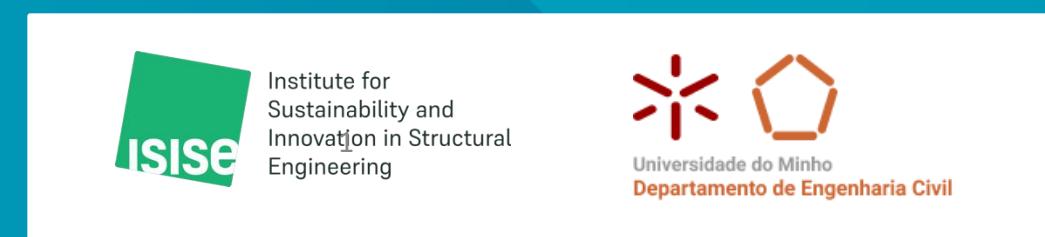




Structural Analysis of Historic Building in the Digital Age

A novel Open BIM approach for Finite Element Analysis

Maria Laura Leonardi Granja
PhD student in Civil Engineering



INTERNATIONAL WORKSHOP
DIGITAL INTEGRATED STRATEGIES TO SAFEGUARD
HERITAGE CONSTRUCTION TECHNOLOGIES
September 30 - October 5, 2024 | Poggioreale, Trapani



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1

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4

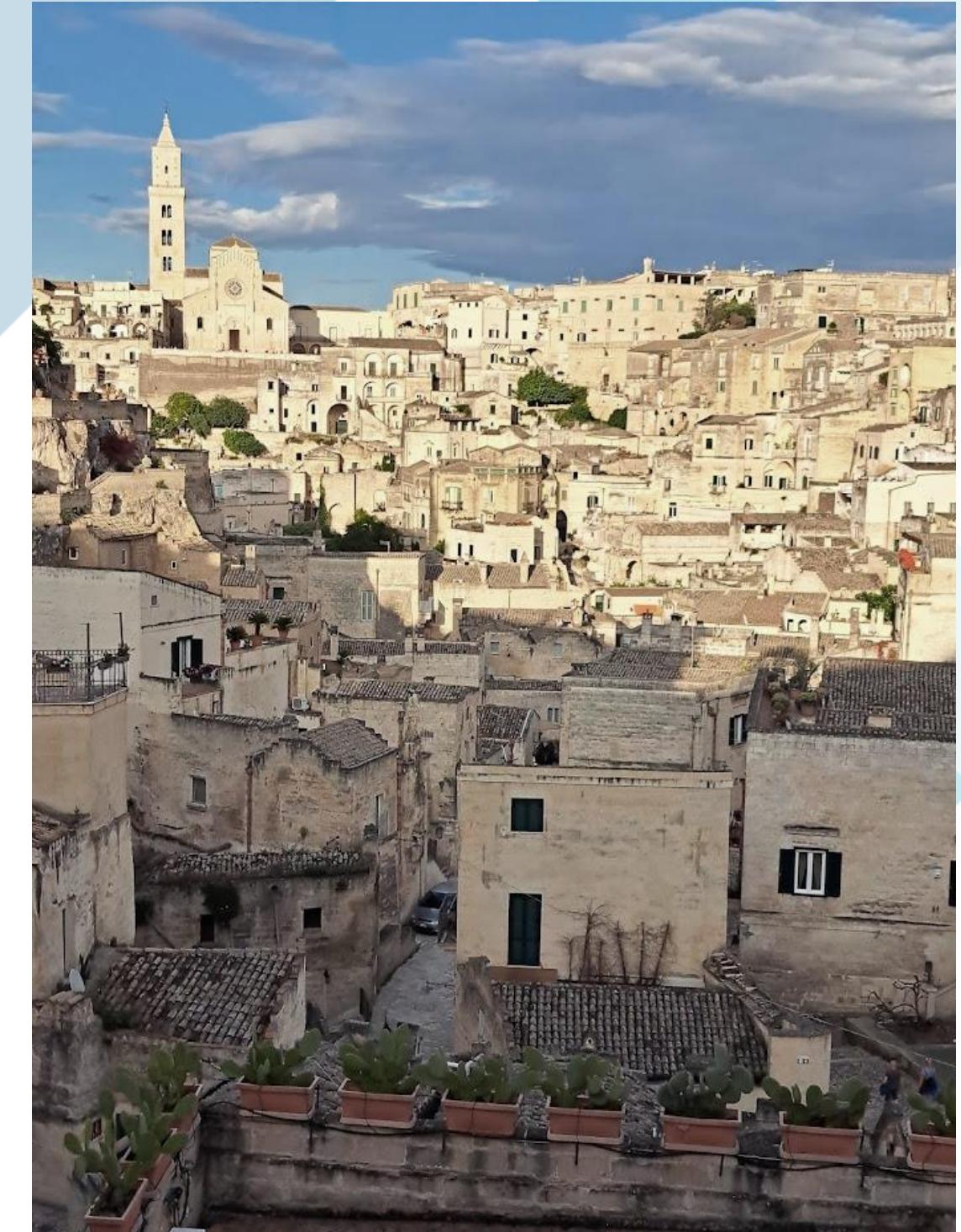
Conclusions

1

General overview of the scope, motivation and proposed methodology

Scope and motivation

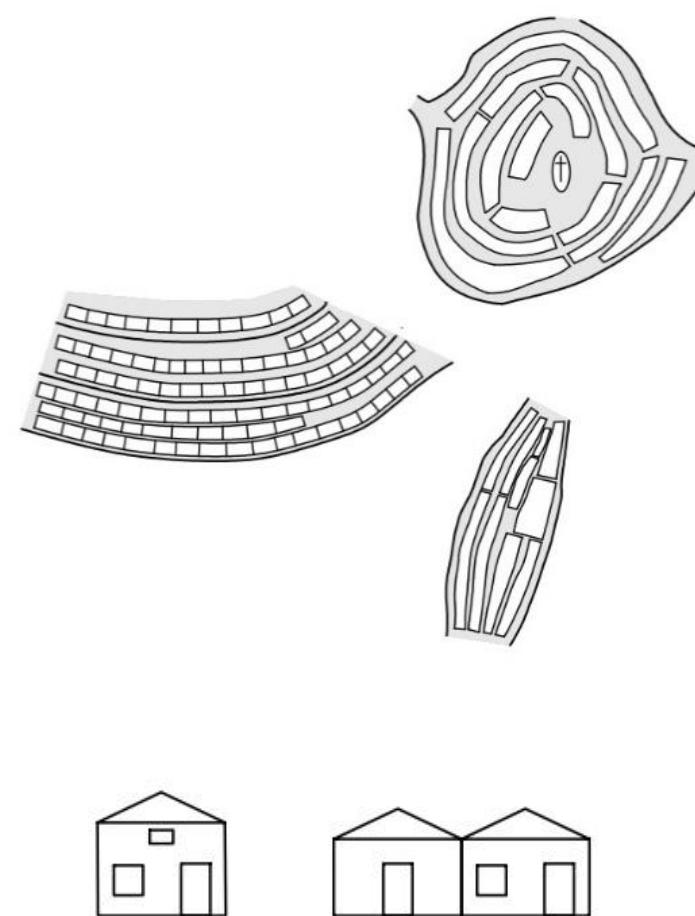
A novel Open BIM approach for Finite Element Analysis



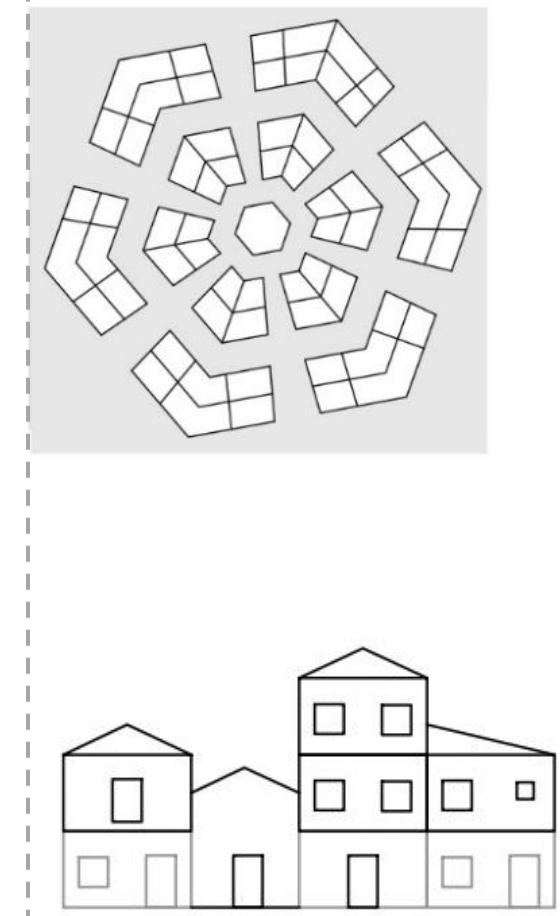
Scope and motivation

A novel Open BIM approach for Finite Element Analysis

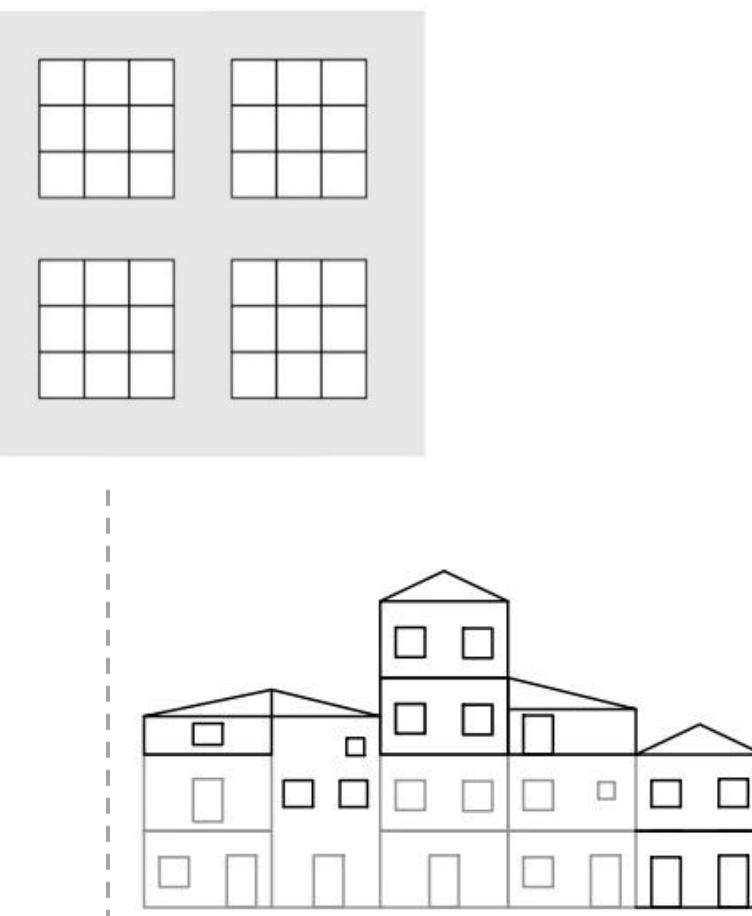
Middle age



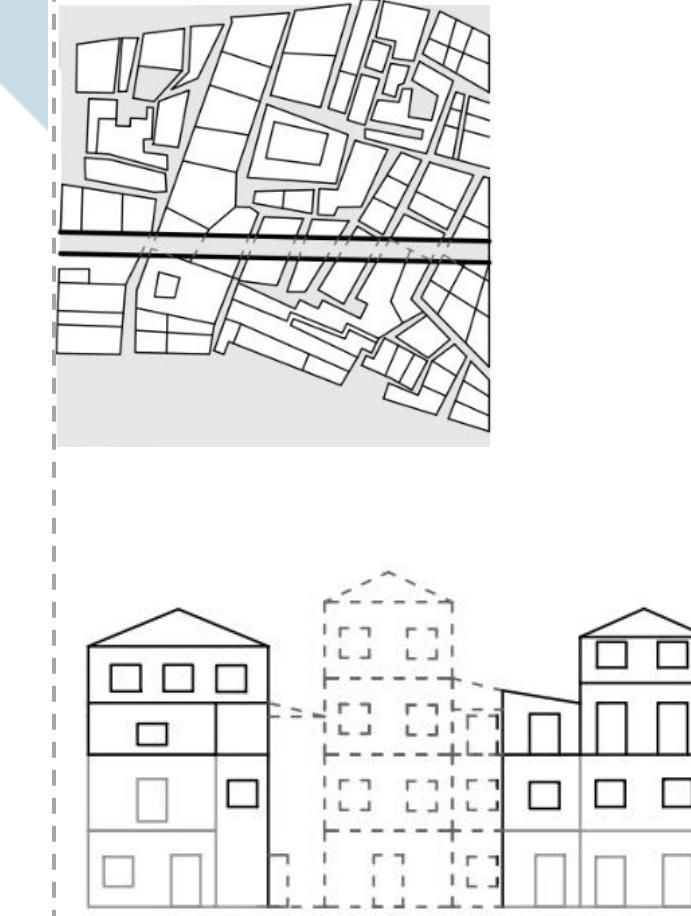
Renaissance



Baroque



19 century



20 century



Scope and motivation

A novel Open BIM approach for Finite Element Analysis



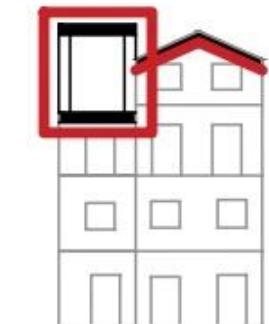
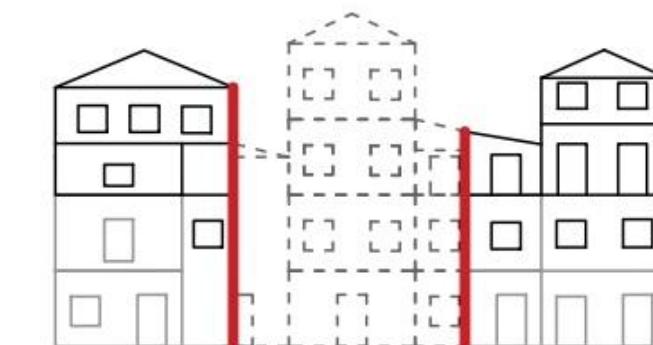
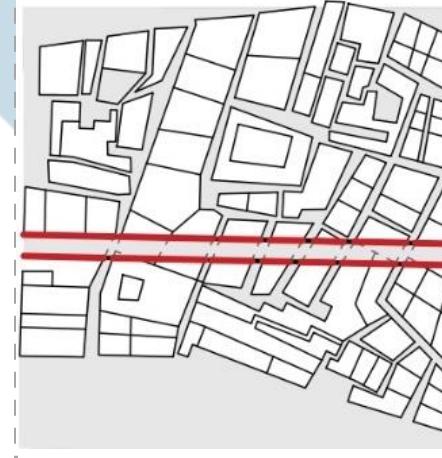
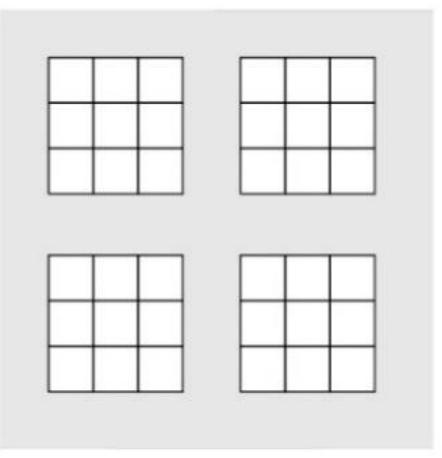
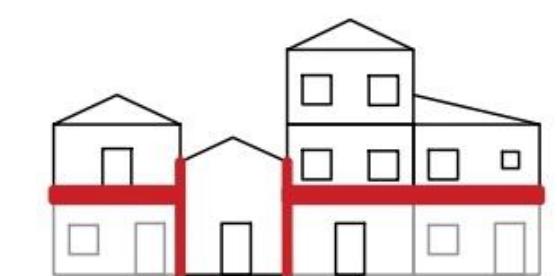
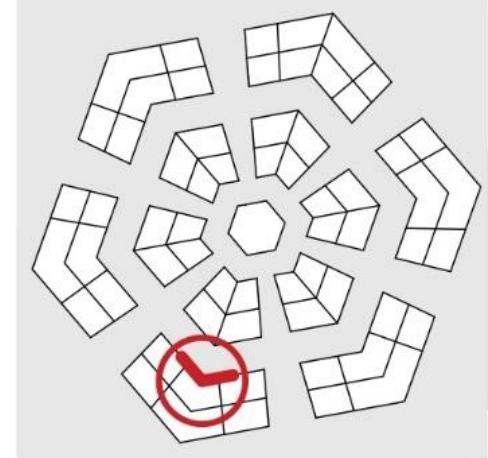
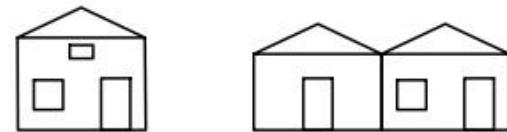
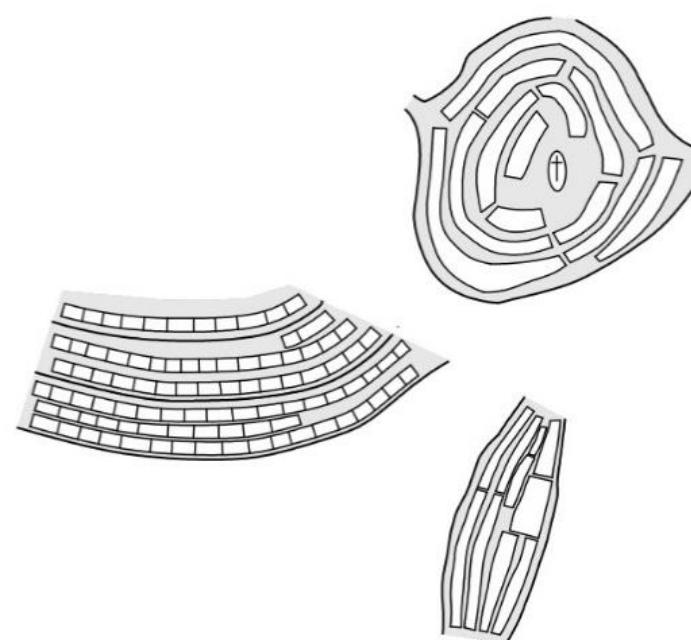
Middle age

