

Building and sharing  
knowledge from quality  
driven content models



STUDY ON QUALITY IN 3D  
DIGITISATION OF TANGIBLE  
CULTURAL HERITAGE

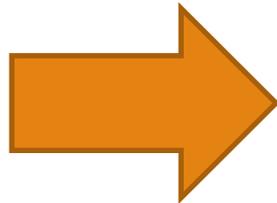


# Building and sharing knowledge from quality driven content models

## WHAT

Define different **degrees of complexity** of tangible cultural heritage, from the point of view of **3D digitisation processes**

## COMPLEXITY



Live Digital Twins

the **complexity** depending from:

- **state of the art ... as resulting from**
- **PAST stratified** results of centuries and transformation phases with its own materials and techniques
- impacted by **CURRENT hazards and pressures** (i.e. earthquakes, flooding, flash water bombs)
- **Within FRAGILE context of the built environment**

with the aim

to **better understand the behaviour**  
to **drive the preservation plans**

and **prevent** damages and **planned preservation (Long Life Cycle)**  
to **deploy knowledge transfer of enriched models.**

**Digitization - Data acquisition and decoding -** has crucial role to continuously FEED **'live' digital twins**

**TO DRIVE THE FUTURE LLCM ACTION**

**TO TRANSFER THE GAINED KNOWLEDGE TO THE FUTURE GENERATION**

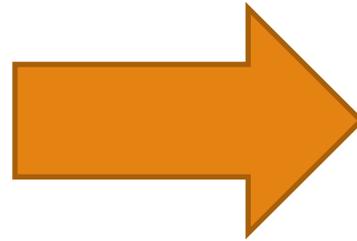
avoiding to loose the time and costs



## WHAT

Define different **degrees of complexity** of tangible cultural heritage, from the point of view of **3D digitisation processes**

**complexity**



## HOW

Identify and analyse the **parameters** that determine quality in 3D digitisation of tangible cultural heritage

**which parameters?**



# Meters to measure the quality : surveying parameters

## Digitization/Surveying data quality acquisition



- [ ] permission for Site access (e.g. official **EARTHQUAKE RED AREA NO ACCESS** area)
- [ ] Environmental conditions (e.g. temperature, humidity, dust) > **TLS** and **IRT** (i.e. active heating)
- [ ] Surface conditions (e.g. reflectivity, material) > **TLS** close distance marble surface
- [ ] For **TLS**, resolution of point cloud Scans Overlap
- [ ] For **SFM** images overlap and resolution in f of scale
- [ ] For **MMS GEOSLAM** robust path and geodetic referment
- [ ] Camera calibration parameters (lens distorsion...)
- [ ] Connection to a robust geodetic network
- [ ] Level of Error, Accuracy and Precision > scales
- [ ] Quality of associated imagery Terrain Pixel and scale
- [ ] Quality Data storage and data sharing for multi-actor coworking and re-use
- [ ] Libraries and metadata in a Common Data Env



# Meters to measure the quality

## Digitization/Surveying data quality acquisition

Surveying methods and restitutions	Few numbers....	Survey methods accuracy (mean square error, sqm ) and required scales Quantities output
Plano altimetric Geodetic Network	27 stations	$\sigma = \pm 1 \text{ mm}$
Geodetic control points -Total Station Leica T70 (GCP for Scan REGISTRY and GCP for SFM images)	260 points	$\sigma = \pm 1.5 \text{ mm}$
Laser Scanner Faro Focus 3D	182 point clouds	$\sigma = \pm 3 \text{ mm}$
Direct hand survey of the column stones ashlar	<b>n. 14 Columns. 574 stone ashlars (9÷13 column courses 1:2 columns</b>	TOT ~53 m <sup>3</sup>
Photogrammetric image blocks Ortophoto / models 3D (external and internal walls surface vaults intrados, .... )	<b>Ground Dimension Pixel Terrain pixel res: 5mm per external fronts 1:50 2mm internal fronts 1:20, 1mm vaults 1:10, 0,5mm the main facade 1:5</b>	TOT ~7.000 m <sup>2</sup>
Plans (horizontal sections)	<b>1:50 Ground level (3000 m2), underground , crypt, first floor 1:20 walls profiles for 3Dmodel analysis 1:5 columns</b>	TOT ~ 4200 m <sup>2</sup>
Vertical Sections (transversal and longitudinal)	<b>1:20</b>	12 sections with double direction)
UAV Falcon8 Covering and facades	RGB (GDP 10 mm) and IRT	TOT ~ 3000 m <sup>2</sup>



WHY? We need a meter to measure the quality: needed/acquired/processed/shared

Model Scale definition (GOAs) and specification helps to **adopt the proper scales** addressing:

- the **surveying** and data acquisition
- the **modeling** phases
- **quality** check
- the models **re-use**
- **Data models recovery**
- model **circulation**

SURVEYING, DRAWING AND 3D HBIM MODEL SCALES	GRAPHIC ERROR G. E.=0,2 mm	Minimum detail in case of raster data G. E.=0,2 mm/2	TOLERANCE VALUE T = 2 ÷ 3	Model accuracy > GOA Grade of Accuracy	GOA HBIM MODEL Minimum detail GRAPHIC ERROR G. E.=0,2 mm	GOA HBIM MODEL TOLERANCE VALUE of the HBIM MODEL
1:10	2 mm	1 mm	4 ÷ 6 mm	GOA 10	2 mm	4 ÷ 6 mm
1:20	4 mm	2 mm	8 ÷ 12 mm	GOA 20	4 mm	8 ÷ 12 mm
1:50	10 mm	5 mm	20 ÷ 30 mm	GOA 50	10 mm	20 ÷ 30 mm
1:100	20 mm	10 mm	40 ÷ 60 mm	GOA 100	20 mm	40 ÷ 60 mm
1:200	40 mm	20 mm	80 ÷ 120 mm	GOA 200	40 mm	80 ÷ 120 mm
1:500	100 mm	50 mm	200 ÷ 300 mm	GOA 500	100 mm	200 ÷ 300 mm
1:1000	200 mm	100 mm	400 ÷ 600 mm	GOA 1000	200 mm	400 ÷ 600 mm
1:2000	...	....				



# Models and scales quality control

The grade of 3D HBIM model accuracy correspondent to the different scales and related tolerance value

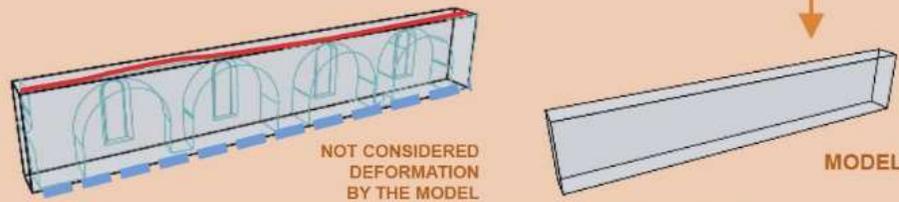
## THREE POSSIBLE MODELS OF THE SAME WALL – FROM URBAN TO HBIM SCALE

### WIREFRAME MODEL FROM POINTCLOUDS AND ITS DEFORMATION



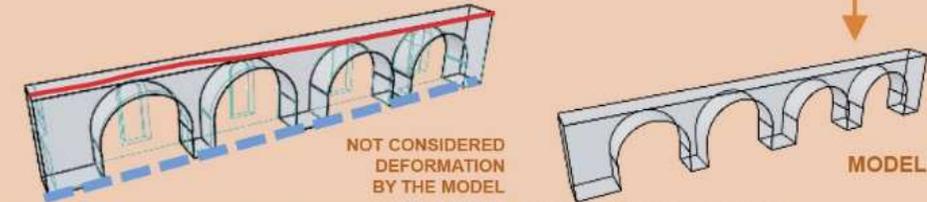
### CASE 1 - URBAN SCALE

GOA 2000 T = 600/1000 mm



### CASE 2 - CONCEPTUAL SCALE

GOA 1000 T=200/300mm

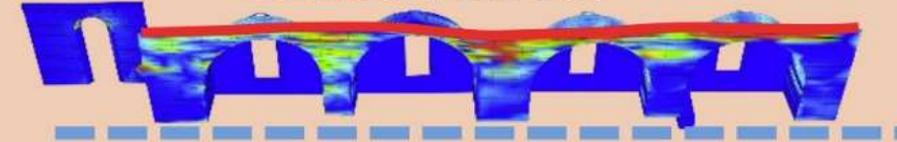


### CASE 3 - SCAN-TO-HBIM PROCESS

GOA 20 T=8/12mm



### CURVATURE ANALYSIS



Tutte le misure sono in metri

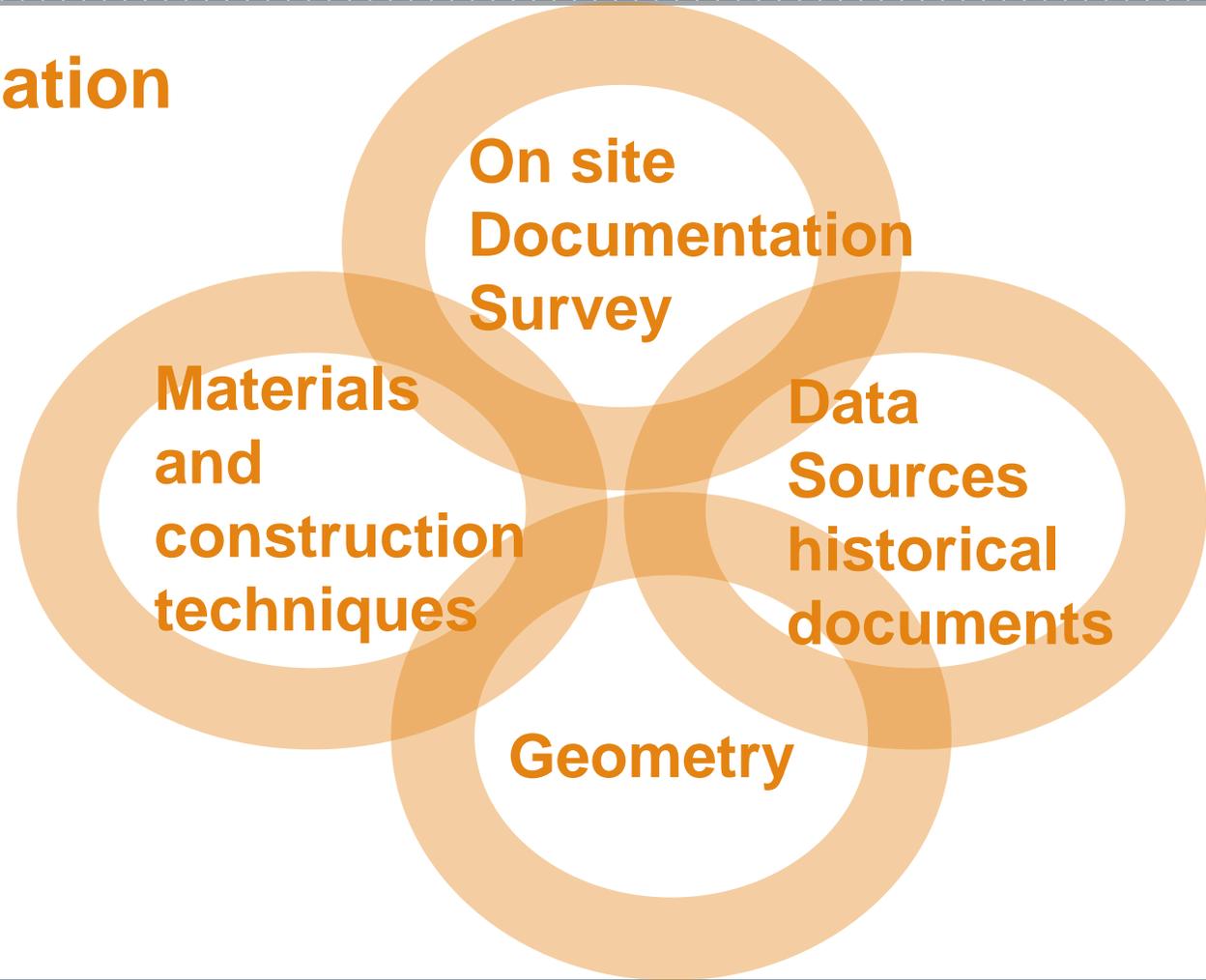
Opzioni			
Angolo prossimità	1.0	Ignora:	1.0
Scala vettori	10.0	Non validi	0.05
<input type="checkbox"/> Visualizza vettori			
<input type="checkbox"/> Rendi vettori permanenti			
Statistiche			
Punti:	211818	Validi:	0.01
Valore medio:	0.0125	Su superficie:	0.0
Deviazione media:	0.01085		
Deviazione standard:	0.009358		

AVS

# 3D quality content models

**NOT JUST A MATTER of MEASURING!**

## Preservation



**3D quality content model**

**INFORMATIVE MODELS**

***Geometry + materials and construction techniques***



# Models quality and knowledge creation

Concept

**Boosting**  
**Common Data Environment**  
**GEOSPATIAL VH**  
**remote**  
**open HBIM access**  
**Citizen fruition**



**Communication**

eXtended  
Realities  
(beyond  
AR,MR,VR...)

**AUGMENTED  
INFORMATION**  
divulgare

**BIM**  
rappresentare

**Modeling phenomena**  
**Data processing**

**CONSERVAZIONE**  
**Preservation**

**Knowledge  
creation**

**RESEARCH**  
conoscere

**3D QUALITY**  
**INFORMATIVE MODELS**  
**HBIM**

**Survey**



**Data  
Sources**  
**Historical  
documents**

**Stratigraphic  
analysis**



*inheriting BIM logic reversing LOG LOD toward geometric complexity HBIM*

**NOT JUST A MATTER  
METER MEASURING!**

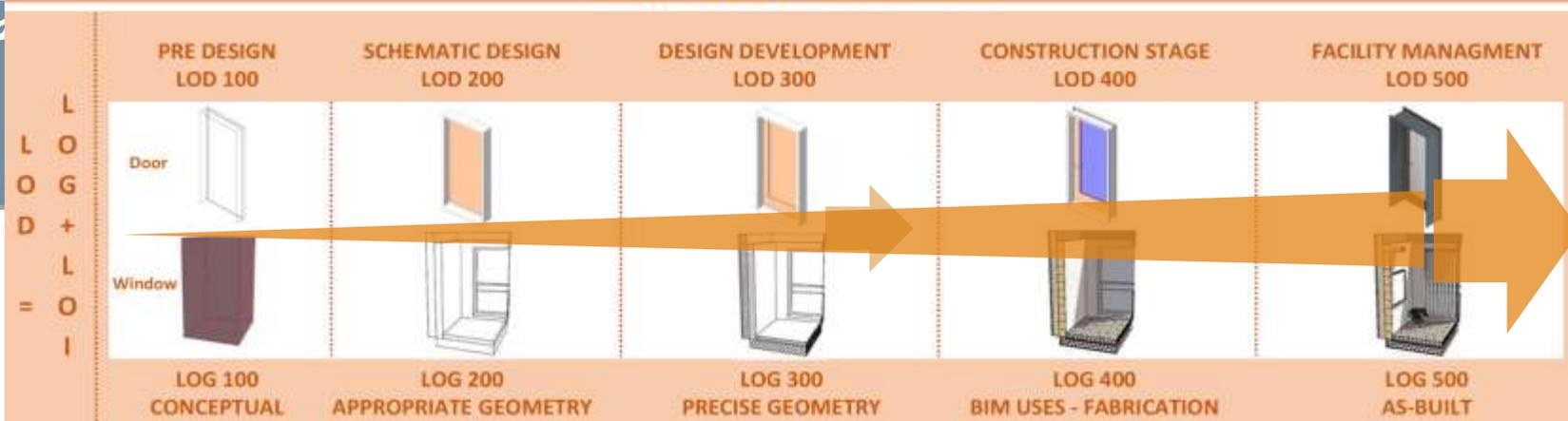
**HBIM logic to 3D quality  
models**

**Content model >**

**Geometry model +  
information**

**Geometry + material and  
construction techniques**

**BIM - NEW BUILDINGS**



H B I M	NEW ENTRY!					
	LEVEL OF DEVELOPMENT (PROCESS PHASES)					
	LOG 100 PRE DESIGN	LOG 200 DIGITAL DOCUMENTATION	LOG 300 AS-FOUND HBIM MODEL	LOG 400 DESIGN DEVELOPMENT CONSERVATION PLAN	LOG 500 CONSTRUCTION STAGE	LOG 600 FACILITY MANAGEMENT
	REQUIRED HBIM LEVEL OF GEOMETRY					
	LOG 100 CONCEPTUAL MODEL, HISTORICAL REPORTS, ARCHIVES	LOG 200 APPROPRIATE GEOMETRY, 3D SURVEY, DATA ACQUISITION	LOG 300 PRECISE GEOMETRY, SCAN-to-BIM MODEL OBJECT	LOG 400 BIM USES CONSERVATION PLAN	LOG 500 CONSERVATION SITE	LOG 600 AS-BUILT, LLCM, CDE, HUBs
	historical building contracts, historical drawings, pictures and photos	on-site data acquisition, 3D surveying, 2D/3D restitutions (plans and sections, 3D meshes)	object modeling, precise drawing extraction	material/decay mapping, IRT, NTD, BIM-to-FEA, energy analysis, BIM implants, on-site construction management, WBS and computation	on-site construction interventions of conservation	Life Cycle Cost Management and Monitoring, VR and sensor-based communication purposes

GOAs 10-1000



# Complexity matters

The grade of 3D HBIM model accuracy correspondent to the different scales and related tolerance value

**Natural hazards  
Built Environment**

**Earthquakes**

**Transformation across the centuries impacted by the hazards**



*Basilica di S. Maria di Collemaggio*

(L'Aquila, Earthquake 6 April, 2009)

2013-2017 design    december 2017 first re-opening to the public

END of the intervention 2019    AWARDED 2020

**History of skilled workers**

**Intangible values**

**Structural damages**

**Holy Door and damaged north wall**



POLITECNICO MILANO 1863

# *Complexity matters*

## *Basilica di S.Maria di Collemaggio (L'Aquila, earthquake 2011)*

**European Heritage Award/Europa Nostra Award 2020**

**The Basilica of Santa Maria di Collemaggio**

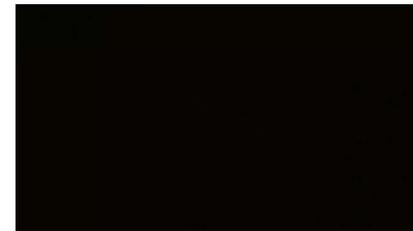
May 07, 2020 | **Conservation** | **Italy** | **L'Aquila**.

