Institute for Sustainability and Innovation in Structural Engineering

Enhancing Finite Element Modeling of Historic Masonry Structures Through Ontology-Driven BIM Integration

Maria Laura Leonardi, PhD student at University of Minho

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Universidade do Minho

About me

Maria Laura Leonardi

MSc in Structural Analysis of Historical Constructions
MSc in Architecture and Building Engineering

ISISE Institute for Sustainability and Innovation in Structural Engineering

Universidade do Minho

BIM A+ European Master in Building Information Modelling

Consiglio Nazionale delle Ricerche

spc Istituto di Scienze del Patrimonio Culturale

Institute for Sustainability and Innovation in Structural Engineering

The Institute for Sustainability and Innovation in Structural Engineering (**ISISE**) is a Research and Development Centre created in 2007, involving the Civil Engineering Departments of the University of Coimbra (UC) and the University of Minho (UM).

HMS

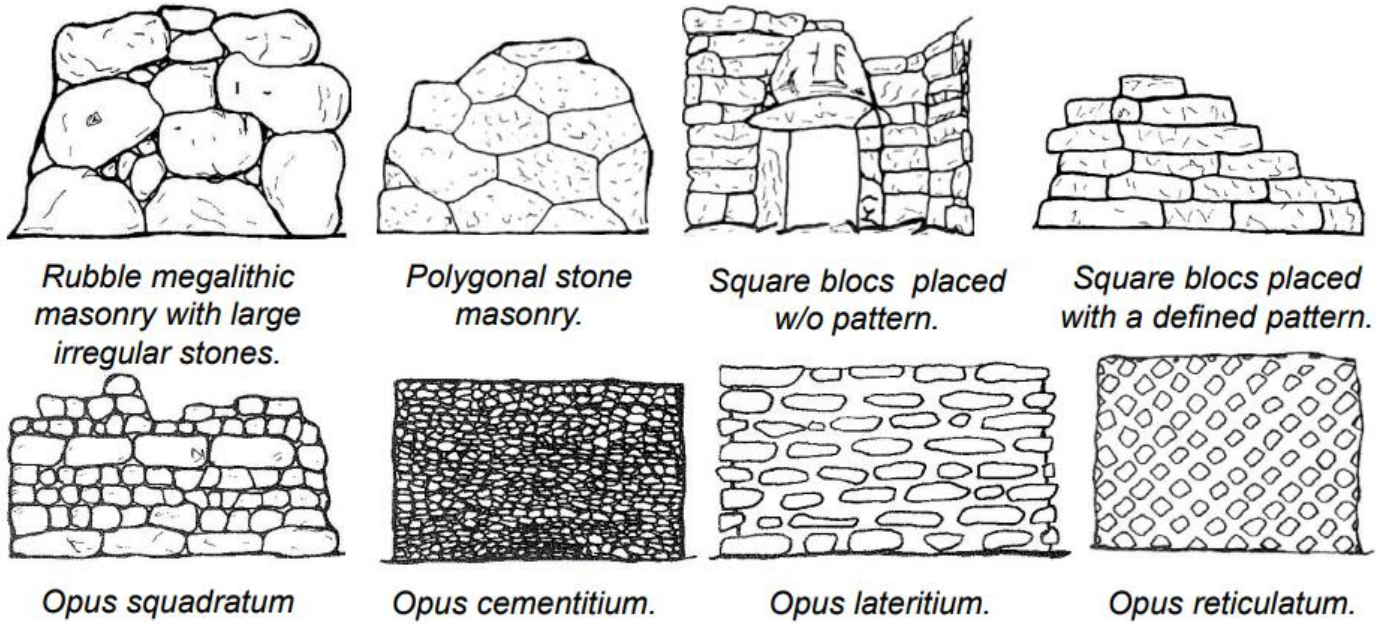
Historical and Masonry Structures (HMS)
at the University of Minho

Cluster MATICH: Masonry, Timber and Cultural Heritage

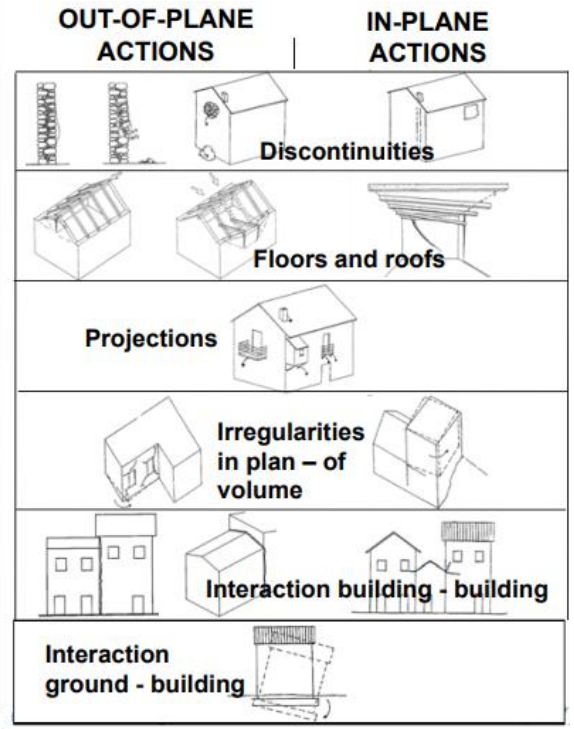
- Conservation strategies for historical buildings
- Seismology and earthquake engineering
- Numerical simulation tools for multiphysics problems

Historic Masonry Structures

- Masonry is one of the most ancient construction techniques
- Heterogeneous material
- Structurally complex nonlinear behaviour
- Constructions often build in clusters (masonry aggregates)