Renaissance

Baroque

19 century

20 century



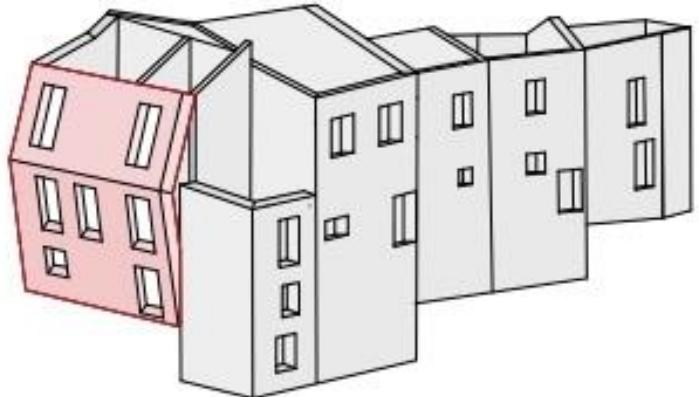
Seismic assessment of masonry aggregates

Existing methods and limitations

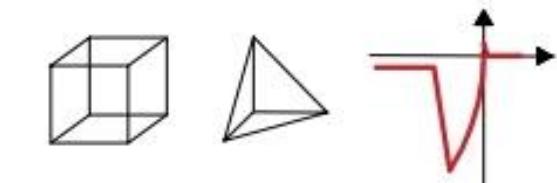
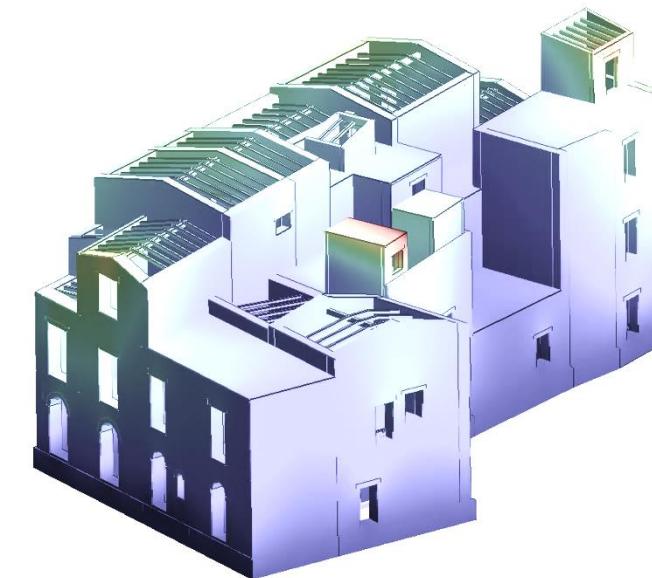
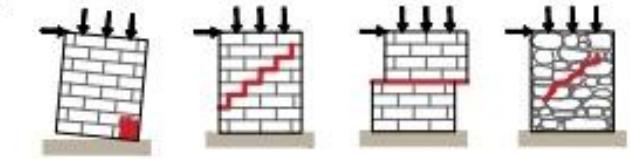
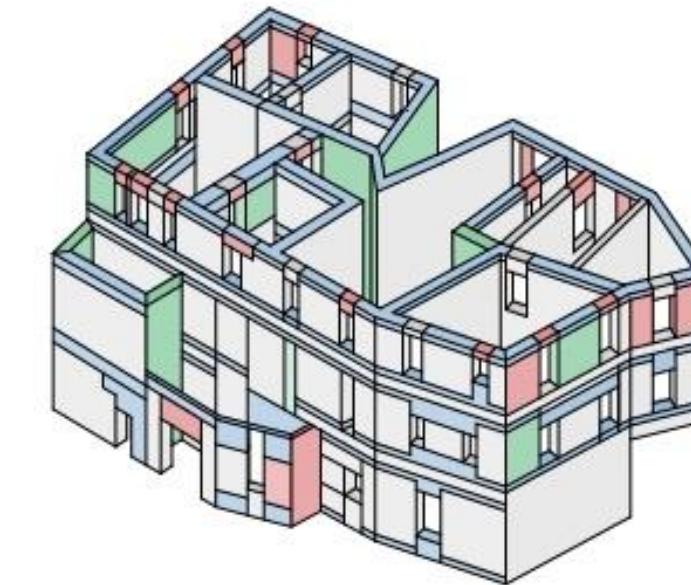
Large scale assessment



Local analysis



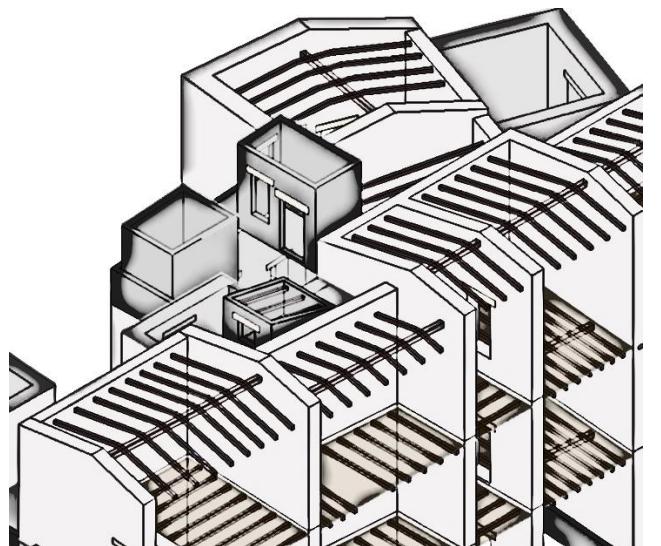
Global models



Continuous solid finite element method

Main challenges of the traditional method

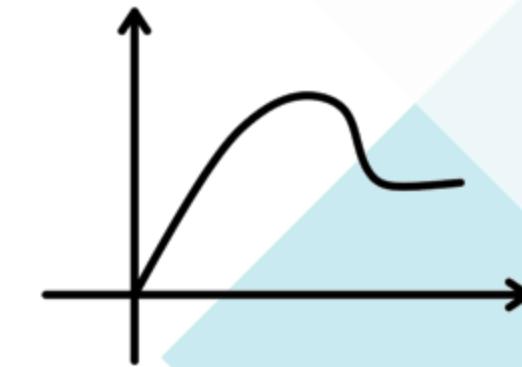
complex geometry



high computational costs



convergency issues



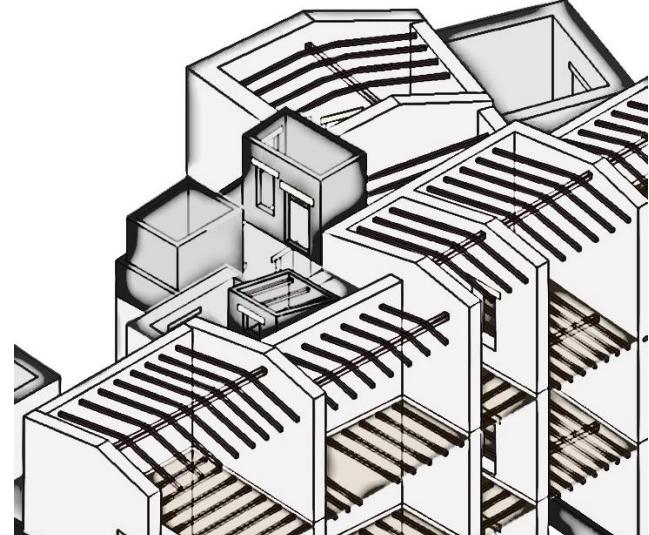
Continuous solid finite element method

Proposed methodology

complex geometry



integration with BIM



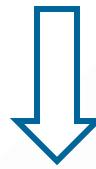
high computational costs



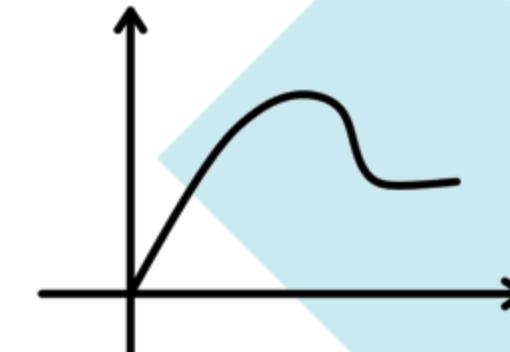
finite element code parallelisation



convergency issues



use of mixed algorithm



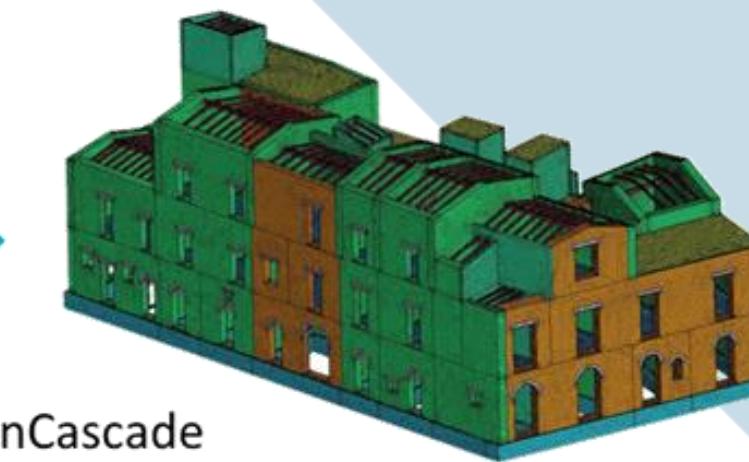
Continuous solid finite element method

Proposed methodology

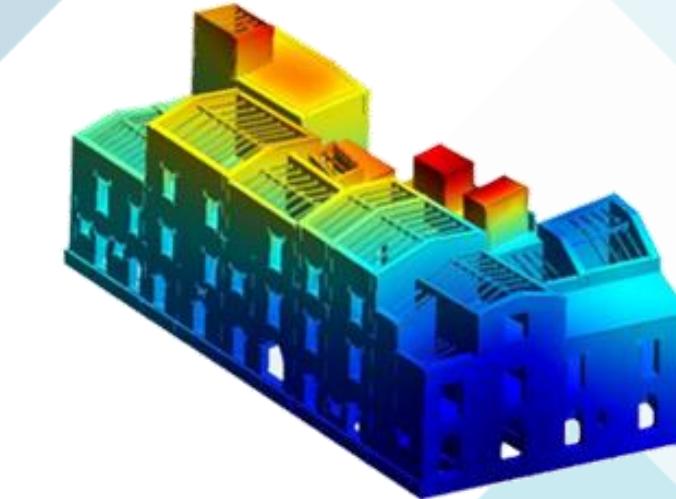
IFC model



FEM mesh



FEM results



GitHub



Contents lists available at ScienceDirect

Computers and Structures

journal homepage: www.elsevier.com/locate/compstruc



Scalable BIM based open workflow for structural analysis of masonry building aggregates

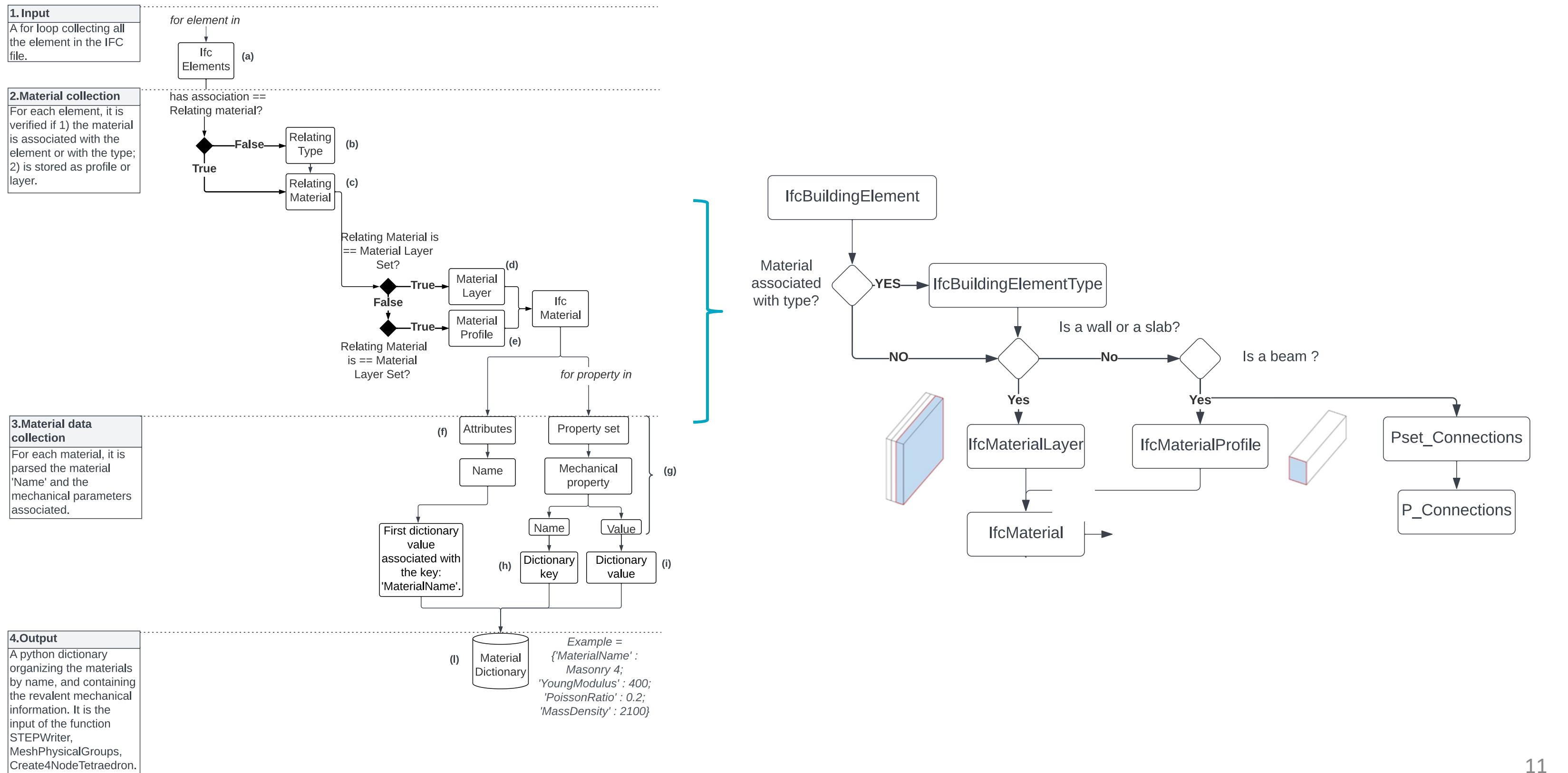
Maria Laura Leonardi*, José Granja, Daniel V. Oliveira, Miguel Azenha

University of Minho, ISISE, ARISE, Department of Civil Engineering, Guimarães, Portugal



