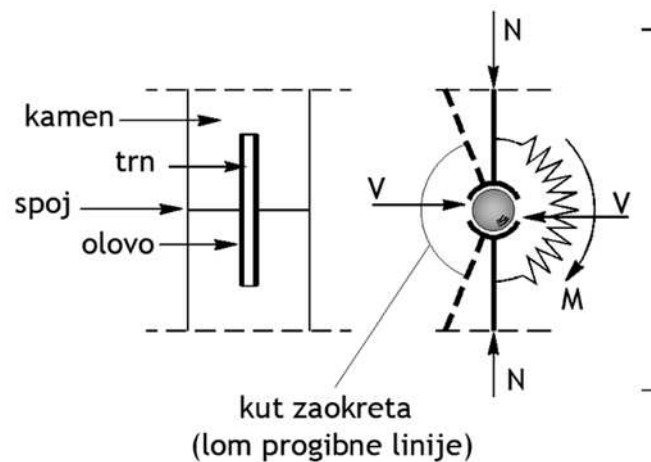
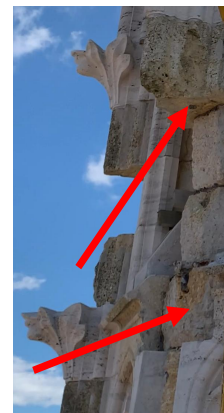
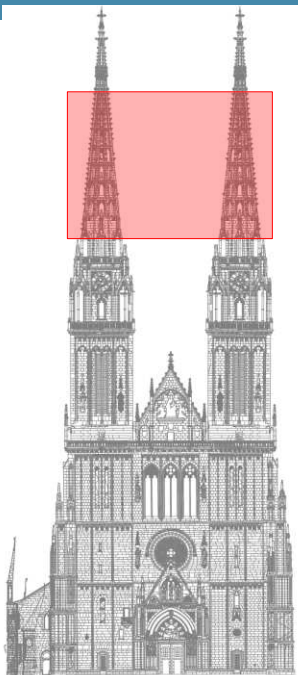


Record of the north-south component of the Zagreb earthquake recorded in the UHS building on March 22, 2020

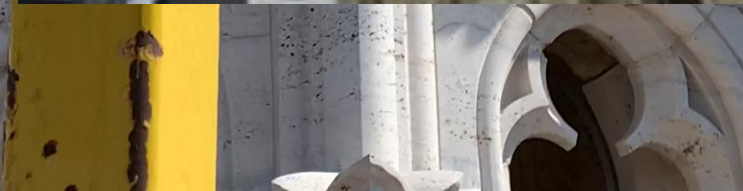
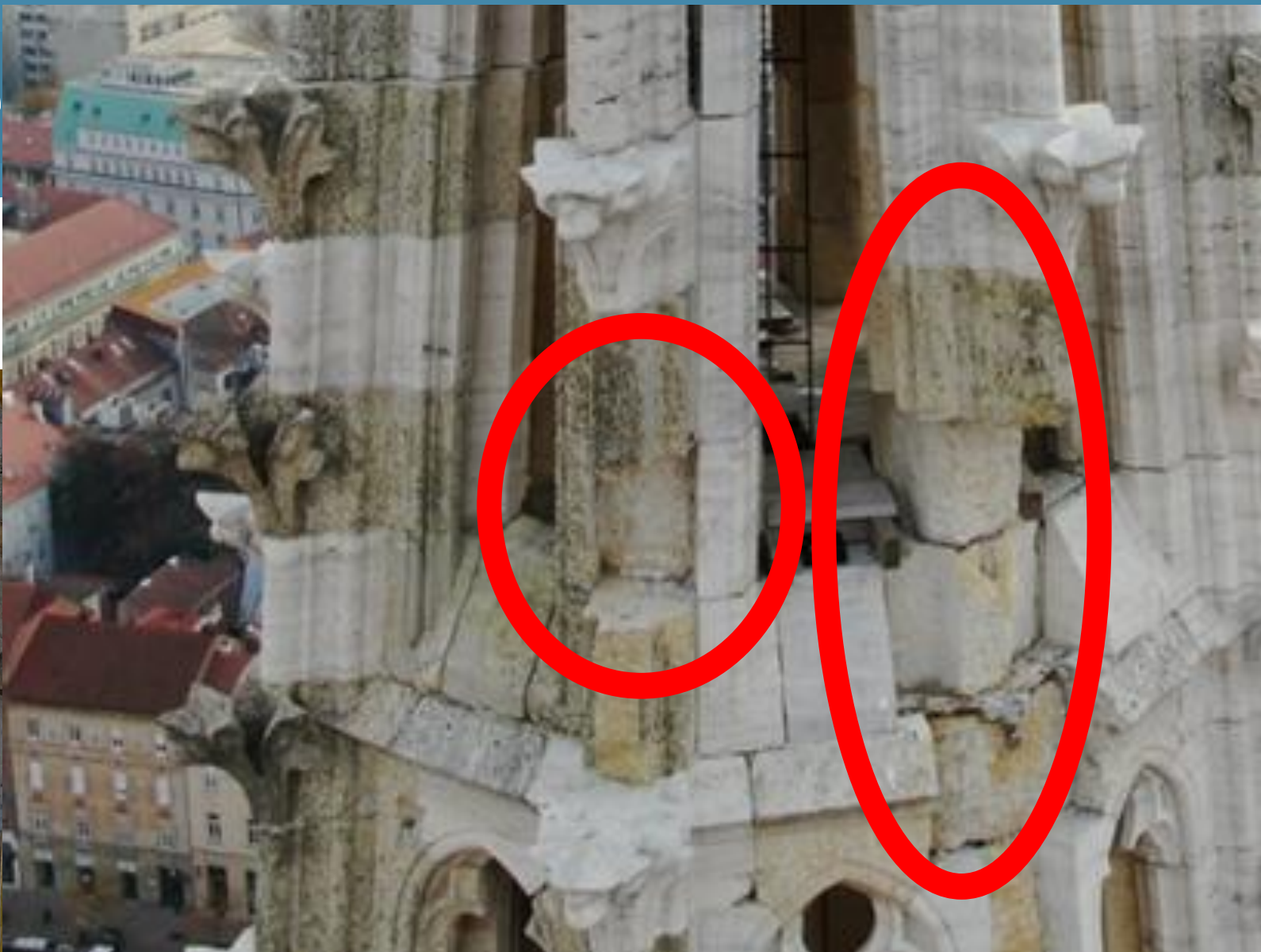
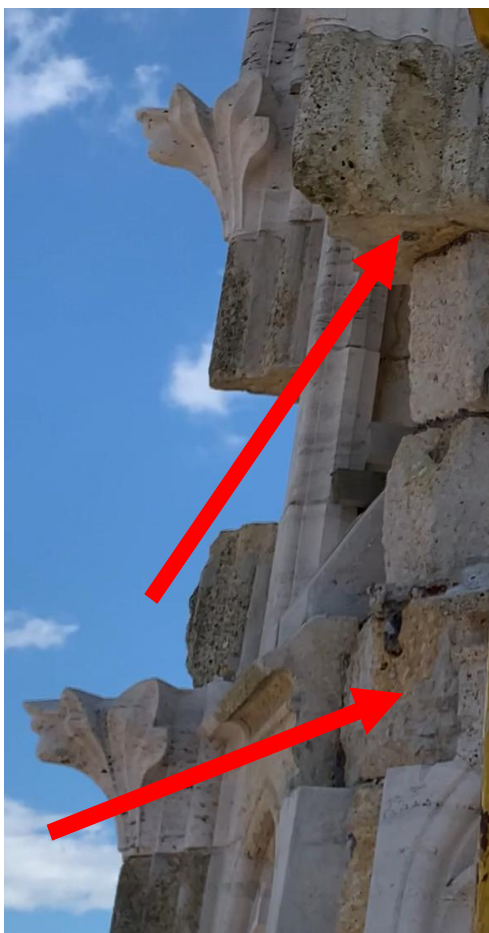
Earthquake in 2020 (March)



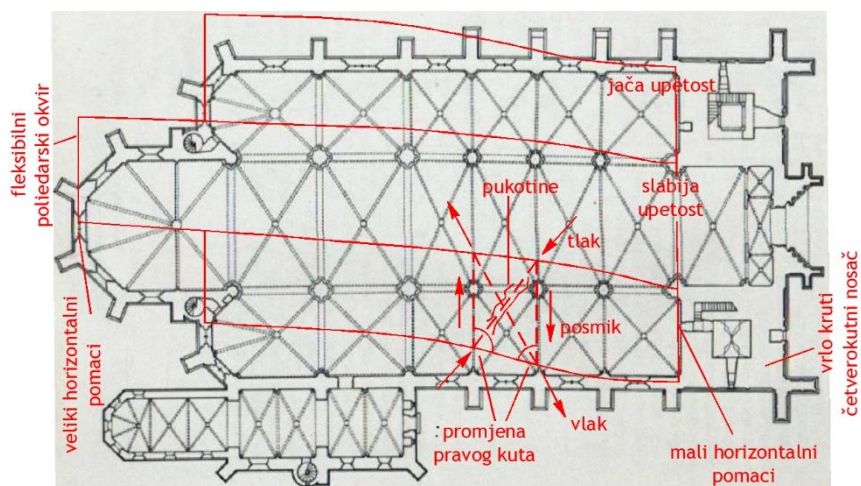
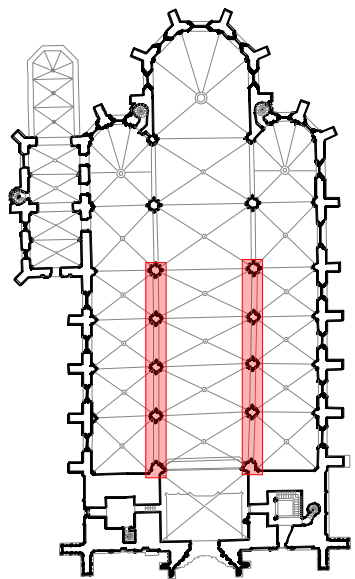
Damages in the 2020 earthquake