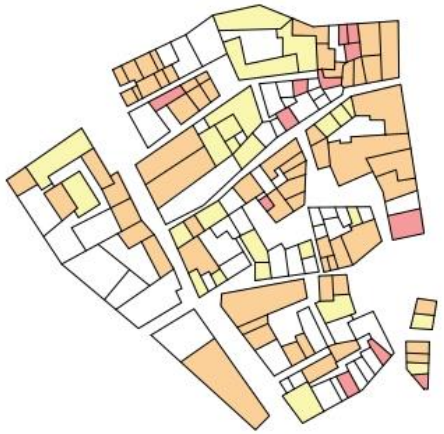


Historic Masonry Structures – seismic behaviour

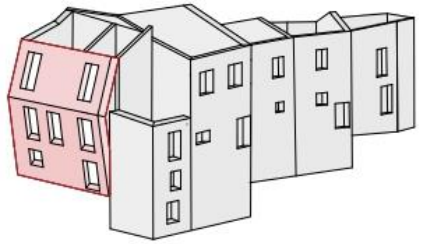


Different seismic assessment methods

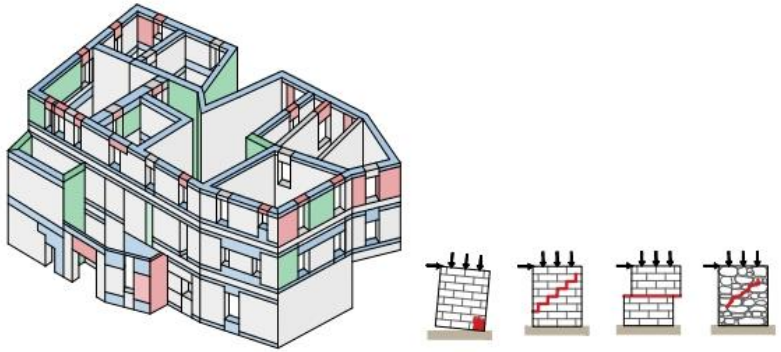
Large scale assessment



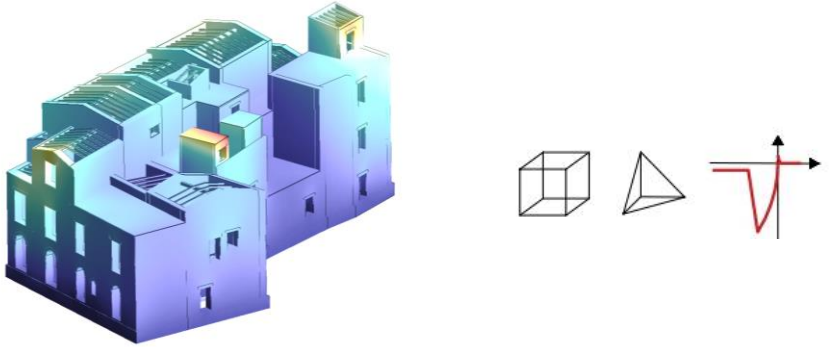
Local analysis



Global models



EQUIVALENT FRAME

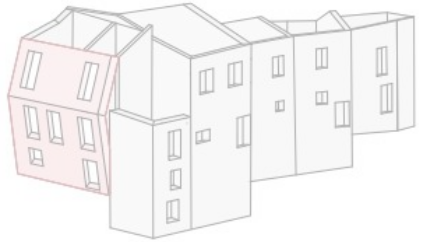


SOLID FEM MODELS

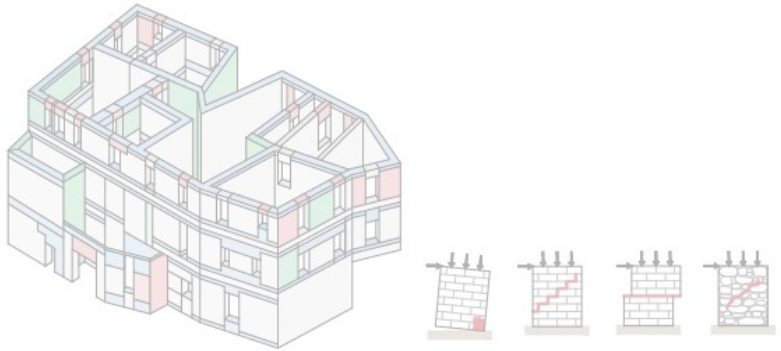
Solid finite element models

Large scale assessment

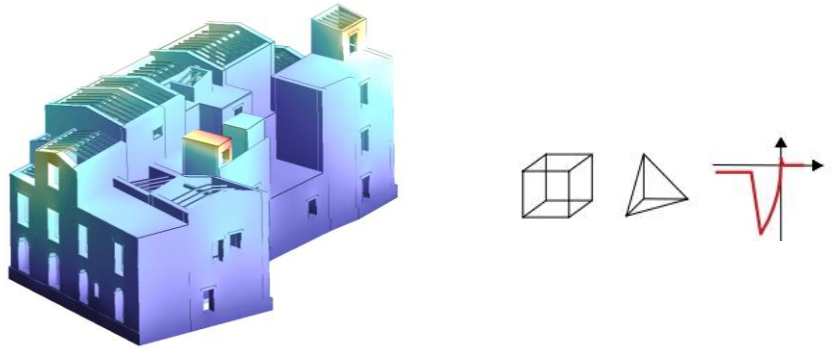
Local analysis



Global models



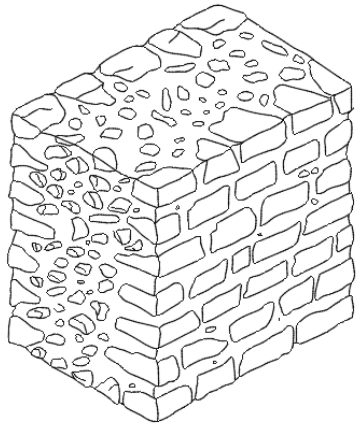
EQUIVALENT FRAME



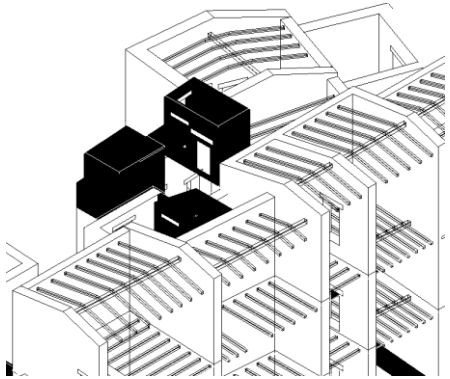
SOLID FEM MODELS

Solid finite element models - challenges

MECHANICAL PROPERTIES

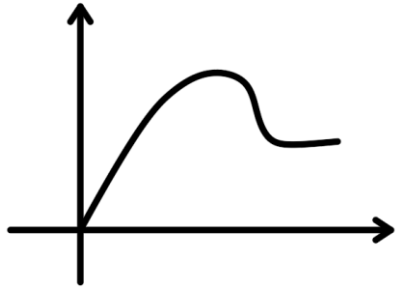


GEOMETRY COMPLEXITY



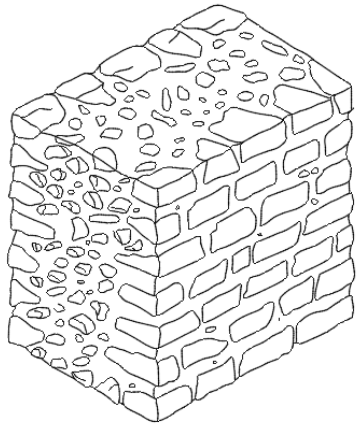
COMPUTATIONAL COSTS

CONVERGENCY PROBLEMS



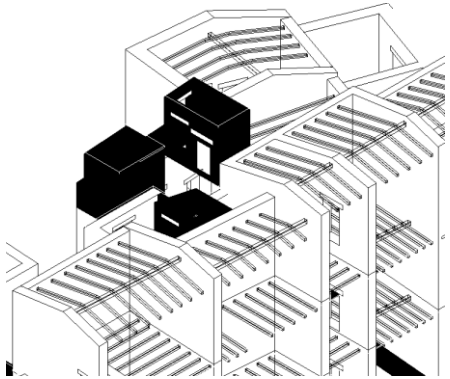
Proposed solutions

MECHANICAL PROPERTIES



Semantic Web Languages

GEOMETRY COMPLEXITY

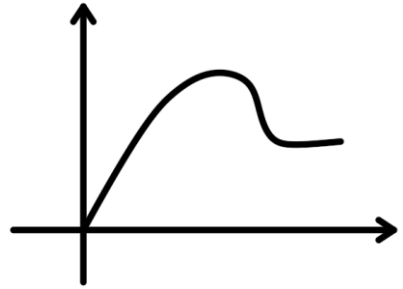


BIM-to-FEM automation

COMPUTATIONAL COSTS

FEM parallelisation

CONVERGENCY PROBLEMS



Implex algorithm

Proposed framework – BIM to FEM interoperability

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

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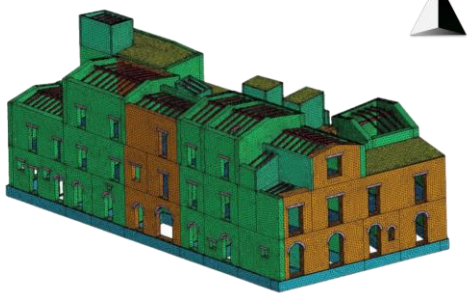
University of Minho, ISISE, ARISE, Department of Civil Engineering, Guimarães, Portugal