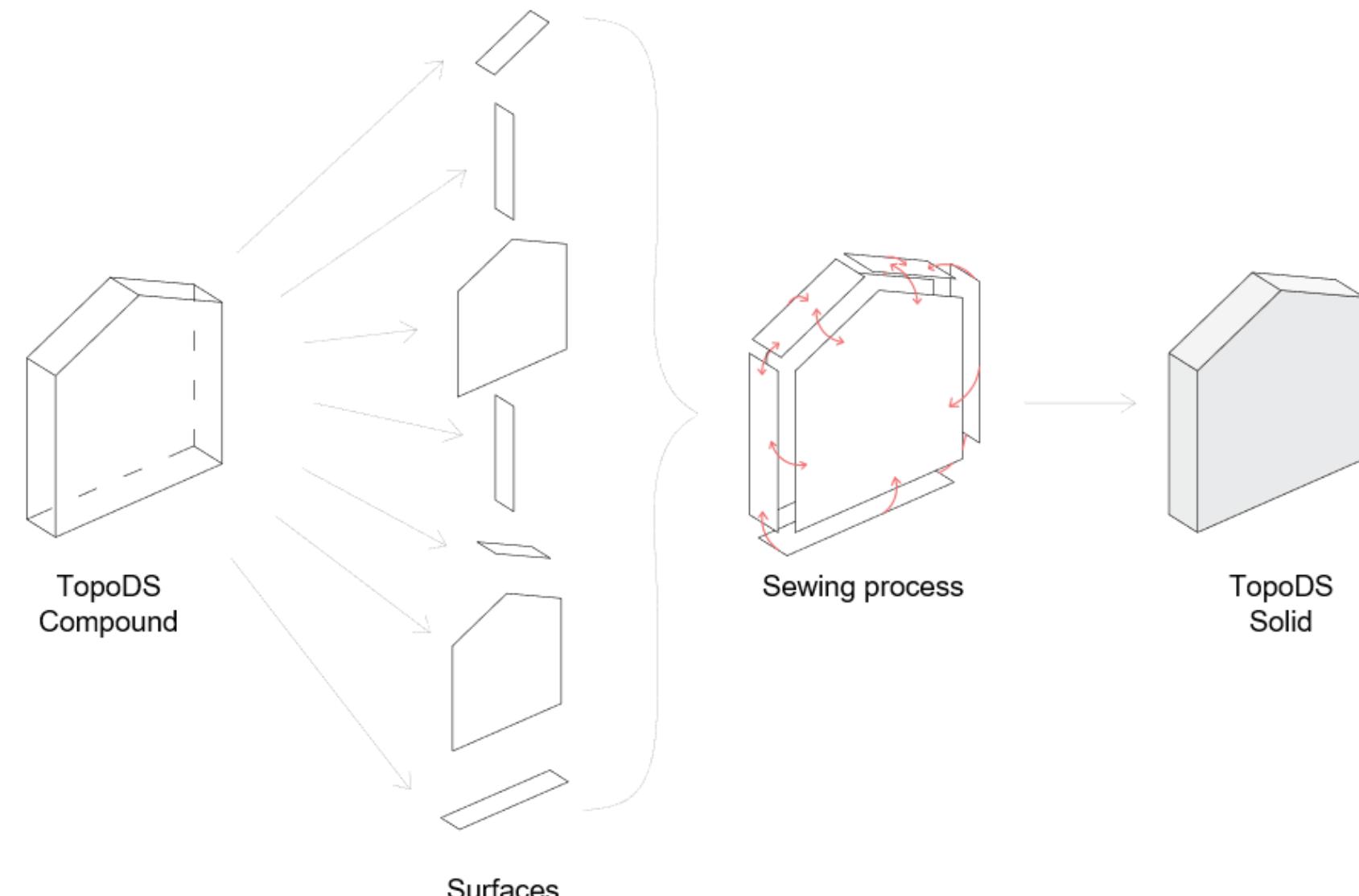
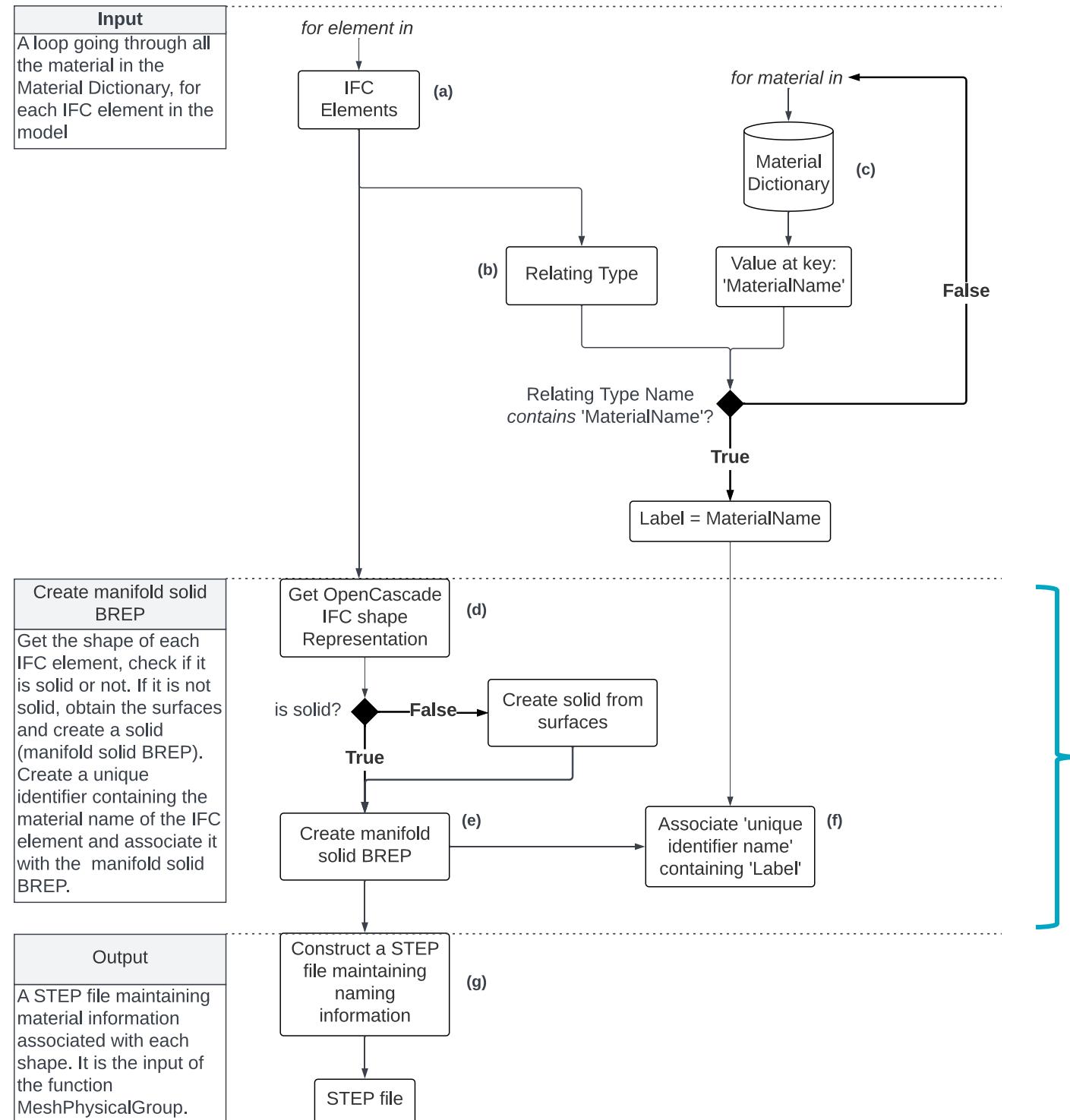
Developed algorithms

Alphanumeric properties



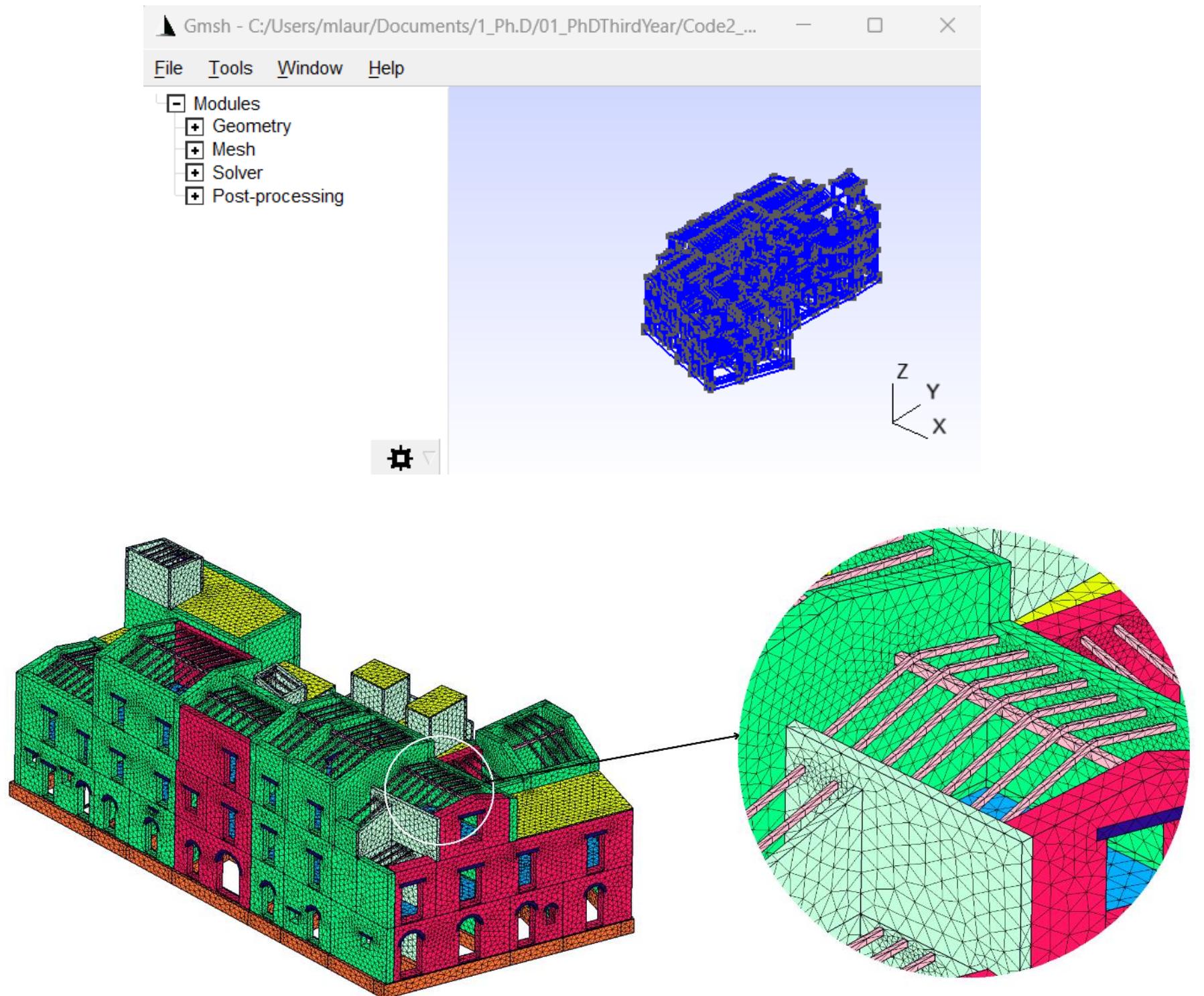
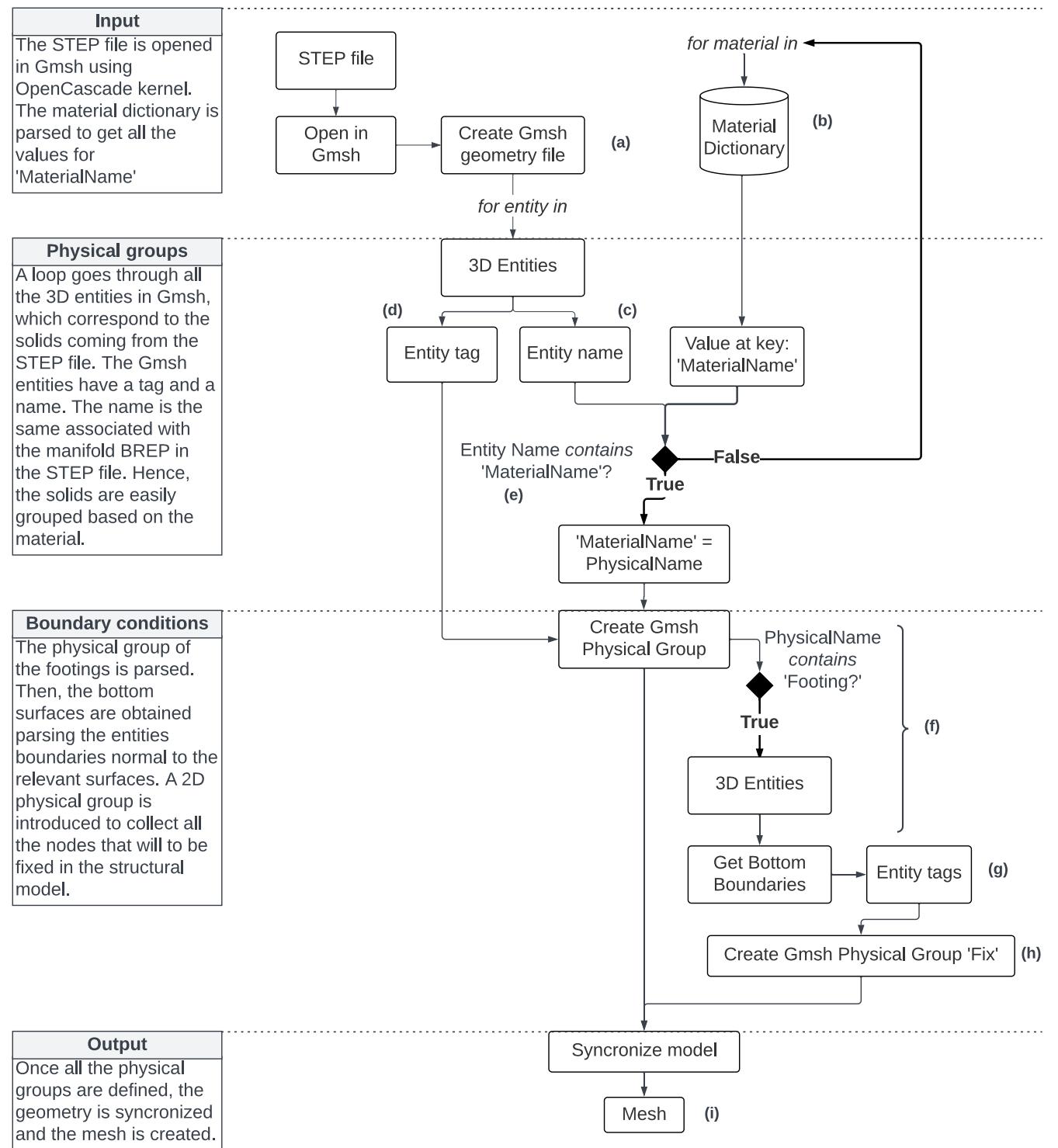
Developed algorithms

Geometry



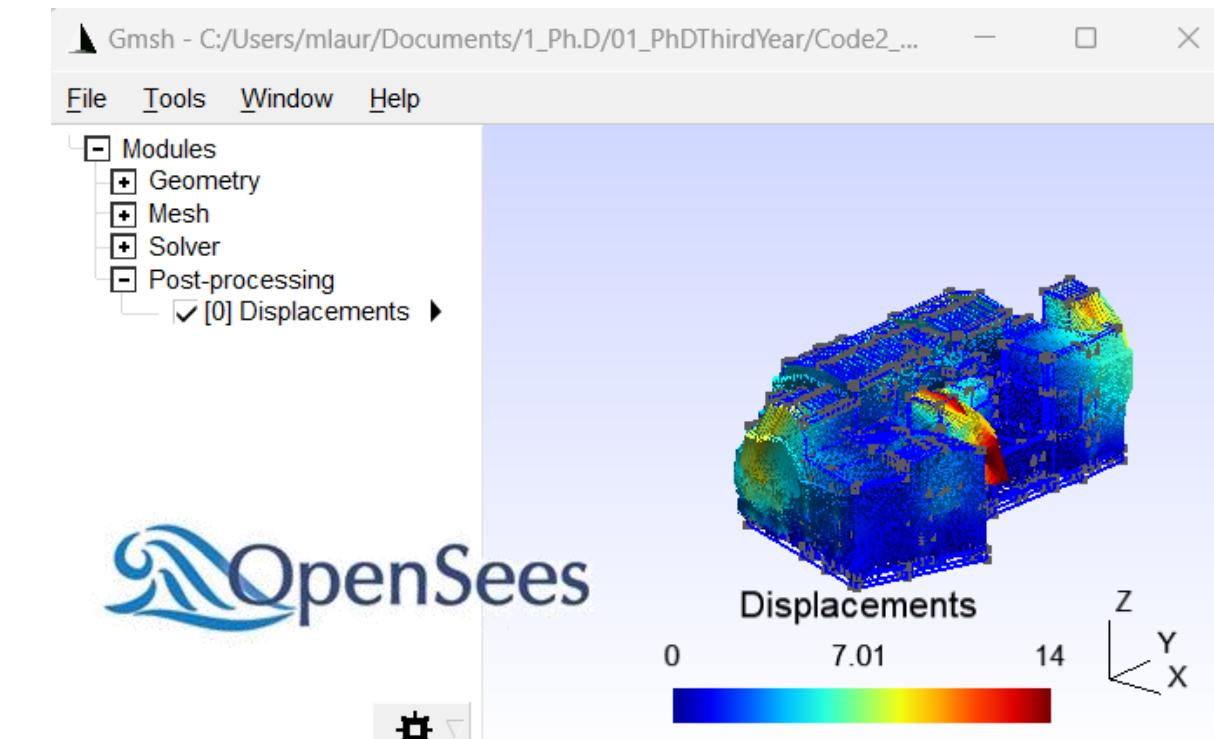
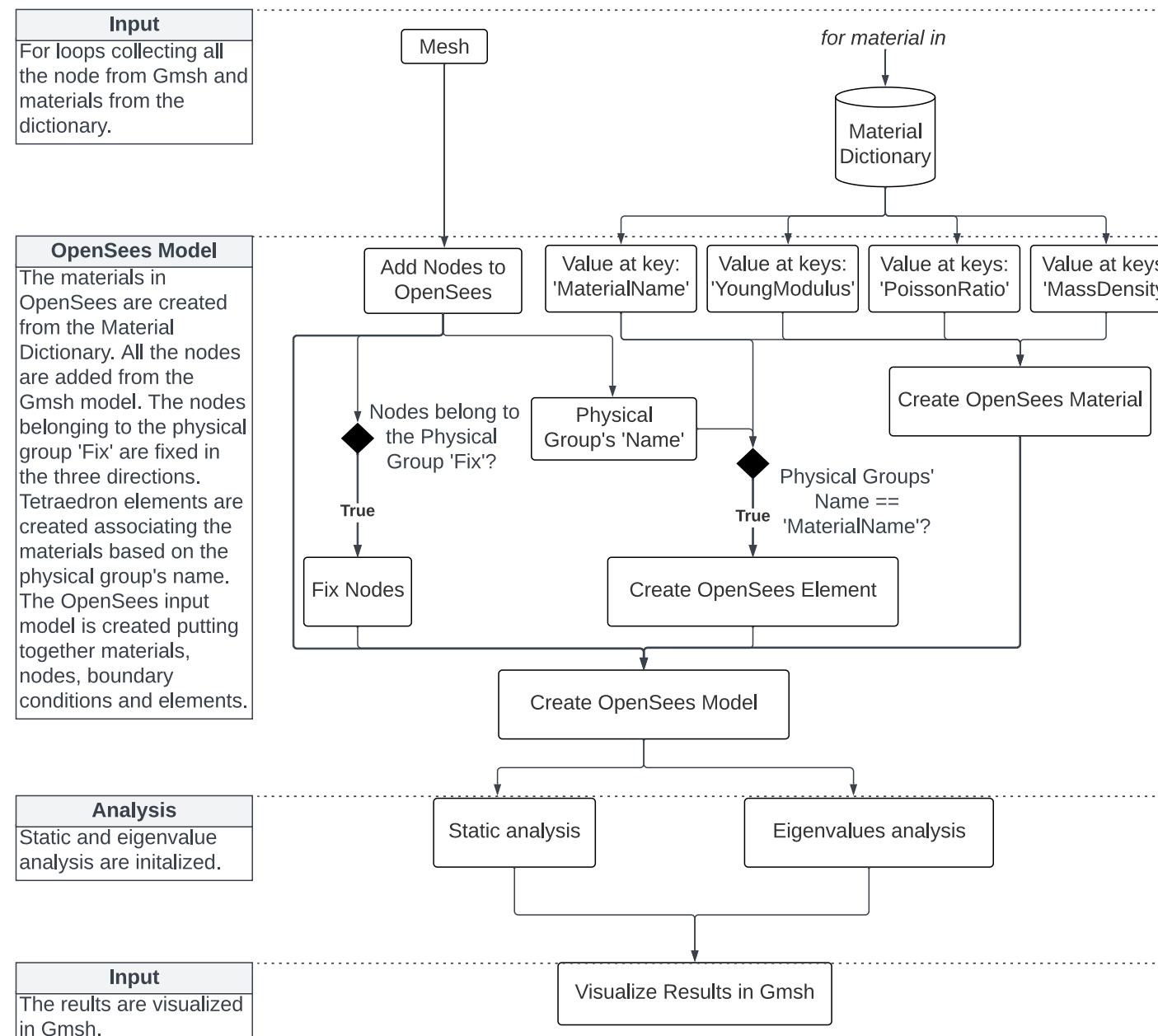
Developed algorithms