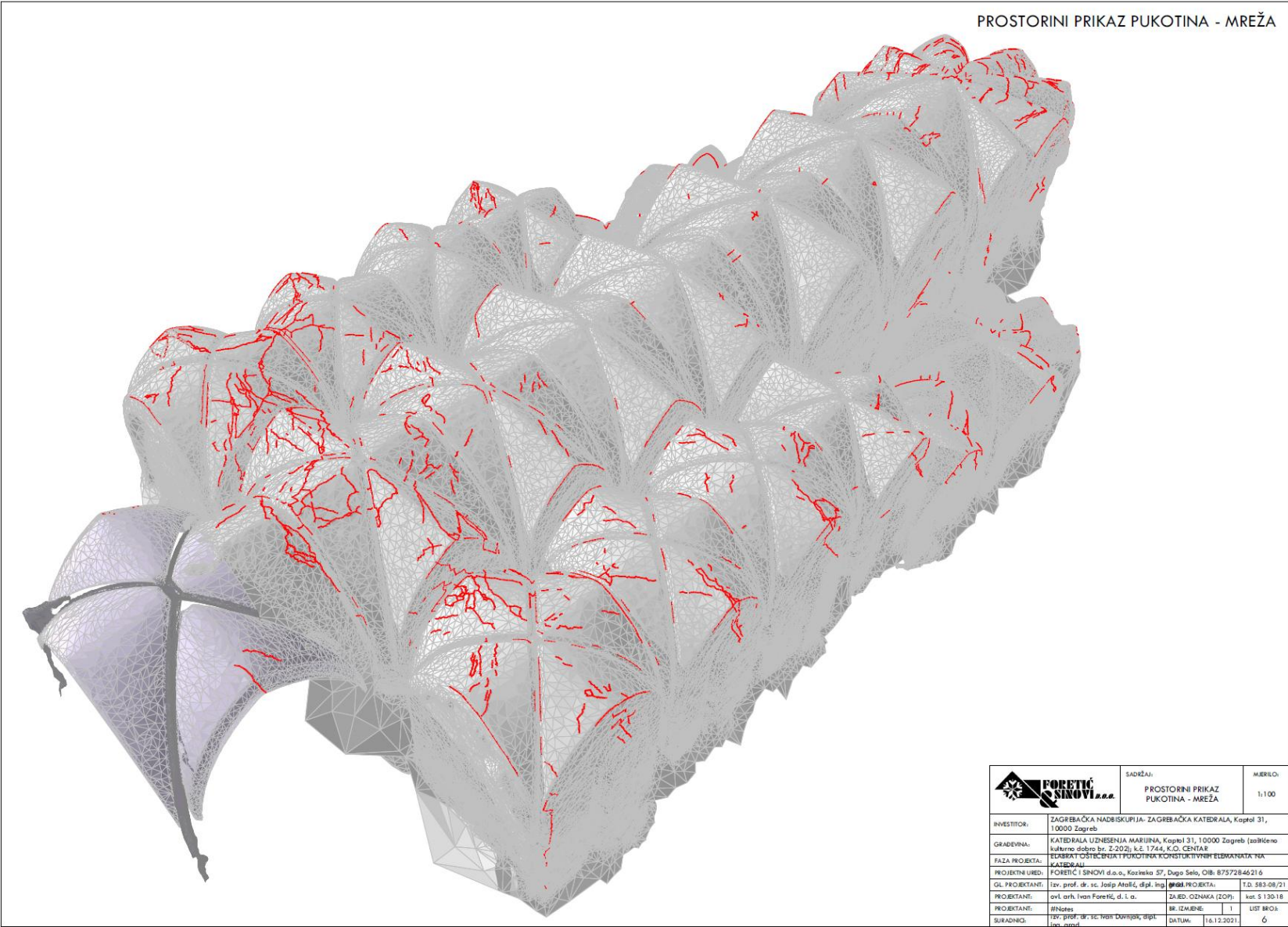
Damage



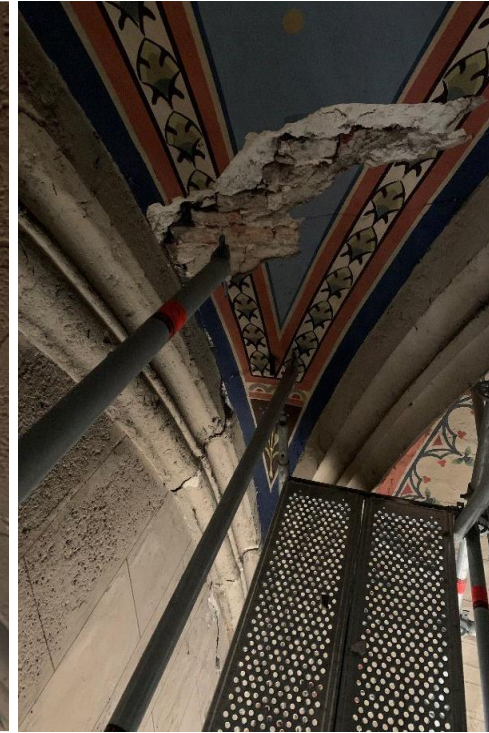
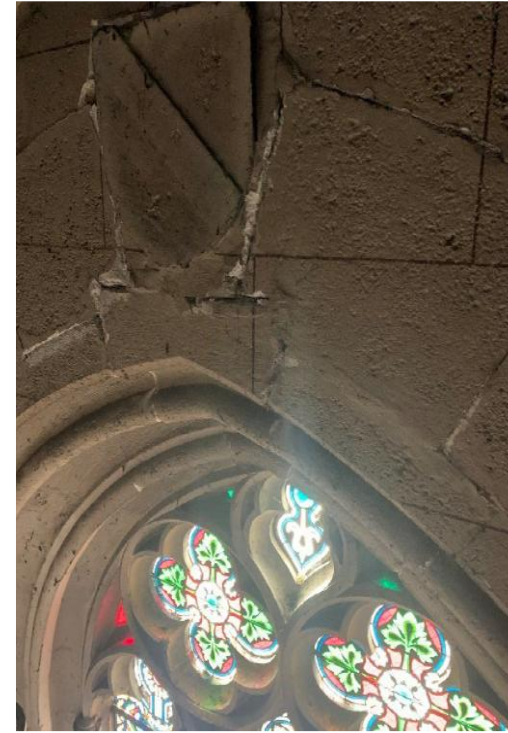
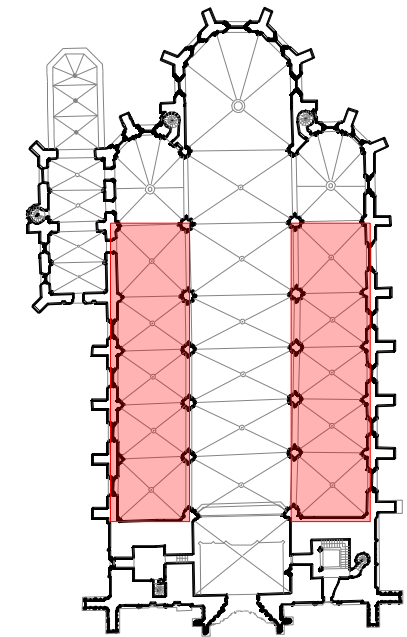
Damage in the 2020 earthquake



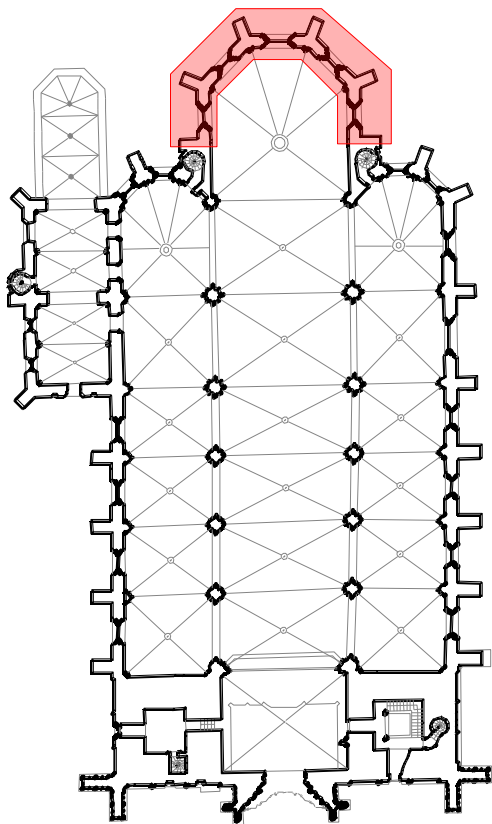
Cathedral after 2020 earthquake



Cathedral after 2020 earthquake



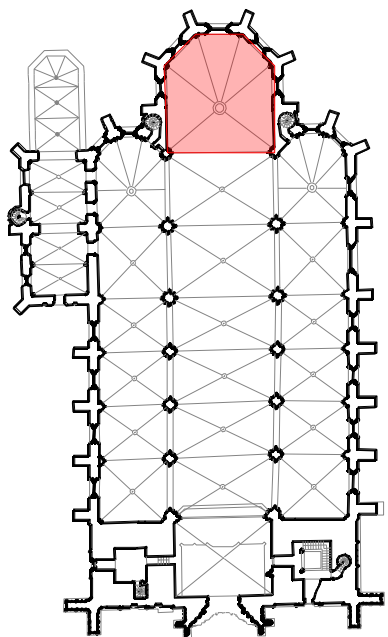
Damage of the Cathedral after 2020 earthquake



After Zagreb 2020 earthquake

After Petrinja 2020 earthquake

Cathedral after 2020 earthquake (apse)



Genesis of the numerical model with distinct elements



Numerical Model Calibration



RAZLOG ZAHVATA

- U sklopu geotehničko / geološkog istraživanja izvedene su četiri geološke bušotine pojedinačnih dubina 35m, šest geotehničkih bušotina pojedinačnih dubina 15m.
- U geološkim bušotinama provedeno je DOWN HOLE geofizičko ispitivanje, MASW ispitivanja kako bi se sukladno Eurokodu 8 utvrdio tip tla u zoni Katedrale.
- Rezultat provedenih istraživanja je izrađena detaljna inženjerskogeološka karta, te tip tla B sukladno EC8 dobiven detaljnim mikrozoniranjem (šire područje Katedrale prije je svrstavano u tip tla C).