GitHub stable version

INPUT – IFC MODEL

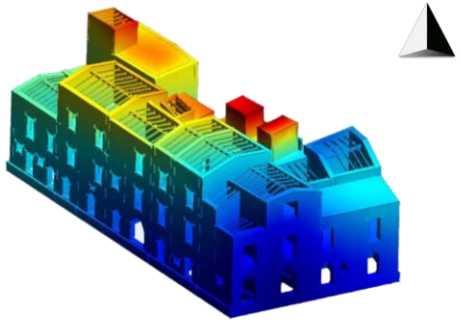
IfcOpenShell and OpenCascade

MESH CONVERSION

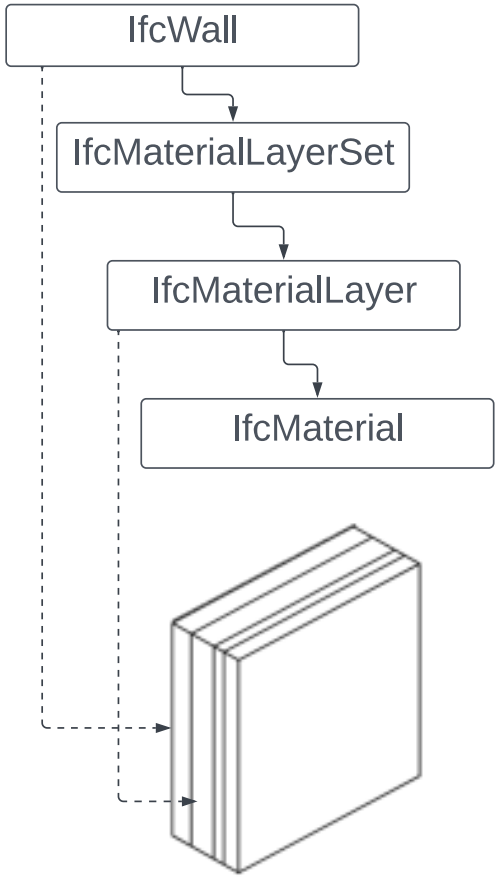


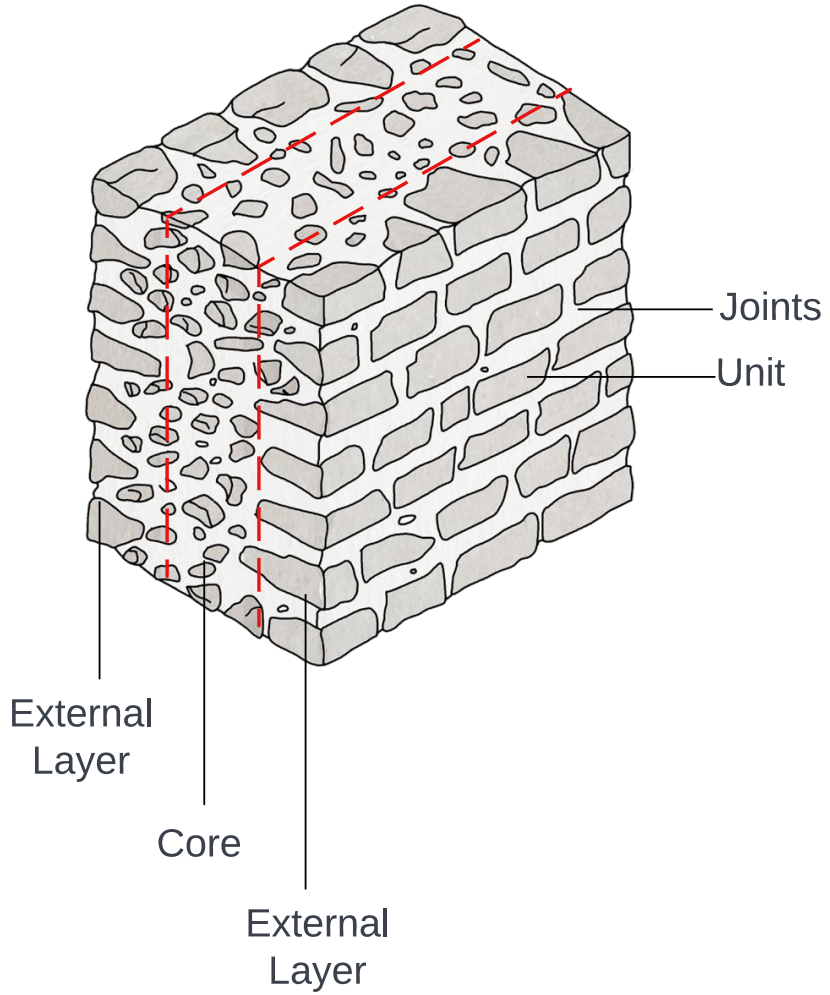
OpenSees

OUTPUT – ANALYSIS RESULT

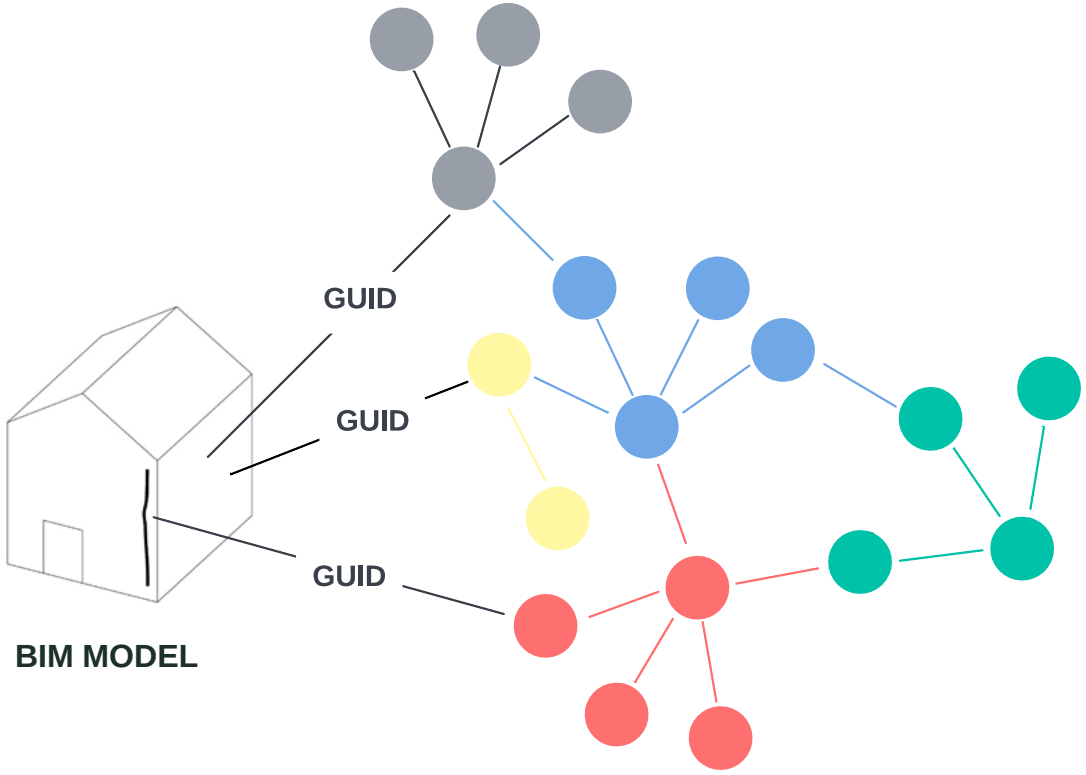


How to inform the BIM model? Limitation of the IFC schema





Towards a Linked Data Approach



ITcon
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LEVERAGING SEMANTIC WEB RULE LANGUAGES TO DEFINE MODELING ASSUMPTIONS FOR THE STRUCTURAL ANALYSIS OF UNREINFORCED MASONRY BUILDINGS

*copyediting

- Bulding Element Ontology
- Material Properties Ontology
- Damage Topology Ontology