Mesh



Developed algorithms

Analyses



revista portuguesa de
engenharia de estruturas
portuguese journal of structural engineering

EVALUATION OF THE SEISMIC BEHAVIOUR OF TRADITIONAL MASONRY
BUILDINGS USING AN INNOVATIVE BIM-BASED APPROACH

MARIA LAURA
LEONARDI
Aluna de
doutoramento
ISISE

MIGUEL
AZENHA
Professor
Associado
ISISE

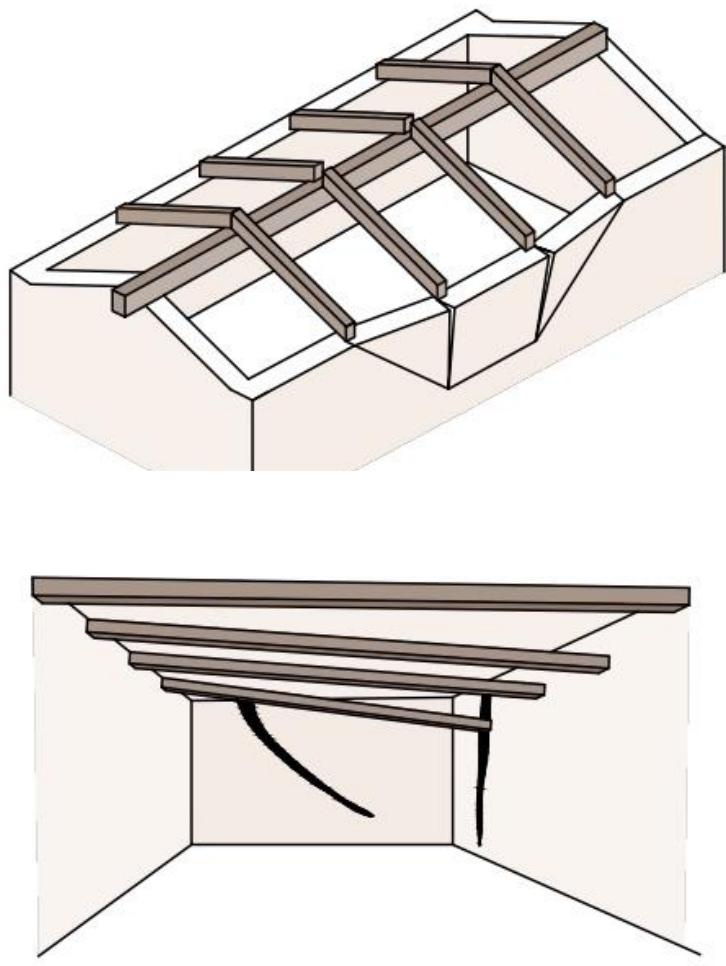
DANIEL V.
OLIVEIRA
Professor
Associado
ISISE

2

Modeling timber-masonry connections

Presence of discontinuities in the structure

Timber – masonry connection



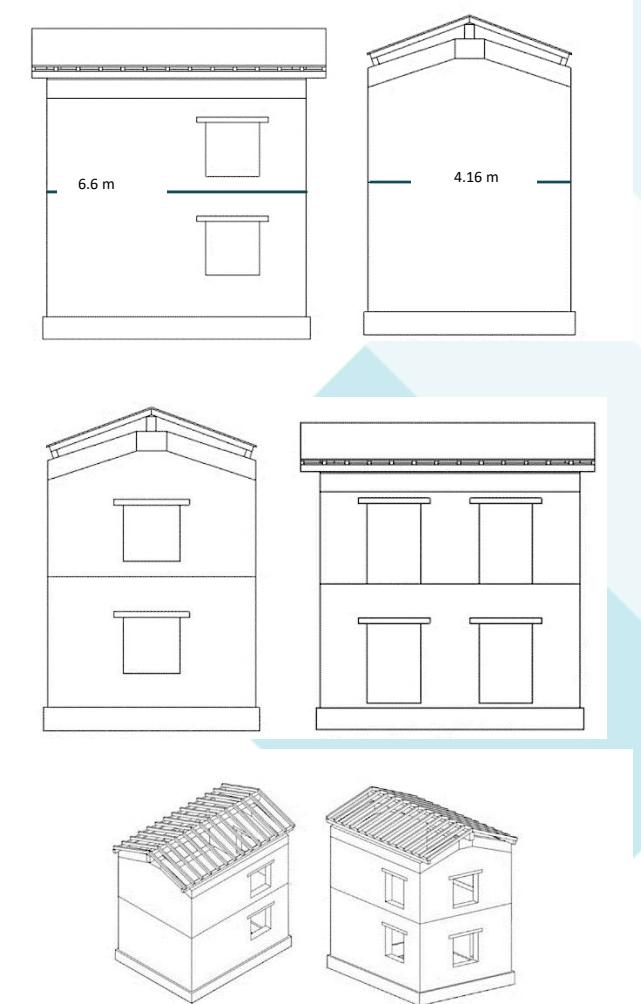
Adapted from (Giuffre, 2010)



Full scale unreinforced masonry building tested in EUCENTRE



Magenes et al., 2015



Practical application

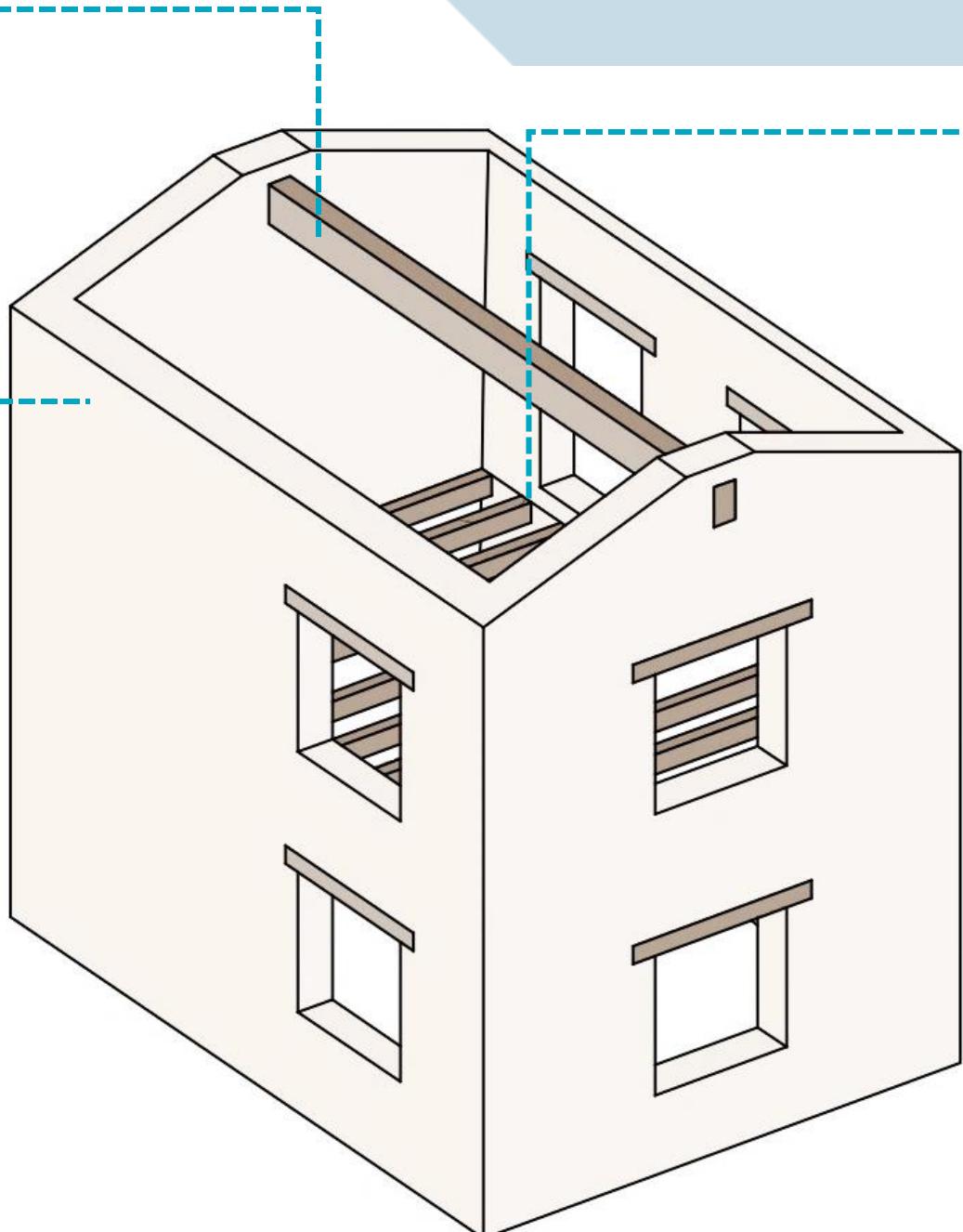
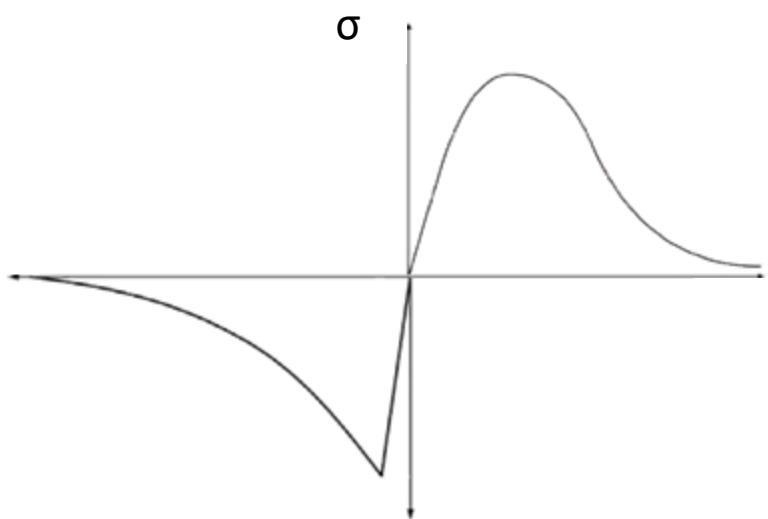
Modeling assumptions

Timber – Linear elastic

Mass density	588	kg/m ³
Young modulus	10000	Mpa
Poisson ratio	0.3	-

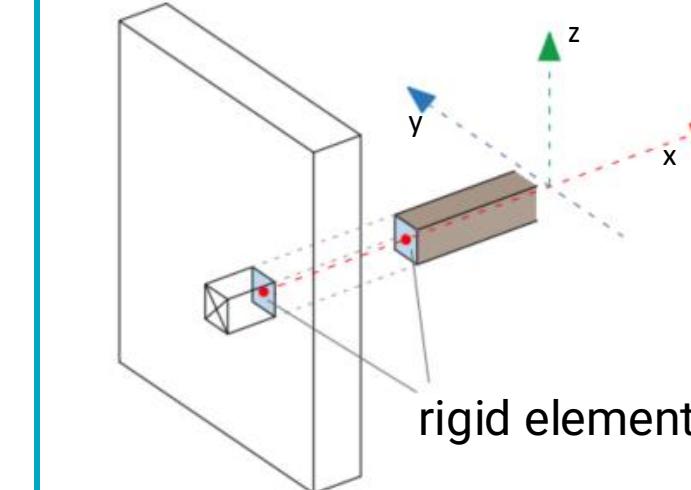
Masonry – ASD Concrete 3D

Mass density	2100	kg/m ³
Young modulus	2537	Mpa
Poisson ratio	0.2	-
Tensile strength	0.138	MPa
Compressive Strength	3.28	Mpa
Fracture energy (comp.)	0.01	N/mm
Fracture energy (tensile)	2	N/mm



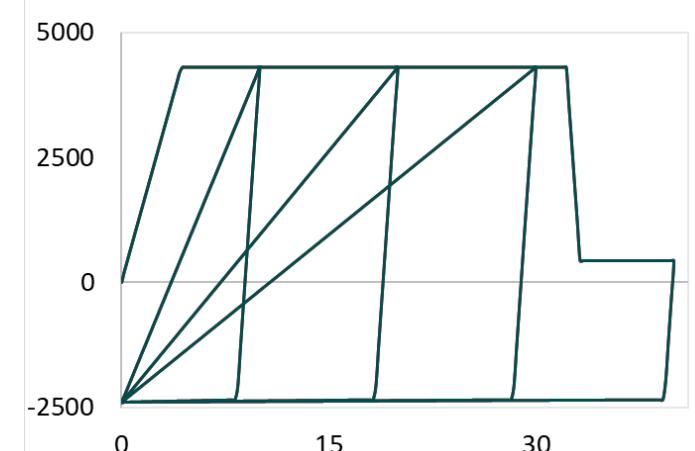
Timber-masonry connections

zero-length element



- Translation along Y: rigid
- Translation along Z: rigid
- Rotation around X: rigid
- Rotation around Y: free
- Rotation around Z: free

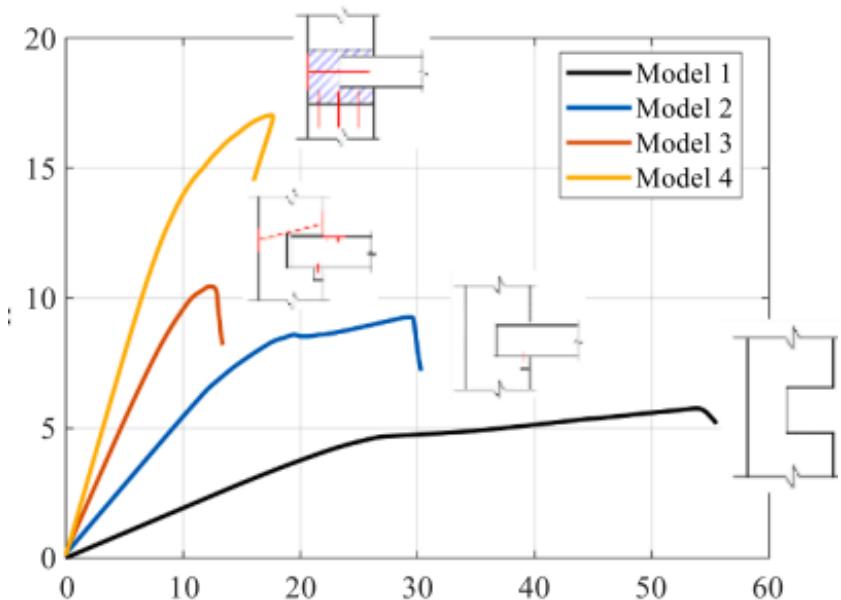
Translation along X axis:



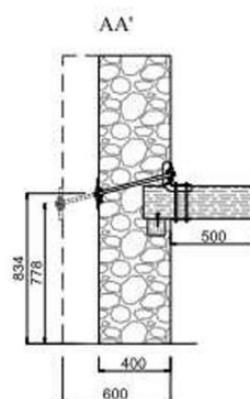
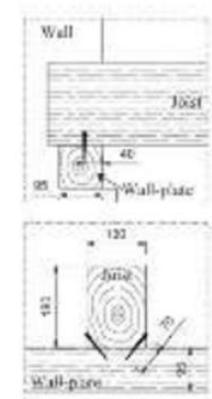
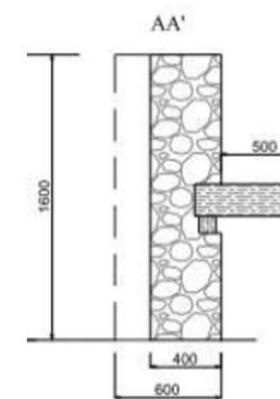
(Solarino et al., 2022)