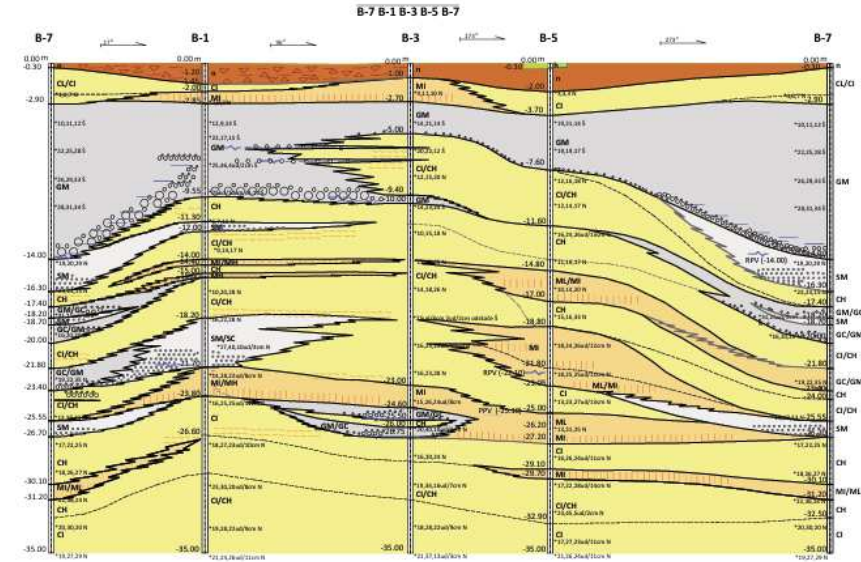
GEOLOŠKA I INŽENJERSKOGEOLOŠKA KARTA ŠIREG PODRUČJA
LOKACIJE KATEDRALE UZNESENJA MARIJINA
M 1:2.000

MJERILO 1:2000
0 20 40 60 80 100 120 140 160 180 200m

LEGENDA:

- SC/GS; Q₁ holocen
- C/M; C₁; Q₁ pleistocen
- geološka granica
- pretpostavljeni rasjed
- povremeni tok
- zamočvarenje
- ulaz vode u gradski kolektor
- gradski bazeni
- B-7 geološka istražna bušotina
- B-4 geotehnička istražna bušotina
- P-1 prospekcijska bušotina
- 5-B5 bušotina preuzeta iz (DIGK-faza I)
- P7-B4 bušotina preuzeta iz (DIGK-faza II)
- M-P7-B4 MASW metoda ispitivanja preuzeta iz (DIGK-faza II)
- prognosti inženjerskogeološki profil preuzeta iz (DIGK-faza II)
- ograda nadbiskupije

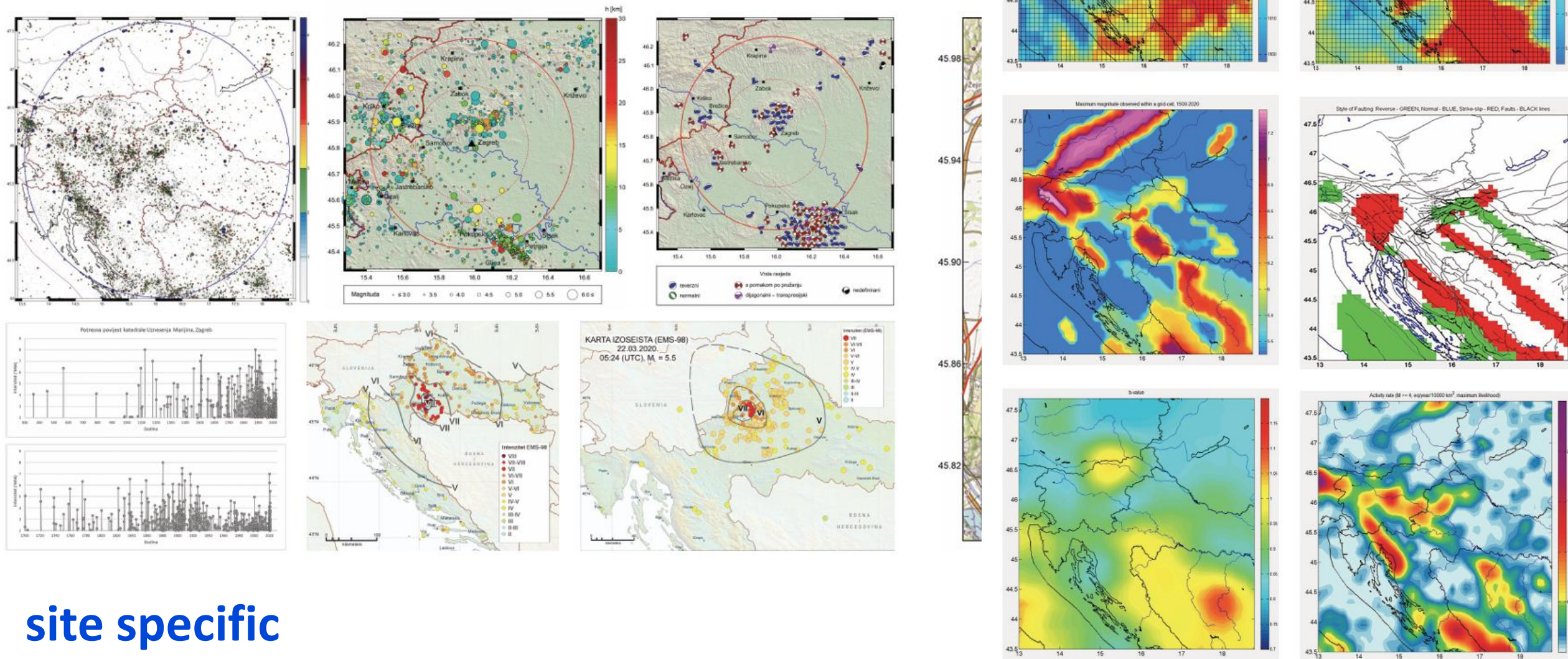
INŽENJERSKOGEOLOŠKI PROGNOZNI RAZVIJENI PROFIL
M 1:200



LEGENDA:

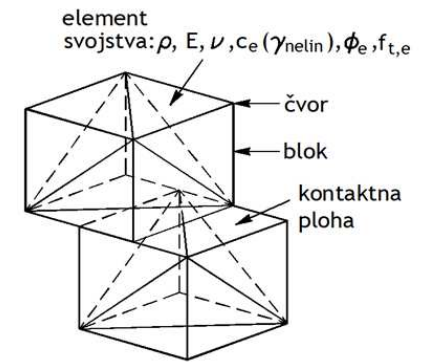
- Humus
- Nekohherentne naslage
 - Nazip
 - Pijesak
 - Šljunak
- Kohherentne naslage
 - Silt (prah)
 - Gline
- Postupni prijelaz
- Podzemna voda
- Geološka istražna bušotina s downhole ispitivanjem
- SPT (S) šljak (N) mrt

Numerical Model Calibration



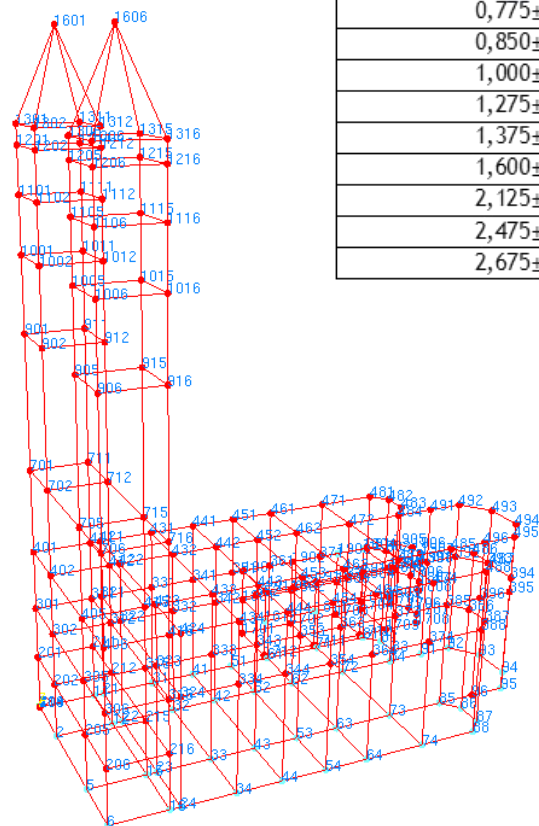
Numerical Model Calibration

- Visible and hidden **cracks**
- Very **discontinuous** material without reinforcement, extremely loose in some places
- During an earthquake, wall elements separate, twist, slide and crack
- The **displacements and angles of rotation** of the modal nodes are not connected
- Natural **anisotropy** of stone

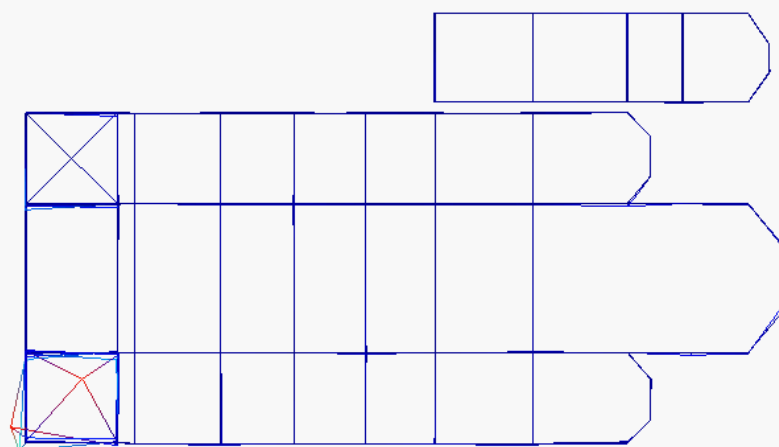


- Numerical model: calibration according to the results of **operational modal analysis (frequencies)**