existing ontologies

- Historic Masonry Ontology
- Failure Mechanism Ontology

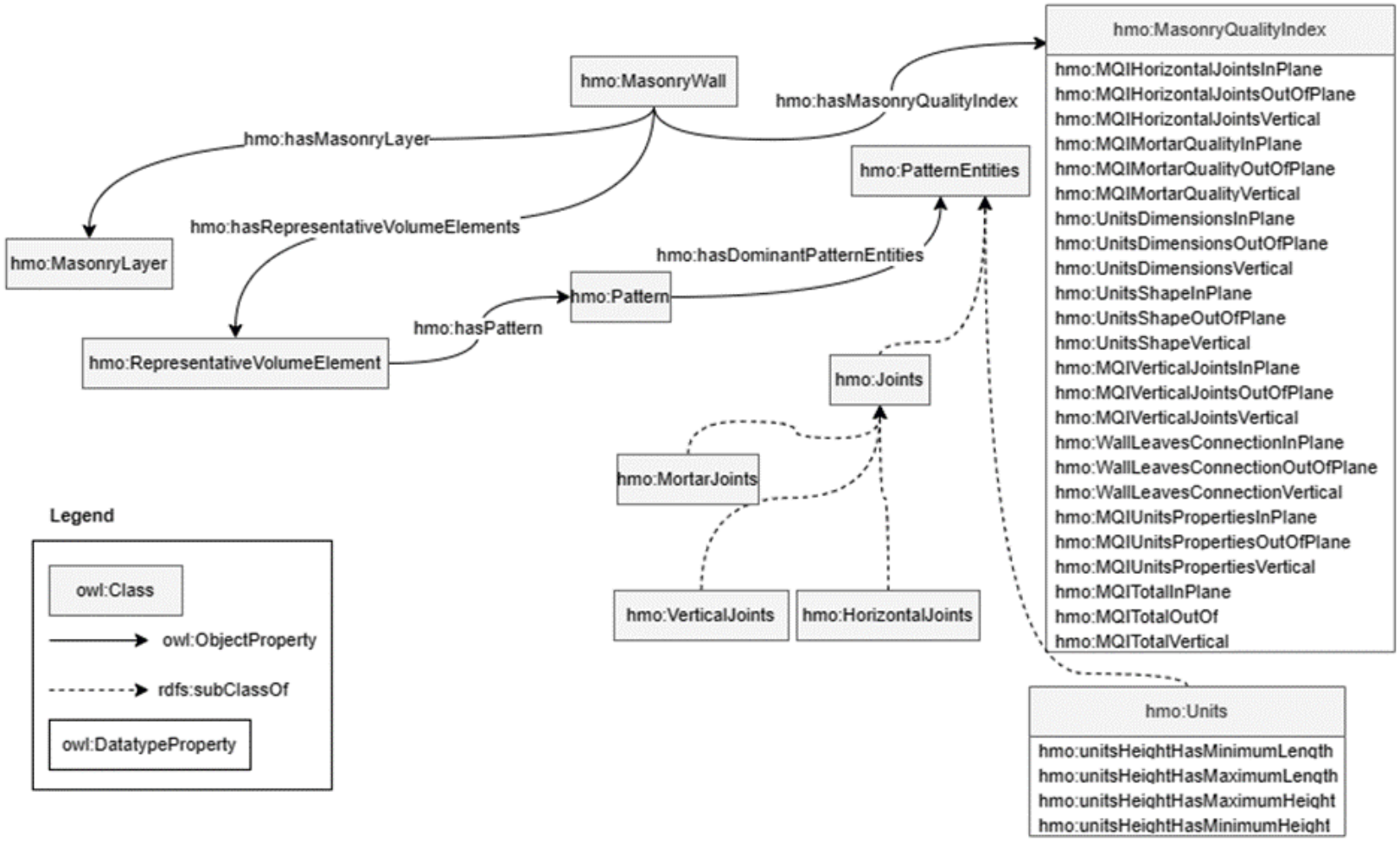
proposed ontologies

The Historic Masonry Ontology (HMO)

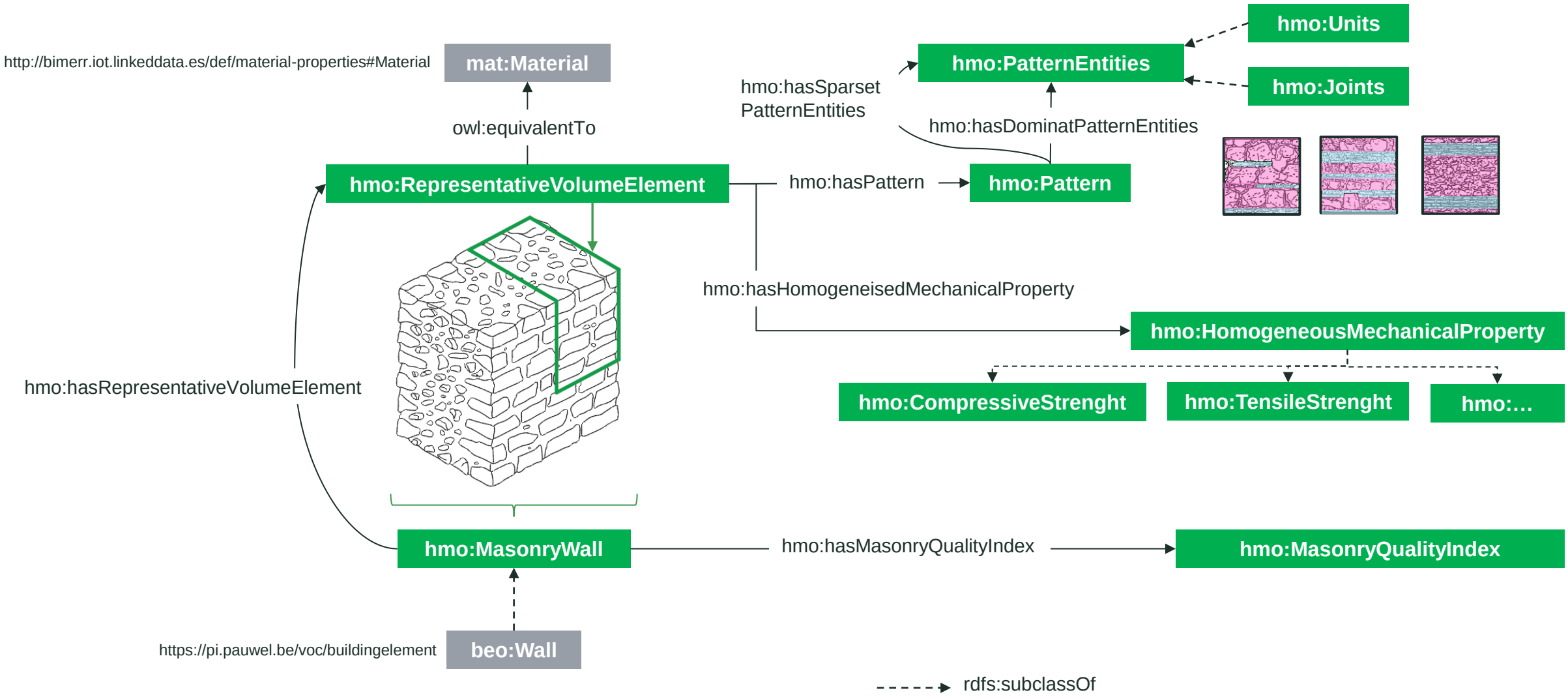
Scope:

"Define masonry mechanical properties from the descriction of masonry morphology features."