Practical application

Modeling assumptions

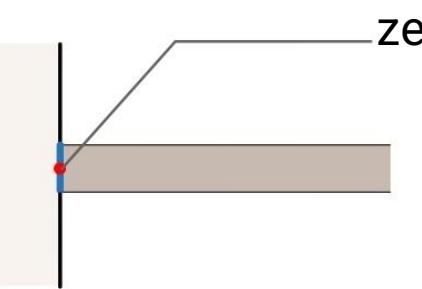


Mechanical model from Solarino et al., 2022

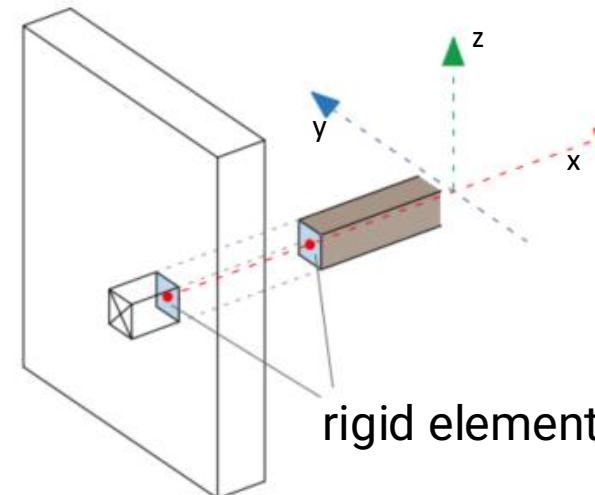


Experimental analysis (Moreira, 2015)

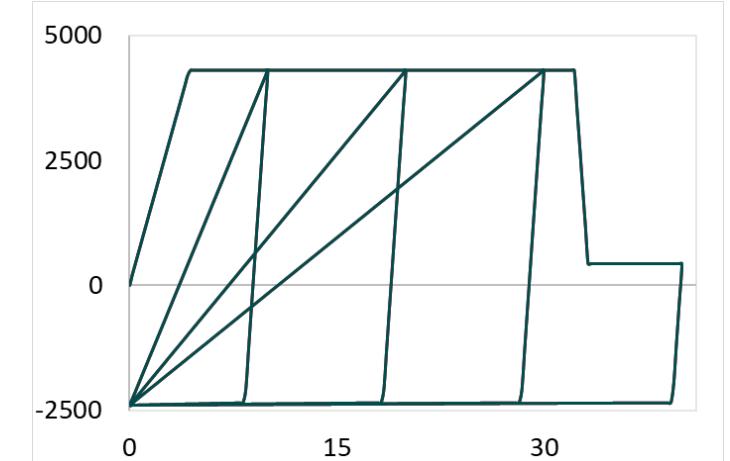
Timber-masonry connections



- Translation along Y: rigid
- Translation along Z: rigid
- Rotation around X: rigid
- Rotation around Y: free
- Rotation around Z: free



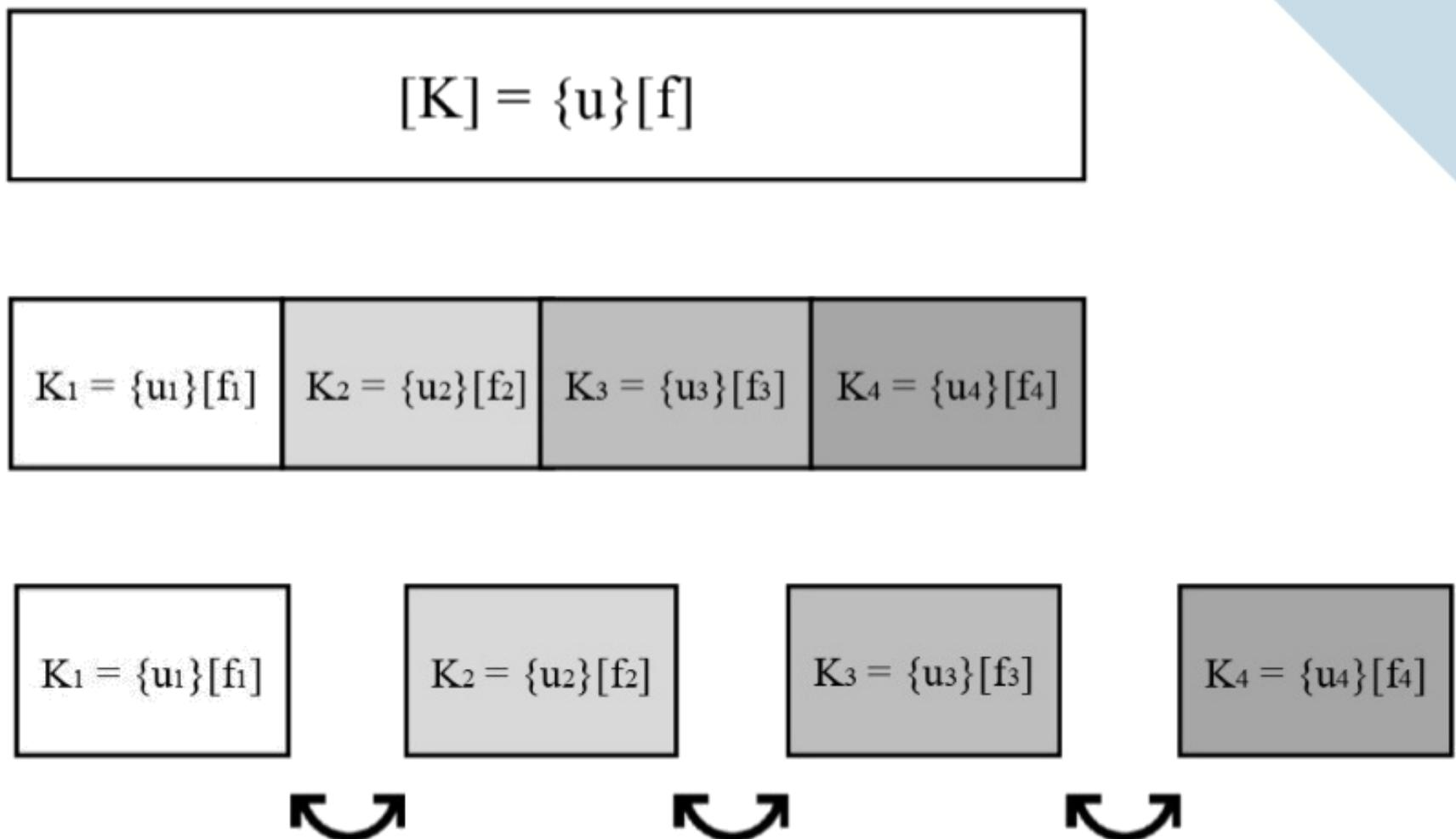
Translation along X axis:



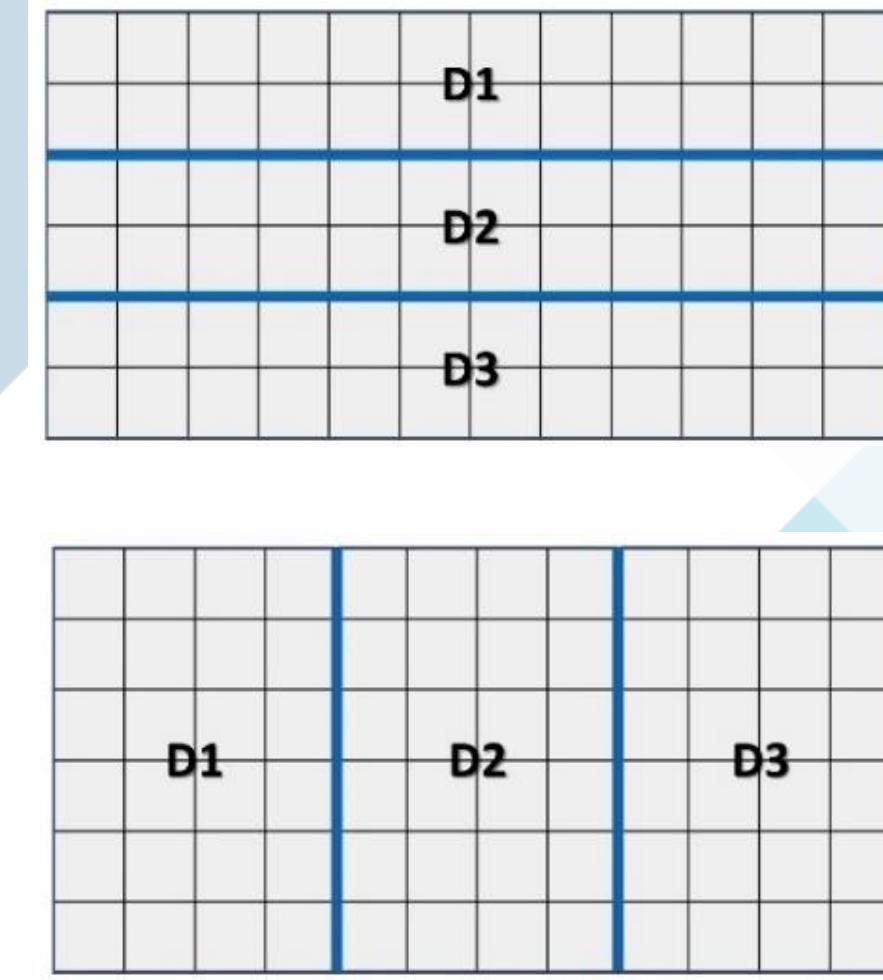
(Solarino et al., 2022)