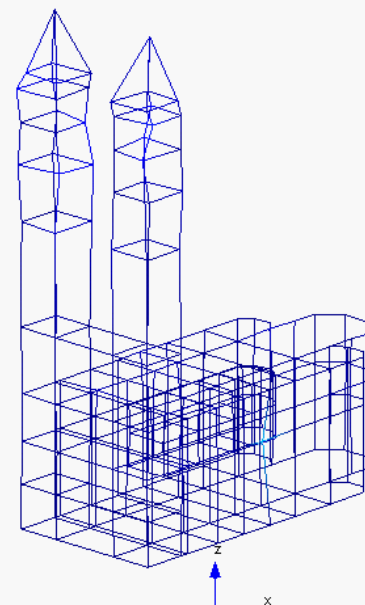
Vlastita frekvencija ± st. odstupanje [Hz]	Koeficijent prigušenja [%]	Dio konstrukcije s dominantnim pomacima
0,775±0,06	2,34 ± 0,28	tornjevi
0,850±0,07	2,28 ± 0,31	tornjevi
1,000±0,08	2,05± 0,34	tornjevi
1,275±0,14	1,74± 0,38	tornjevi
1,375±0,12	1,66 ± 0,41	lađa
1,600±0,12	1,71 ± 0,44	lađa
2,125±0,11	1,92 ± 0,39	lađa i tornjevi
2,475±0,20	0,98 ± 0,29	lađa
2,675±0,19	1,44 ± 0,38	lađa



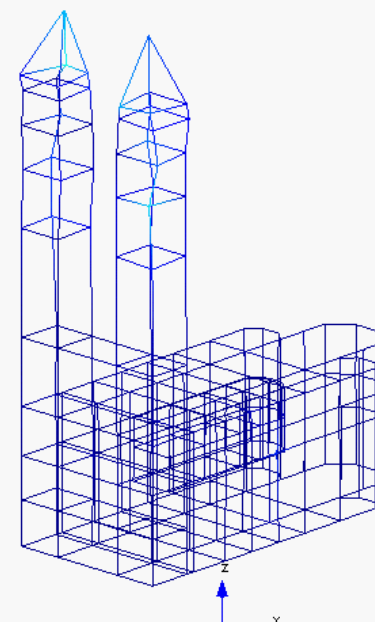
FDD - Frequency Domain Decomposition



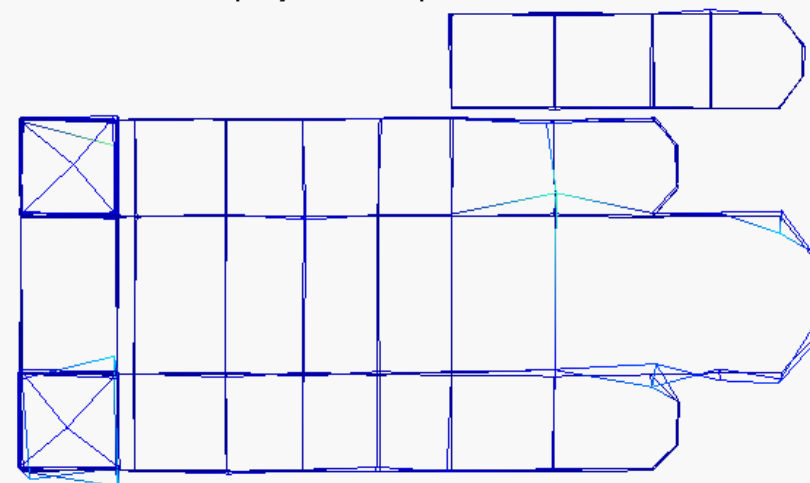
FDD - Frequency Domain Decomposition



FDD - Frequency Domain Decomposition



FDD - Frequency Domain Decomposition



Razina 3

horizontalno vršno ubrzanje: 0,23g
magnituda u epicentralnom području Medvednice: $M_L \approx 6,2$

kategorija tla B

— neoštećeni blokovi

— neoštećena

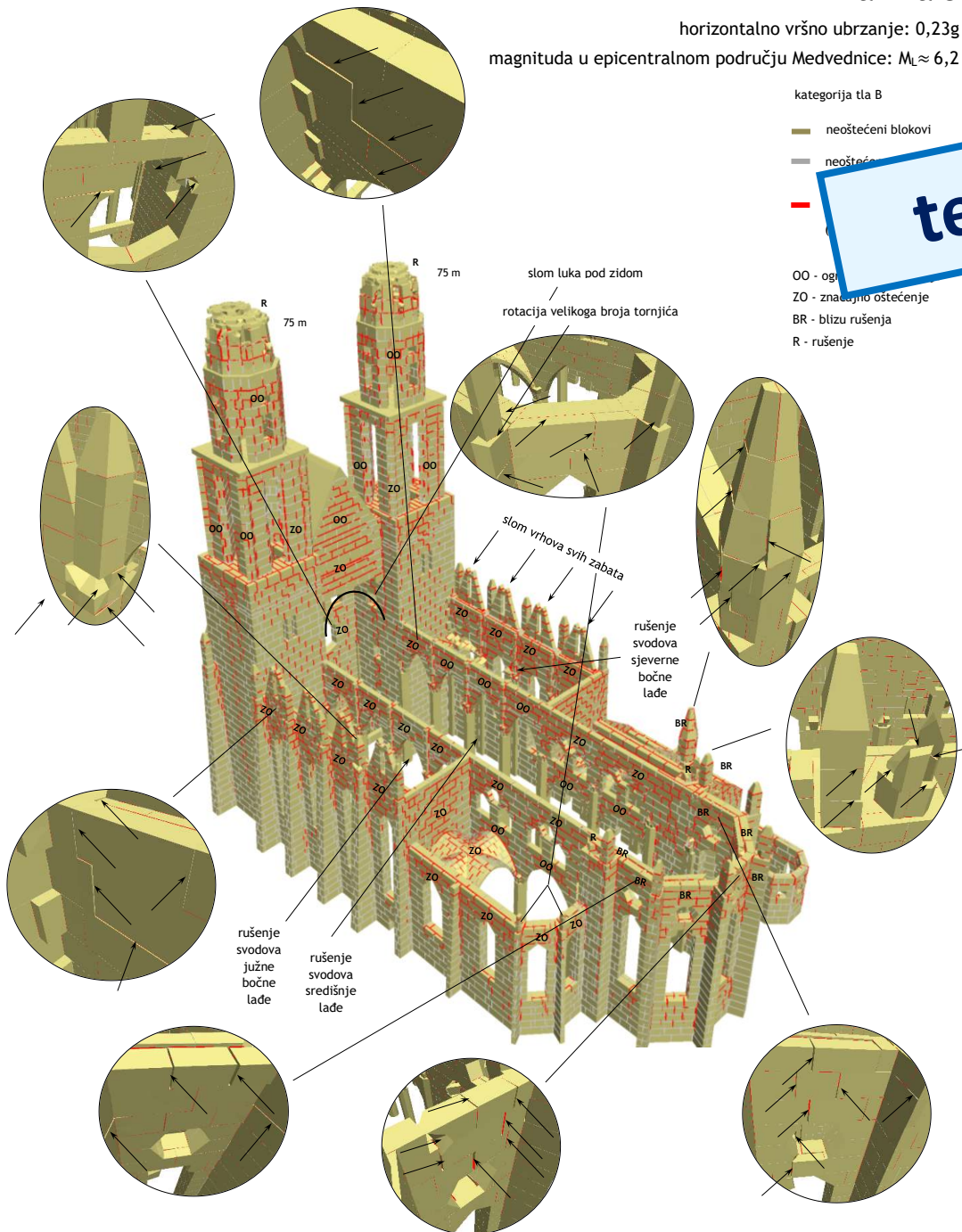
OO - ograničeno oštećenje

ZO - značajno oštećenje

BR - blizu rušenja

R - rušenje

teaser ...



Razina 2

horizontalno vršno ubrzanje: 0,15g
magnituda u epicentralnom području Medvednice: $M_L \approx 5,7$

kategorija tla B

— neoštećeni blokovi

— neoštećena sijubnica

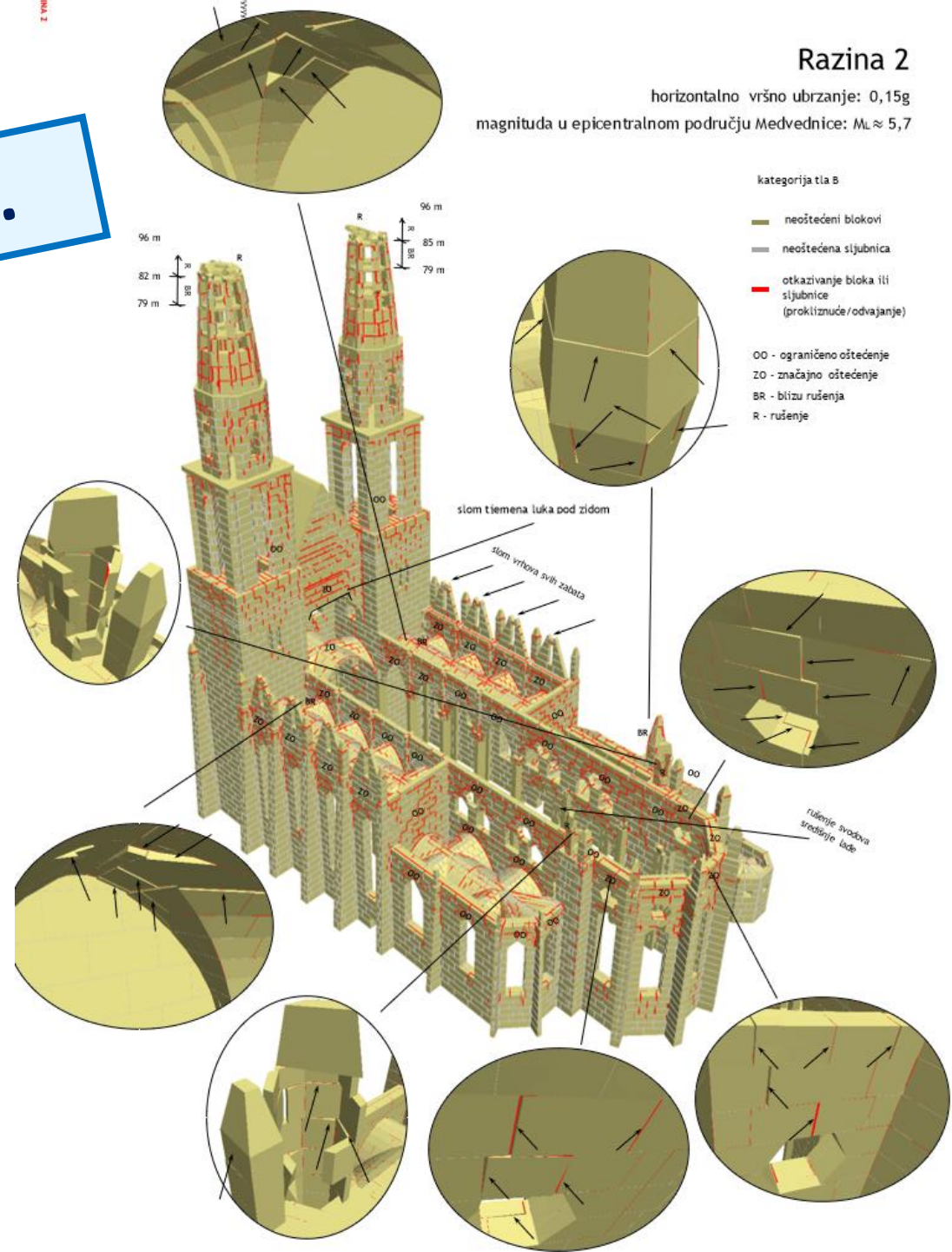
— otkazivanje bloka ili sijubnice (prokliznuće/odvajanje)