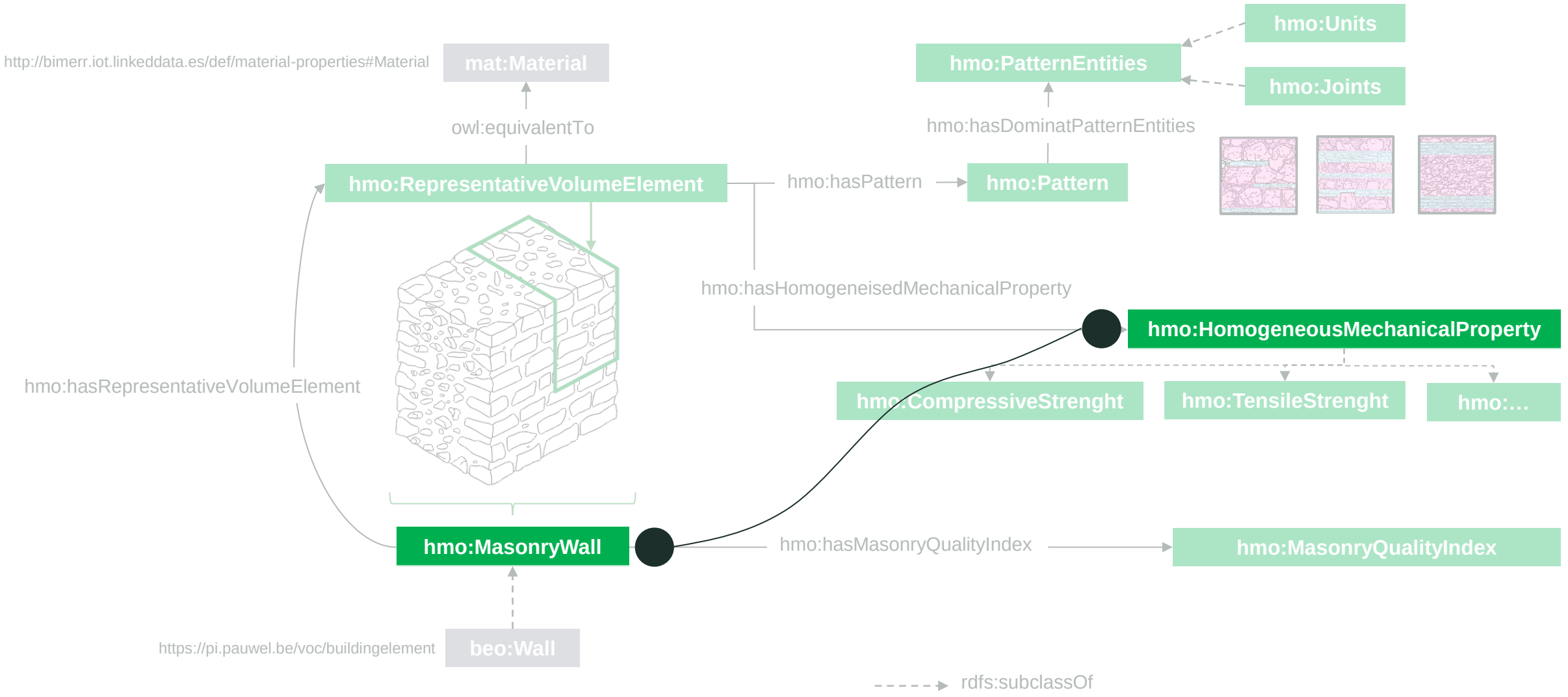
https://w3id.org/hmo#



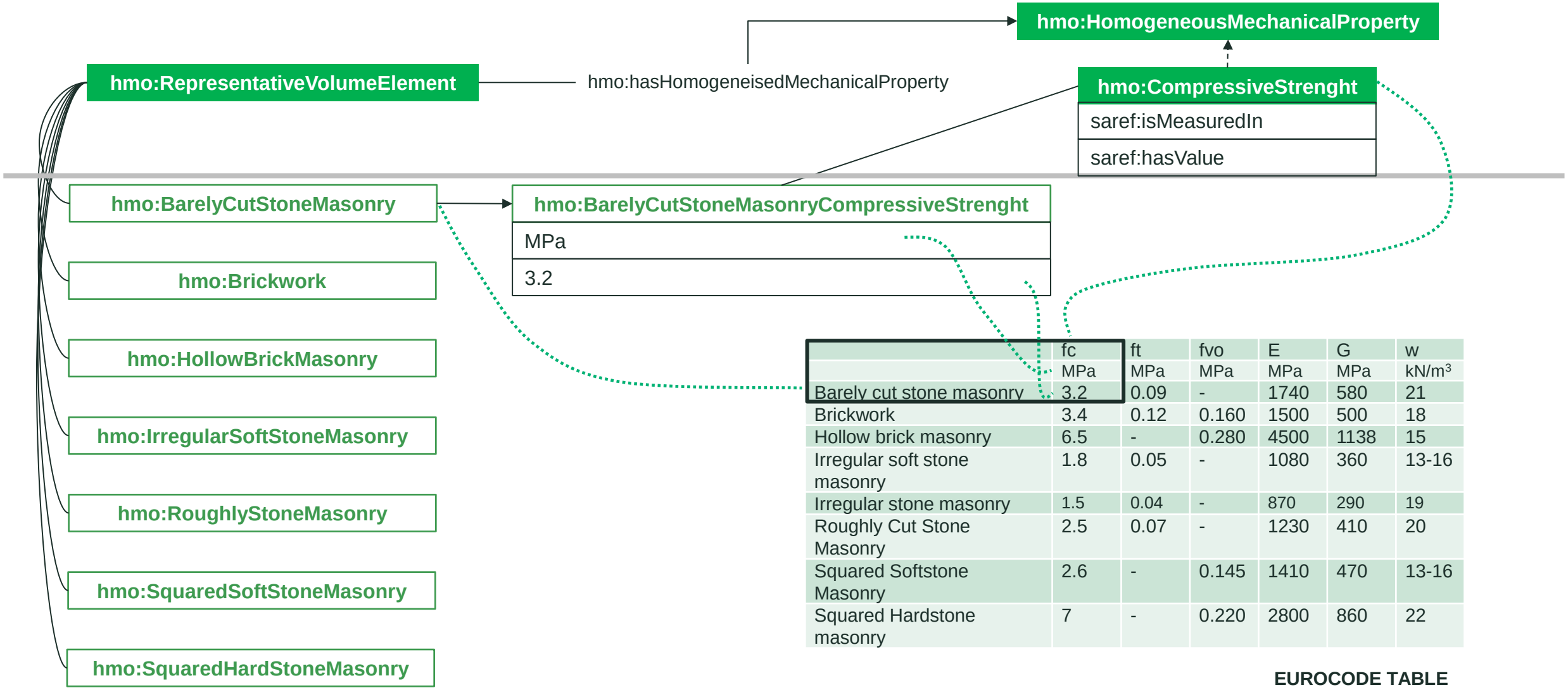
The Historic Masonry Ontology



The Historic Masonry Ontology



Guideline's masonry types (NTC 2018 – last generation Eurocode)



	fc	ft	fvo	E	G	w
	MPa	MPa	MPa	MPa	MPa	kN/m³
Barely cut stone masonry	3.2	0.09	-	1740	580	21
Brickwork	3.4	0.12	0.160	1500	500	18
Hollow brick masonry	6.5	-	0.280	4500	1138	15
Irregular soft stone masonry	1.8	0.05	-	1080	360	13-16
Irregular stone masonry	1.5	0.04	-	870	290	19
Roughly Cut Stone Masonry	2.5	0.07	-	1230	410	20
Squared Softstone Masonry	2.6	-	0.145	1410	470	13-16
Squared Hardstone masonry	7	-	0.220	2800	860	22

EUROCODE TABLE

Masonry Quality Index and pattern entities' features

$$MQI = SM\ x\ (WC + VJ + HJ + SS + SD + MM)$$

Data Property	Definition	
hmo:MQIHorizontalJointsInPlane	Horizontality of bed joints	HJ
hmo:MQIHorizontalJointsOutOfPlane		
hmo:MQIHorizontalJointsVertical		
hmo:MQIMortarQualityInPlane	Quality of the mortar / contact between masonry units / pinnings	MM
hmo:MQIMortarQualityOutOfPlane		
hmo:MQIMortarQualityVertical		
hmo:MQIUnitsDimensionsInPlane,	Dimensions of the masonry units	SD
hmo:MQIUnitsDimensionsOutOfPlane		
hmo:MQIUnitsDimensionsVertical		
hmo:MQIUnitsShapeInPlane	Shape of the masonry units	SS
hmo:MQIUnitsShapeOutOfPlane		
hmo:MQIUnitsShapeVertical		
hmo:MQIVerticalJointsInPlane	Staggering of vertical mortar joints	VJ
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hmo:MQIVerticalJointsVertical		
hmo:MQIWallLeavesConnectionInPlane	Level of connection between adjacent wall leaves / headers	WC
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hmo:MQIWallLeavesConnectionVertical		
hmo:MQIUnitsPropertiesInPlane	Mechanical characteristics and quality of masonry units	SM
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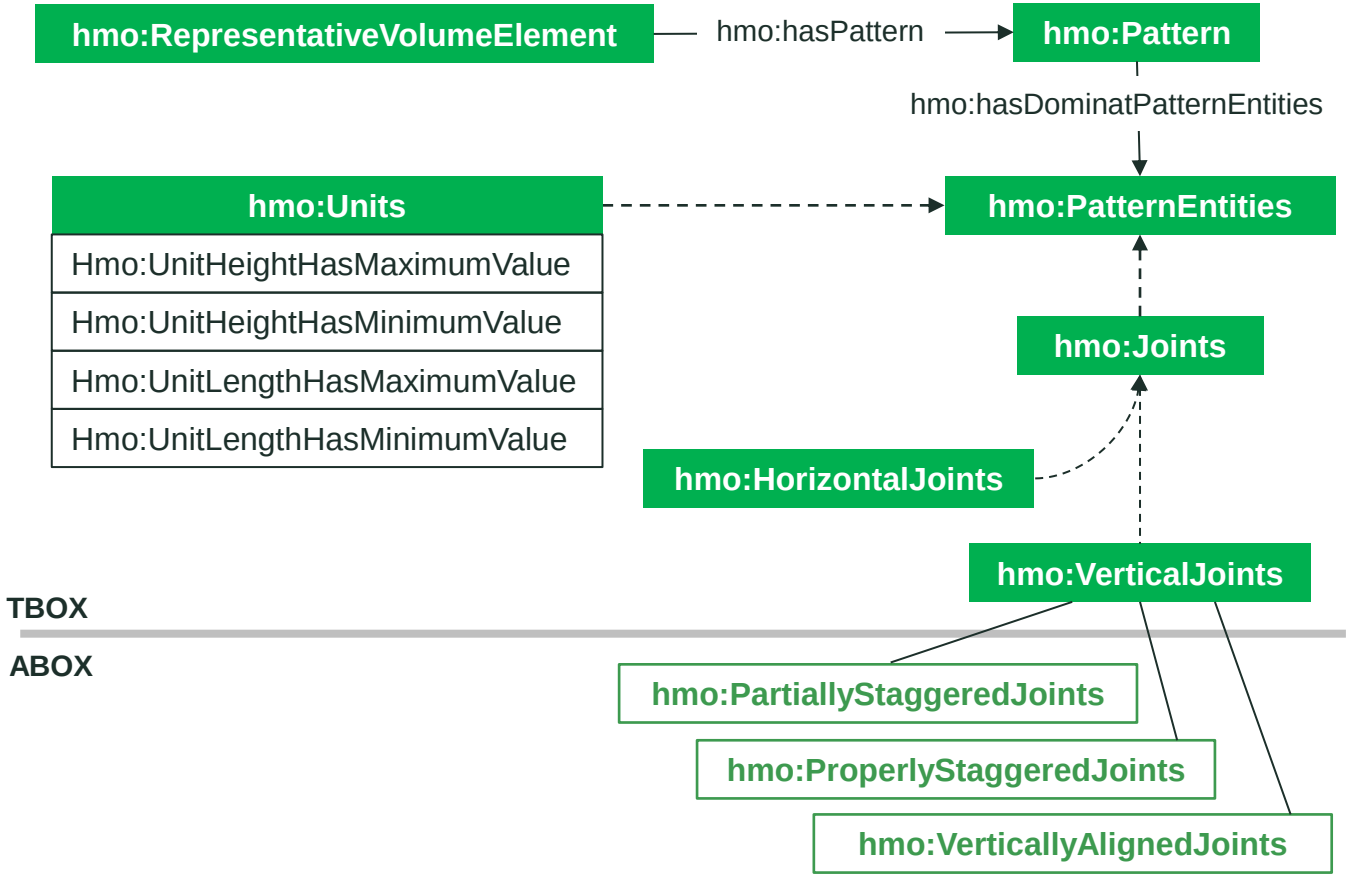