Practical application

Parallelisation of finite element code



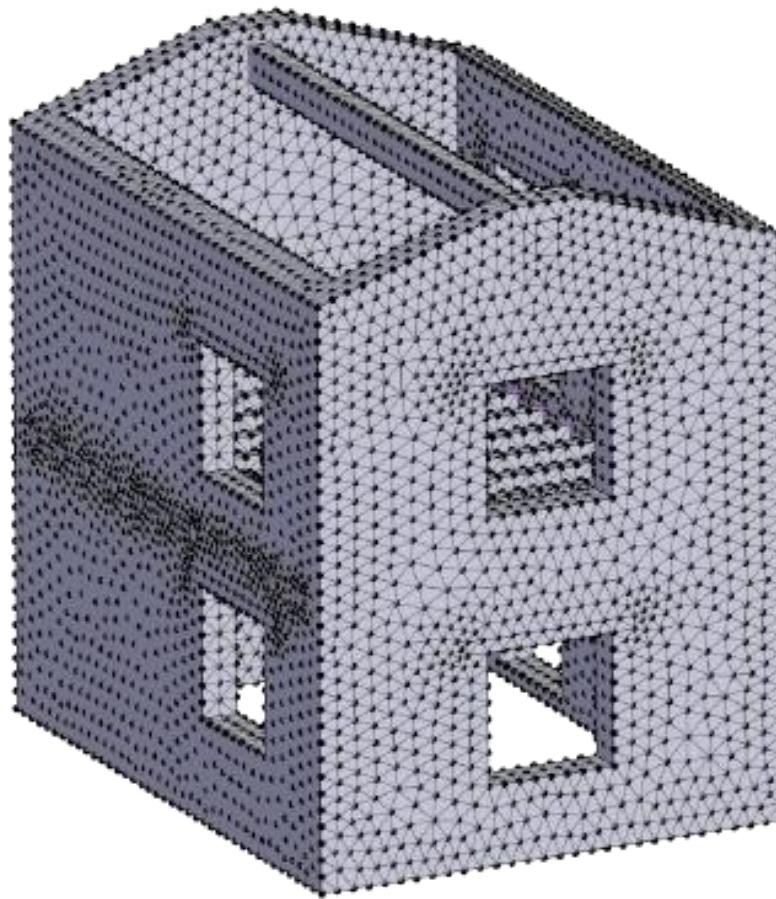
Decomposition of the stiffness matrix



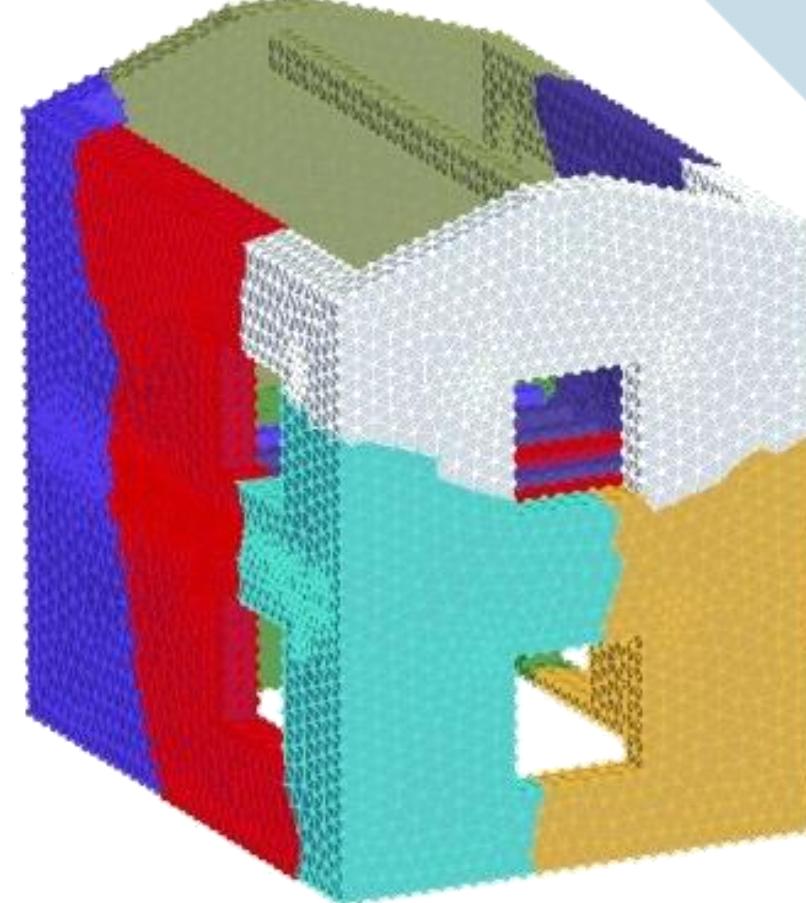
Efficient decomposition

Practical application

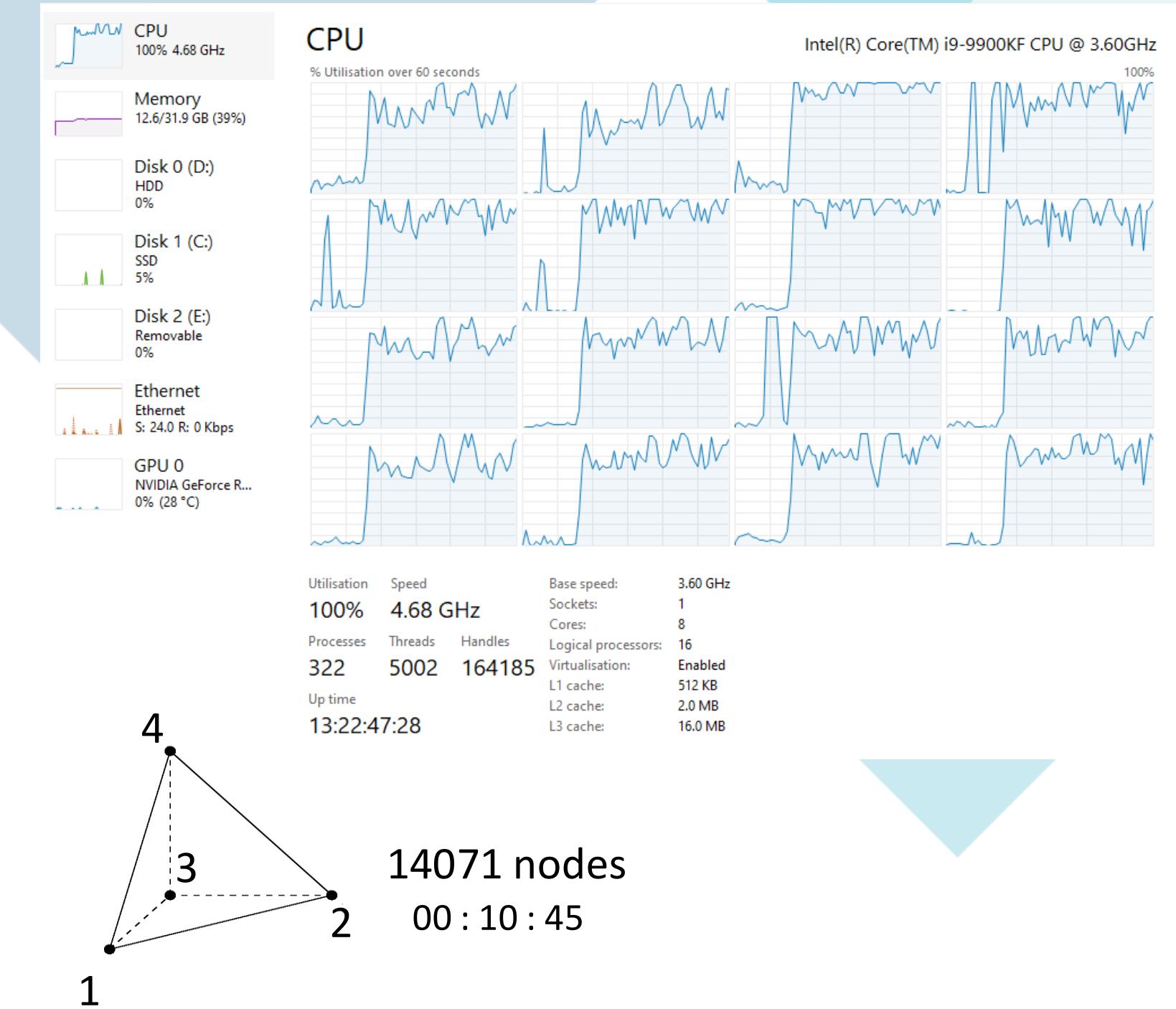
Parallelisation of finite element code



Finite element mesh

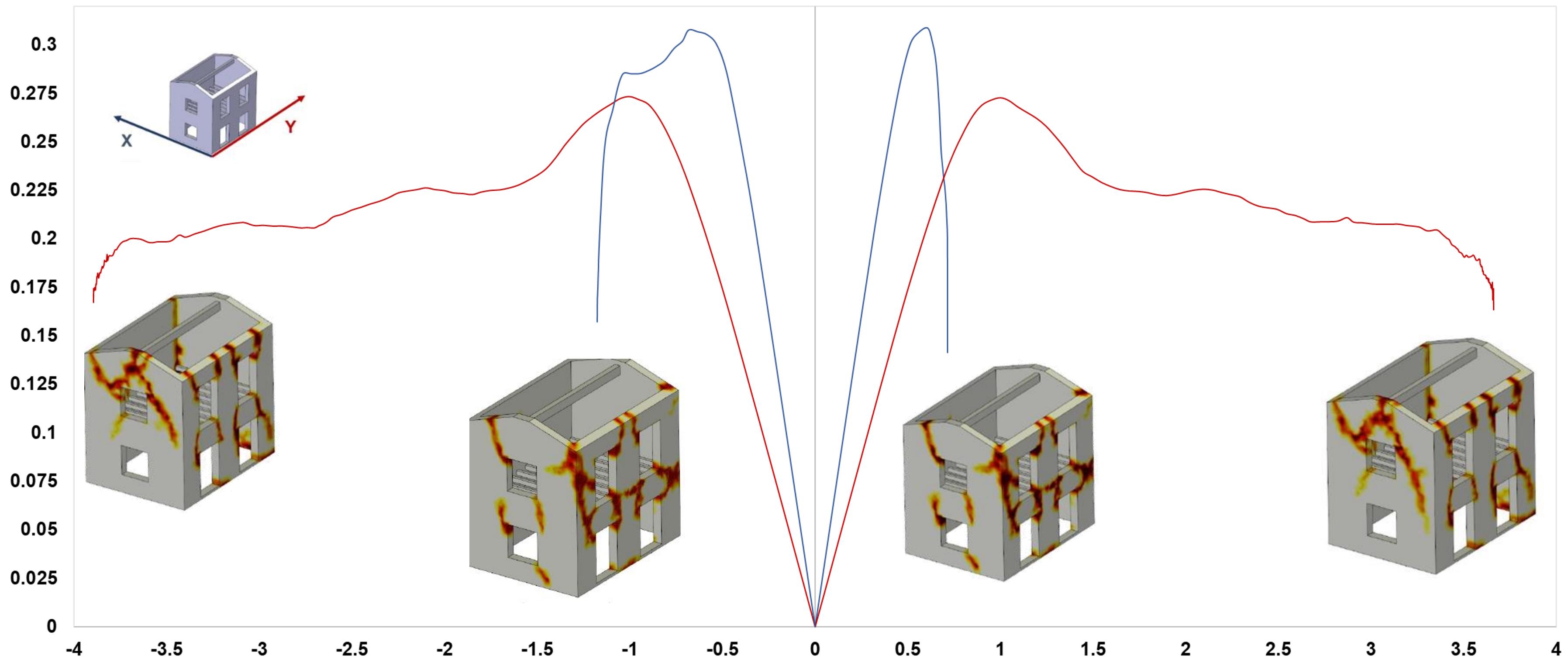


Partition



Results

Pushover analysis



3

The case study of Castelnuovo di Porto

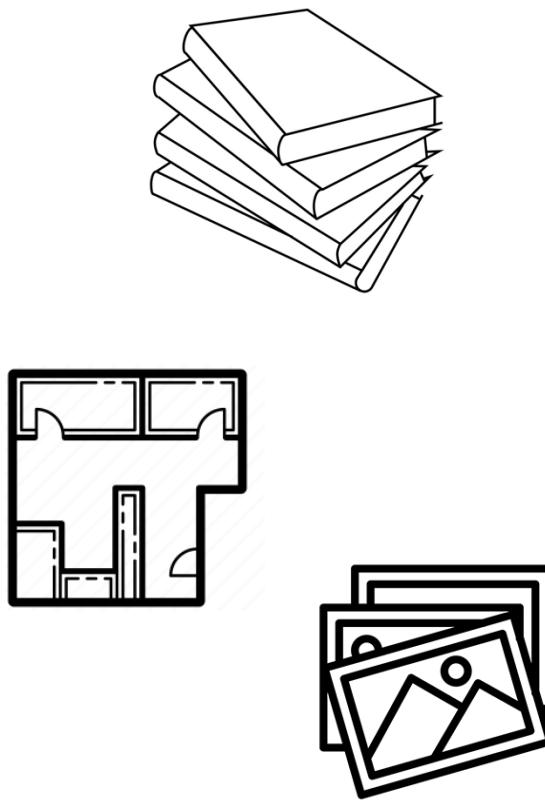
Study case of a real aggregate

The historic center of Castelnuovo di Porto

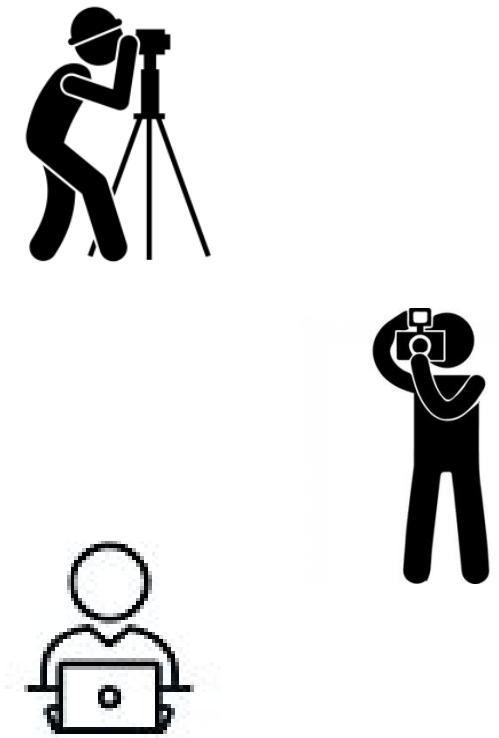


The historic center of Castelnuovo di Porto

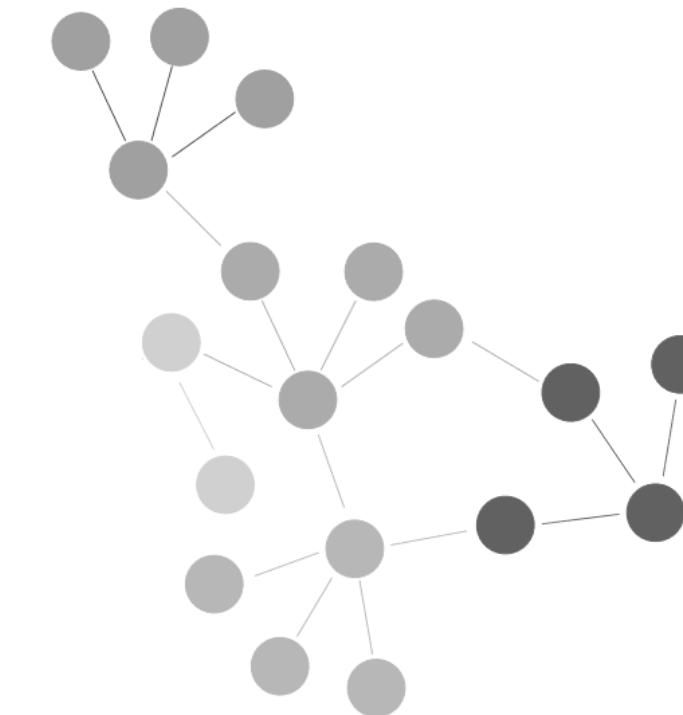
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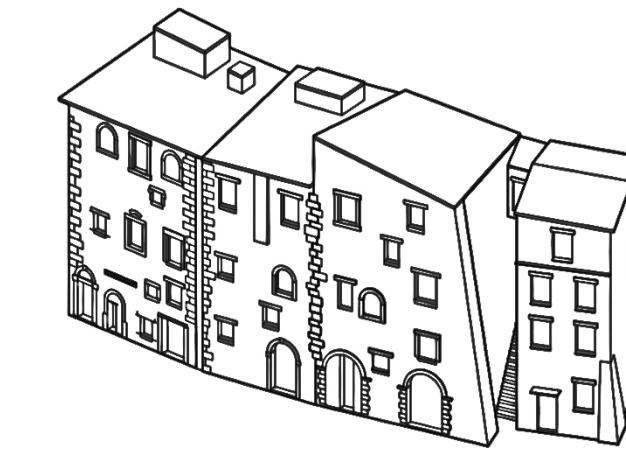
Indirect analysis



Direct analysis



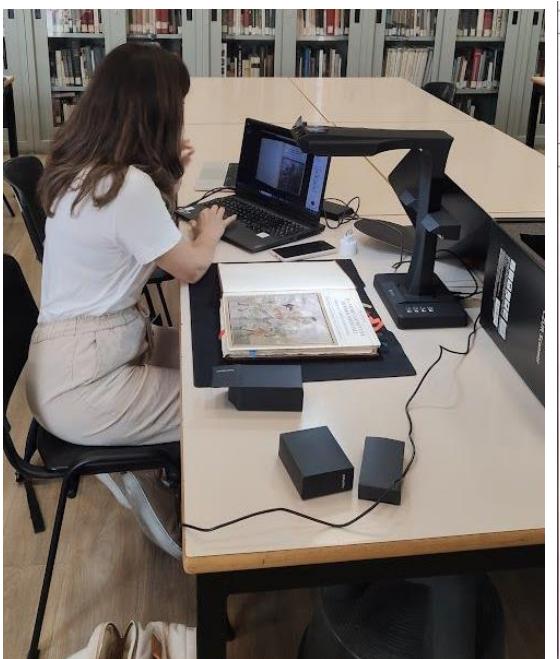
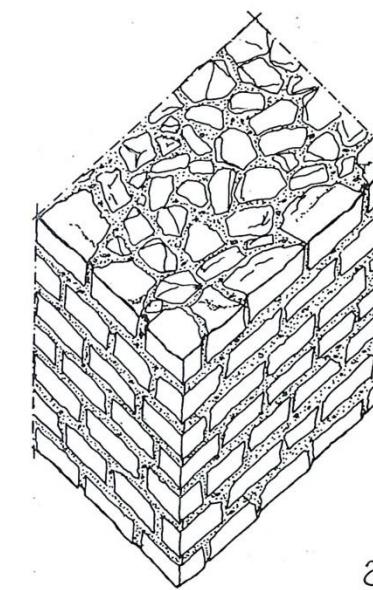
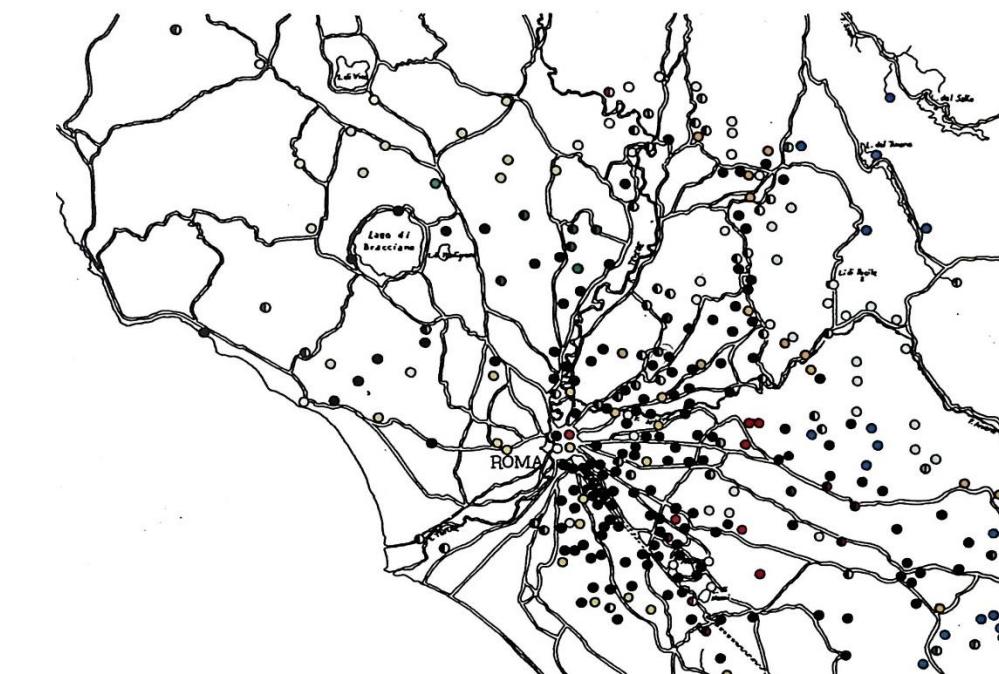
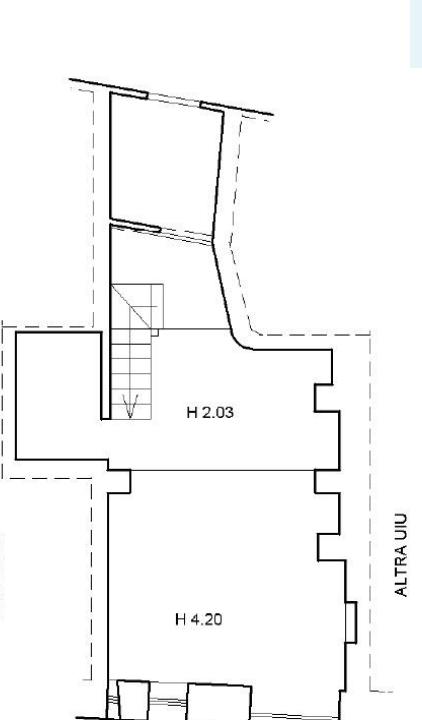
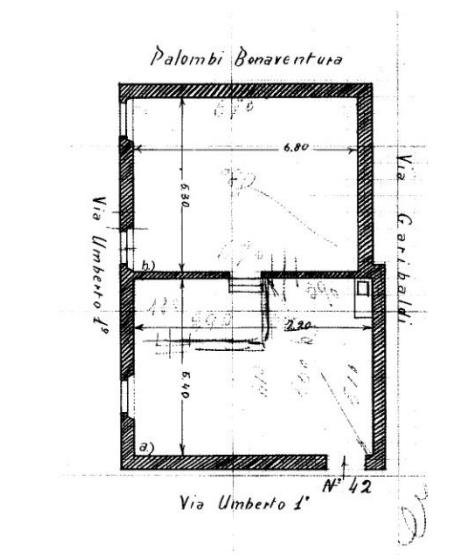
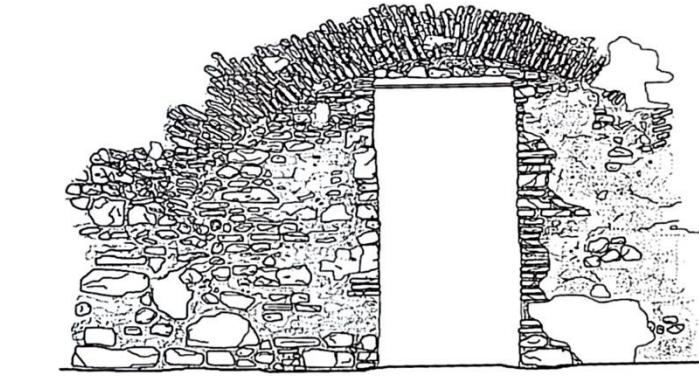
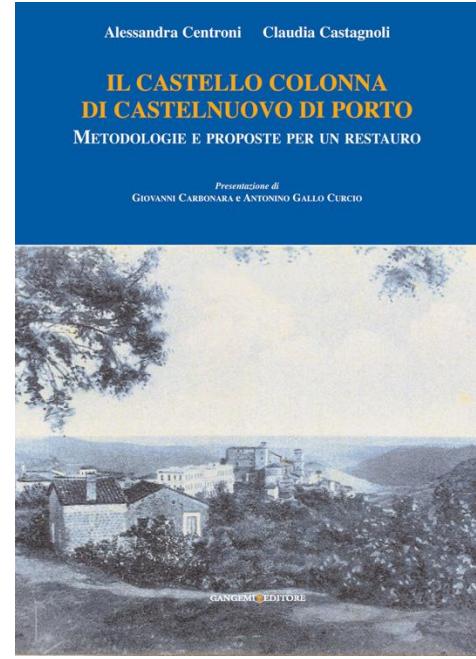
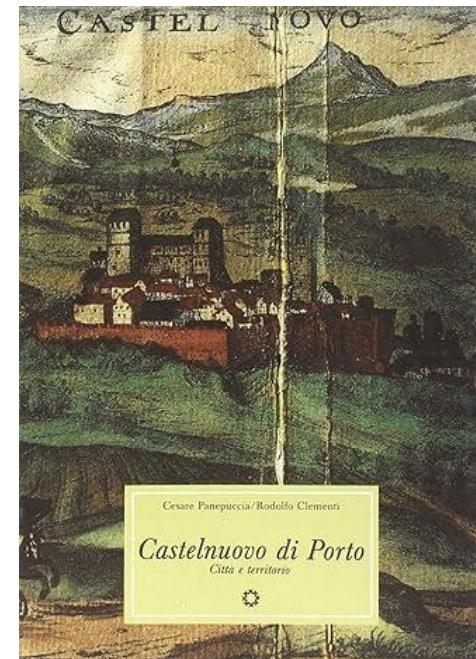
Interpretation