***Superintendency Office of L'Aquila > Responsible for the  
> Design Project > Preservation Plan > Conservation Site.***

***ITALIANA COSTRUZIONI SPA Construction Company***

***POLIMI S. Della Torre Coordinator of the Support to the Preservation project  
(POLITECNICO DI MILANO, UNIV L'Aquila and ROMA LA SAPIENZA)***

***R.Brumana responsible of the Scan-to-HBIM consultancy contract to support the preservation  
design project on site management, and video production.***



# The Basilica di Collemaggio (1274) yearly joined by 30.000 pilgrims for the Jubilee: an important church in the history of Christianity

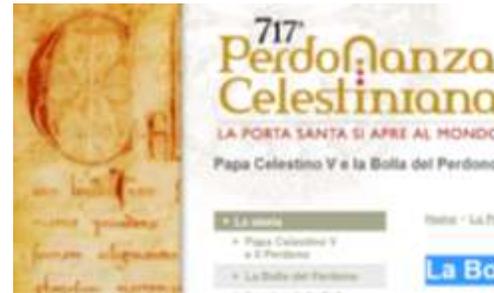
**POPE Celestino V is famous for establishing at the Basilica di Collemaggio the Papal Bull of 29 September 1294**

**On the 28-29th August the Holy Door is yearly opened and it is celebrated the feast called Festa della Perdonanza (Jubilee - forgiveness) yearly joined by more than 30.000 pilgrims.**



1274 Pope Gregory X in the Council of Lyon recognized the Order of Celestines founded by Pietro Angeleri del Morrone (**Ascetic Benedictin monk**)

1294 Pietro Angeleri del Morrone was **elected Pope Celestino V** e moved the Roman seat to the Basilica di Collemaggio (**29 agosto 1294 - 13 dicembre 1294**)

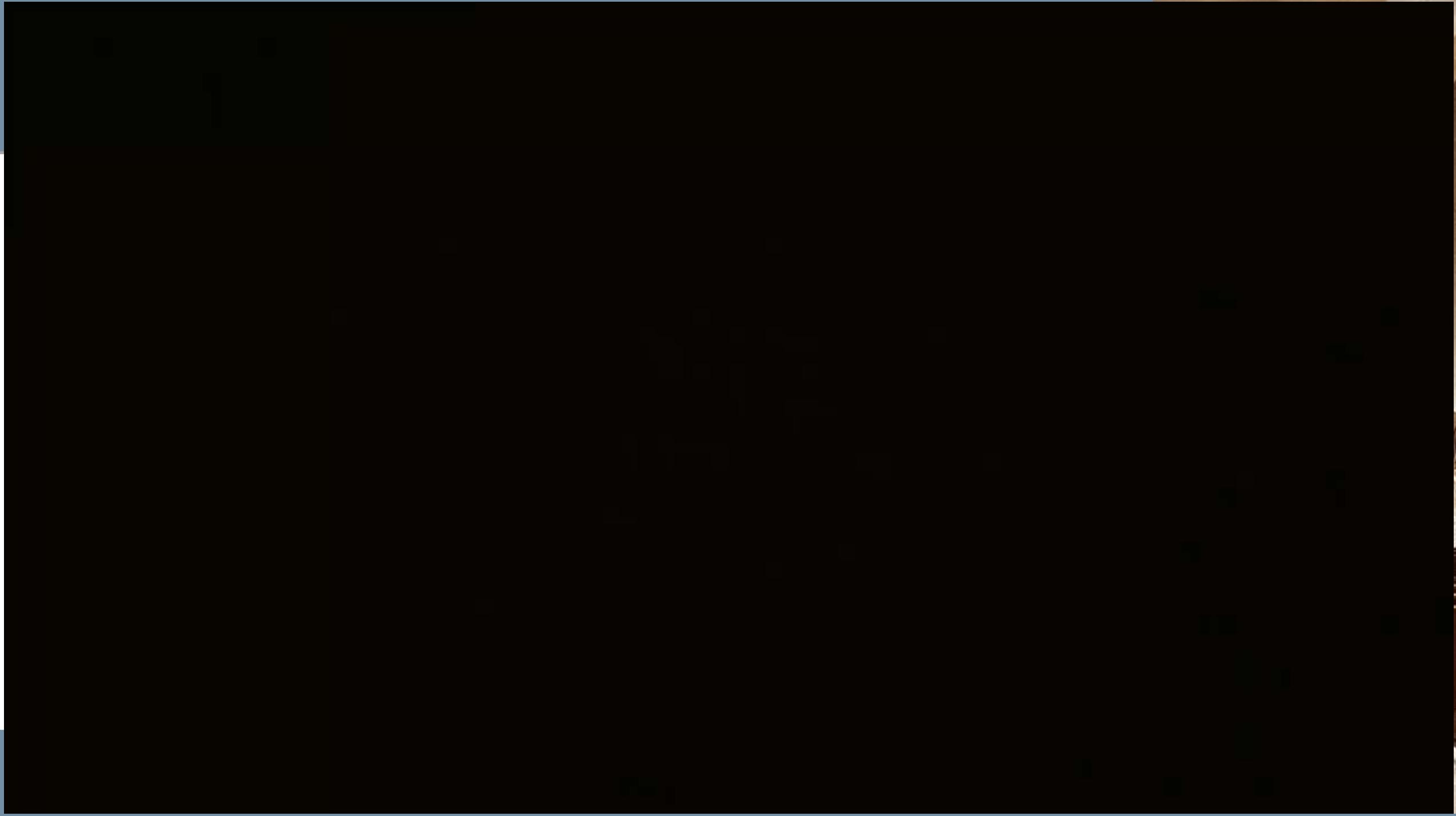


I saw and recognized the shade of him  
Who by his cowardice made the great refusal.  
—*Inferno* III, 59–60  
But some historians hypotized he might have been killed by Bonifacio VIII inserted by Dante in the *Inferno* as well



Altre immagini





*Complexity matters*

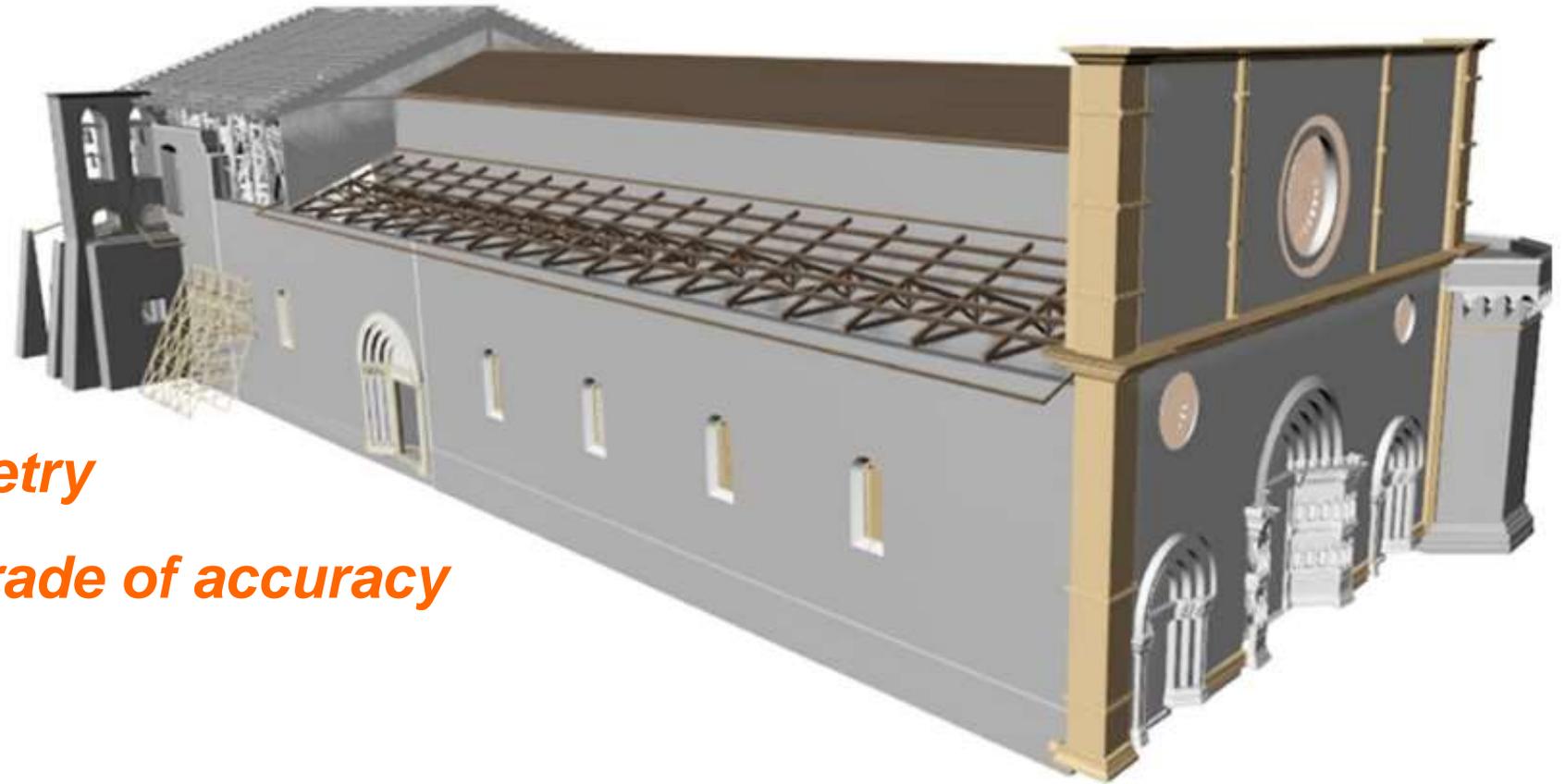
*on the back end ...*

GENERATIVE MODELLING PROCESS BIM-ENABLE

SCAN-to-BIM MODEL

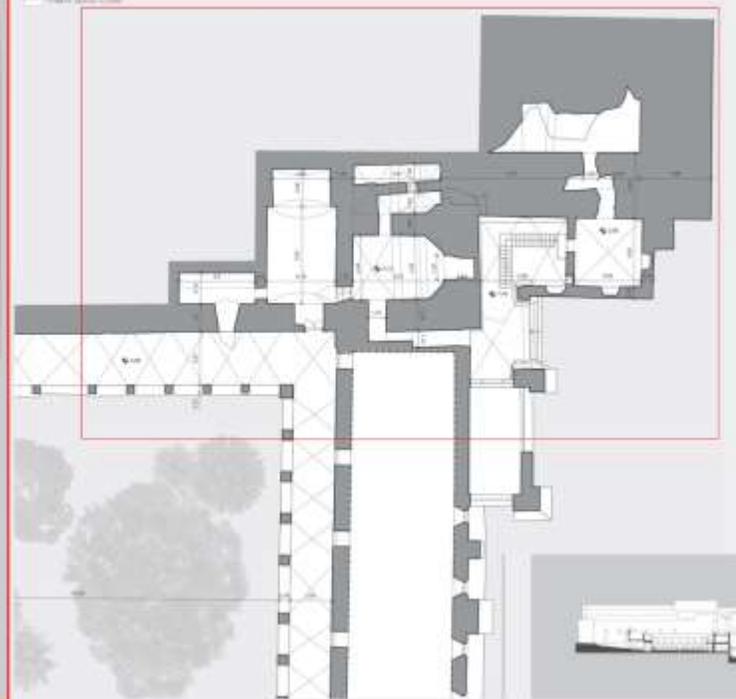
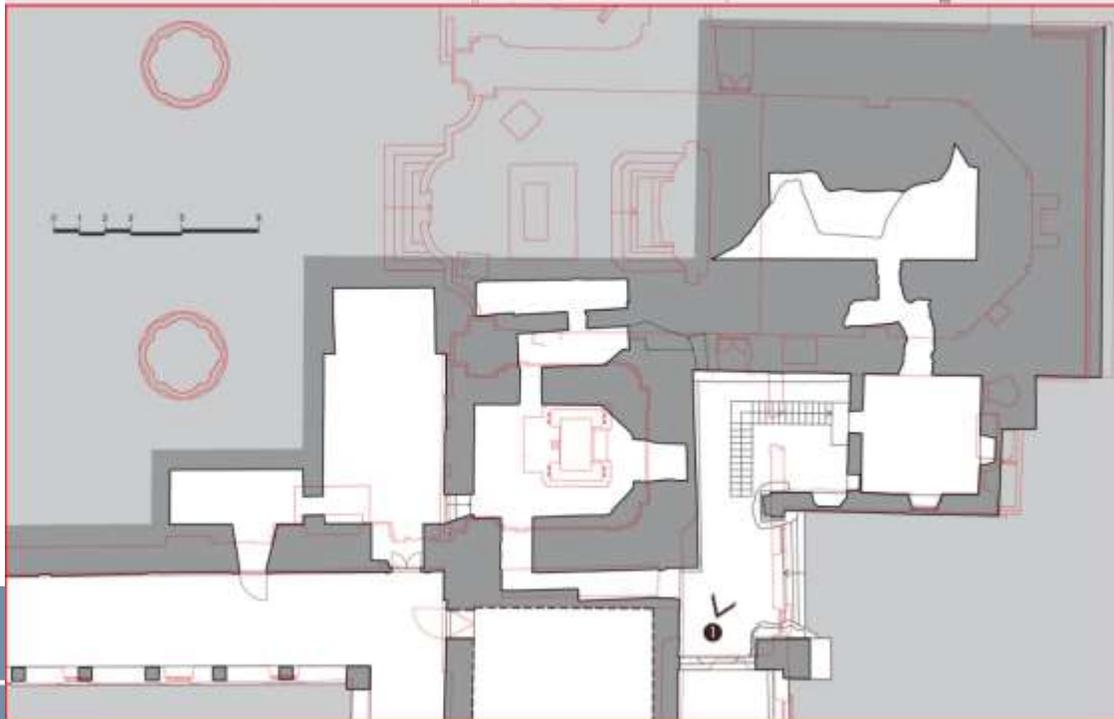
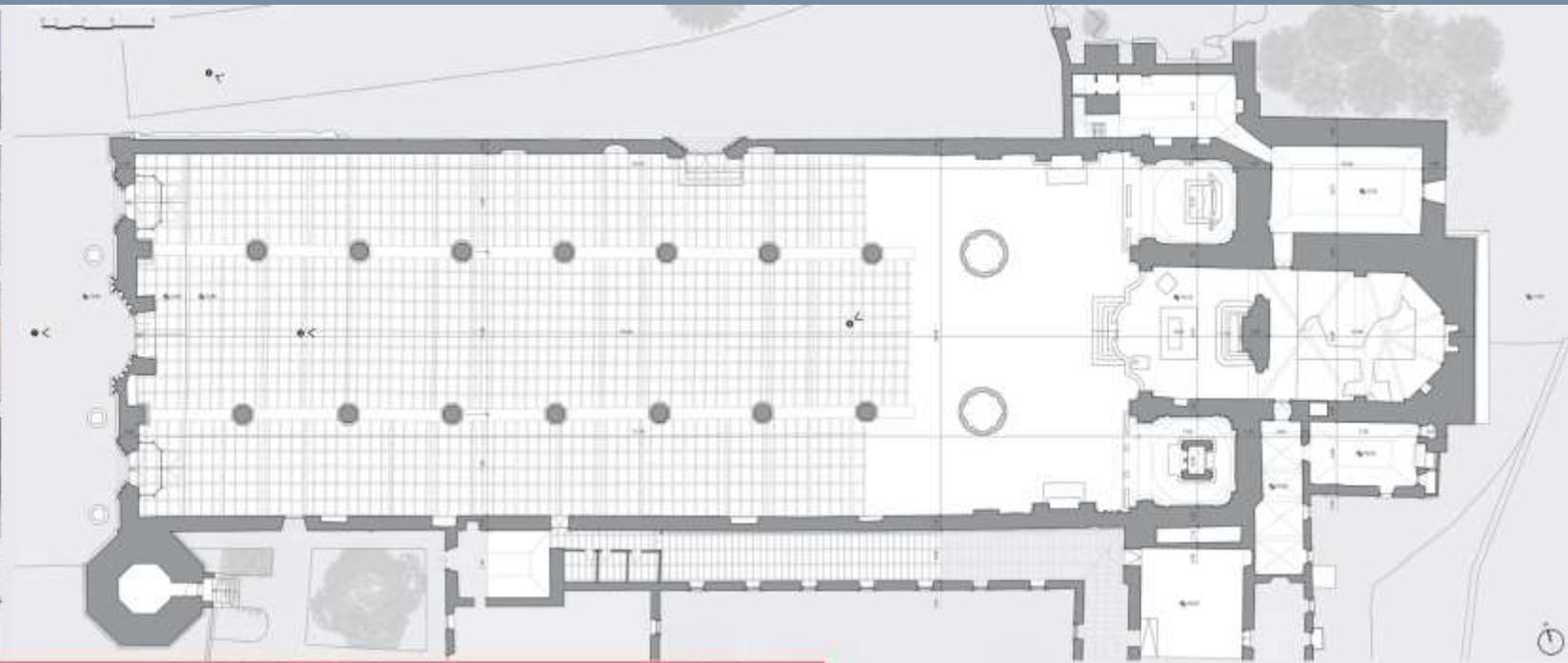
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*Appropriate Geometry  
and the different grade of accuracy  
GOAs*



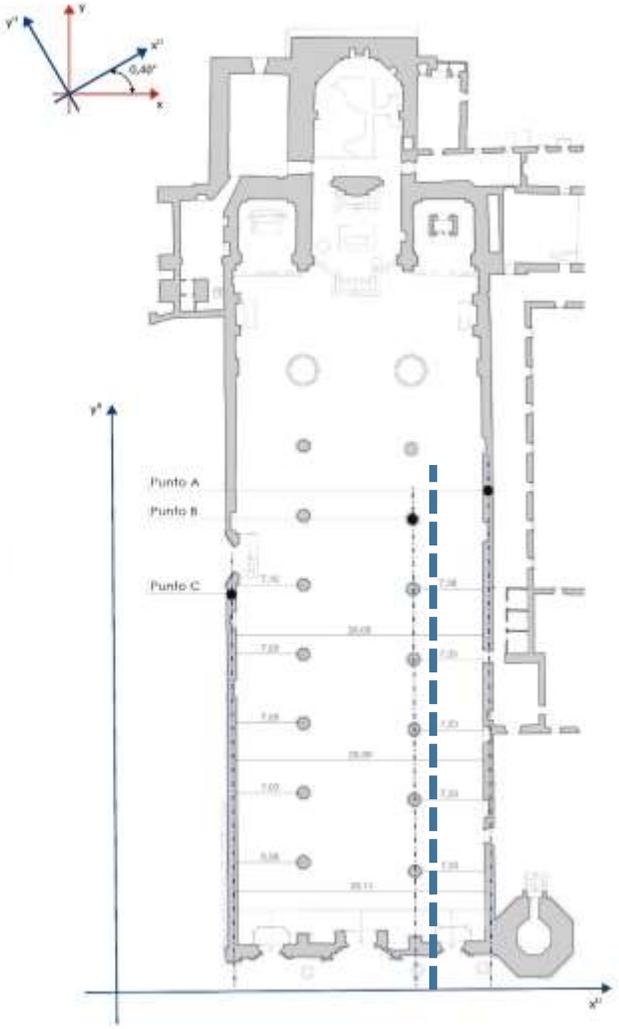
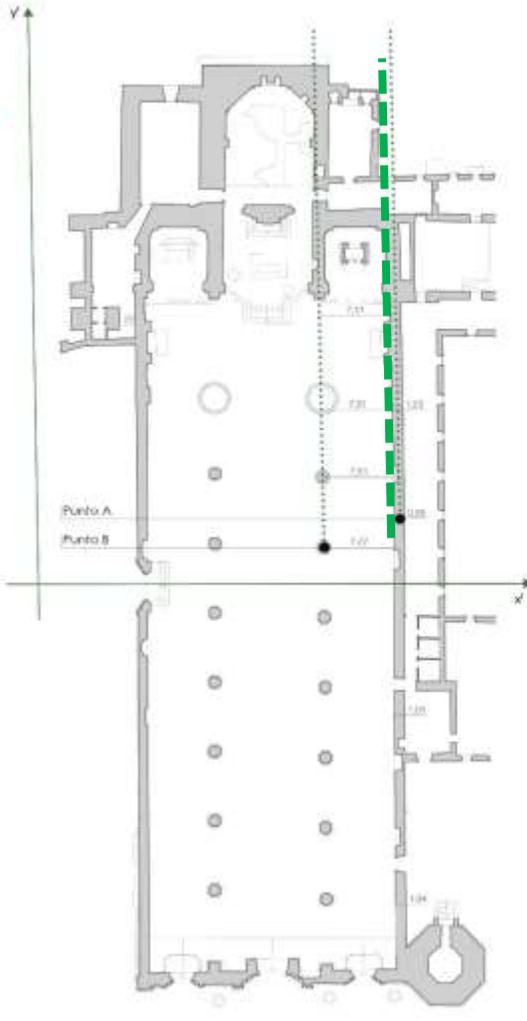
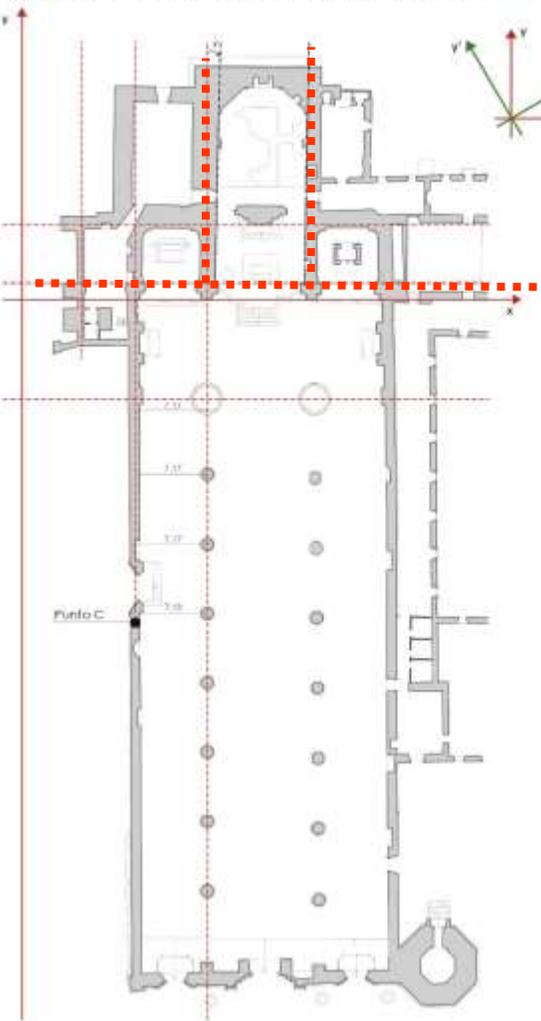