OO - ograničeno oštećenje

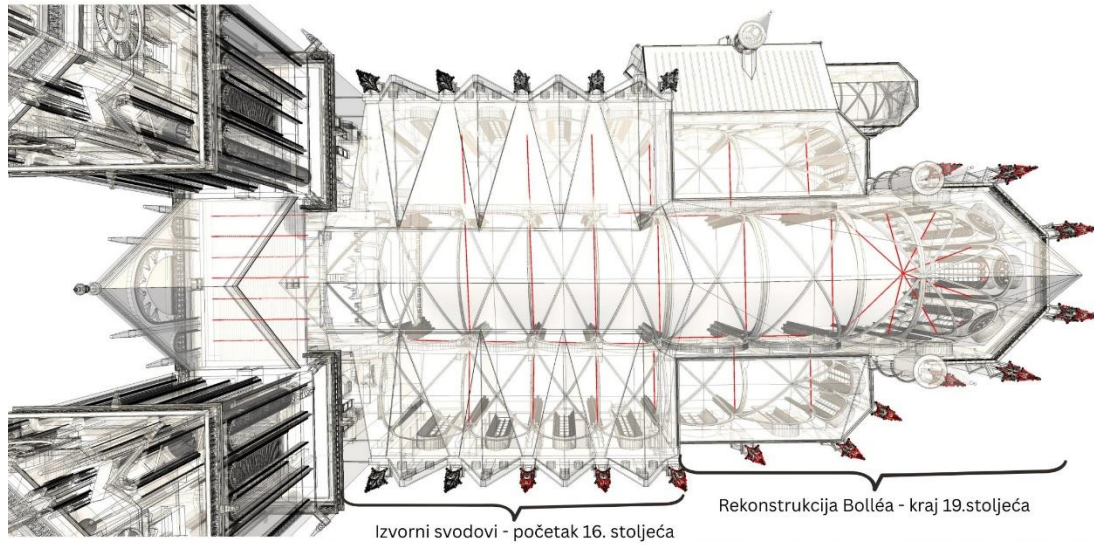
ZO - značajno oštećenje

BR - blizu rušenja

R - rušenje



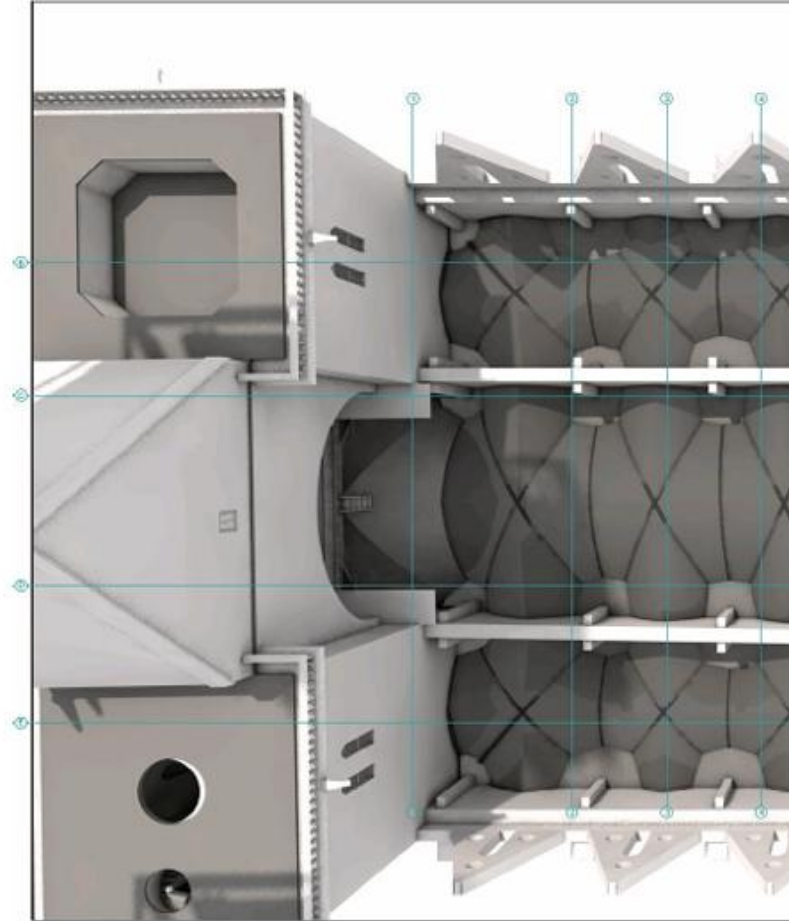
Urgent measures for structural repair (strengthening)



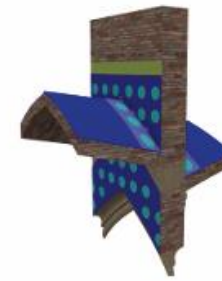
Urgent measures for structural repair (strengthening)



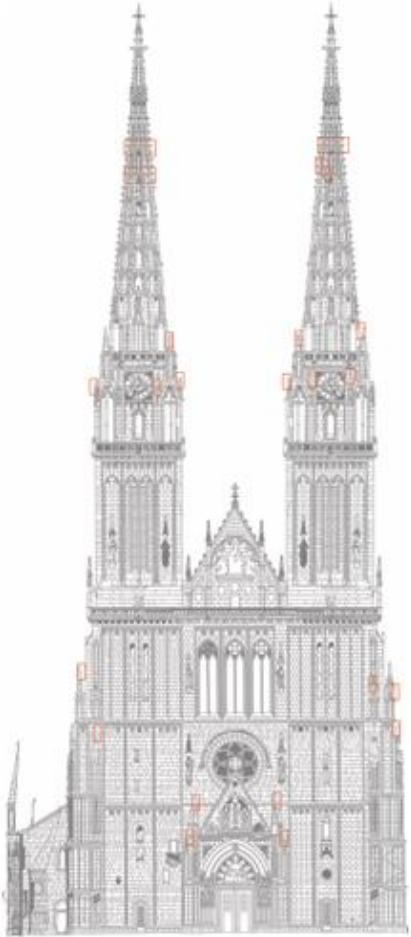
Urgent measures (vaults)