Modeling

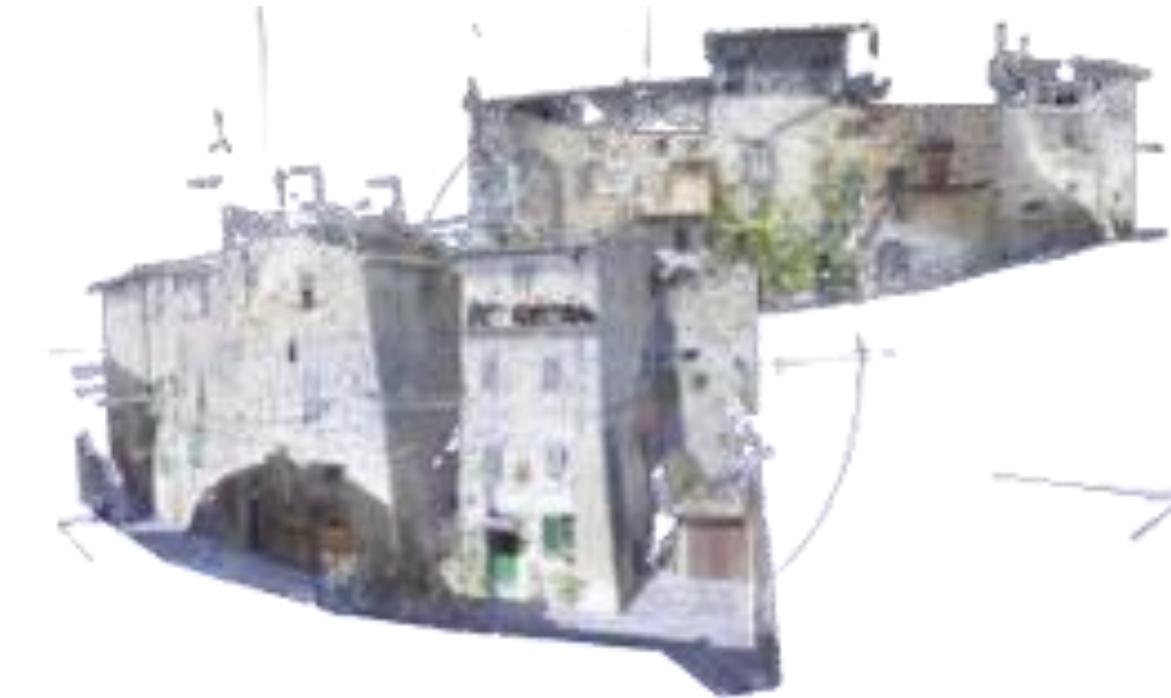
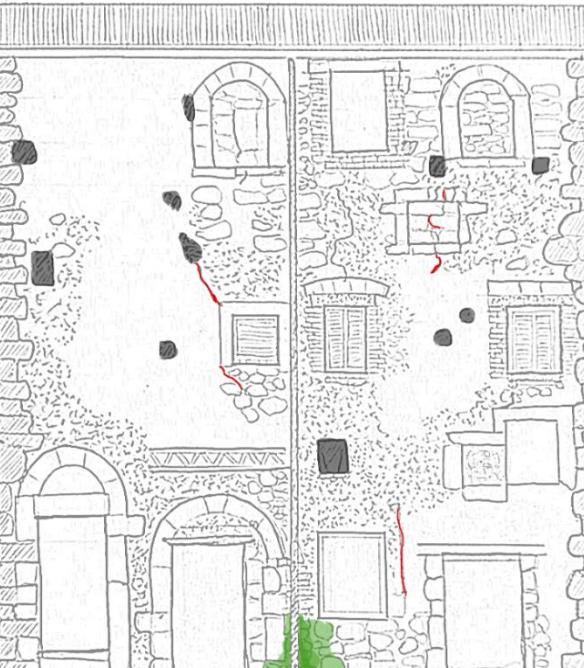
The historic center of Castelnuovo di Porto

Indirect analysis



The historic center of Castelnuovo di Porto

Direct analysis



The historic center of Castelnuovo di Porto

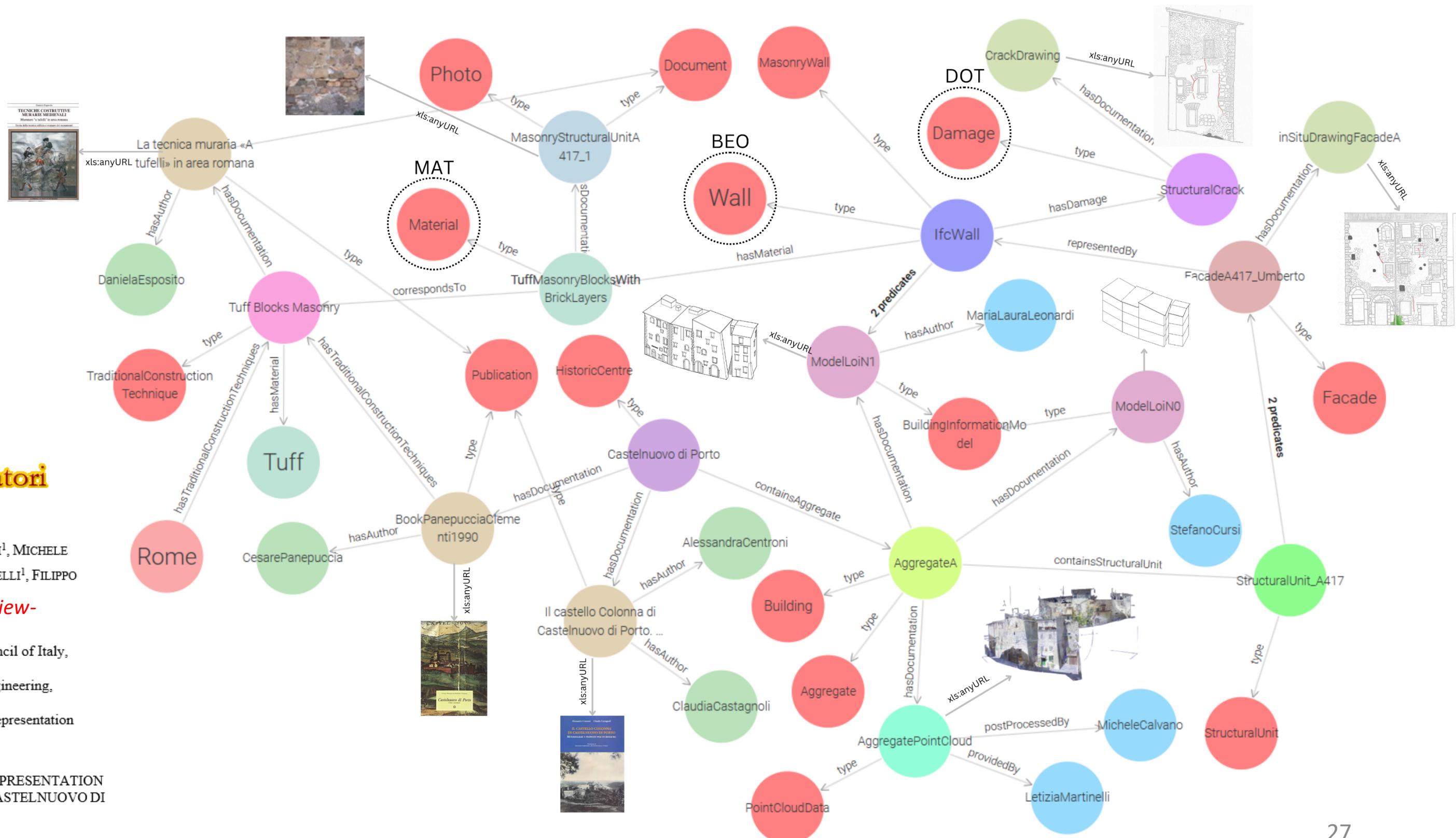


Archeologia e Calcolatori

STEFANO CURSI¹, MARIA LAURA LEONARDI²(*), LETIZIA MARTINELLI¹, MICHELE CALVANO³, MIGUEL AZENHA², DANIEL V. OLIVEIRA², ELENA GIGLIARELLI¹, FILIPPO CALCERANO¹ *-under review-*

-under review

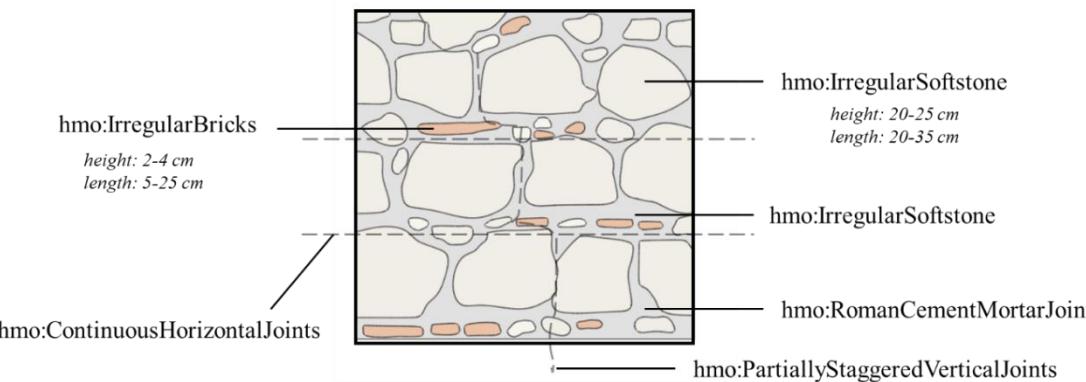
- 1) ISPC Institute of Heritage Science, CNR National Research Council of Italy
Naples, Italy
 - 2) University of Minho, ISISE, ARISE, Department of Civil Engineering,
Guimarães, Portugal
 - 3) Sapienza University of Rome, DSDRA Department of History, Representation
and Restoration of Architecture, Rome, Italy



The historic center of Castelnuovo di Porto

Interpretation – Mechanical properties

<https://w3id.org/hmo/0.1>
<https://w3id.org/fmo/0.1>



ITcon

www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753
LEVERAGING SEMANTIC WEB RULE LANGUAGES TO DEFINE MODELING ASSUMPTIONS FOR THE STRUCTURAL ANALYSIS OF UNREINFORCED MASONRY BUILDINGS - *manuscript accepted* -

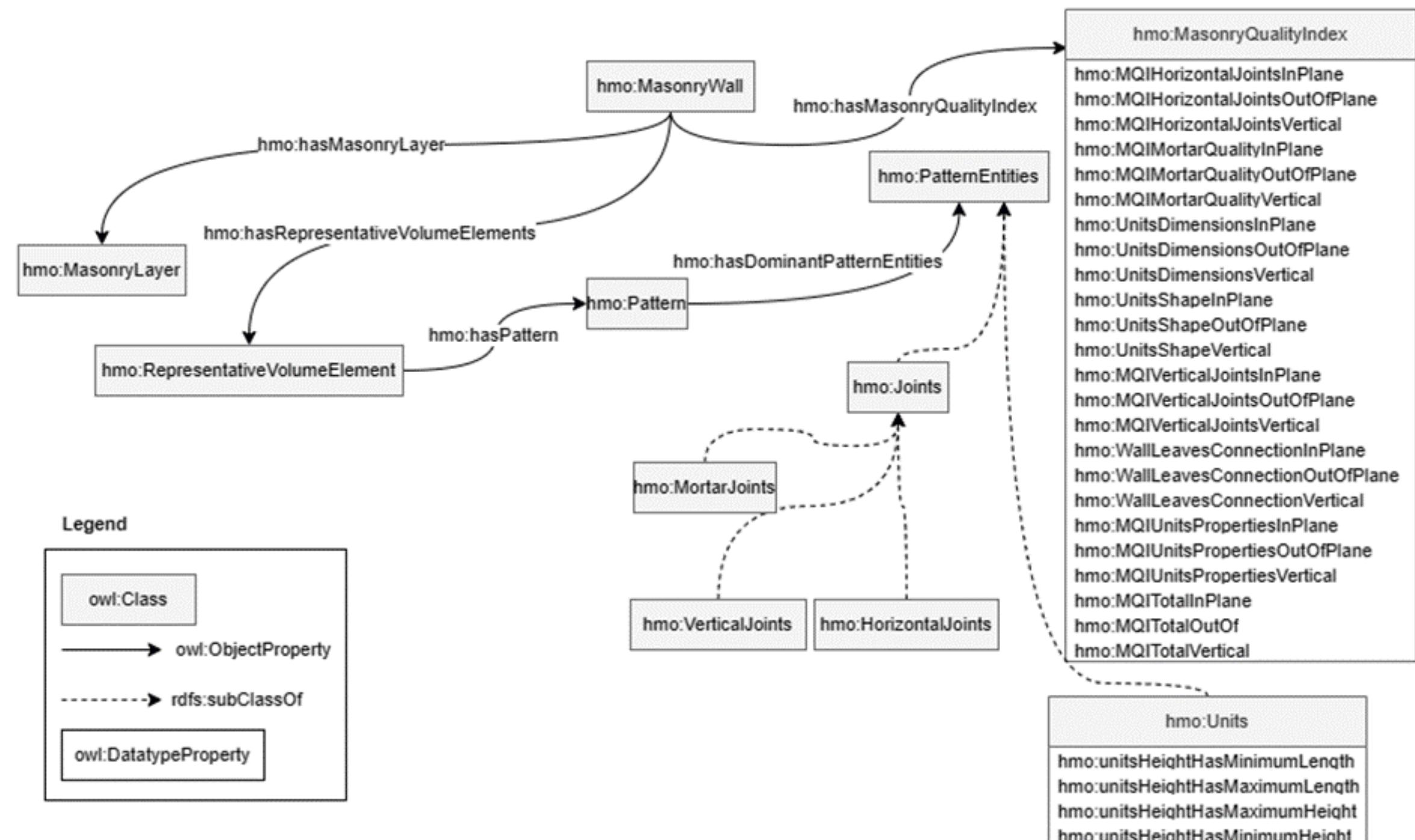
M.L. Leonardi, PhD student,
 University of Minho, ISISE, ARISE, Department of Civil Engineering, Guimarães, Portugal;

S. Cursi, Postdoctoral researcher,
 ISPC Institute of Heritage Science, CNR National Research Council of Italy, (RM), Italy;

E. Gigliarelli, Full Researcher,
 ISPC Institute of Heritage Science, CNR National Research Council of Italy, (RM), Italy;

D.V. Oliveira, Associate Professor,
 University of Minho, ISISE, ARISE, Department of Civil Engineering, Guimarães, Portugal;

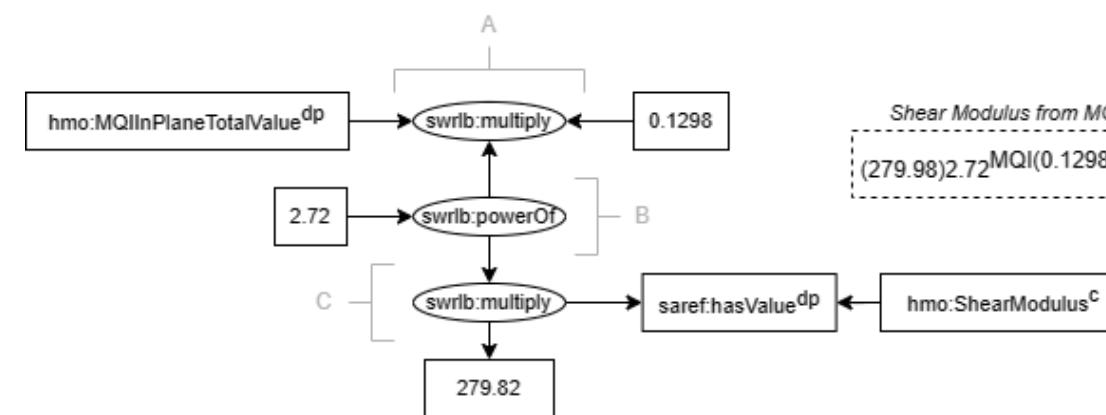
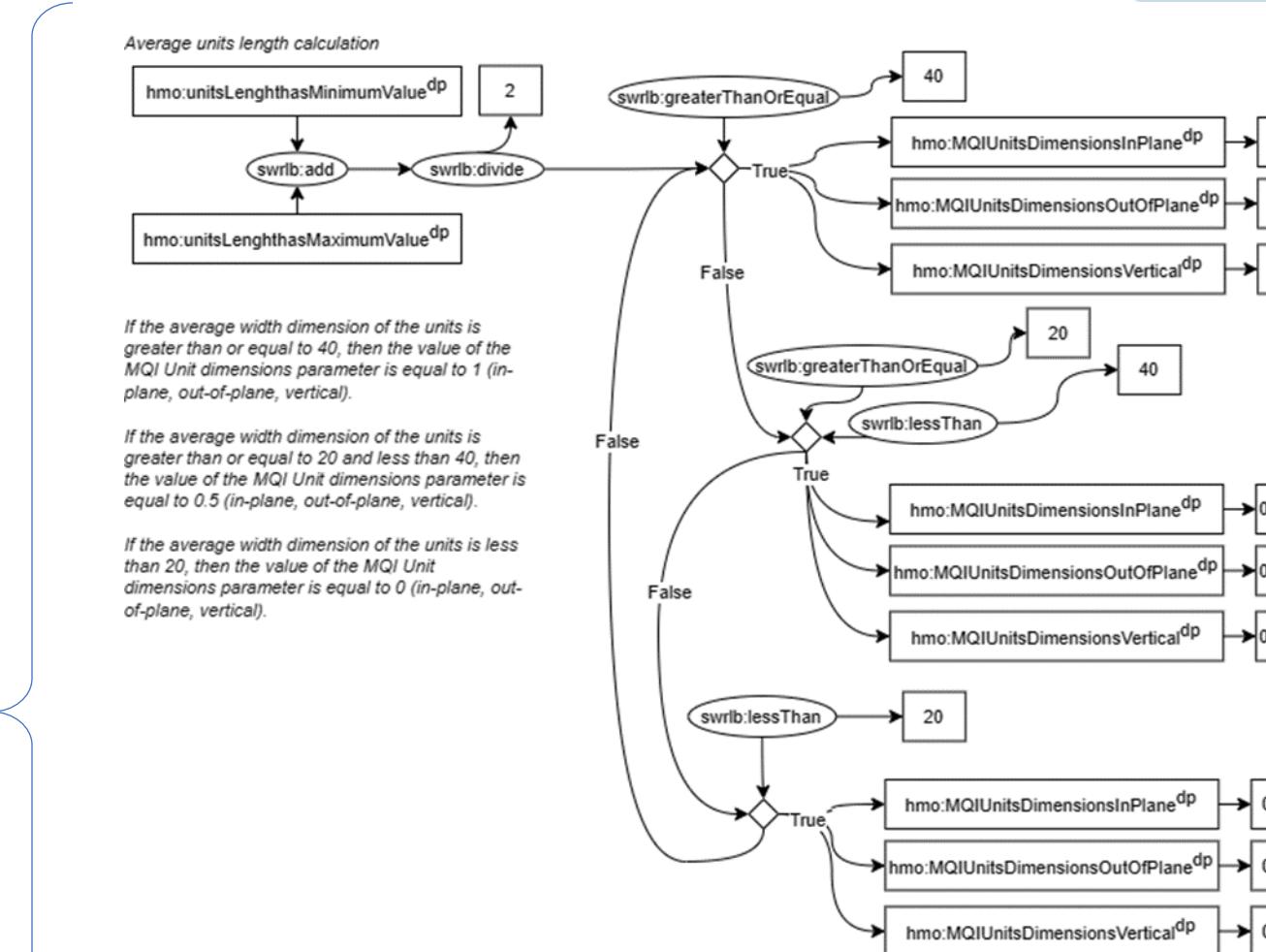
M. Azenha, Associate Professor,
 University of Minho, ISISE, ARISE, Department of Civil Engineering, Guimarães, Portugal;