# Complexity matters



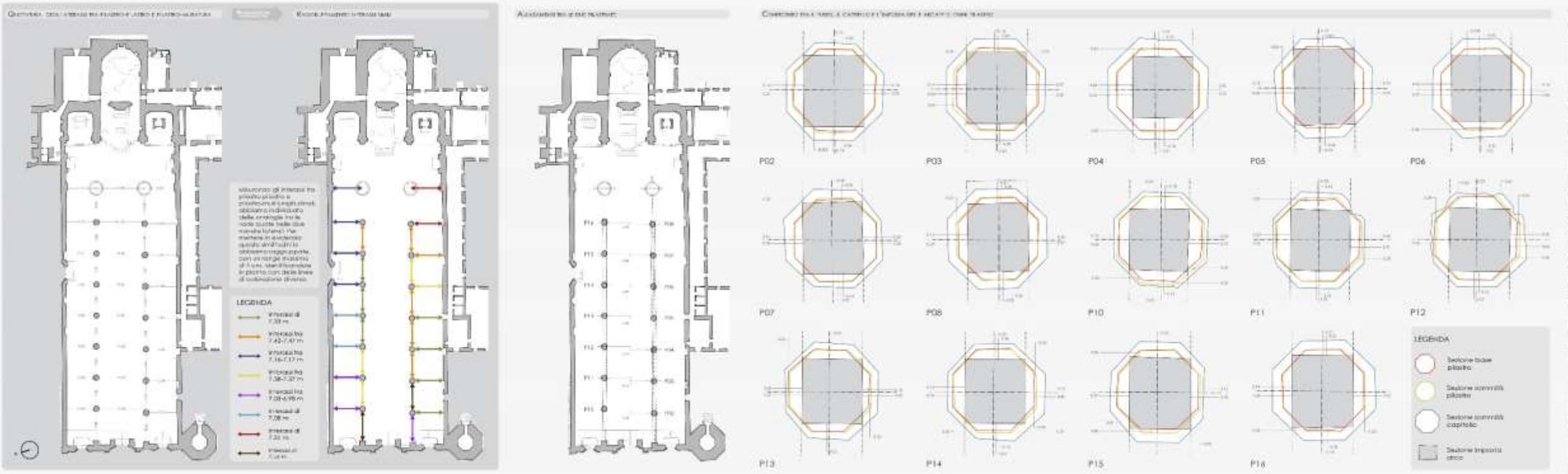
# Models and transformation phases surveying + documents + stratigraphic units

INDIVIDUAZIONE DEGLI ALLINEAMENTI SU CUI SI BASA L'IMPIANTO BASILICALE



# 3D quality models and structural behaviour

## Columns out of plumbs



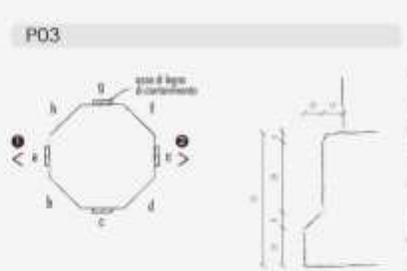
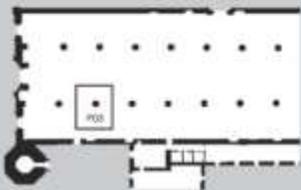
# Models and scales quality control the stone ashlar direct surveying 1:1



Lato D-E-F



Particolare fessura nel giunto filare I-III lato F



### Legenda

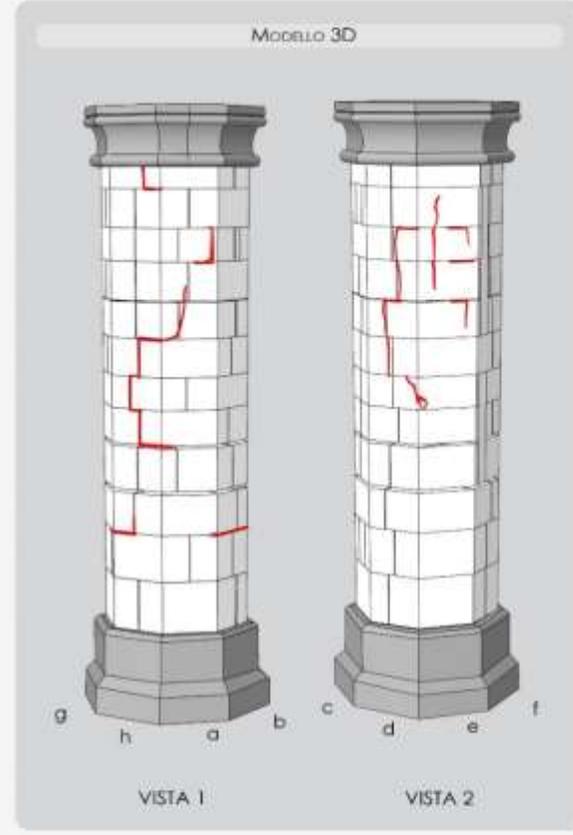
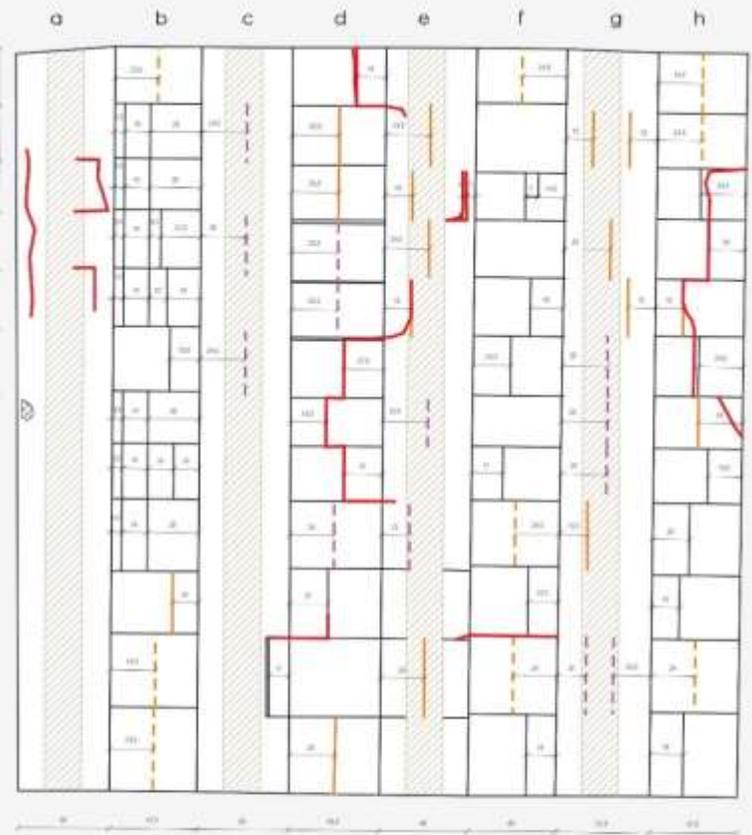
#### Analisi geometrica

- Spigolo concio certo (rilevato o da foto)
- Spigolo concio rilevato
- Spigolo concio incerto da foto
- Spigolo concio ipotizzato
- Concio certo (due lati rilevati)
- Concio con un lato rilevato
- Concio con lato da foto
- Concio ipotizzato
- Elemento di riscultura

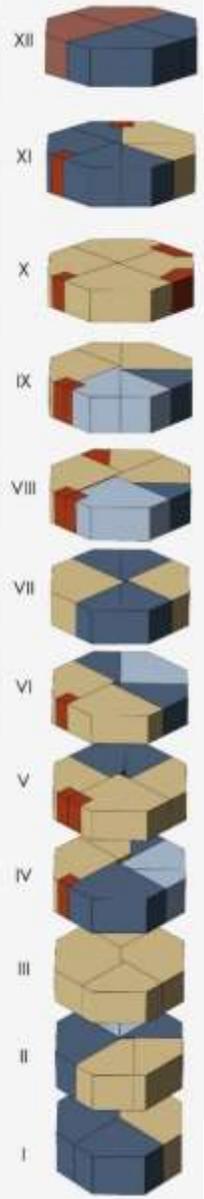
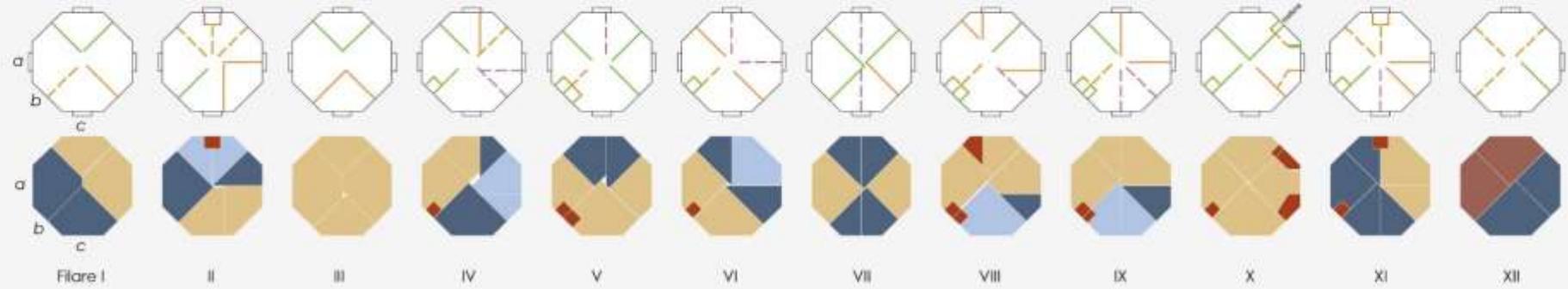
#### Analisi del degrado

- Fessura osservata
- Mancaenza

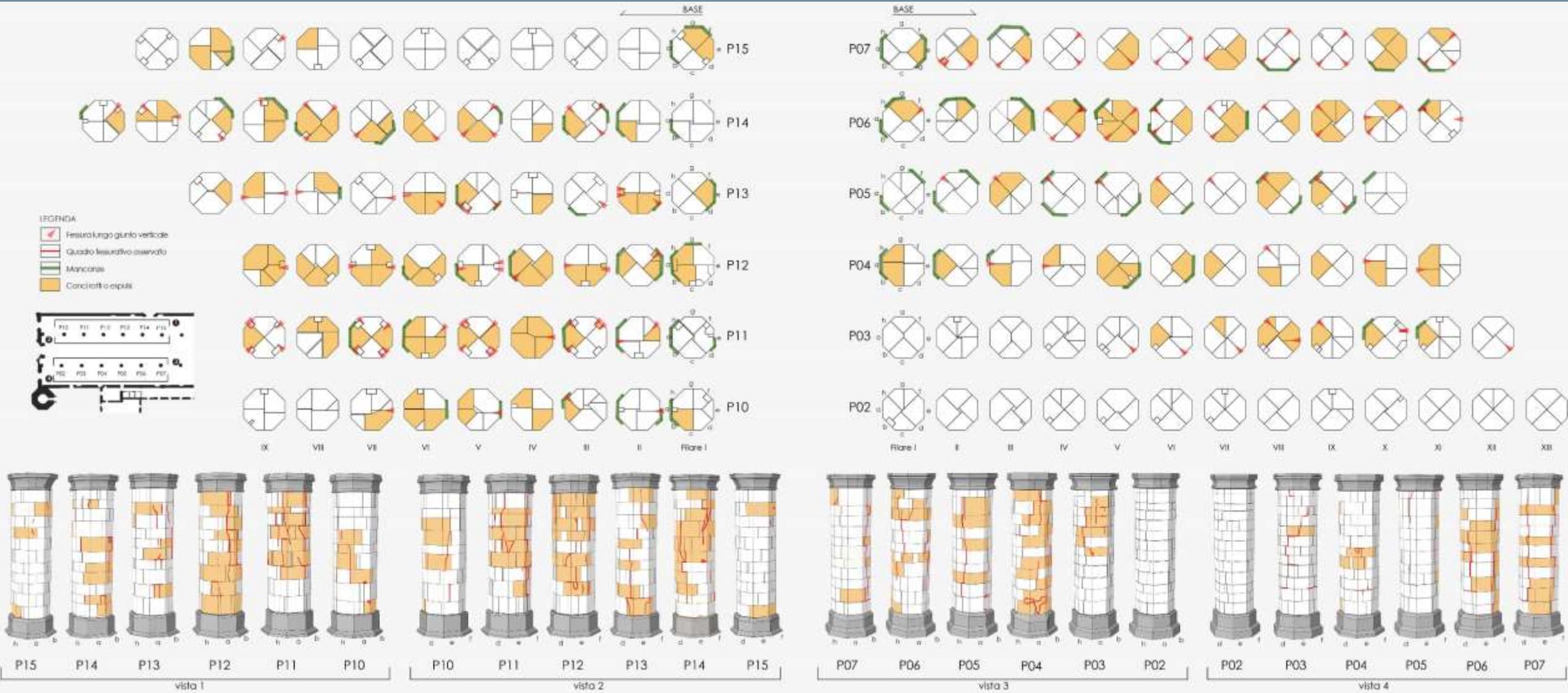
0 50 100 200cm



### DEFINIZIONE DELLA GEOMETRIA DEI FILARI



# Models and scales quality control the stone ashlar direct surveying 1:1



# Models and scales quality control

## LOG400 (HBIM-USES - Conservation Plan)

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### BIM USES

MATERIAL-DECAY ANALYSIS  
DIAGNOSTICS, NDT-IRT, WBS,  
PRESERVATION PLAN

BIM-to-FEA MODEL

BIM ENERGY MODEL

COSIM

**LOG400 (HBIM uses – Conservation Plan) within the LOD400 (Design development – Conservation Plan).**

The HBIM model LOG300 support **BIM-based analysis** to improve their results using different oriented-model types to perform the **decision making phases** of the Conservation Plan, as in the case of the **material and decay analysis with the related cost computation and Work Breakdown Structures, BIM-to-FEA or BIM Energy Models, Design development** (i.e. implants, new components, new structural elements) and Construction Site Management.



# Complexity matters

## Models supporting Decision Making System

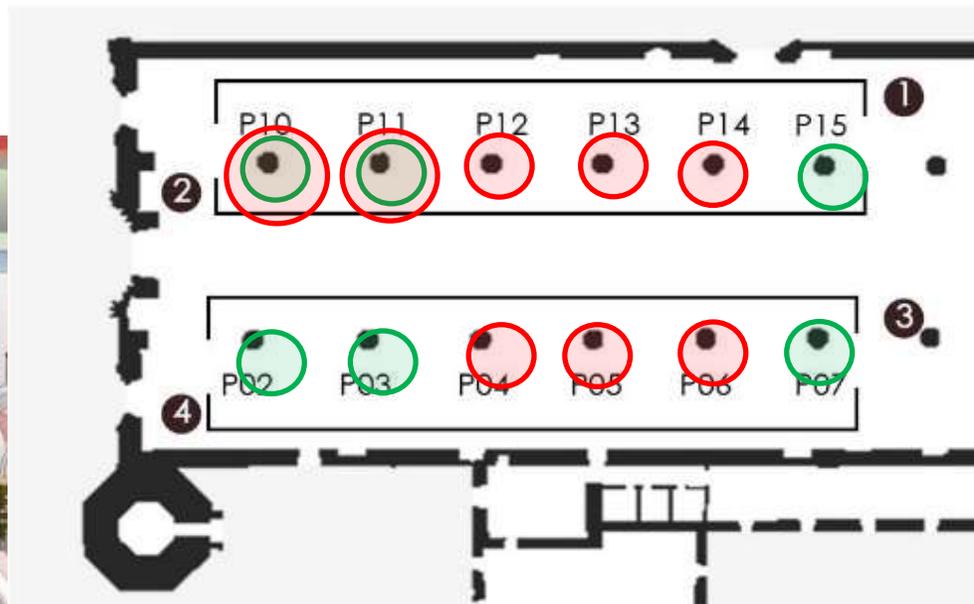
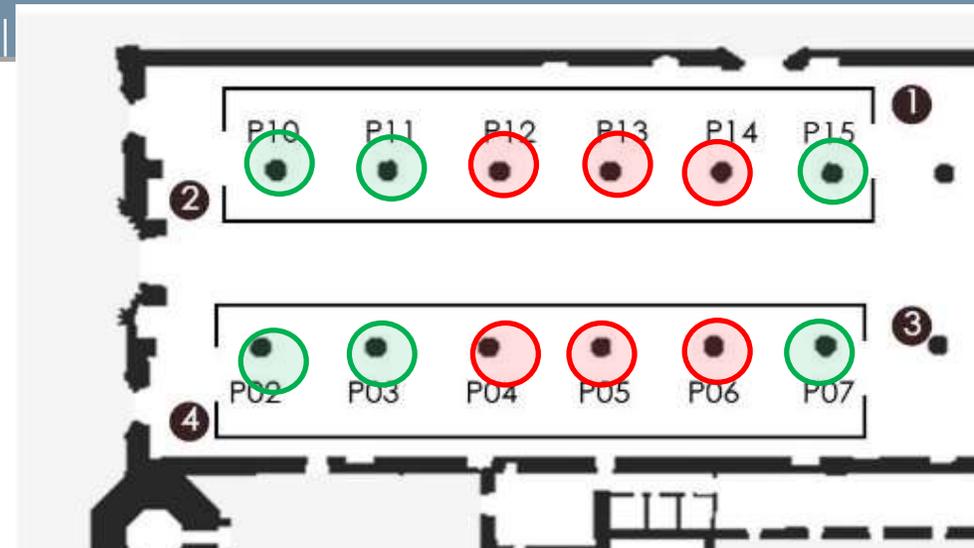
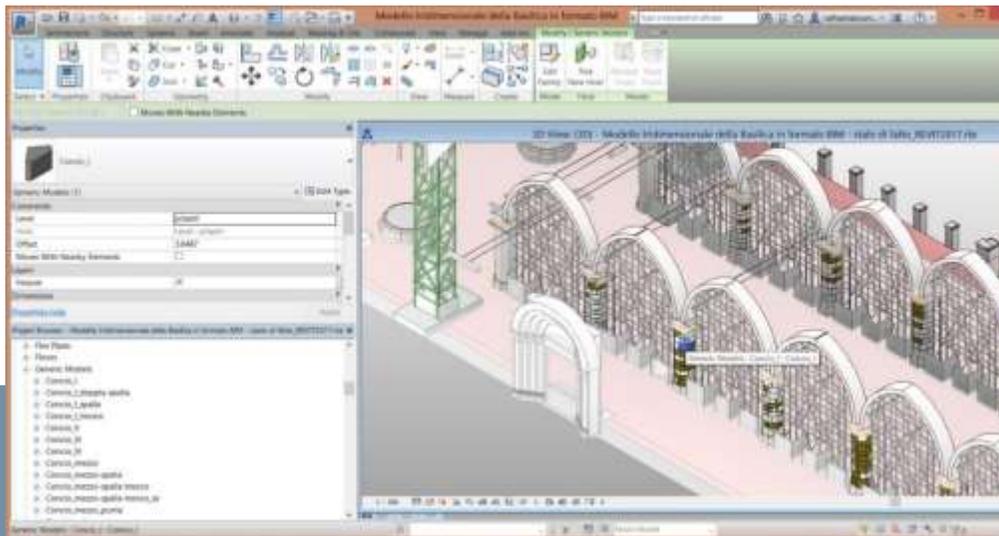
**Green** – «Scuci cuci» Design project on 3-4-5 10-11-12 columns  
punctual on site replacement of less damaged ashlar

**Intervention>>>>** For pillars 3 4 5 12 more than **50% of the stone ashlar SAVED IN PLACE!!!!** According to the Design project!!!!