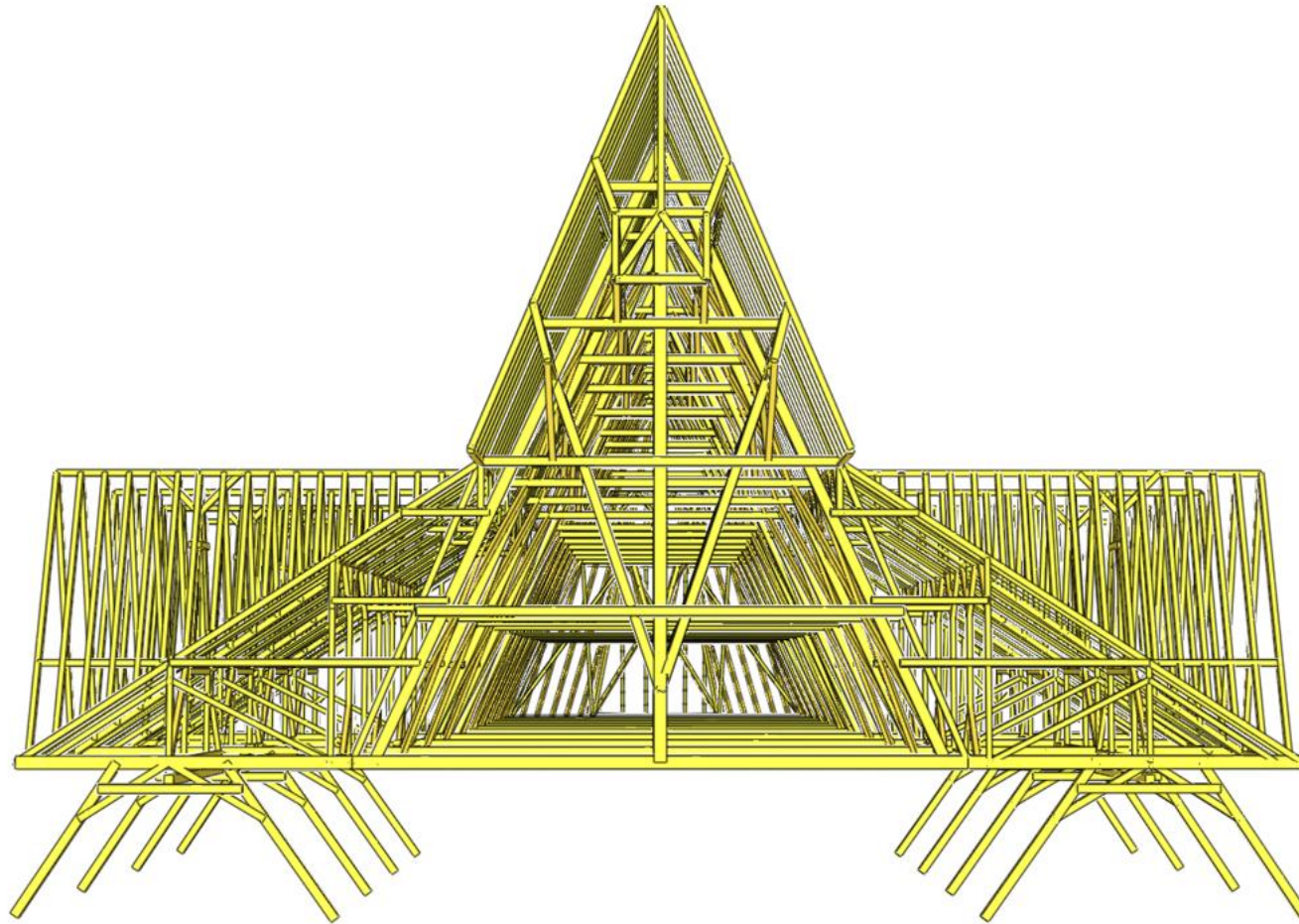
druga polovica 15.st - početak 16.st



Urgent measures

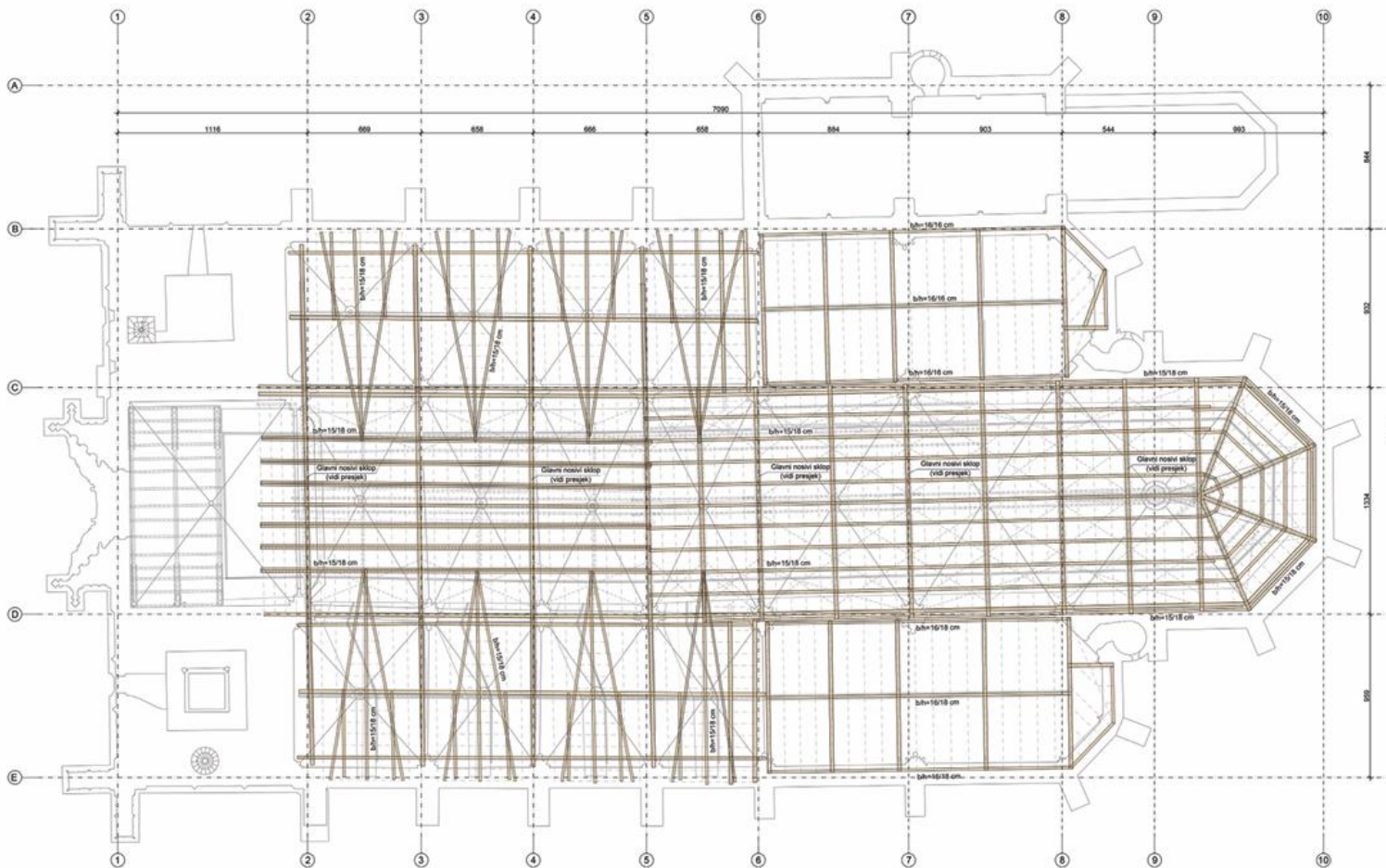


Roofing

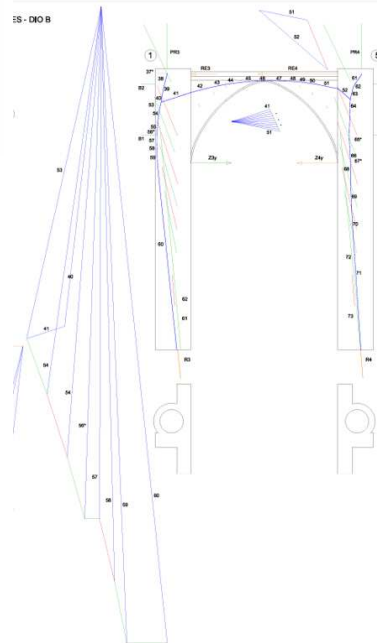
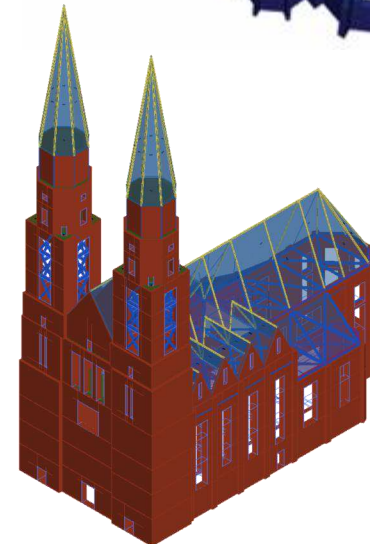
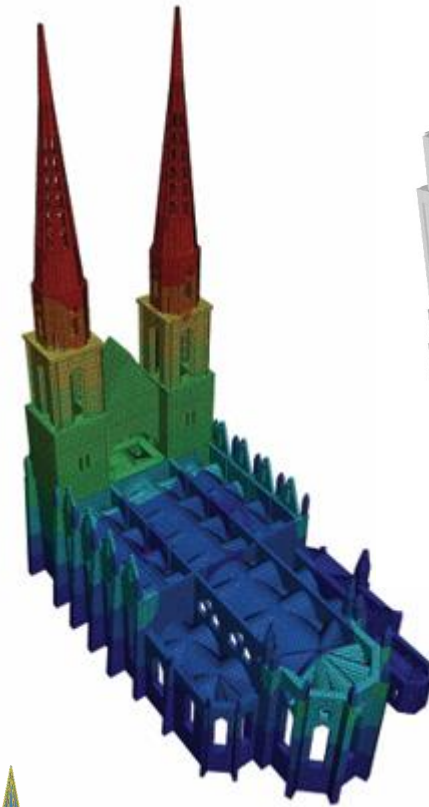
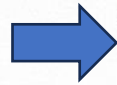


The "5-storey" : the tallest and largest historic wooden roof in the Republic of Croatia ...

Roofing



Numerical Models – reconstruction

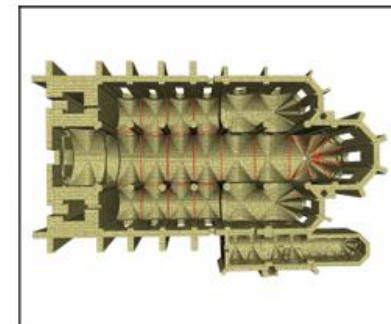
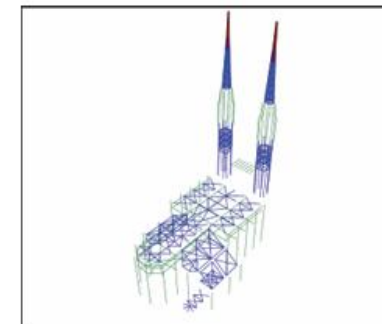
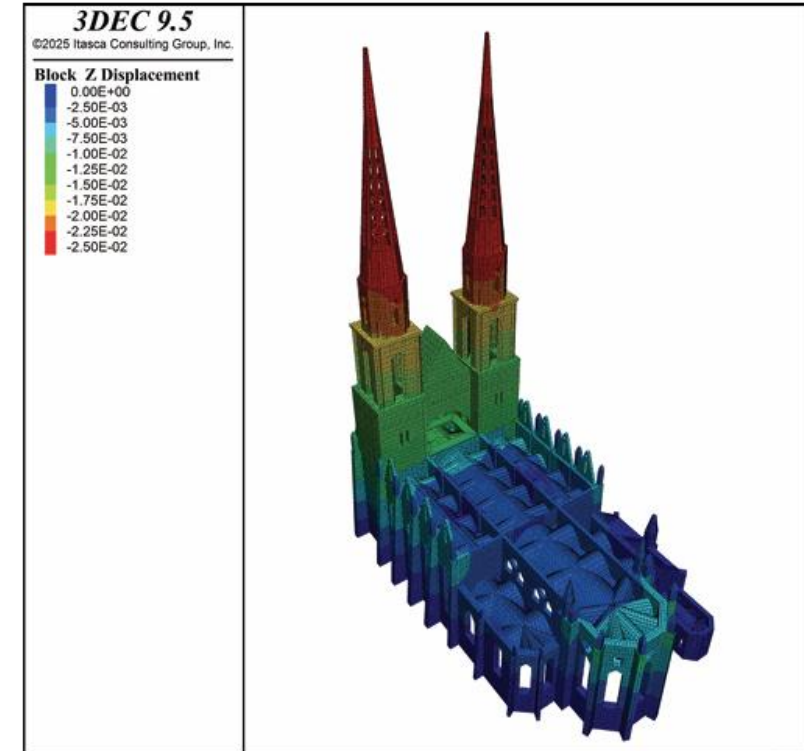