The historic center of Castelnuovo di Porto

Interpretation – Mechanical properties – use of rules

RULES
examples



Asserted Properties

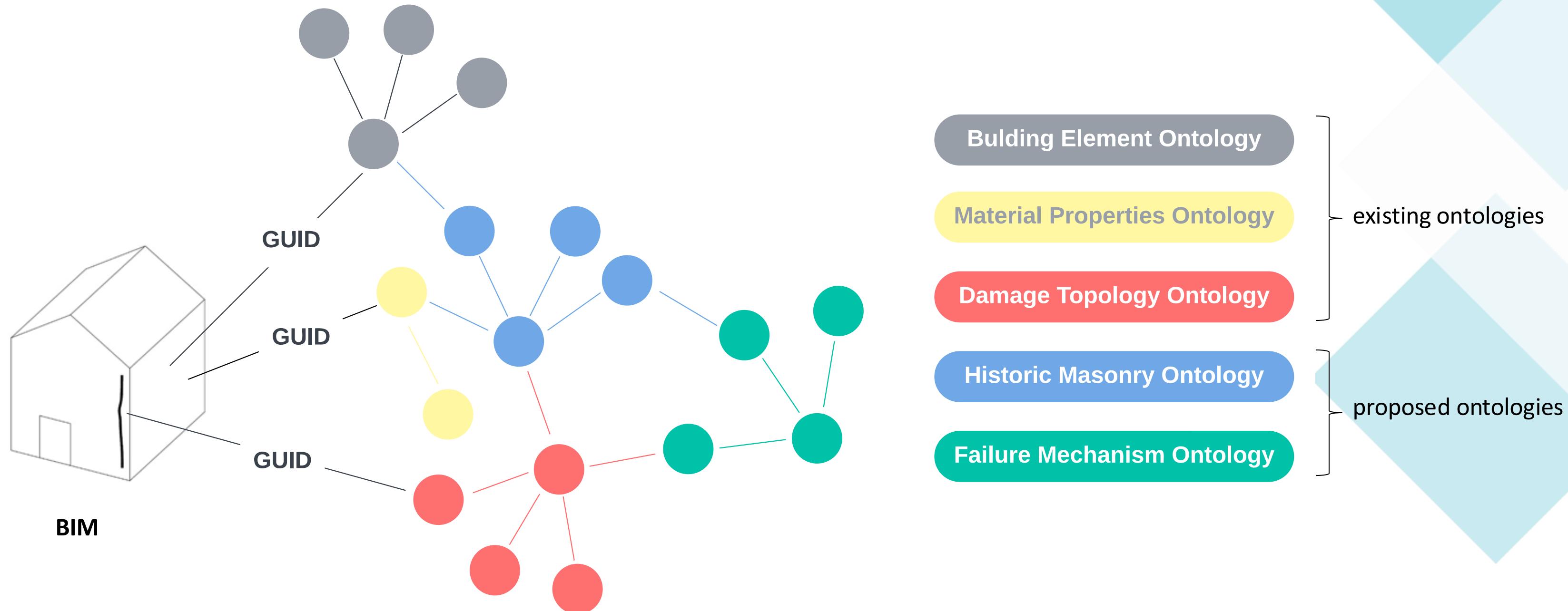
Property assertions: SurveyedWall	
Object property assertions	+ +
hasRepresentativeVolumeElement CastelnuovoDiPortoMasonryType6	
hasMasonryQualityIndex SurveyedWallMQI	
Property assertions: CastelnuovoDiPortoMasonryType6	
Object property assertions	+ +
hasPattern IrregularSoftStoneWithSomeBricks	
Property assertions: SurveyedWallMQI	
Object property assertions	+ +
Data property assertions	+ +
Negative object property assertions	+ +
Property assertions: IrregularSoftStoneWithSomeBricks	
Object property assertions	+ +
hasSparsePatternEntities IrregularBricks	
hasDominantPatternEntities IrregularSoftstone	
hasDominantPatternEntities PartiallyStaggeredJoints	
hasDominantPatternEntities RomanCementMortarJoints	
isPatternOf CastelnuovoDiPortoMasonryType6	
hasDominantPatternEntities ContinuousHorizontalJoints	

Inferred Properties

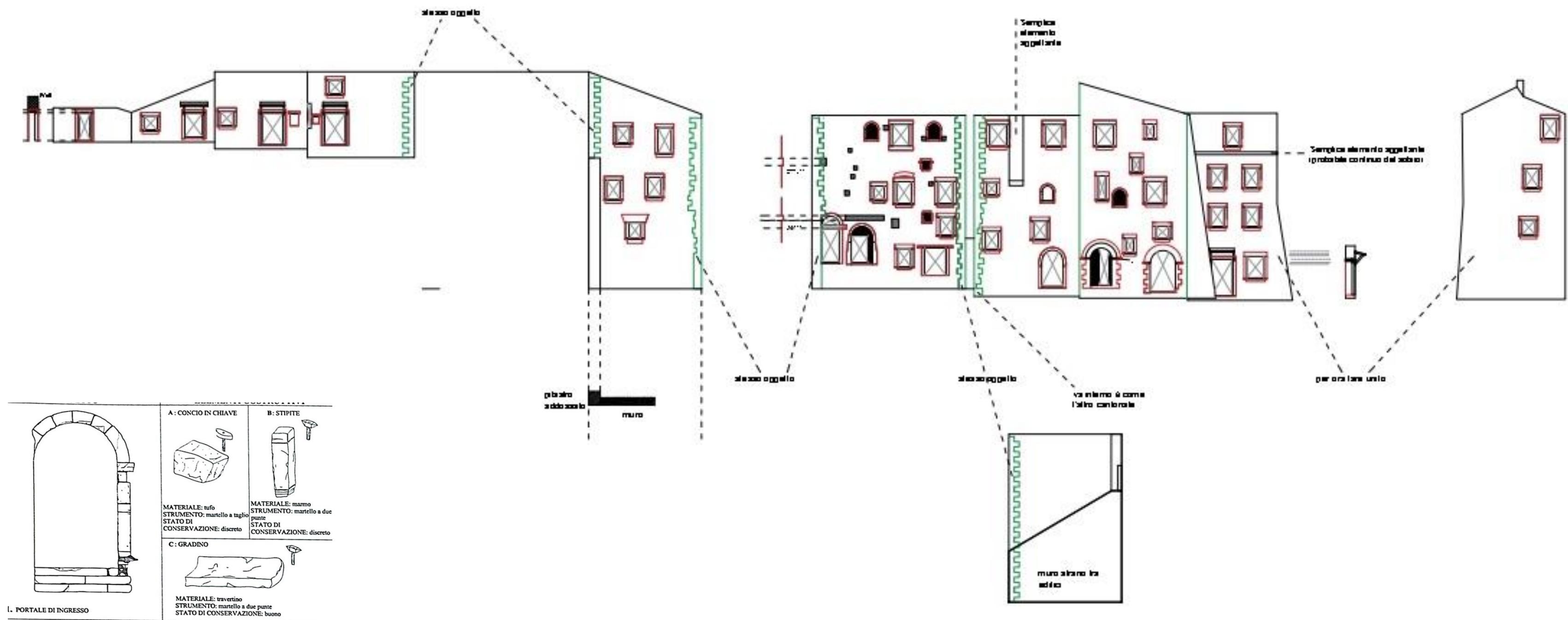
Property assertions: SurveyedWallMQI	
MQITotalInPlane	4.55
MQIUnitsDimensionsOutOfPlane	0
MQIUnitsShapeInPlane	1
MQIUnitsPropertiesOutOfPlane	0.7
MQIVerticalJointsOutOfPlane	0.5
MQIMortarQualityInPlane	1
MQITotalVertical	4.90
MQIHorizontalJointsOutOfPlane	1
MQIUnitsPropertiesInPlane	0.7
MQIVerticalJointsVert	0.5
MQIVerticalJointsInPlane	1
MQITotalOutOfPlane	3.15
MQIUnitsDimensionsVert	0
MQIMortarQualityOutOfPlane	1
MQIUnitsDimensionsInPlane	0
MQIMortarQualityVert	2
MQIWALLLeavesConnectionsOutOfPlane	1
MQIUnitsShapeOutOfPlane	1
MQIUnitsPropertiesVert	0.7
MQIUnitsShapeVert	1.5
MQIWALLLeavesConnectionsInPlane	1.5
MQIHorizontalJointsInPlane	2
MQIHorizontalJointsVert	2
Property assertions: CastelnuovoDiPortoMasonryType6	
Object property assertions	+ +
hasHomogenisedMechanicalProperty SurveyedWallYoungModulus	
hasPattern IrregularSoftStoneWithSomeBricks	
hasHomogenisedMechanicalProperty SurveyedWallShearStrength	
hasHomogenisedMechanicalProperty SurveyedWallCompressiveStrength	
hasHomogenisedMechanicalProperty SurveyedWallShearModulus	
Property assertions: SurveyedWallYoungModulus	
Object property assertions	+ +
isHomogenisedMechanicalPropertyOf CastelnuovoDiPortoMasonryType6	
Data property assertions	+ +
hasValue 814.06	

The historic center of Castelnuovo di Porto

Link between BIM and ontologies

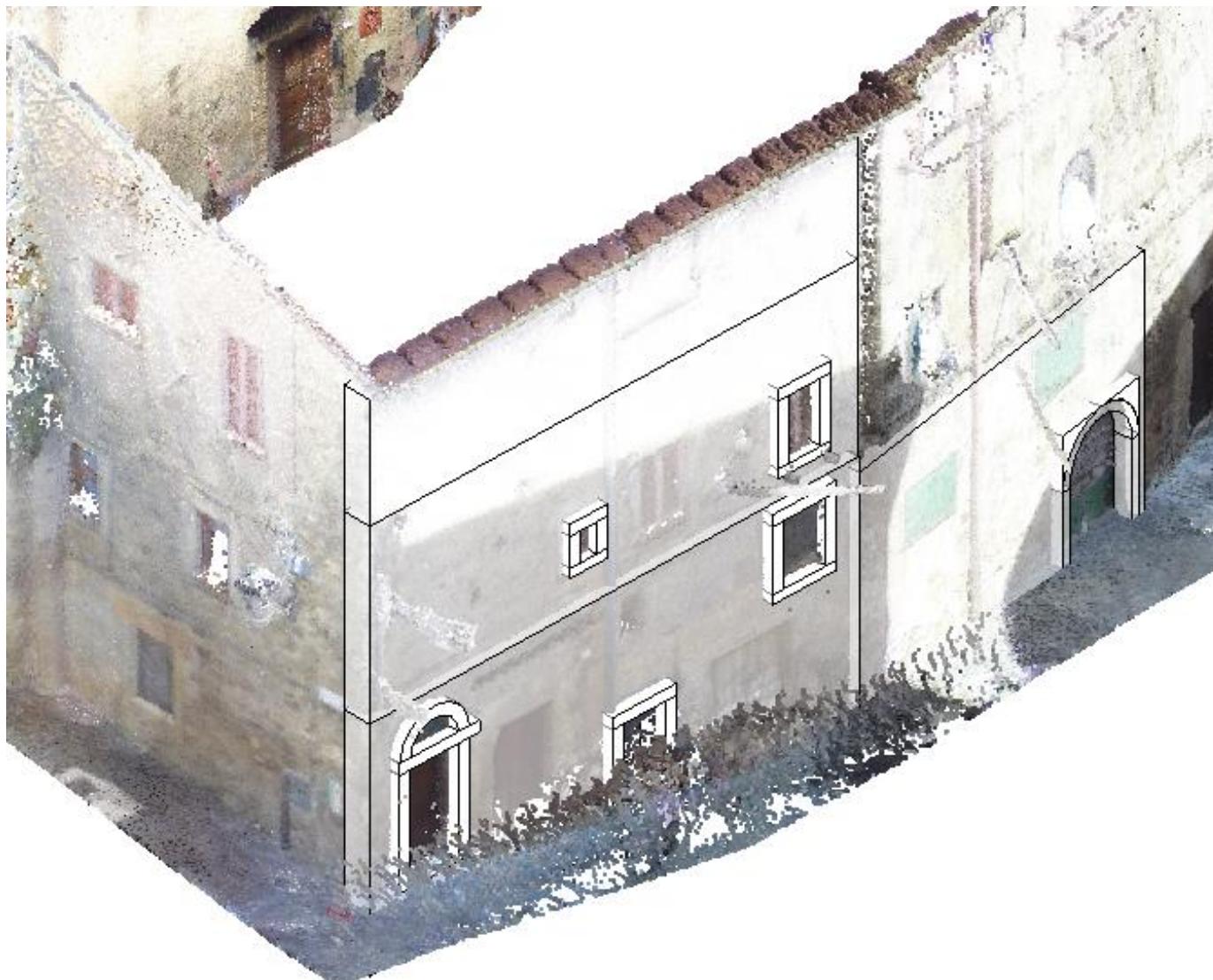


The historic center of Castelnuovo di Porto Model – geometry challenges



The historic center of Castelnuovo di Porto

Model – geometry challenges



```
for door in doors:
    AllShapes = []
    shape = ifcopenshell.geom.create_shape(settings, door)
    shape = OCC.Core.TopoDS.TopoDS_Iterator(shape.geometry).Value() #This is the shape of the door
    location = shape.Location() #This is the location of the main door compound
    locationXYZ = location.Transformation().TranslationPart()
    locationPoint = gp_Pnt(locationXYZ)
    #Create a empty compound at the location of the shape
    EmptyCompound = create_empty_compound_at_location(shape)
    label = []
    shapes = []
    doorTypeRels = door.IsTypedBy
    for doorTypeRel in doorTypeRels:
        doorType = doorTypeRel[5]

        for repMap in doorType.RepresentationMaps:
            MappedRepresentation = repMap.MappedRepresentation
            ShapeAspects = repMap.HasShapeAspects

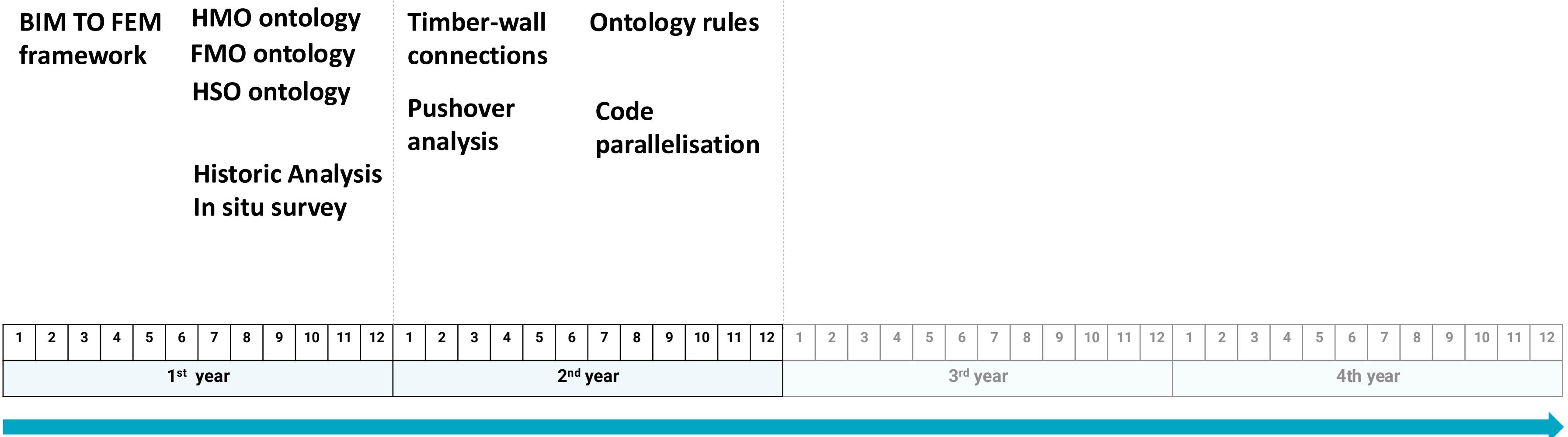
            for shapeAspect in ShapeAspects:
                label = shapeAspect[1]
                print(label)
                shapeOfshape = []
                labels.append(label)
                for rpr in shapeAspect[0]:
                    items = rpr[3]

                    for item in items:
                        shape = ifcopenshell.geom.create_shape(settings, item)
                        AllShapes.append(shape)
```

4

Conclusions and future work

Work timeline



Work timeline

BIM TO FEM framework	HMO ontology	Timber-wall connections	Ontology rules	Framework Improvement (complex multimaterial elements)	Dynamic analyses	Implementation of javascript platform					
	FMO ontology										
	HSO ontology										
		Pushover analysis	Code parallelisation								
				Cycling testing							
Historic Analysis											
In situ survey											
1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 7 8 9 10 11 12					
1st year			2nd year			3rd year			4th year		



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Thanks for your attention!

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