**For pillars 10-11 round 100% Scuci cuci ...**

**Red - Column reconstruction Design project on 13-14-15 5-6-7 columns**  
On site reconstruction of the most damaged columns with replacement and re-use of integer stones

**Intervention as planned**



# Models and scales quality control

LOG600 (As-Built, LLCM, CDE, HUBs) within LOD600 (Facility Management)

LOG500: Conservation site and HBIM management of the interventions of preservations

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## CONSERVATION SITE



AS-FOUND MODEL

AS-DESIGNED MODEL

ON-SITE

AS-BUILT MODEL

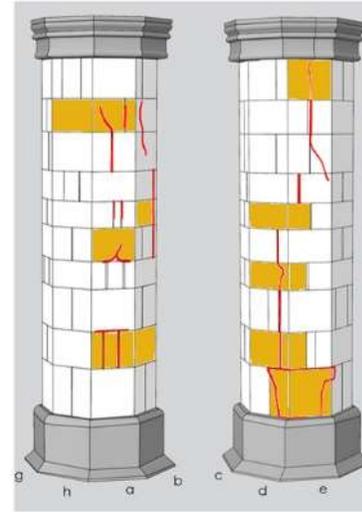


# Models and scales quality control

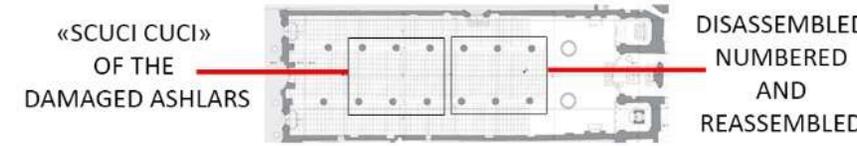
## AS-DESIGNED BIM FOR THE RESTORATION OF THE DAMAGED PILLARS



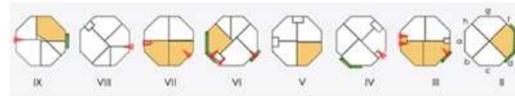
PILLAR N°13 OUTSIDE AND INSIDE VIEW



3D MODEL



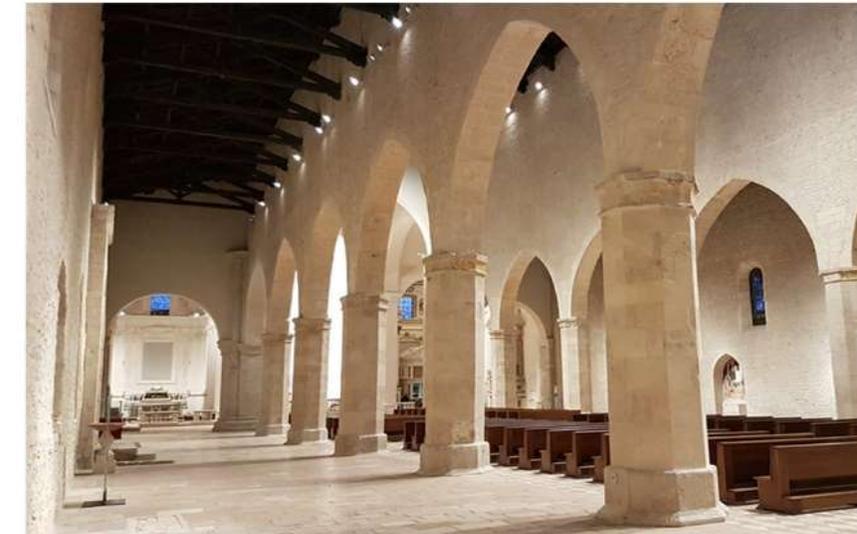
FROM AS-FOUND TO AS-DESIGNED HBIM



DISASSEMBLED PILLAR



REASSEMBLED PILLAR

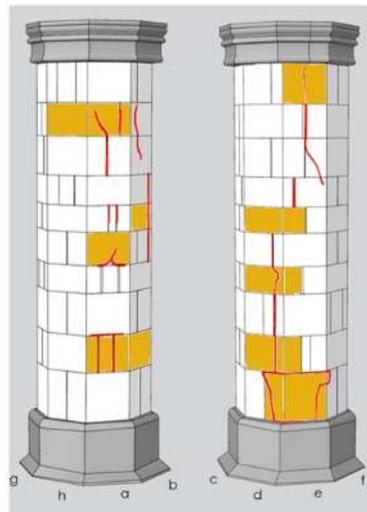


AFTER RESTORATION



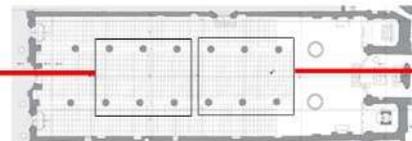


## THE RESTORATION OF THE DAMAGED PILLARS

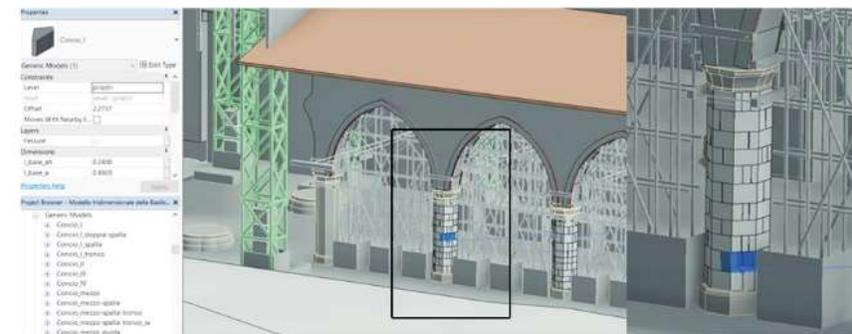


3D MODEL

«SCUCI CUCI»  
OF THE  
DAMAGED ASHLARS



DISASSEMBLED  
NUMBERED  
AND  
REASSEMBLED



FROM AS-FOUND TO AS-DESIGNED HBIM



REASSEMBLED PILLAR



AFTER RESTORATION

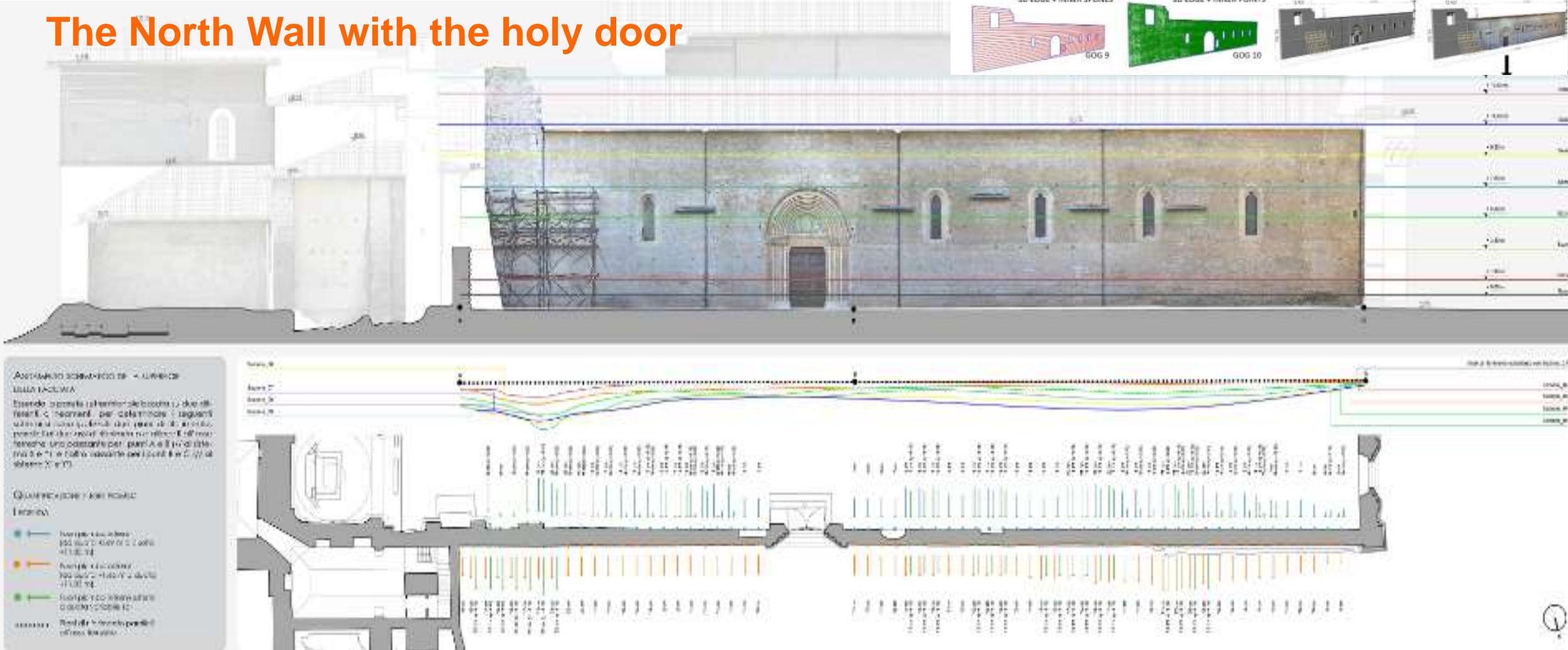
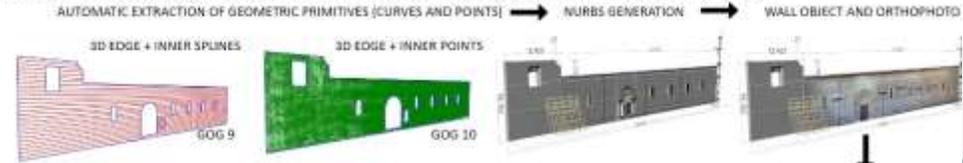
# Models and scales quality control structural analysis (BIMtoFEA)

## The North Wall with the holy door

### PHASE 1 - DATA SOURCES ORIENTATION FOR NURBS GENERATION



### PHASE 2 - NURBS SURFACE GENERATION OF WALL OBJECT AND DECAY AREAS

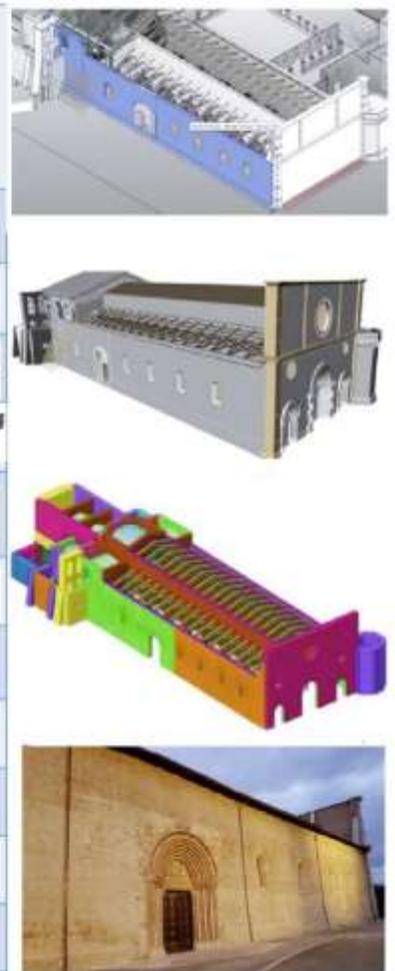


# Models and scales quality control

## GOA 1:20 out of plumb

### Generative modeling + materials and construction techniques for the preservation plan → geometry + materials → BIMtoFEA

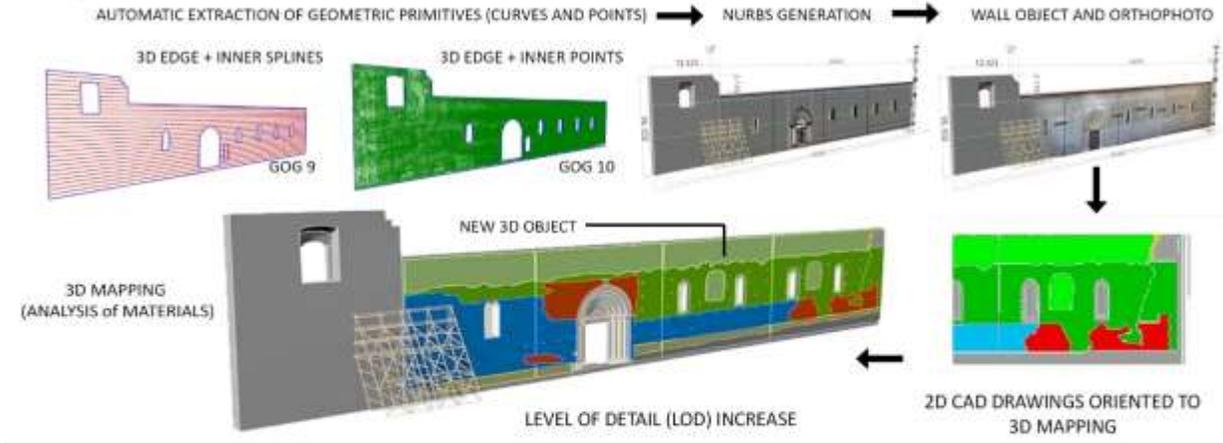
WALL	INTERNAL SPACE VOLUME	WALL VOLUME	GROSS FLOOR AREA	TIME REQUIRED BIM GENERATION BY GOG	TIME REQUIRED BIM GENERATION BY TRADITIONAL PROCESS	LEVEL OF DETAIL	REF. HBIM OBJECTS
	m <sup>3</sup>	m <sup>3</sup>	m <sup>2</sup>	2013 (GOG 9-GOI 1-2) & 2017 (GOG 10-GOI 1-2) (Hours - h)	(GOG 9) (Hours - h)	(LOD)	
MAIN FACADE	/	1274	/	30h, 2013 & 15h, 2017	35-40	300	
TOWER	929	190	LEV.01+02=140	6h, 2013 & 2h, 2017	10-12	300	
NORTH WALL	/	1141	/	20h, 2013 & 3h, 2017	30-35	500	
SOUTH WALL	/	941	/	8h, 2013 & 3h, 2017	12-15	500	
INTERNAL NORTH WALL ARCHES	/	537	/	20h, 2013 & 3h, 2017	12-15	500	
INTERNAL SOUTH WALL ARCHES	/	460	/	15h, 2013 & 6h, 2017	20-25	500	
BELL TOWER	437	180	LEV.01+02=25	20h, 2013 & 15h, 2017	25-30	400	
APSE WALLS	11491	1790	LEV.01+823	60h, 2013 & 25h, 2017	70-80	500	
APSE VAULTS	/	160-190	/	50h, 2013 & 20h, 2017	60-70	500	
CRYPT	977	250	LEV.00=336 LEV.01=280	60h, 2013 & 20h, 2017	50-60	400	
ROOF	36987	7244	LEV.01=2194	120h, 2013 & 50h, 2017	130-140	500	
TOT.	51 000~	14 000~	3798~	409h~ , 2013 162h~ , 2017	522~		



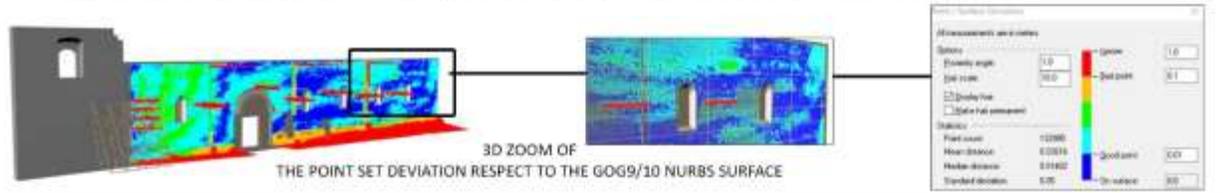
#### PHASE 1 - DATA SOURCES ORIENTATION FOR NURBS GENERATION



#### PHASE 2 - NURBS SURFACE GENERATION OF WALL OBJECT AND DECAY AREAS



#### PHASE 3 - AUTOMATIC VERIFICATION SYSTEM OF THE GRADE OF ACCURACY



#### PHASE 4 - HBIM PARAMETRIZATION AND DATABASE GENERATION

LEVEL OF INFORMATION (LOI) INCREASE

NEW PROPERTIES AND PARAMETERS RELATED TO BIM OBJECT

HBIM DATABASE

A	B	C	D	E	F	G	H
Model	Family and Type	Description	Function	Place Class	Volume	Area	History
4004 Basilica of Colonna Basilic Wall_1001	Masonry apparatus with sub-horizontal courses in compact limestone blocks and Rales (1971 addition)	Exterior	Existing	0.42 m <sup>3</sup>	39.75 m <sup>2</sup>		As Built after 2000
4004 Basilica of Colonna Basilic Wall_1002	Masonry apparatus with sub-horizontal courses in compact limestone blocks and Rales (1971 addition)	Exterior	Existing	0.29 m <sup>3</sup>	30.61 m <sup>2</sup>		As Built after 2000
4004 Basilica of Colonna Basilic Wall_1003	Masonry apparatus with sub-horizontal courses in compact limestone blocks and Rales (1971 addition)	Exterior	Existing	0.37 m <sup>3</sup>	36.75 m <sup>2</sup>		As Built after 2000
4004 Basilica of Colonna Basilic Wall_1004	Masonry apparatus with sub-horizontal courses in compact limestone blocks and Rales (1971 addition)	Exterior	Existing	0.32 m <sup>3</sup>	31.66 m <sup>2</sup>		As Built after 2000
4004 Basilica of Colonna Basilic Wall_1005	Masonry apparatus with sub-horizontal courses in compact limestone blocks and Rales (1971 addition)	Exterior	Existing	0.67 m <sup>3</sup>	7.32 m <sup>2</sup>		As Built after 2000
4004 Basilica of Colonna Basilic Wall_1006	Masonry apparatus with sub-horizontal courses in compact limestone blocks and Rales (1971 addition)	Exterior	Existing	0.67 m <sup>3</sup>	7.32 m <sup>2</sup>		As Built after 2000

EXTERNAL DATABASE

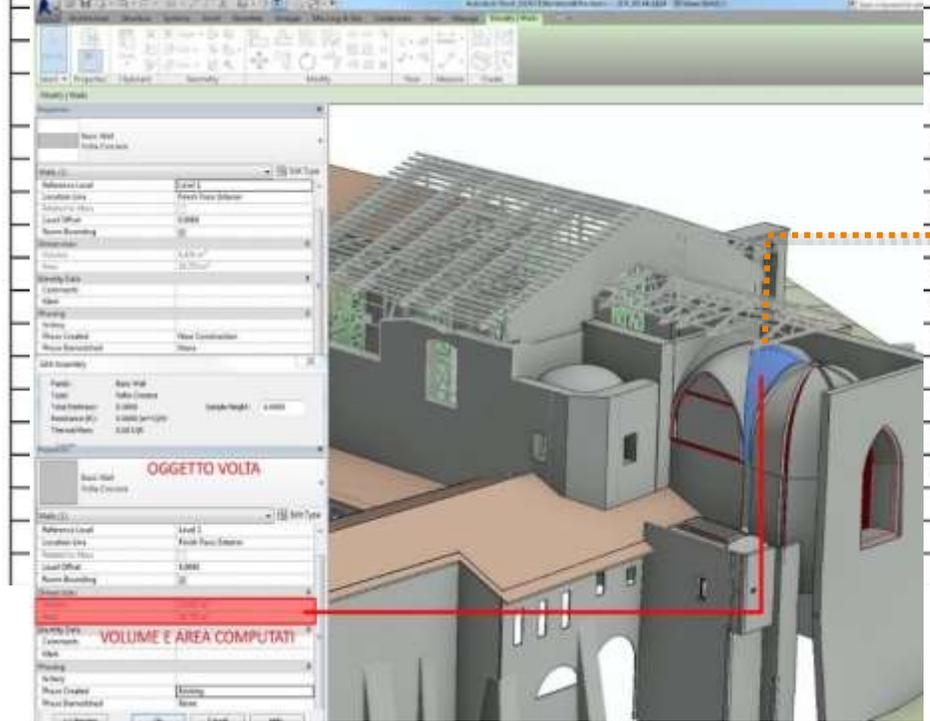
Tutti gli oggetti...