Numerical models

3DEC Day 2025 Model Contest

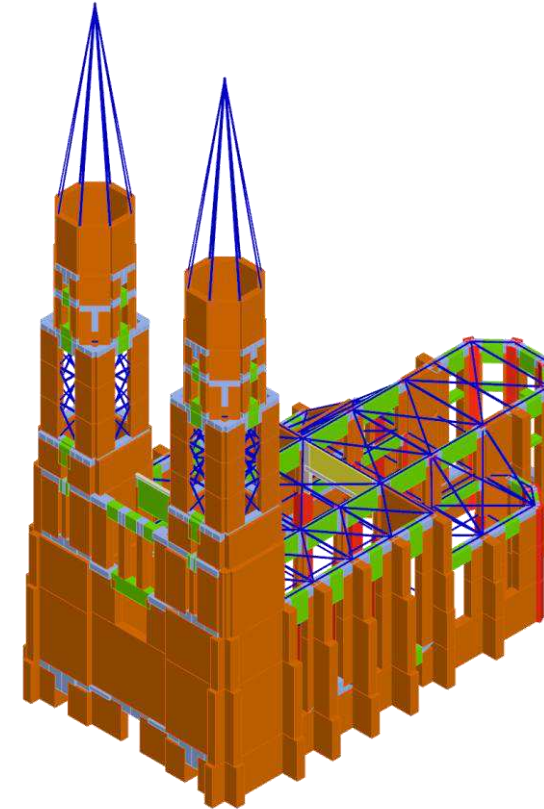
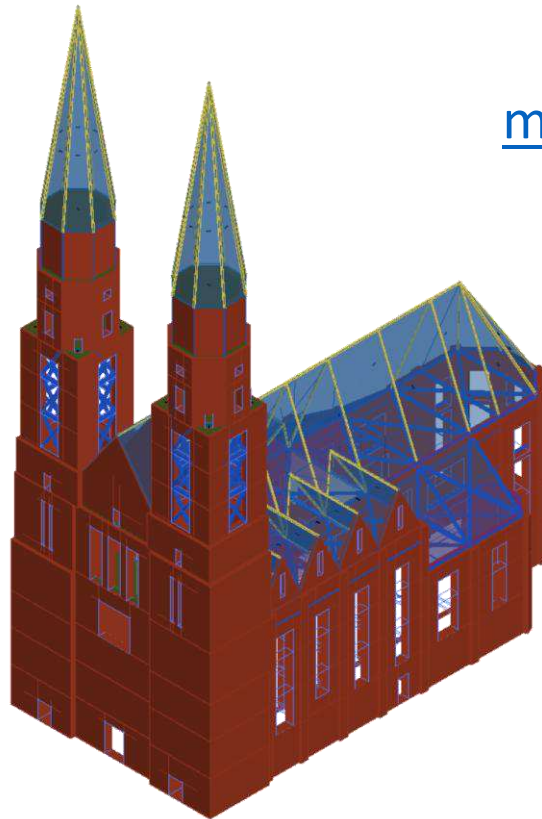
INNOVATION THAT
DIGS DEEP!

► Thank you for your amazing
model submissions!



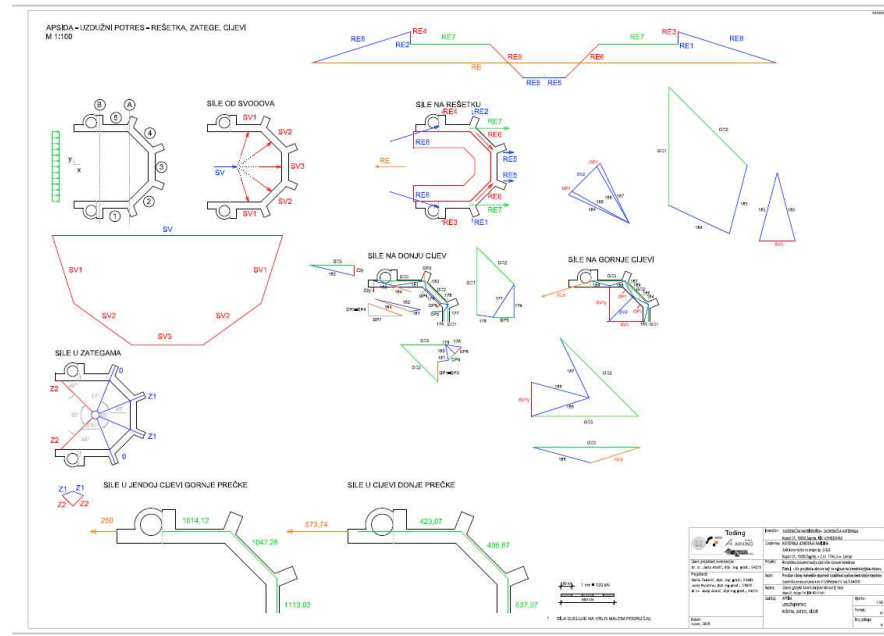
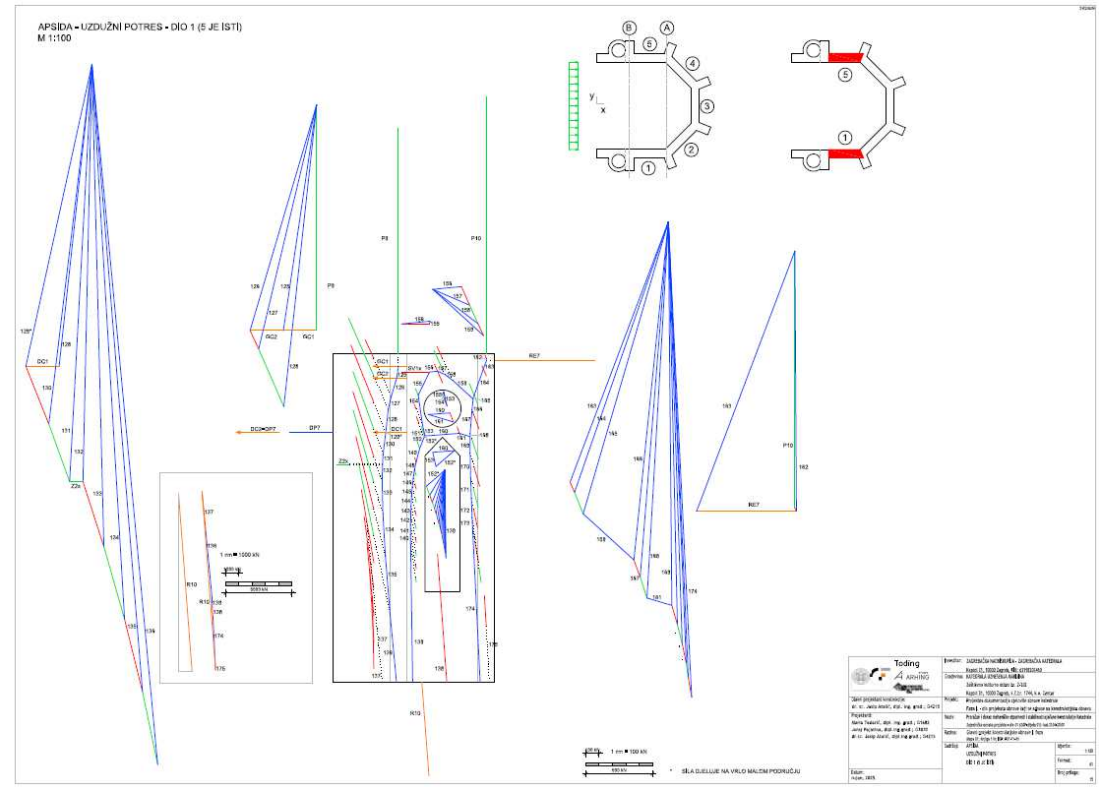
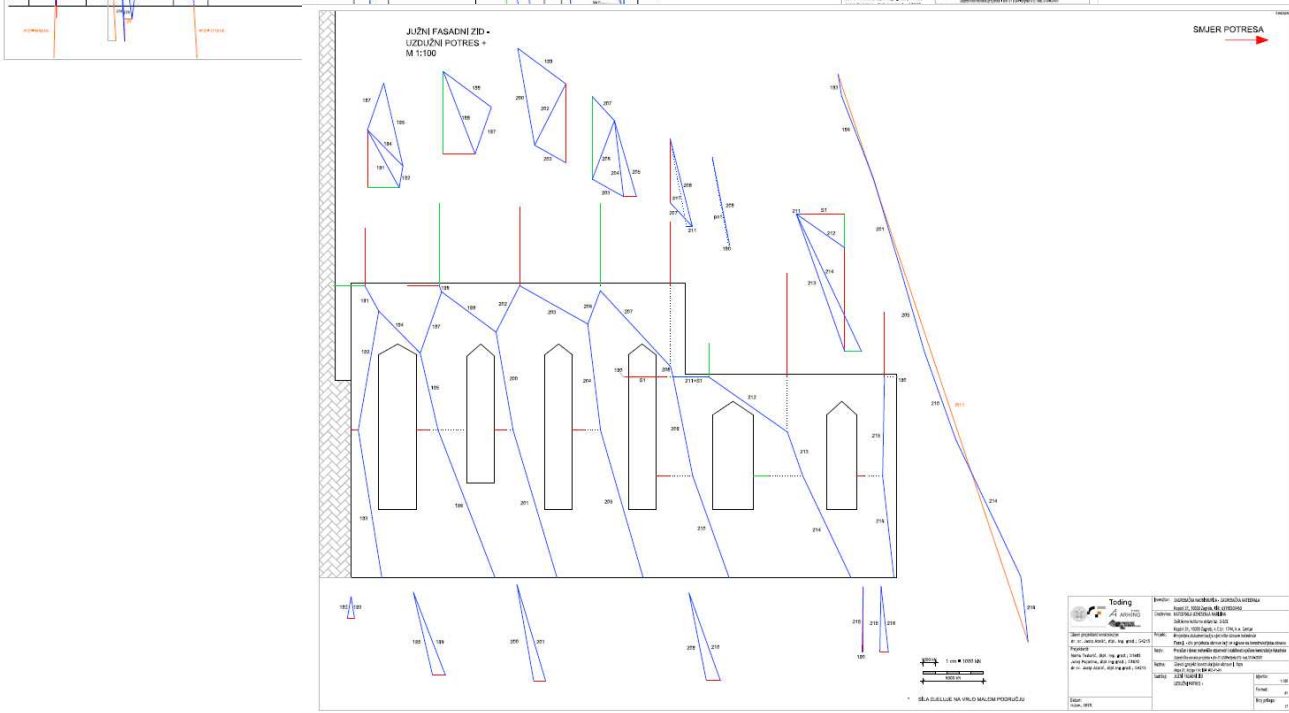
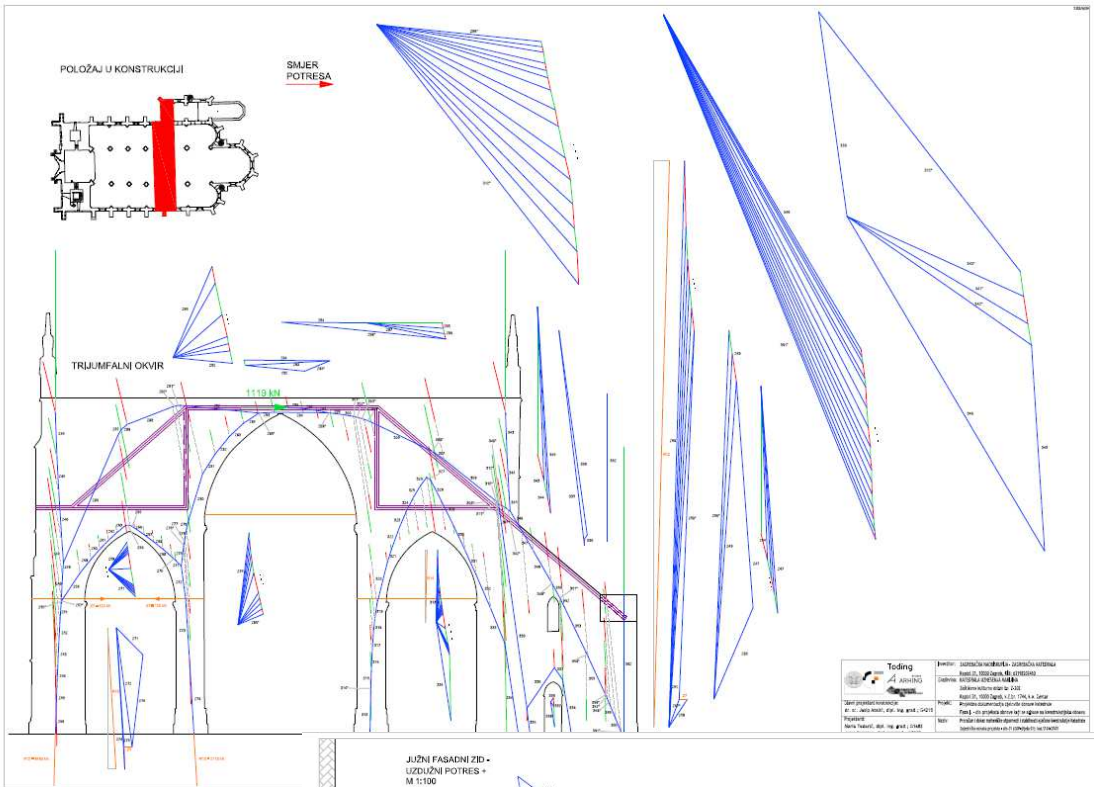
Zagreb Cathedral – Equivalent Frame Model