Masonry Quality Index and pattern entities' features

$$MQI = SM\ x\ (WC + VJ + HJ + SS + SD + MM)$$

Data Property	Definition	
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hmo:MQIMortarQualityVertical		
hmo:MQIUnitsDimensionsInPlane, hmo:MQIUnitsDimensionsOutOfPlane hmo:MQIUnitsDimensionsVertical	**Dimensions of the masonry units**	**SD**
hmo:MQIUnitsShapeInPlane	Shape of the masonry units	SS
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hmo:MQIUnitsShapeVertical		
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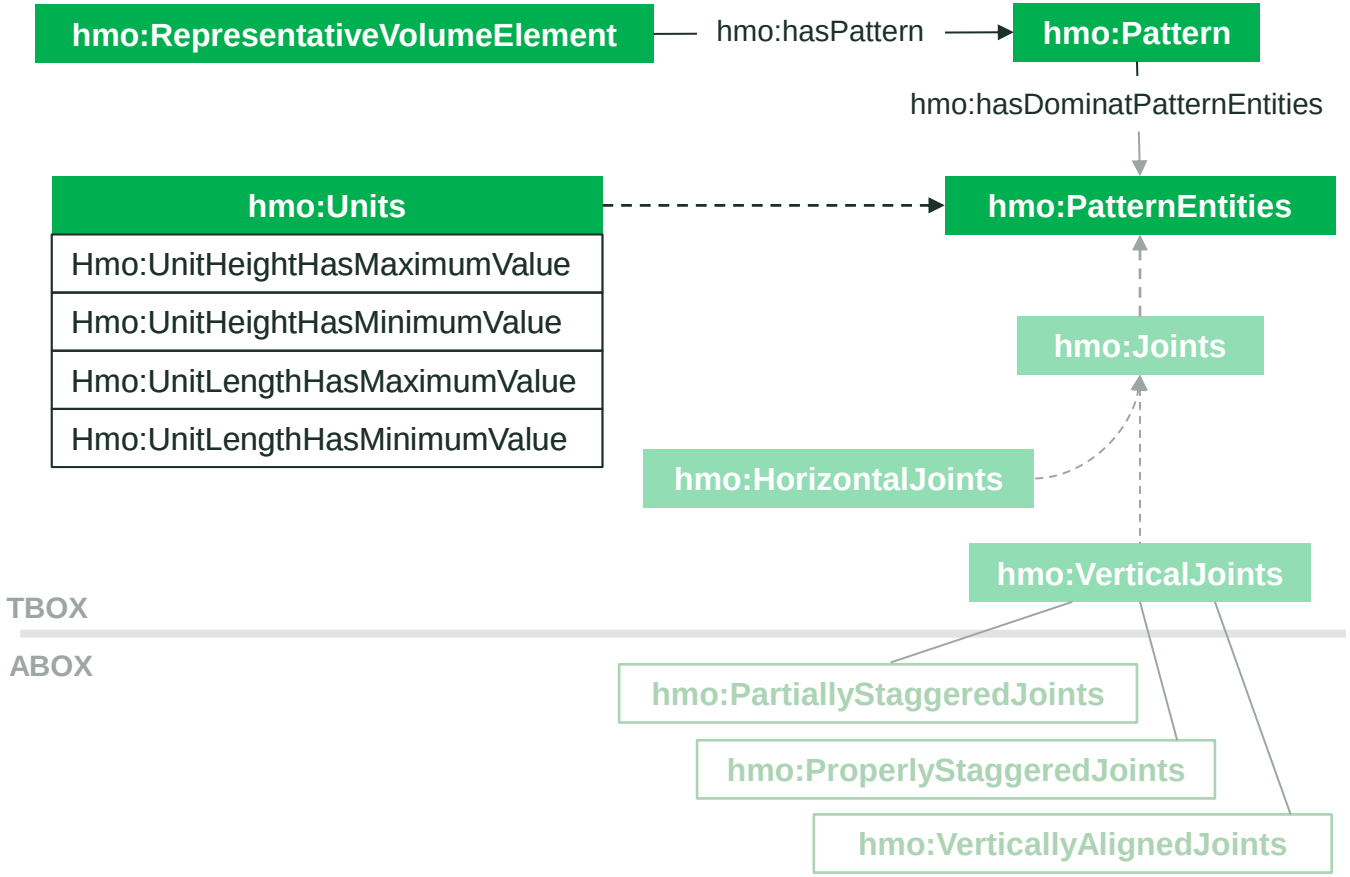

Masonry Quality Index and pattern entities' features

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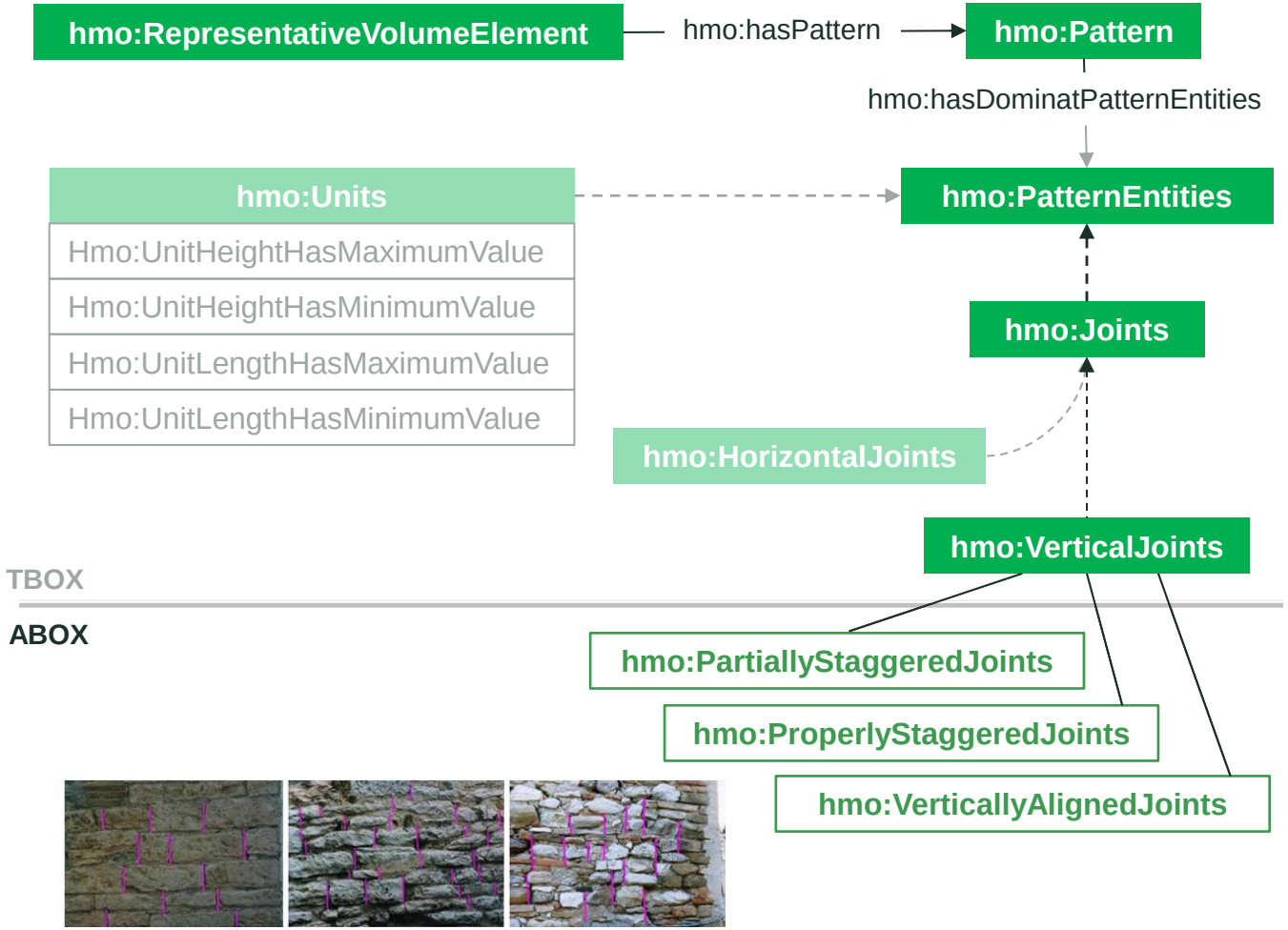