# HBIM to support the Conservation Plan and Planned Maintenance across the Life Cycle Management (LCM)

## Decision Support System DSS

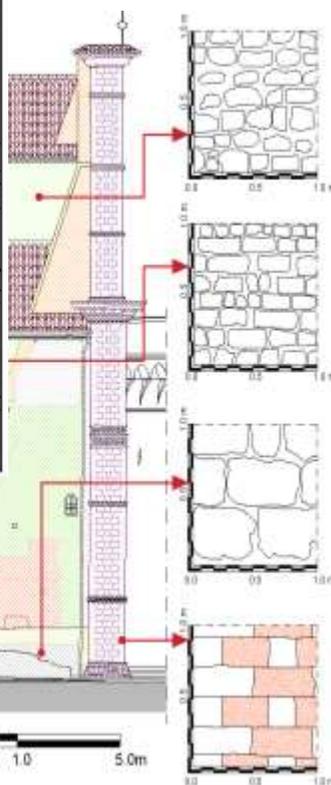
LOCALIZZAZIONE	CLASSE TECNOLOGICA	ELEMENTO COSTRUTTIVO	N. ELEM.	CODICE			
CR	CORRIDOIO	ADe	Apparati decorativi esterni	Co	Cornice	2	CR_ADe.Co.2
CR	CORRIDOIO	SV	Strutture verticali	Mp	Muratura portante	1	CR_SV.Mp.1
CR	CORRIDOIO	SV	Strutture verticali	Mp	Muratura portante	2	CR_SV.Mp.2
CR	CORRIDOIO	SV	Strutture verticali	Mp	Muratura portante	3	CR_SV.Mp.3

### HOLISTIC HBIM CHALLENGES



CLASSE TECNOLOGICA	ELEMENTO COSTRUTTIVO	N. ELEM.	CODICE
Fi	Finestra	2	CR_RVI.Fi.2
Fi	Finestra	1	CR_RVI.Fi.1
Gr	Canale di gronda	1	CR_RVI.Gr.1
Po	Portale	1	CR_RVI.Po.1
Po	Portale	1	CR_RVI.Po.2
Po	Porta	1	CR_RVI.Po.3
Vo	Volta	1	CR_RVI.Vo.1
Vo	Volta	1	CR_RVI.Vo.2
Vo	Volta	1	CR_RVI.Vo.3
St	Struttura	1	CR_RVI.St.1
St	Struttura	1	CR_RVI.St.2
Mc	Manto di copertura	1	CR_RVI.Mc.1
Mc	Manto di copertura	1	CR_RVI.Mc.2
In	Intonaco	3	CR_RVI.In.3
In	Intonaco	1	CR_RVI.In.1
In	Intonaco	1	CR_RVI.In.2

Classe Tecnologica	Elemento Costruttivo	N. Elem.	Codice	Descrizione
1Ma	Stone Masonry M	101 M01	M01	Regular limestone blocks masonry with white and pink color
2Ma	Stone Masonry M	102 M02	M02	Coarse masonry texture composed by white and rose elements with different size
3Ma	Stone Masonry M	103 M03	M03	Small stone blocks masonry with different size
4Ma	Stone Masonry M	104 M04	M04	Regular texture with small stones in contact (square limestone blocks), regular masonry apparatus
5Ma	Stone Masonry M	105 M05	M05	Masonry apparatus with rough-hewn natural courses in contact (limestone blocks and holes [LST] addition)

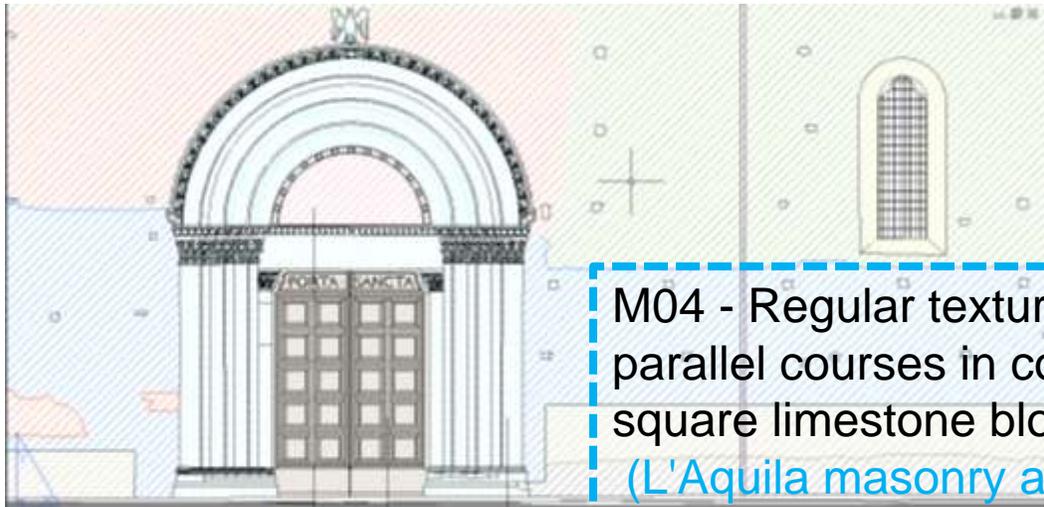


- M05 - roughly cut stone blocks**  
 Dating: 1970 addition  
 Description: roughly cut blocks masonry texture with sub-horizontal joints.
- M04 - Calcarenite stone blocks**  
 Dating: 1294  
 Description: mixed masonry texture formed by roughly shaped stone blocks and more regular cut stones.
- M02 - Large blocks masonry texture**  
 Dating: before 1294  
 Description: masonry texture composed by calcarenite large blocks belonging to a pre-existing fortress.
- M01 - Cut stone blocks**  
 Dating: 1970 restoration work.  
 Description: masonry texture formed by cut blocks of white and rose calcarenite stone with regular proportions.



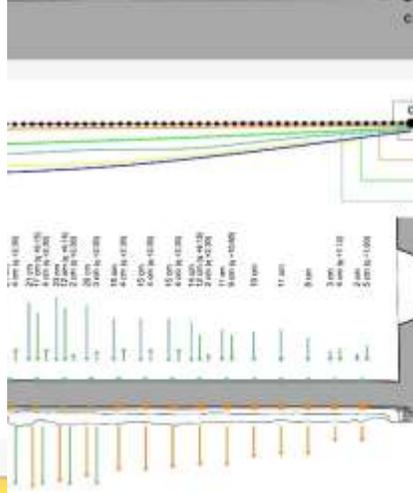
# Informative Models

## HBIM DB Materic analysis



M04 - Regular texture with parallel courses in compact square limestone blocks (L'Aquila masonry apparatus)

ID-CODE	Symbol	Description	Layout	Texture information
Stone Masonry Walls (M)				
100		M01 - Regular limestone blocks masonry with white and pink color		base x height (cm): 22.0x20.0; 32.0x20.0; 48.0x20.0
101		M02 - Chaotic masonry texture composed by bricks and stone elements with different size		base x height (cm): 22.0x24.0; 34.0x24.0; 32.0x15.0
102		M03 - Rough stone blocks Masonry with different size		base x height (cm): 57.0x32.0; 22.0x32.0
103		M04 - Regular texture with parallel courses in compact square limestone blocks (L'Aquila masonry apparatus)		base x height (cm): 19.0x12.0; 23.0x12.0; 17.0x10.0



Tutti gli oggetti...  
Cerca...  
Tabelle  
Decay DataBase  
Materials-Stone Masonry Walls

ID	Legend (Mat)	Type	COD	ID-CODE	ID	Description	Texture information
1	Ma	Stone Masonry	M	101	M01	M01 - Regular limestone blocks masonry with white and pink color	base x height (cm): 22.0x20.0; 32.0x20.0; 48.0x20.0
2	Ma	Stone Masonry	M	102	M02	M02 - Chaotic masonry texture composed by bricks and stone elements with different size	base x height (cm): 22.0x24.0; 34.0x24.0; 32.0x15.0
3	Ma	Stone Masonry	M	103	M03	M03 - Rough stone blocks Masonry with different size	base x height (cm): 57.0x32.0; 22.0x32.0
4	Ma	Stone Masonry	M	104	M04	M04 - Regular texture with parallel courses in compact square limestone blocks (L'Aquila masonry apparatus)	base x height (cm): 19.0x12.0; 23.0x12.0; 17.0x10.0
5	Ma	Stone Masonry	M	105	M05	M05 - Masonry apparatus with sub-horizontal courses in compact limestone blocks and flakes (1971 addition)	base x altezza (cm): 26.0x12.0; 16.0x12.0
6	Ma	Stone Masonry	M	106	M06	M06 - Masonry with irregular stone-blocks and sub-horizontal joints	base x altezza (cm): 19.0x12.0; 23.0x12.0
7	Ma	Stone Masonry	M	107	M07	M07 - Masonry with large square compact and alveolar limestone blocks	base x altezza (cm): 53.0x24.0; 31.0x24.0
8	Ma	Stone Masonry	M	108	M08	M08 - Shaped stone elements	base x altezza (cm): 57.0x32.0; 22.0x32.0
9	Ma	Stone Masonry	M	109	M09	M09 - Regular stone blocks	arch
10	Ma	Stone Masonry	M	110	M10	M10 - Stone-blocks masonry with different size (reparation)	arch
11	Ma	Stone Masonry	M	111	M11	M11 - Masonry with compact limestone rough blocks	arch
12	Ma	Stone Masonry	M	112	M12	M12 - Brick masonry	arch
13	Ma	Stone Masonry	M	113	M13	M13- Others	arch



M04 - Regular texture with parallel courses in compact square limestone blocks (L'Aquila masonry apparatus)

# Models and scales quality control

An open BIM-cloud platform:  
a common data environment  
for different BIM uses. The  
bottom-up methodologic  
workflow: from building  
scale to complex scenarios  
(model and information) with  
different LOG-LOI

Energy efficiency  
and plants

AN OPEN BIM-CLOUD PLATFORM: A COMMON DATA ENVIRONMENT FOR DIFFERENT BIM USES

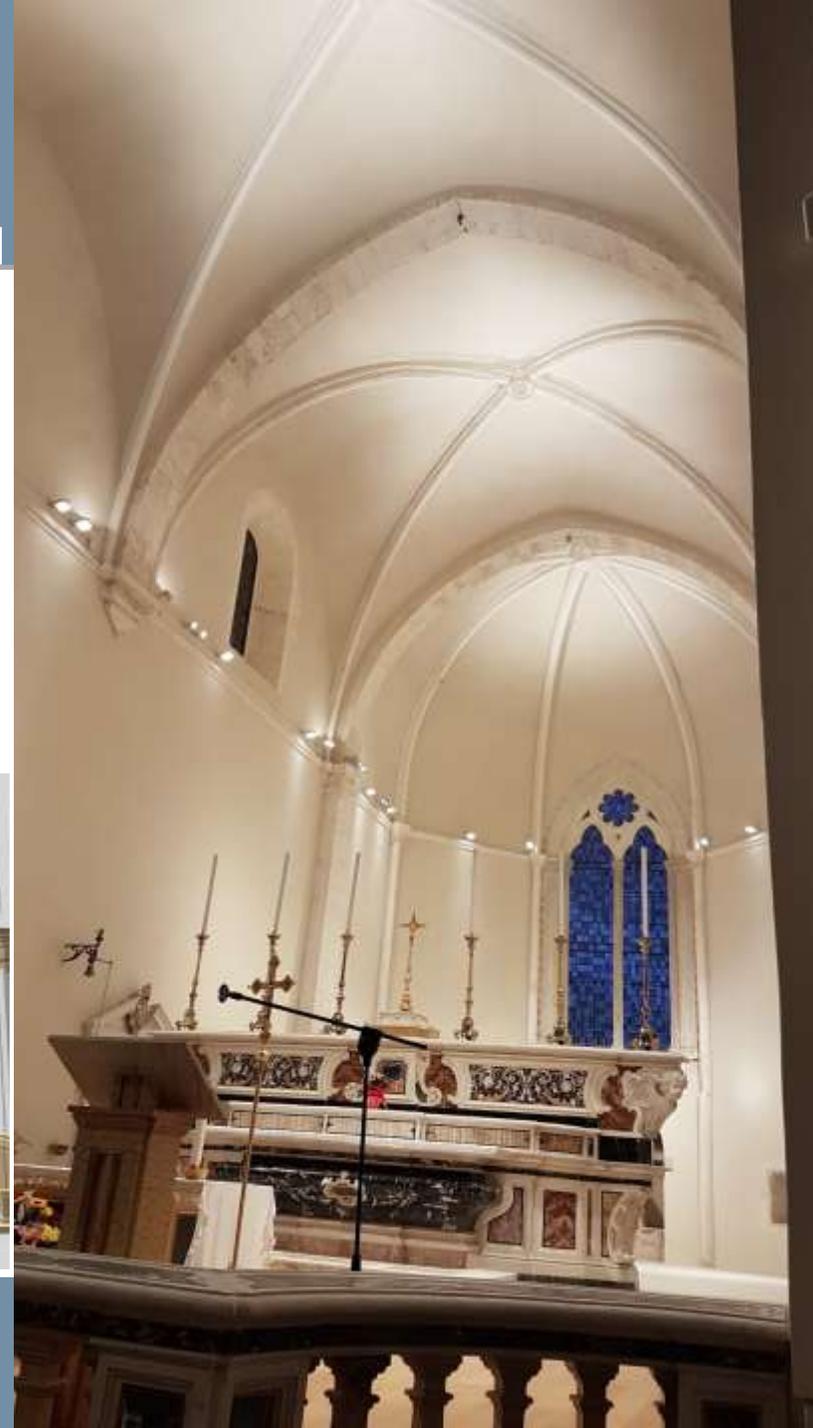
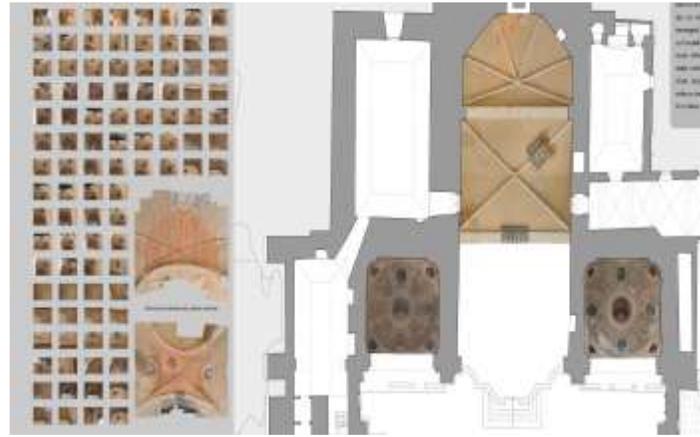
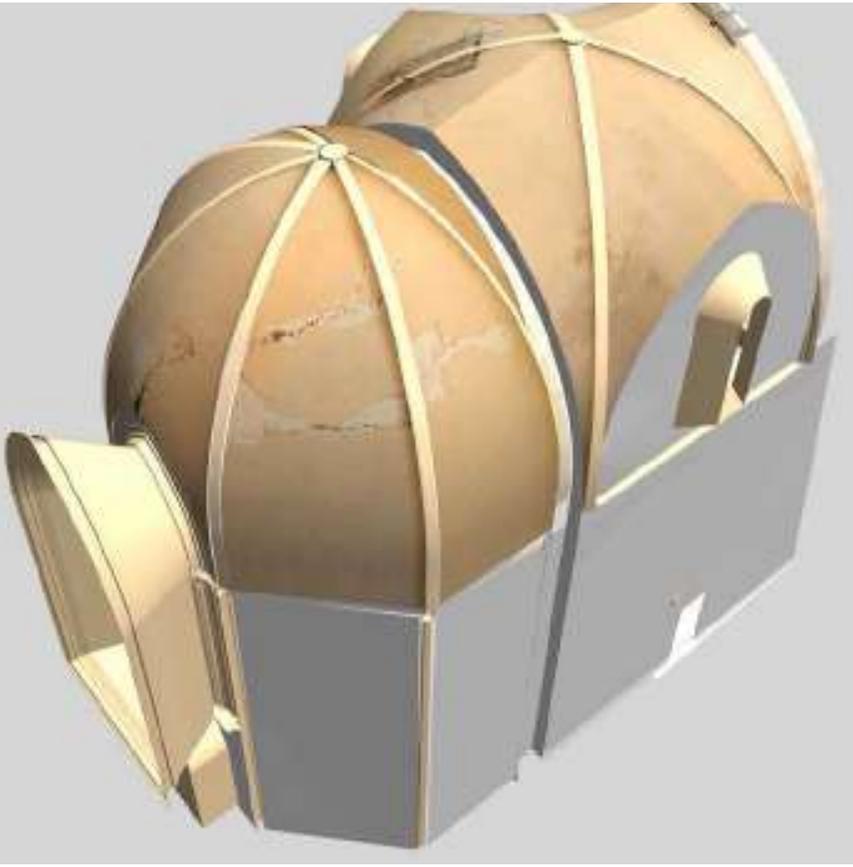
PARAMETRIC OBJECTS    SENSORS    BIM    TIME LINE    MONITORING    ANALYSE    SHARING

1    2    3    4    5    6    7

The screenshot displays a software interface for a BIM platform. At the top, a navigation bar contains seven categories: PARAMETRIC OBJECTS, SENSORS, BIM, TIME LINE, MONITORING, ANALYSE, and SHARING, each with a corresponding numbered icon (1-7). Below this, a central 3D model of a building is shown with various components labeled with the same numbers. To the left of the model is a hierarchical tree view for 'Cinisello\_01' with sub-items like 'GFM', 'Elect\_Equipment\_P.', 'FLOOR\_1', 'SENSOR\_072...', 'SENSOR\_072...', 'Elect\_Equipment\_P.', 'FLOOR\_2', and 'SENSOR\_072...'. To the right of the model is a 'GFM Chart' panel with two options: 'Nuovo Grafico' (represented by a plus sign) and 'Metriche Assegnate' (represented by a line graph icon). Below the main 3D view is a timeline with a play button and a progress bar. At the bottom of the interface, there are four smaller preview windows: a bar chart, a 3D model of a building with a red and blue highlighted area, a 3D model of a dome structure, and a 3D rendering of a person walking in a virtual environment.