Marija Demšić
mdemsic@grad.hr

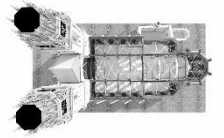


University of Zagreb
Faculty of Civil Engineering
Department of Engineering Mechanics
Chair for Statics, Dynamics and Structural Stability

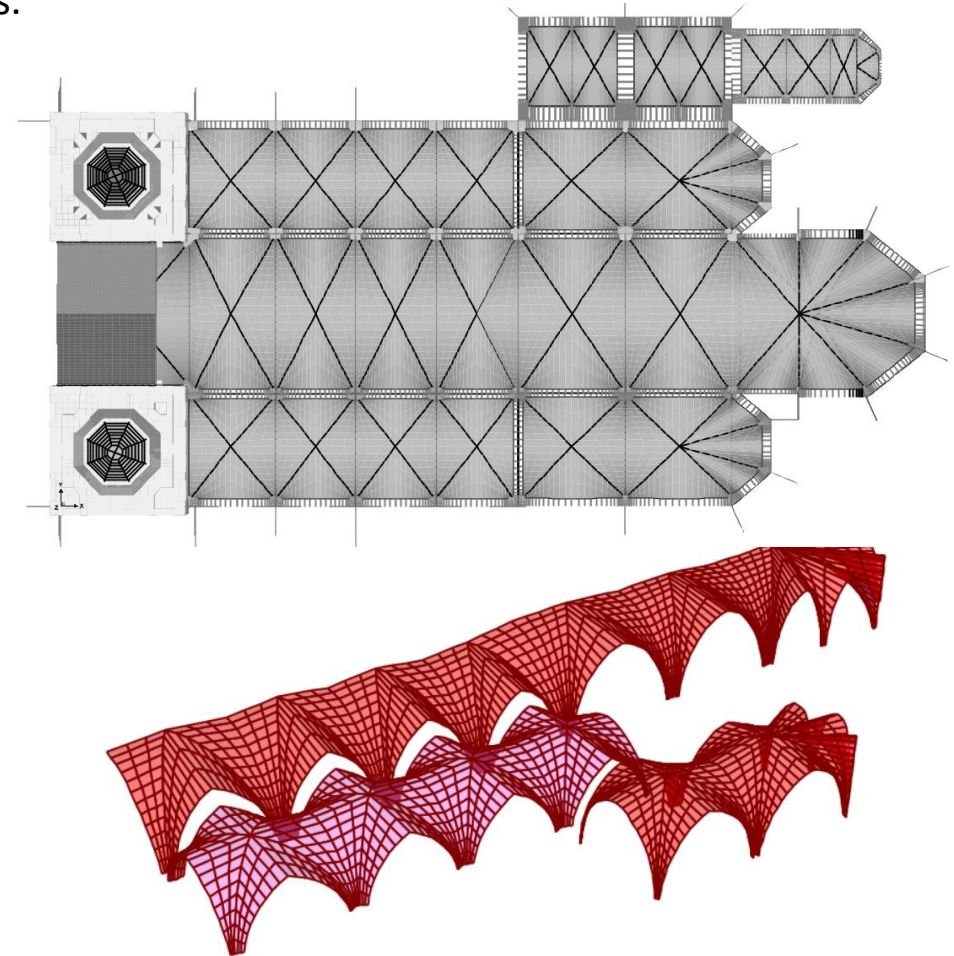
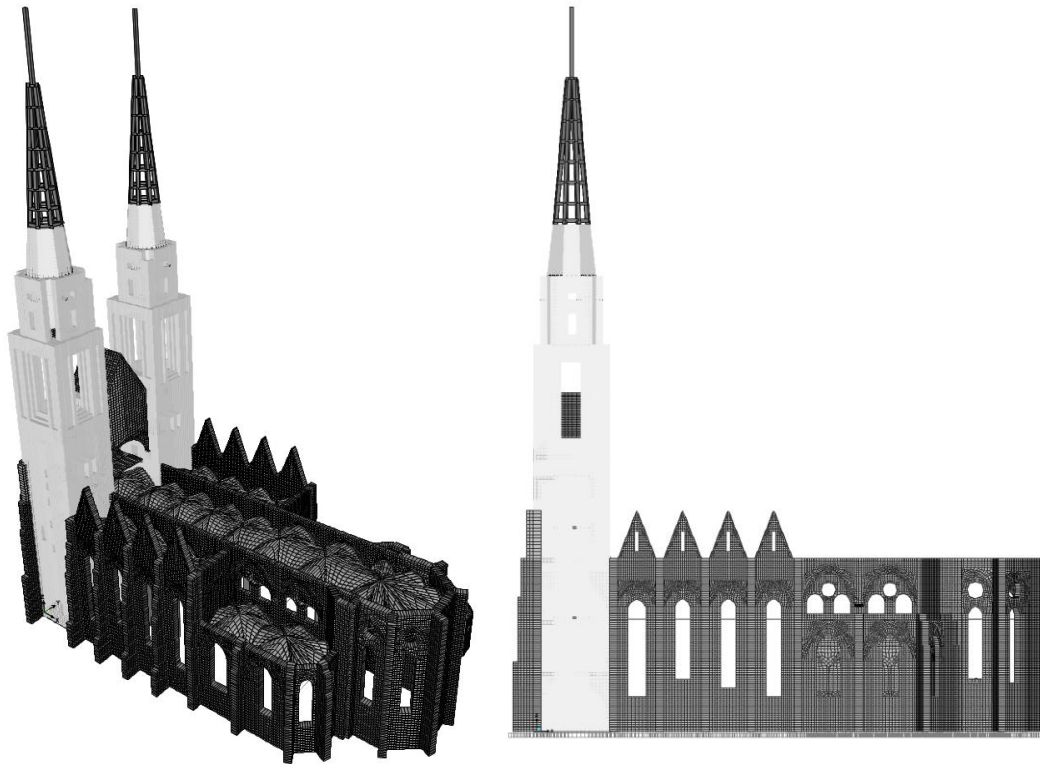




SAP2000 Numerical Model



- The structural analysis was carried out using the finite element method with the SAP 2000 software package, which is used for three-dimensional structural models.



This technical drawing illustrates a complex roof truss system, likely for a large industrial or commercial building. The structure is composed of numerous interconnected steel members forming a dense triangular pattern. Key components include:

- Primary Trusses:** Labeled with codes such as CHS 76x9, CHS 89x10, CHS 102x12, and CHS 114x15, indicating their cross-sectional dimensions.
- Secondary Members:** Smaller diagonal and horizontal bracing elements labeled with codes like DSE 27x6, DSE 30x8, and DSE 33x10.
- Grid System:** A coordinate grid is overlaid on the plan, with letters A through M along the top and bottom edges, and numbers 1 through 10 along the left and right edges.
- Structural Details:** The drawing shows connections between trusses, support points, and integration with surrounding structural elements like walls and other roof sections.

Reopened (this Christmas)



24.12.2025.