Masonry Quality Index values

$$MQI = SM\ x\ (WC + VJ + HJ + SS + SD + MM)$$

Data Property	Definition	
hmo:MQIHorizontalJointsInPlane	Horizontality of bed joints	HJ
hmo:MQIHorizontalJointsOutOfPlane		
hmo:MQIHorizontalJointsVertical		
hmo:MQIMortarQualityInPlane	Quality of the mortar / contact between masonry units / pinnings	MM
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hmo:MQIUnitsDimensionsInPlane,	Dimensions of the masonry units	SD
hmo:MQIUnitsDimensionsOutOfPlane		
hmo:MQIUnitsDimensionsVertical		
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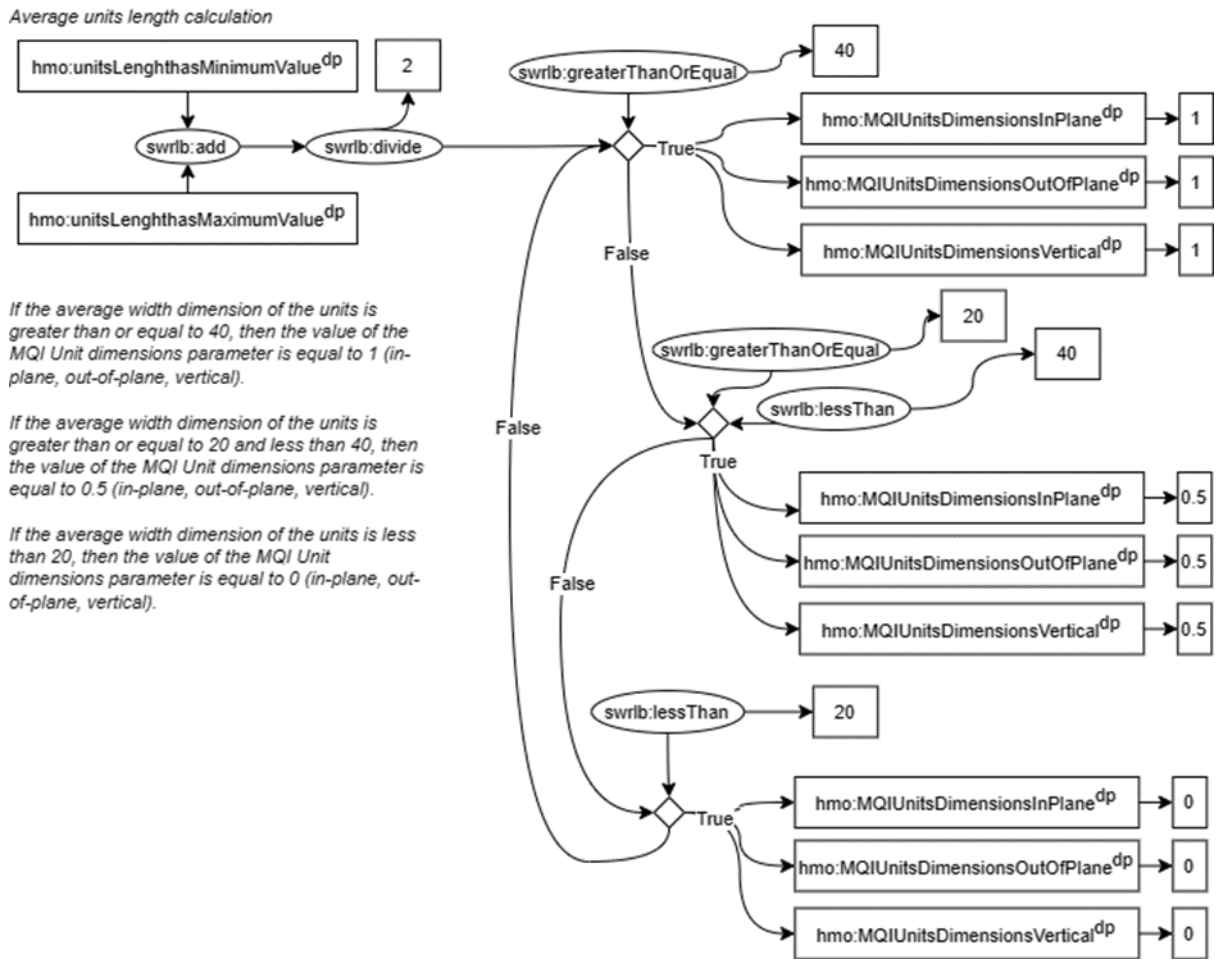

Masonry Quality Index total value

$$MQI = SM\ x\ (WC + VJ + HJ + SS + SD + MM)$$

Data Property	Definition	
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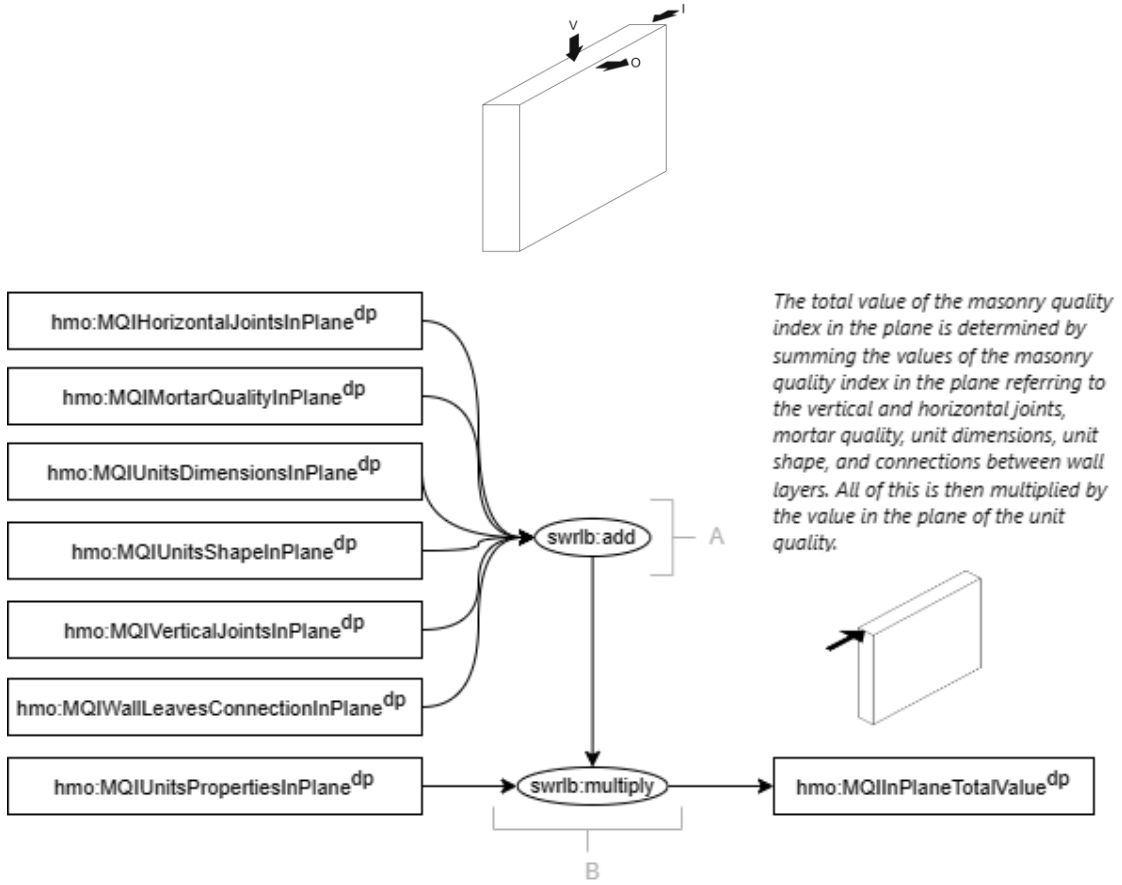