# Complexity matters



# As-design Models

DSS

The different design solutions

3D simulation

## AS-FOUND and AS-DESIGNED BIM

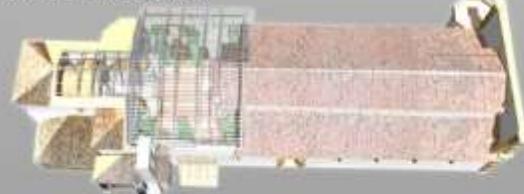
AS-FOUND BIM side view



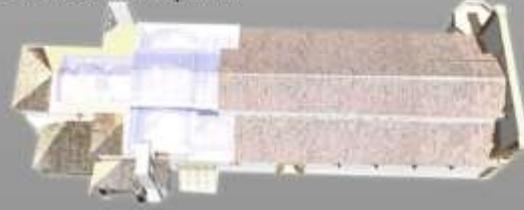
AS-DESIGNED BIM side view



AS-FOUND BIM top view



AS-DESIGNED BIM top view



AS-FOUND BIM internal view



AS-DESIGNED BIM internal view



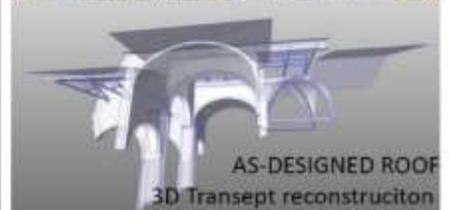
AS-DESIGNED BIM ROOF



AS-DESIGNED ROOF internal view

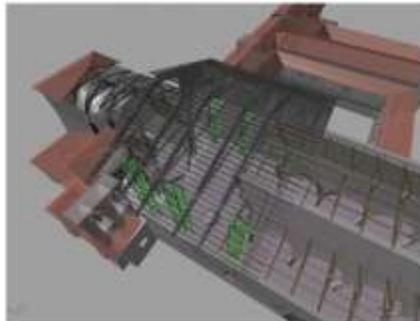


AS-DESIGNED ROOF 3D Transept reconstruction

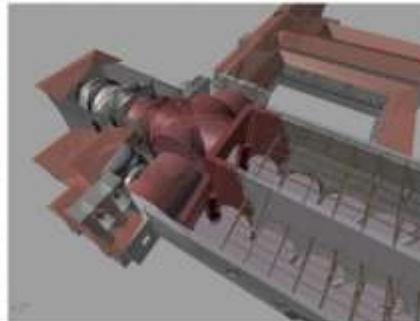


## 3D SIMULATION - DESIGN SOLUTIONS

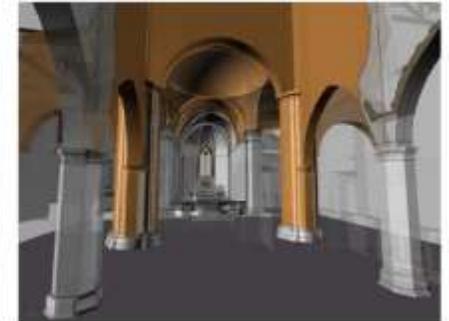
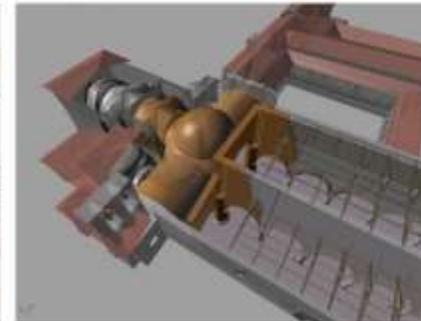
TEMPORARY ROOF



GROIN VAULT



DOMES ON PENDENTIVES



POLITECNICO MILANO

# Models and scales quality control

## GOA 20 facade modeling GOA5 surface finishing mapping



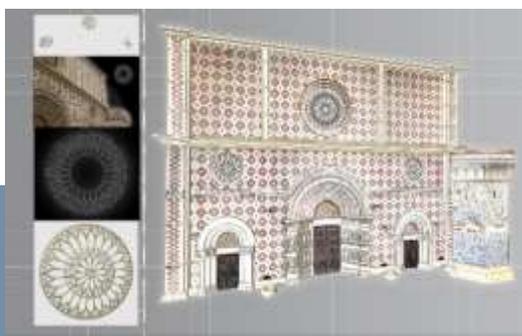
Il fotopiano è stato realizzato in scala 1:20 con risoluzione 1 pixel=2.5 mm a partire da immagini acquisite con distanza di presa progettata per ottenere immagini a risoluzione geometrica di 2 mm pixel terreno (equivalente a 0.1 mm, ovvero metà errore di graficismo, 0.2 mm alla scala 1:20 come da convenzioni cartografica in uso). Il blocco fotogrammetrico è composto da 58 immagini.



# Models quality control

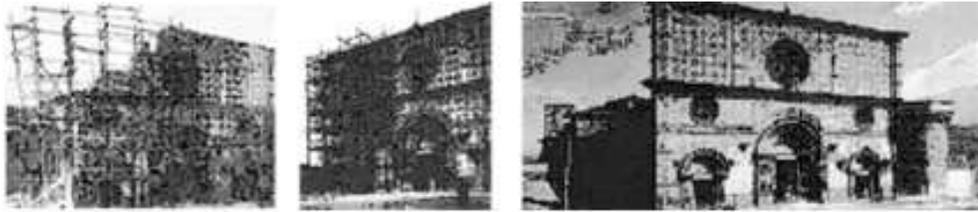


**GOA 20 GOA 20 facade modeling GOA5 surface finishing mapping**



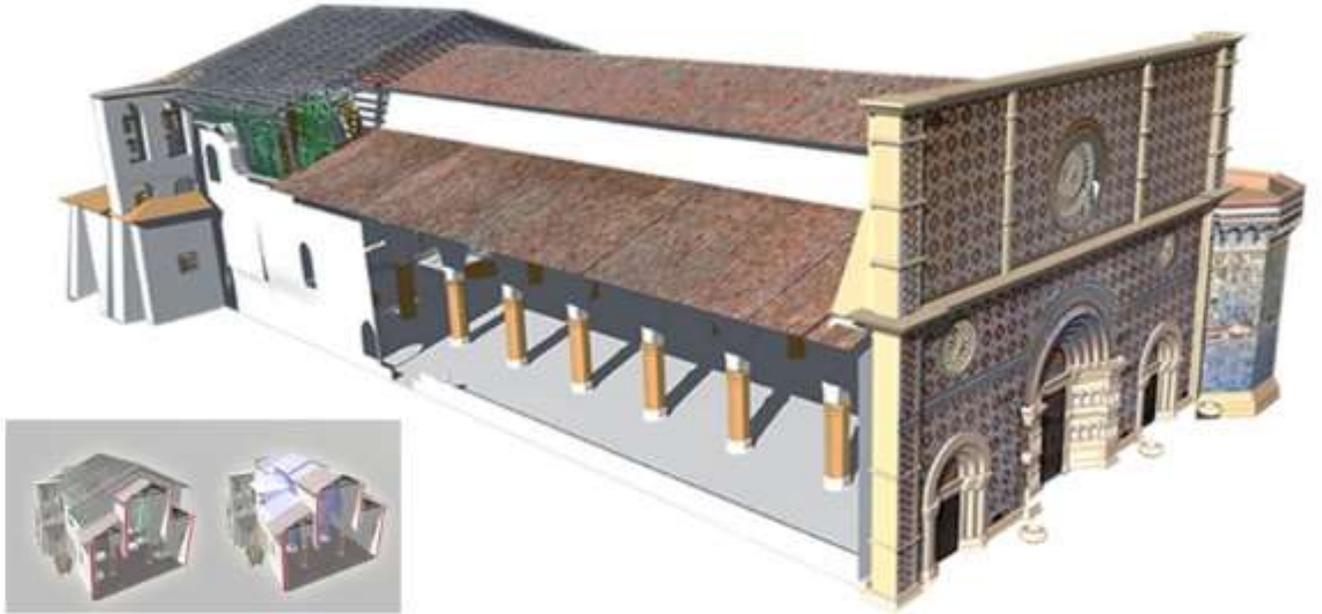
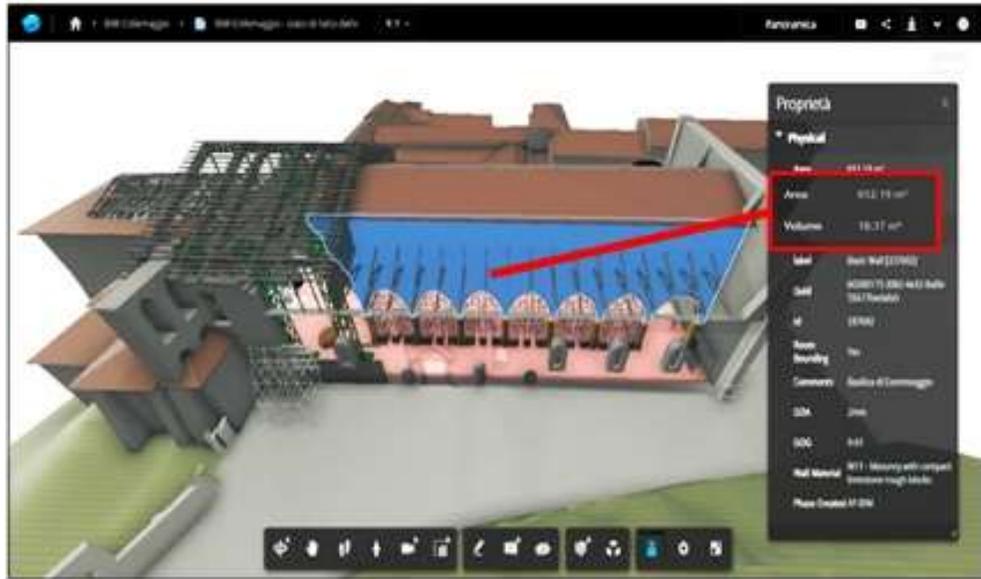
# Intangible values communications by mean of content models

**Previous hazards (earthquakes) and damages**



**Different skilled workers capacity building on stone and marble finishing across the centuries**

**GOA5**



POLITECNICO MILANO 1863

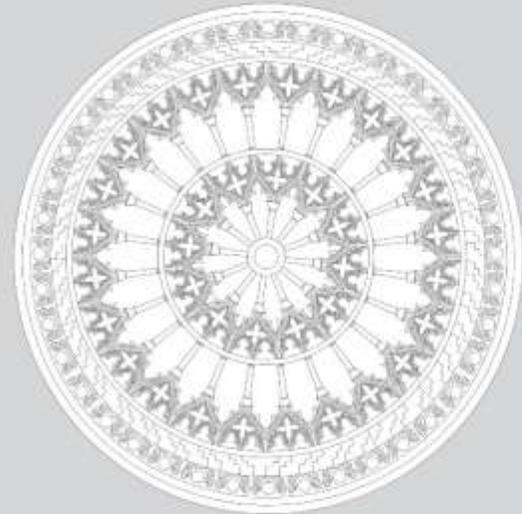
**Models managing the complexity of the facade  
Stone by stone surveying to detect the different surface finishing and  
the simplification process in the different reconstruction**

# Intangible values communications by mean of content models

GOA 10



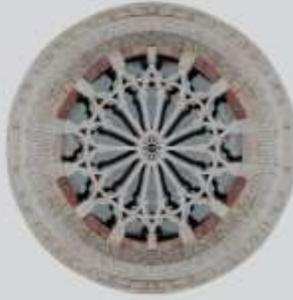
3 ROSONE CENTRALE FACCIATA



4 ROSONE SINISTRO FACCIATA



5 ROSONE DESTRO FACCIATA



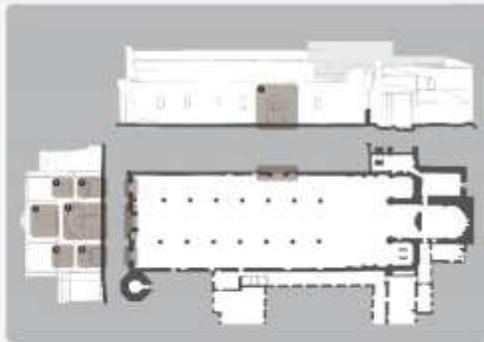
6 ROSONE SINISTRO FACCIATA



7 ROSONE DESTRO FACCIATA



8 ROSONE DESTRO FACCIATA



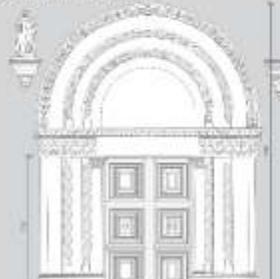
9 PORTALE SINISTRO FACCIATA



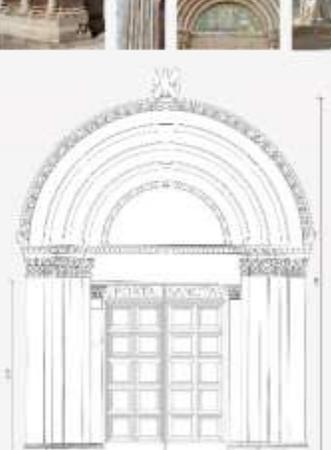
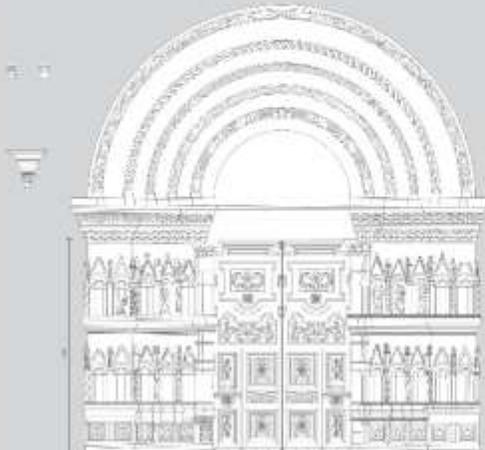
10 PORTALE DESTRO FACCIATA



11 PORTALE SINISTRO FACCIATA



12 PORTALE DESTRO FACCIATA

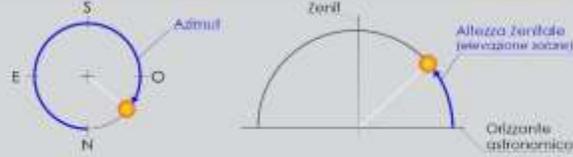


# Intangible values communications by mean of content models

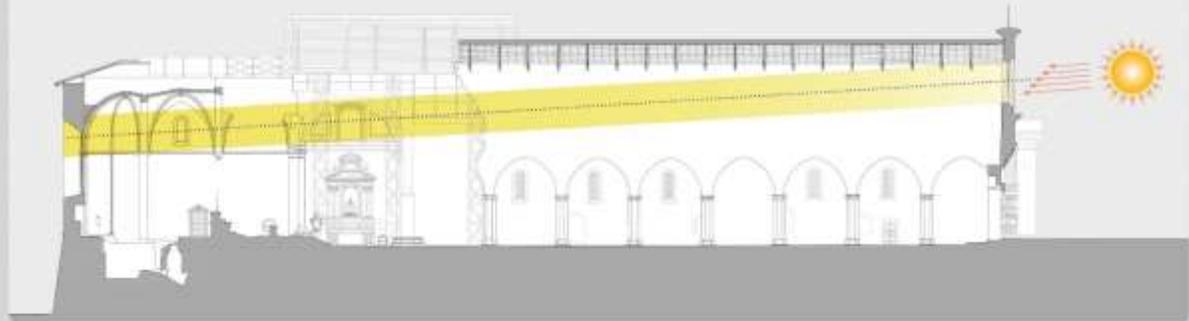
ANDAMENTO SOLARE DURANTE IL GIORNO DELL'ASSUNZIONE DELLA BEATA VERGINE MARIA (15 AGOSTO)

Nel 15 Agosto tra le 19.40 e le 19.50, il sole penetra dal rosone della fronte principale (ovest) e inonda un punto specifico della basilica, più precisamente, cade sulla parte alta della bifora posta nel fronte opposto.

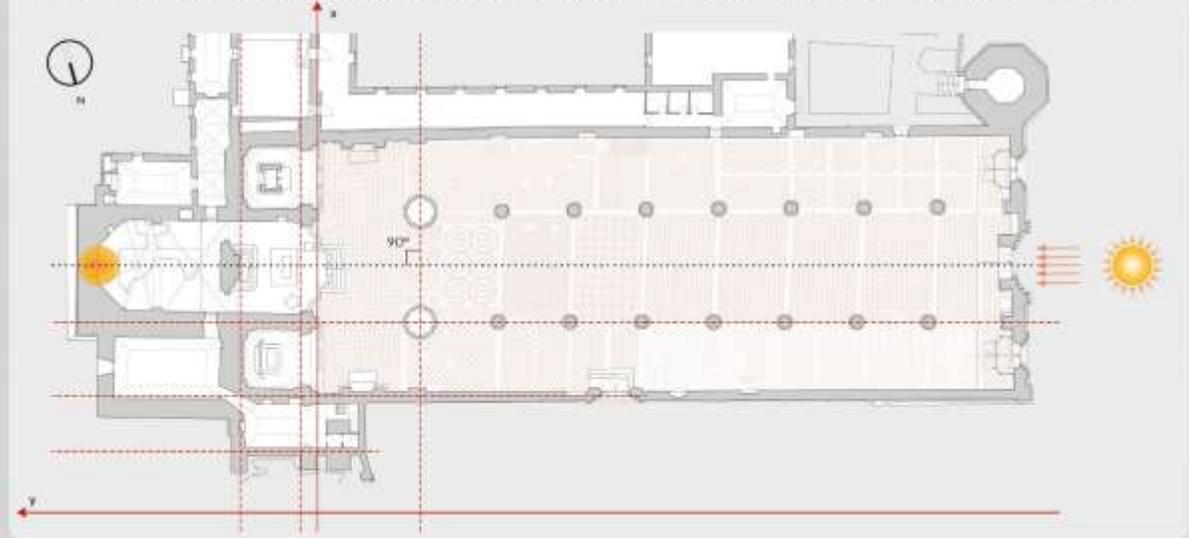
**Parametri utilizzati nelle verifiche**  
Coordinate geografiche basilica:  
- latitudine  $41^{\circ} 21' 57'' 60$  N (pari a  $42,366^{\circ}$ )  
- longitudine  $13^{\circ} 23' 39'' 84$  E (pari a  $13,3944^{\circ}$ )  
Coordinate astronomiche sole:  
- Azimut  $286^{\circ}$   
- Altezza zenitale (o elevazione solare)  $3,4^{\circ}$



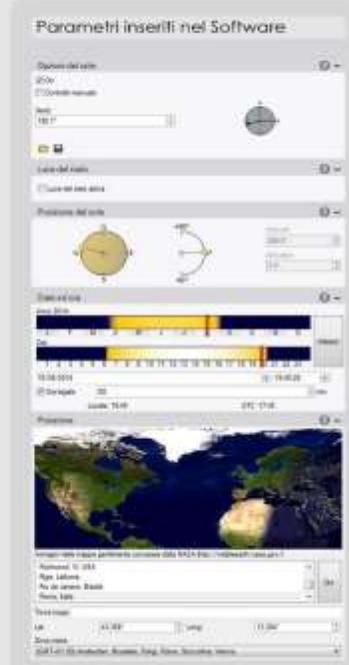
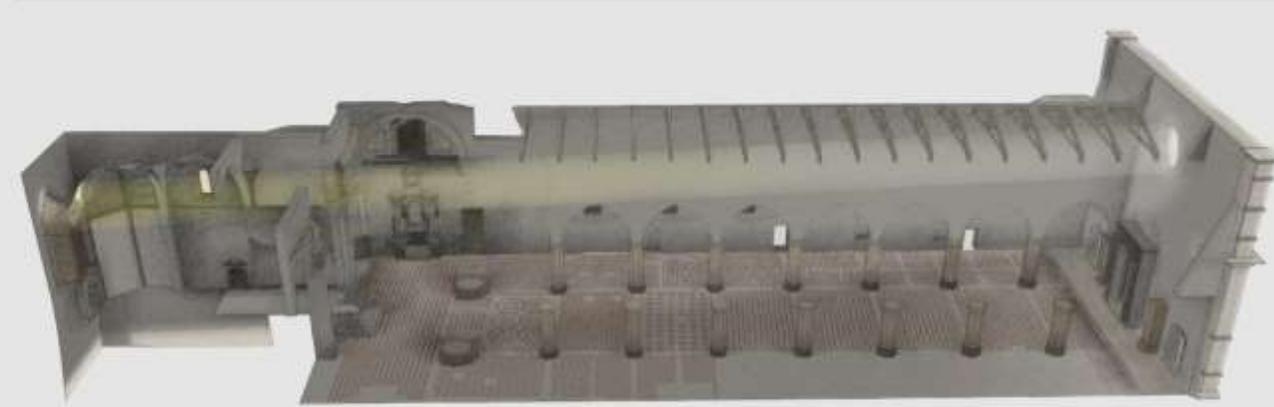
Verifica dell'altezza solare in sezione



Verifica dell'azimut e comparazione della direzione dei raggi solari con il sistema di riferimento degli allineamenti principali (X-Y)



SIMULAZIONE ORBITA SOLARE COL MODELLO 3D







***Toward the definition of specifications***

***(GOA-LOG)***

***for the generation, use, re-use and communication***

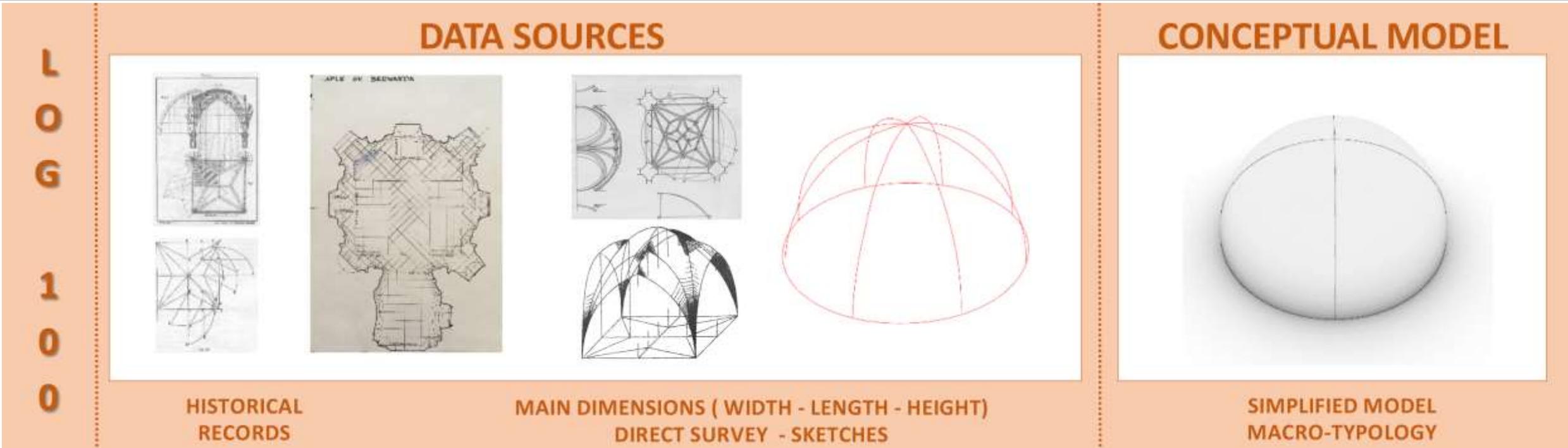
***of HBIM Object Libraries***

***in a Common Data Environment***



# Models and scales quality control :

## turning the LOD LOG from new building to Heritage matters



**LOG100: historical records and conceptual simplified models** decoded from the object and from the treaties

the LODs and LOGs have been turned as follows: the LOD100 (Pre Design) has been addressed to LOG100 “Conceptual model, historical reports and archives”;



# Models and scales quality control

LOG200 (Appropriate geometry, on site data acquisition, 3D survey)

## DATA SOURCES – 3D SURVEYING

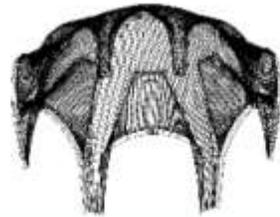


PHOTOGRAMMETRY  
ORTHOPHOTO

1)

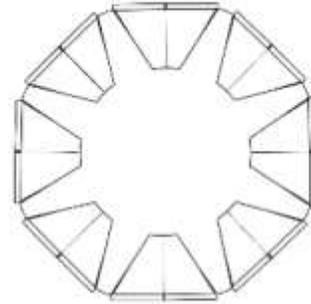


2)

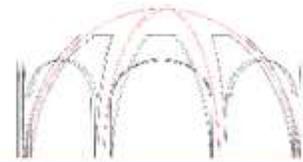


POINTCLOUDS (1) & MESH (2)

3)



4)



LUNETTE'S GEOMETRY  
EXTRACTION 2D

## SURFACE BASED MODEL



APPROPRIATE GEOMETRY

LOG200 (Appropriate geometry) turned to the surveying purpose addressed to support appropriate geometric analysis

LOG200 includes surveying

**Lidar data (i.e. Terrestrial Laser Scanner)**

**GEOSLAM Based Mobile Mapping Systems:**

**Photogrammetric image blocks:** such data are commonly used

**Output:** (2D-3D plans, sections, fronts), 3D meshes, DTM, TIN, Orthophoto clouds, meshes, orthophoto, 3D textured meshes, local 2D profiles, plans and sections.



# Models and scales quality control

## LOG300 (Precise Geometry): SCAN-to-BIM MODEL OBJECT

### GENERATIVE MODELLING PROCESS BIM-ENABLE

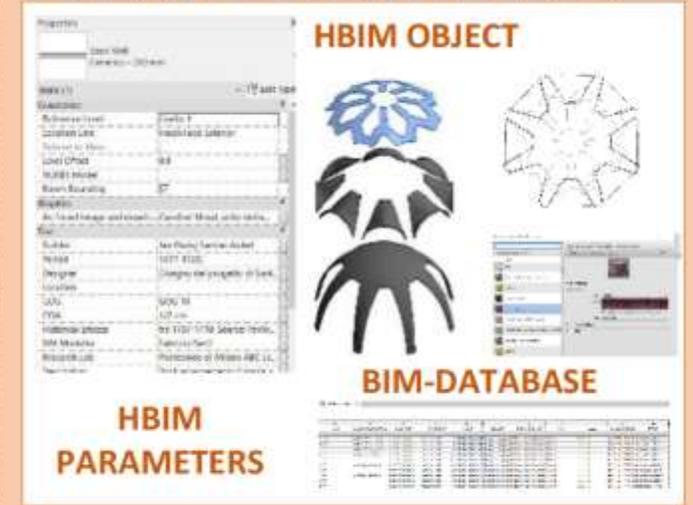


1) 3D PRIMITIVES EXTRACTION

2) NURBS MODEL

3) CLOUD-MODEL STANDARD DEVIATION & CURVATURE ANALYSIS

### SCAN-to-BIM MODEL



HBIM PARAMETERS

PRECISE GEOMETRY

**LOG300 (Precise Geometry, SCAN-to-BIM model object)** (As-found HBIM model). On the left: the HBIM model generation process adopting different GOAs. LOG300 for the HBIM of St. Bernard's chapel star vault models with different Grades of Accuracy correspondent to the scales (GOA20-50-10) and the **data model validation (AVS)**.

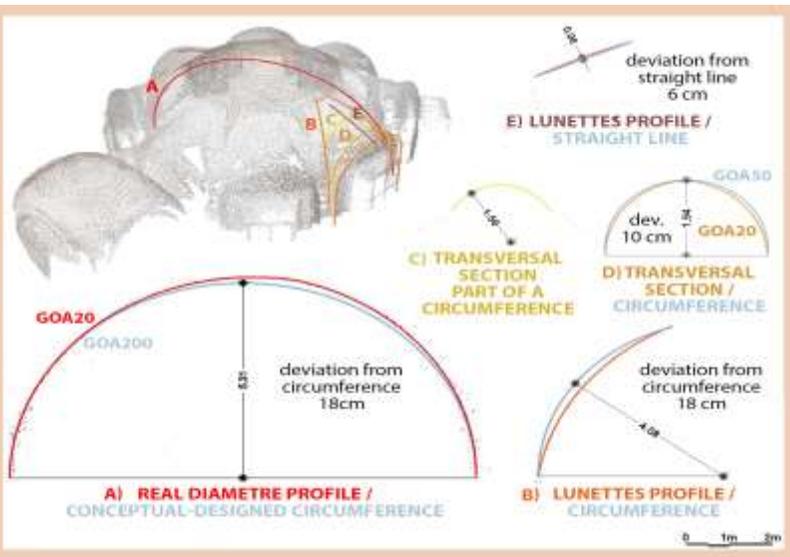
On the right the LOI information process and HBIM parameters with the **GOAs** attributes



# Complexity matters : Geometry + Materiality matters Grade of Accuracy to properly detect the geometry and construction techniques



GEOMETRIC ANALYSIS



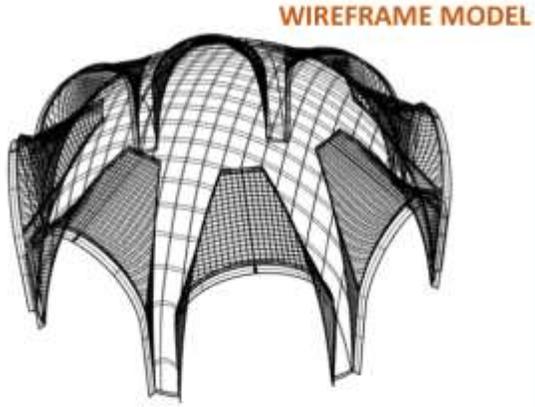
**Grade of Accuracy to properly detect the geometry + materials + construction techniques**

## THE RESEARCH CASE STUDY (GOA 20 AND 50)

GOA 20 INTRADOS

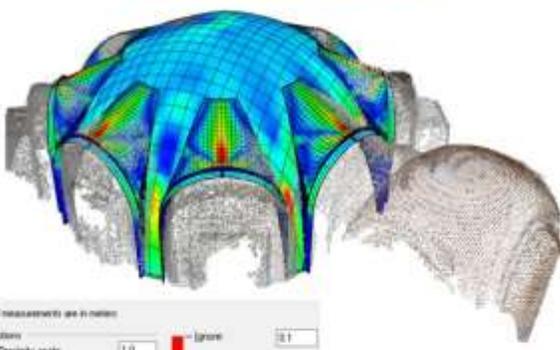


Point cloud



WIREFRAME MODEL

MODEL based on GOG 10



All measurements are in meters

Options			
Opacity angle	1.0	Bad point	0.01
Star scale	10.0	Good point	0.001
<input type="checkbox"/> Display face		On surface	0.0
<input type="checkbox"/> Make face permanent			
Statistics			
Point count	20252		
Mean distance	0.00130		
Median distance	0.000540		
Standard deviation	0.00229		

GOA 50 EXTRADOS



Point cloud

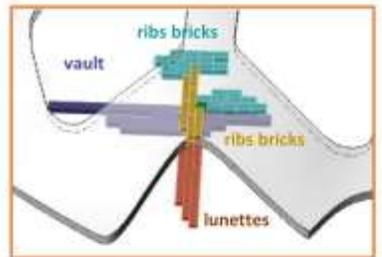


WIREFRAME MODEL

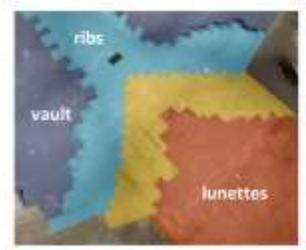
ORTHOPHOTO



GOA 10 FOCUS ON BRICK ARRANGEMENT



lunettes bricks  
ribs bricks parallel to lunettes  
ribs bricks parallel to vault  
header  
vault bricks



# Quality control to re-use and share content models

Linked HBIM vault library and its exchange formats for LOG 600 through the Geospatial Hub and the BIM based cloud platform (upper). The GeopanAPP implemented within the Geospatial Virtual Hub with the Vault GEODB and linked HBIM object libraries. Queries based on the GeoDB can be performed correlating the different objects libraries (in this case the Plazy St. Bernrd Chapel with some star vaults in Northern Italy, and the GOAs information)

CUSTOM BIM PARAMETERS
DRAWINGS
HBIM VAULT LIBRARY
EXCHANGE FORMATS
LOG 600

GEO Spatial HUB

BIM-BASED cloud platform

### DB Vaults

ID_Phase	Description	Phase_1	Phase_2	Phase_3	Century
11	Plazy Monastery		Phase_1		18
12	Plazy Chapel	1711	Phase_2		18th
13	Plazy Chapel - restoration	1724	Phase_3		18th

ID	Constructive Element	Structure	Topology	Sub-component	Assignment
11	Plazy Chapel	Thinning structure	Star vault	Some	Concentric displacement
12	Plazy Chapel	Thinning structure	Star vault	Lantern	Along the generatrix
13	Plazy Chapel	Thinning structure	Star vault	Radial structure	Along the generatrix

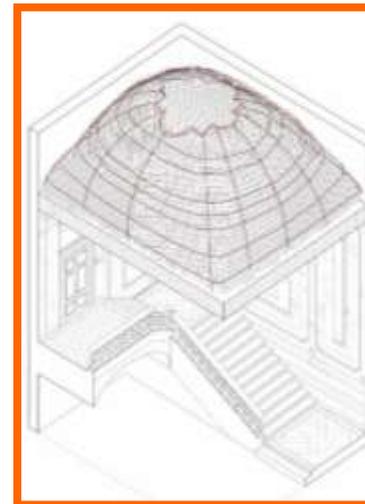
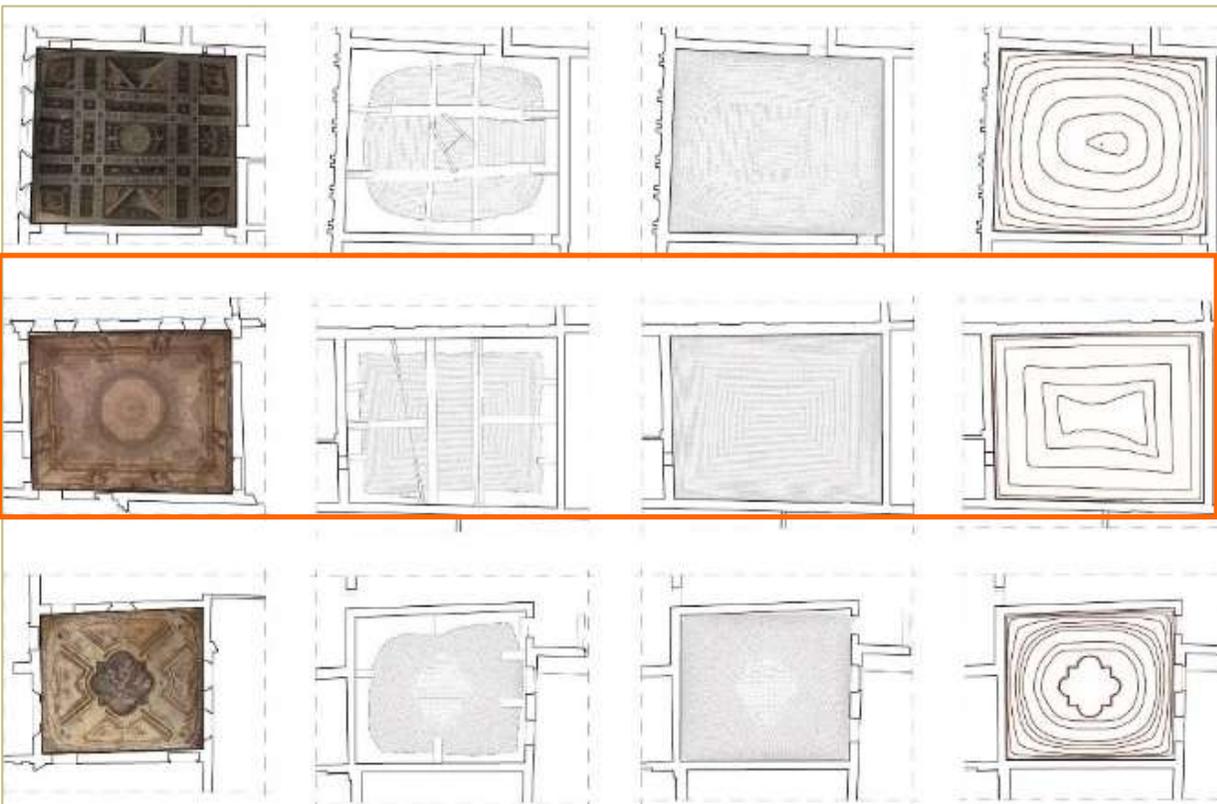
  

### Building

ID_Building	Short Name	Latitude	Longitude	Country	Region (Italy only)	Address	Building Type
12	Plazy Monastery	49,934673	13,39018	Czech Republic		Plzeň (Region), Plzeňská, N.2 (Address), Plazy (City) - 33101 (City Code)	Monastery
13	Klementinum Baroque Library	50,086824	14,416042	Czech Republic		Prague (Region), Šporkova Malá Strana, 5, Prague (City), 11000 (City)	Library

## STAR VAULTS IN NORTHERN ITALY - PIEDMONT - TURIN

# Models matters: geometry + arrangement + construction technologies rediscovery

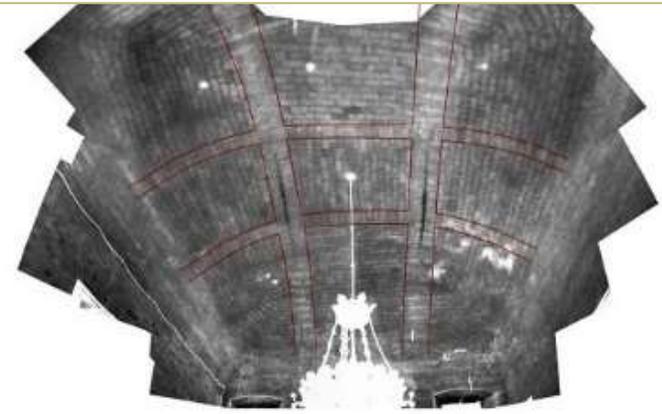
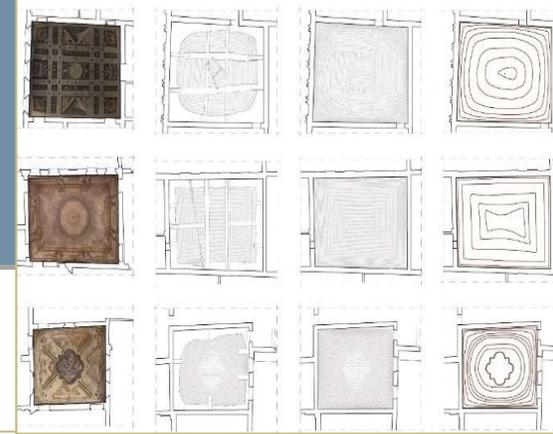


Proprietà	
	Muro di base
	Volta_Scalone
Muri (1) <span style="float: right;">Modifica t</span>	
Livello di riferimento	00_Piano Terra
Linea di ubicazione	Superficie di finitura: esterno
Relativo a massa	<input type="checkbox"/>
Offset del livello	0.0000 m
Delimita il locale	<input checked="" type="checkbox"/>
Testo	
02_Structure	Trusting Structure
03_Typology	Vault
04_Construction Technology	Degenerative
08_Arrangement	Course - Harringbone
10_Materials	Bricks
13_Texture	A coltello
11_Geometry	Circumference
00_ID_Element	EL_2
05_Sub-typology	
01_Element_nick	Stairs - Hall
07_Elements	
09_Arrangement description	Arches rotated by 45° to the major axis o...
12_Building	Palazzo Magio_Grasselli
14_Sub-texture	Single texturing
15_Description EN	Thin pavillion vault degenerative to dome
15_Description IT	Volta sottile a padiglione degenerativa i...
16_Bibliography	
06_Room Code	1.26



# Models and scales quality control

Non Destructive Techniques NDT > i.e. IRT Infrared Thermal Images to detect the texturing and arrangement under plaster



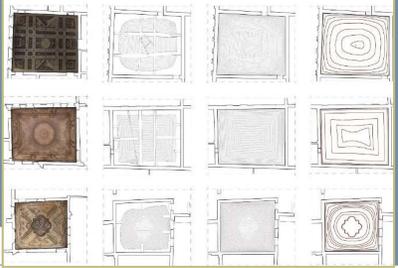
Cremona, palazzo Magio Grasselli (1743)



3 'similar' construction solutions obtained on the common 'cloister' typology. some details of the 2 deviations: the Manfredini Hall, Cloister - to -Trompe solution (centre), and the Stair Hall, Cloister-to-Dome-to Trompe corners (below); Magio Grasselli Palace.

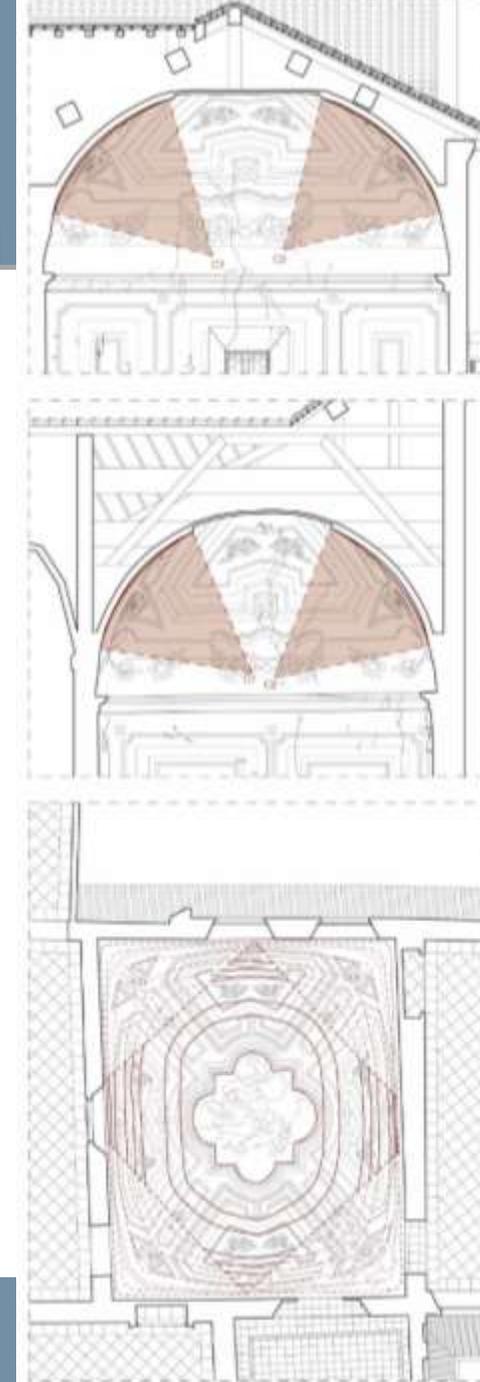
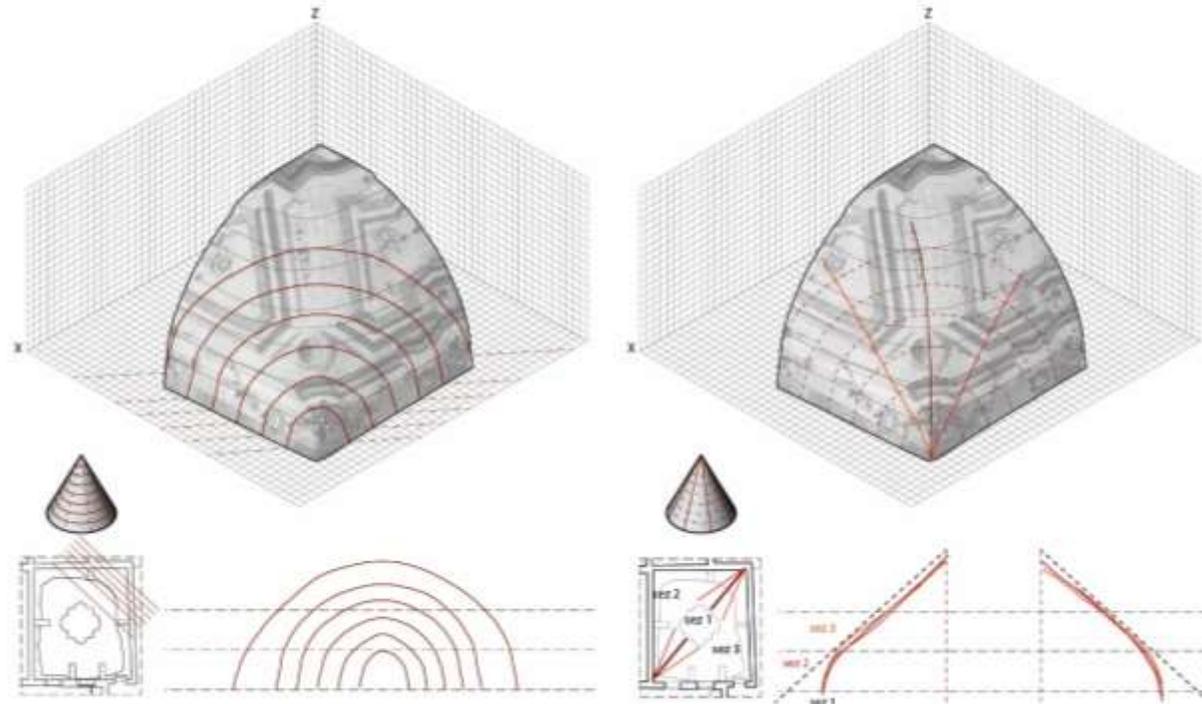
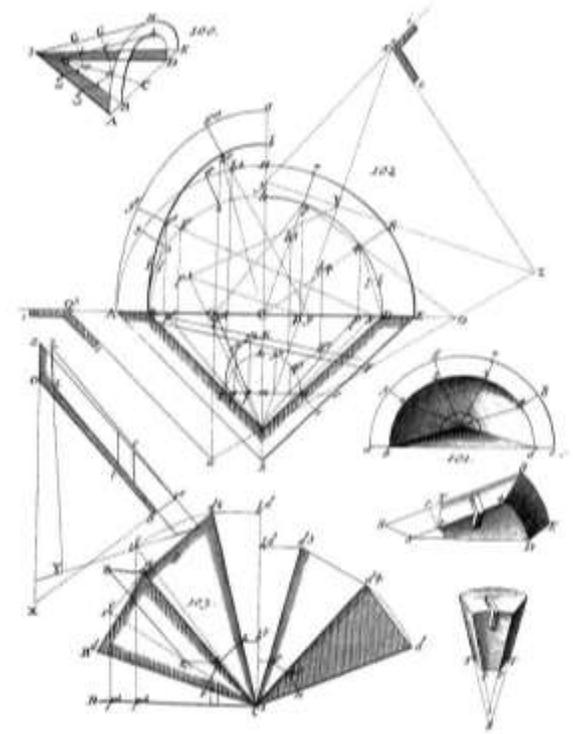


# Models and scales quality control



# Models and scales quality control

## Geometry to detect the construction phases



*Treatise roles and theoretical geometry to manage the spatial construction :*

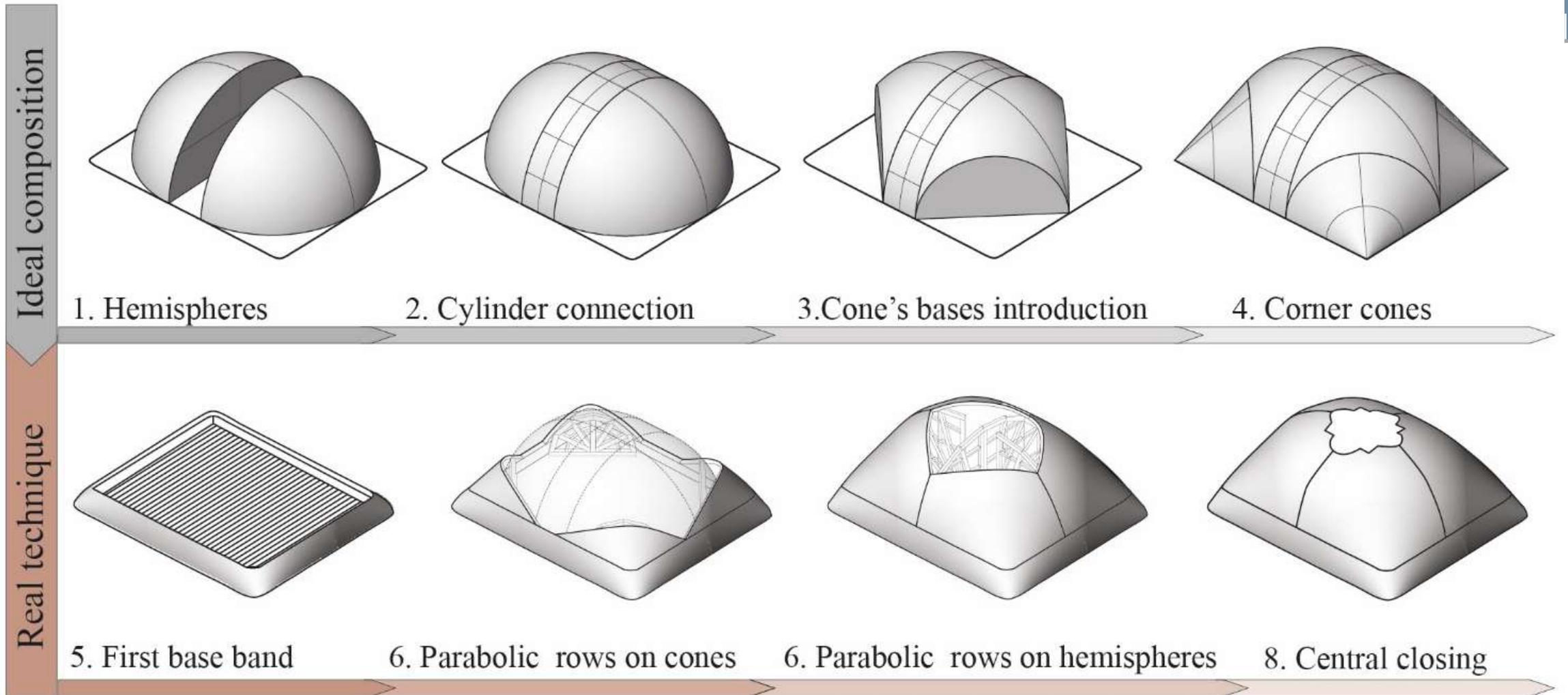
*Trompe (Guarino Guarini)*

*The geometric model analysis GOA10*

*Double curvature solid to limit the centrings*



## Geometry to detect the construction phases



# Sharing model data > enriched metadata

## the added value of vocabularies in the creation of common shared knowledge

### Vault and Dome Construction Typology

- Arch and Vault (mixed)
- Barrel Vault
- Cloister to Dome (centre)
- Cloister to Trompe (corners)
- Cloister Vault
- Cloister-Pavillion Vault
- Dome
- False Dome
- False Vault
- 'Frenelli'
- Groined Vault
- Lintel (Filler Tiles)
- Lowered brick tile vaults and iron girders
- Lunette
- Others
- Pavillion Vault on circular plan
- Pendentive Dome
- Planterian Vault
- Reinforced arches
- Ribs
- Sail Dome to Groined
- Sail-Dome
- Star Vault (Dome with lunettes)
- Trompe (Switch)
- Umbrella (Dome)
- 'Volte reali' (Wooden vaults)

The Vault Data Base with the different description tables related to the Buildings, the Typologies and the Historical Phases of the vaulted systems. The DB has been populated by the HBIM information gathered.

The vault vocabulary derived from the HBIM of palace (the Magio Grasselli Palace in Cremona): the bottom up process will allow to compare different HBIM nodes within the Hub platform.

### Vault and Dome Construction Typology

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### DB Vaults

#### Add data

- Add new building
- Add historical phase for the specified building
- Add person and specify the historical phase it refers
- Add a construction element and specify the historical phase it belongs
- Add component and specify the element it belongs to
- Add a geometric survey and specify the element it belongs to
- Add a crack survey
- Add a structural analysis

#### Edit fields

- Building
  - Typology\_Building
- Structure typology
  - Structure
- Element vaults
  - Arrangement
  - Materials
- Vault\_Dome\_Typology
  - Element\_type
  - Sub-typology
- Geometry
  - Texture
  - Sub-texture
- Component
  - Component typology
- Survey
  - Scale / tolerance
  - Surface

### Building

ID_Building	Short Name	Latitude	Longitude	Country	Region (Italy only)	Address	Building Type
8	Palazzo Magio	45,081135	10,114252	Italy	Lombardia	Corso IX Settembre, 87	Palace
9	Santa Maria di Scario	45,591048	9,024497	Italy	Lombardia	Piazza Carloni	Church
10	Villa Reale di Monza	45,353627	9,162909	Italy	Lombardia	Villa Reale di Monza	Villa
12	Plasy Monastery	49,934678	13,30018	Czech Republic		Plasy (Region), Plzeňský územní úřad, Plzeň (City) - 33101 (City Code)	Monastery
13	Klementinum Baroque Library	50,066824	14,416042	Czech Republic		Prague (Region), Šporkova Malá Strana, 5, Prague (City), 11800 (City Code)	Library
14	Italian Cultural Institute	50,087505	14,397638	Czech Republic		Prague (Region), Šporkova, Malá Strana, N320/14 (Address), Prague (City) 11800	Chapel

### Historical Phase

ID_Phase	Description	From (if known)	To (if known)	Building	Nickname of the Phase	Century (if known)
12	Plasy-Monastery-St. Bernard Chapel	1711	1740	Plasy Monastery	Plazy-2	XVIII
13	Plasy-Monastery-St. Bernard Chapel	1724		Plasy Monastery	Plazy-3	XVIII



# Models and scales quality control

## Quality control to re-use and share content models

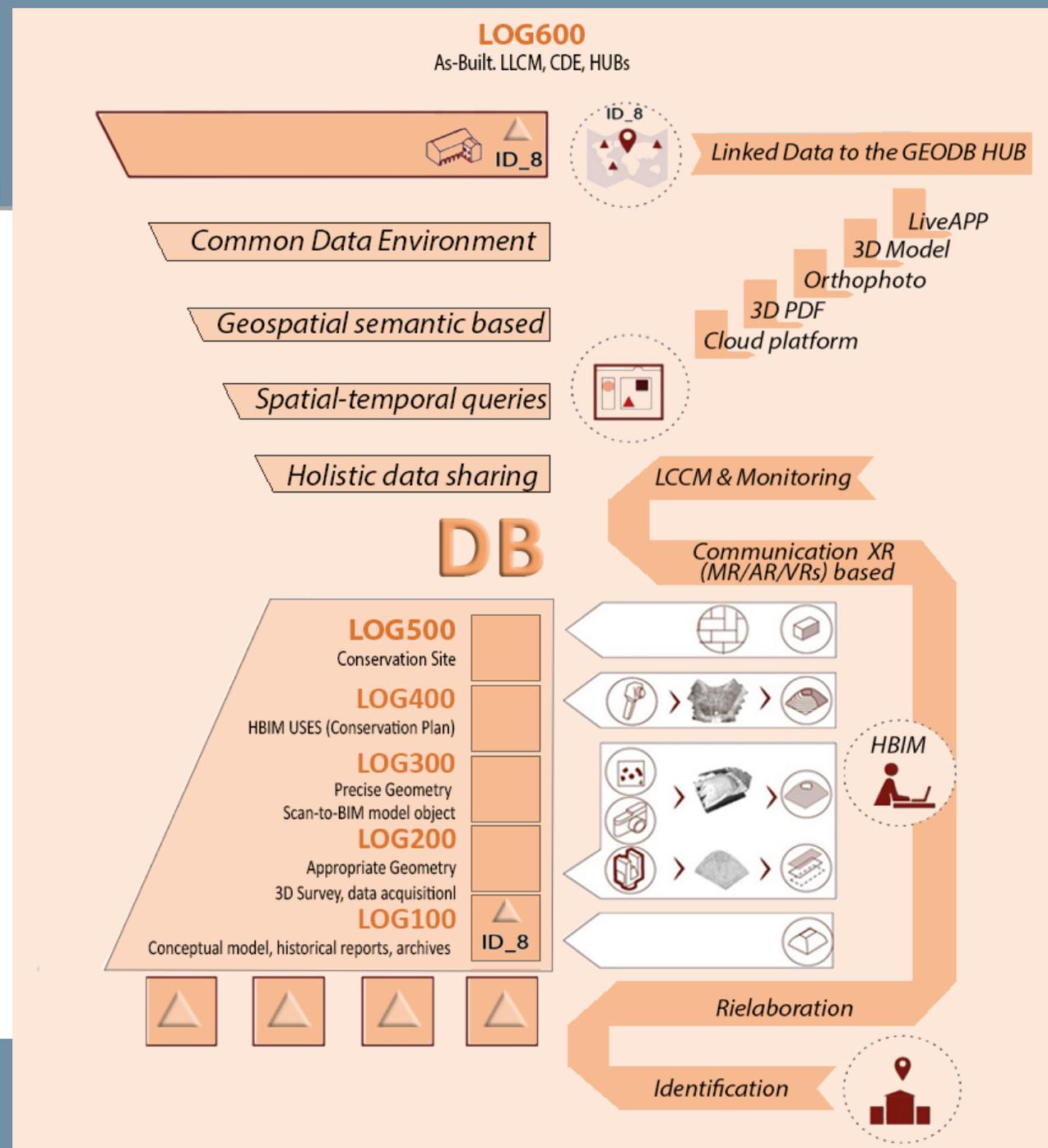
### LOG 600: GeoSpatial Virtual Hub with Linked HBIM implementation to manage Object Libraries and a BIM-based collaborative cloud platform

LOG600:  
the work flow of the single **object libraries** sharing data by mean of:

- ❖ **GEODB Virtual Hub**
- ❖ **Common Data Environment**

to support:

- **Life Cycle Management and Monitoring** continuously fed up by sensors
- **Communication** purposes to large public



*ENRICHED CONTENT Models > transferring the complexity  
of the knowledge gained toward communication purposes MR*



Gicarus LAB (4D BIM - HBIM - WEBGIS - SDI)

**Geospatial Information Content modeling: Architectural heritage & built environment, eUrbanAtl@s, Data Surveying**



GICARUS

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POLITECNICO MILANO 1863