Masonry Quality Index – correlation with mechanical properties

$$MQI = SM\ x\ (WC + VJ + HJ + SS + SD + MM)$$

Data Property	Definition	
hmo:MQIHorizontalJointsInPlane	Horizontality of bed joints	HJ
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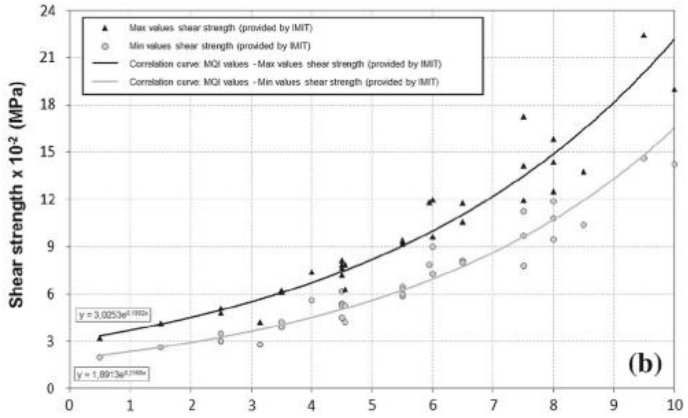
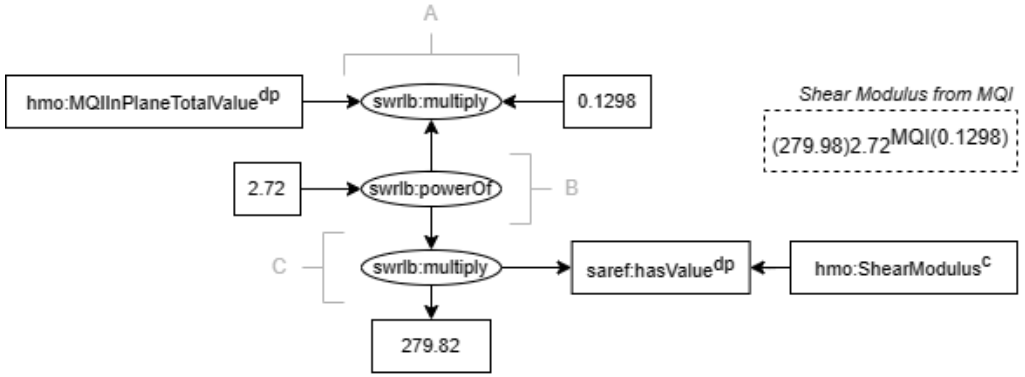
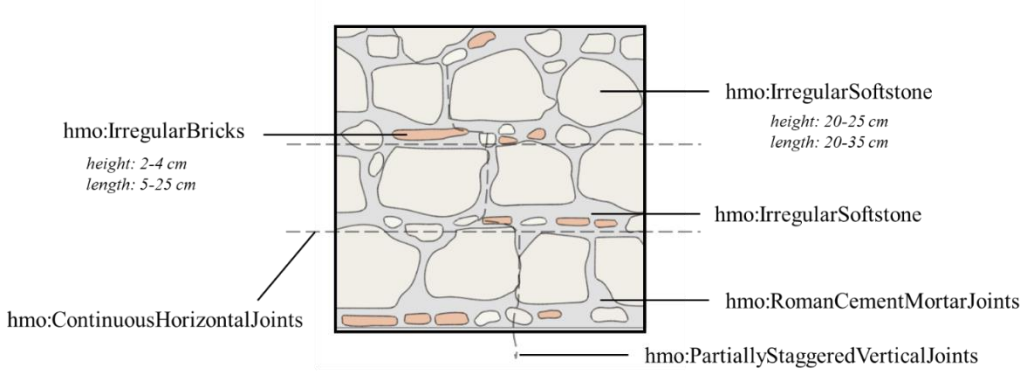
hmo:MQIUnitsPropertiesOutOfPlane		
hmo:MQIUnitsPropertiesVertical		





Example of HMO application



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 SurveyedWallShearStrenght
- hasHomogenisedMechanicalProperty SurveyedWallCompressiveStrenght
- hasHomogenisedMechanicalProperty SurveyedWallShearModulus

Property assertions: SurveyedWallYoungModulus

Object property assertions
- isHomogenisedMechanicalPropertyOf CastelnuovoDiPortoMasonryType6

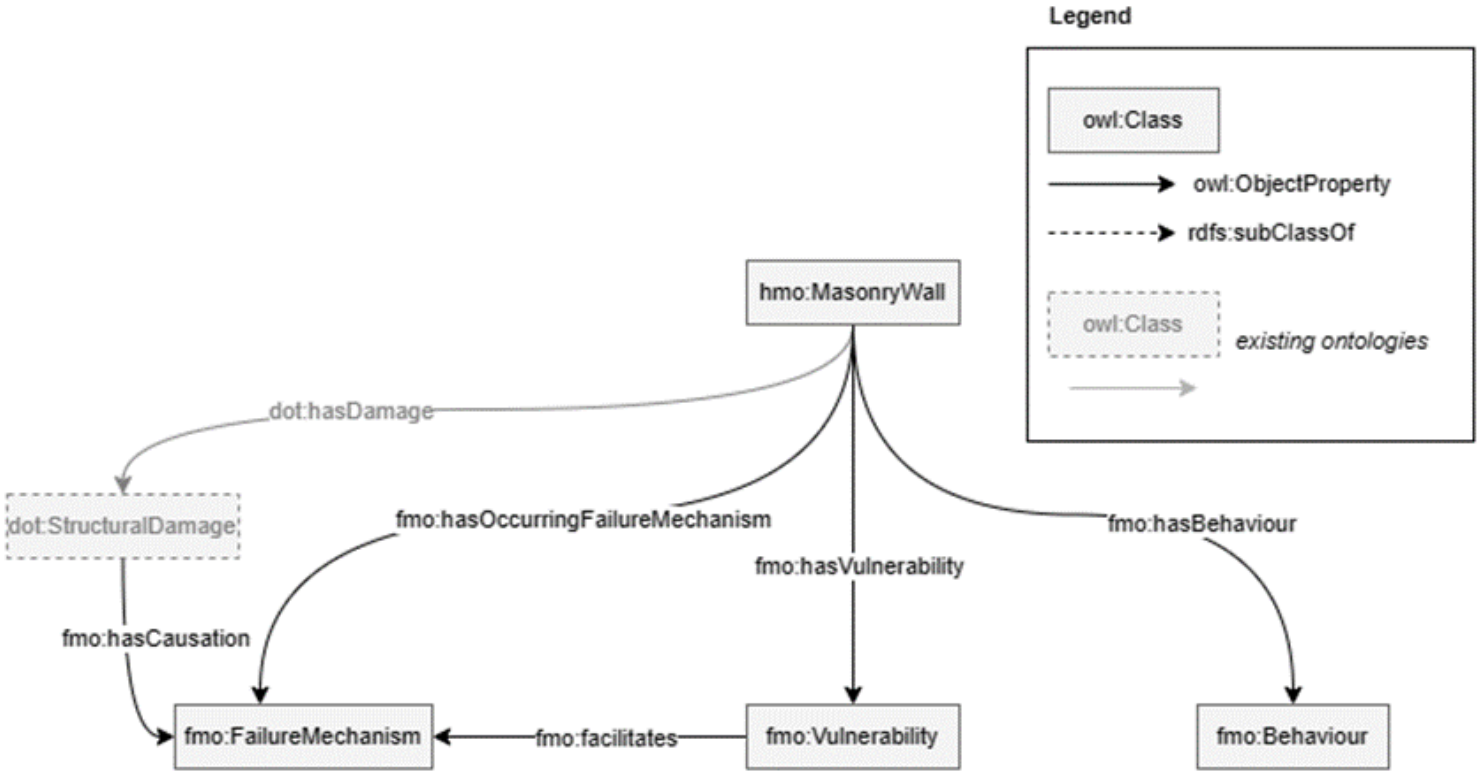
Data property assertions
- hasValue 814.06

The Failure Mechanism Ontology (FMO)

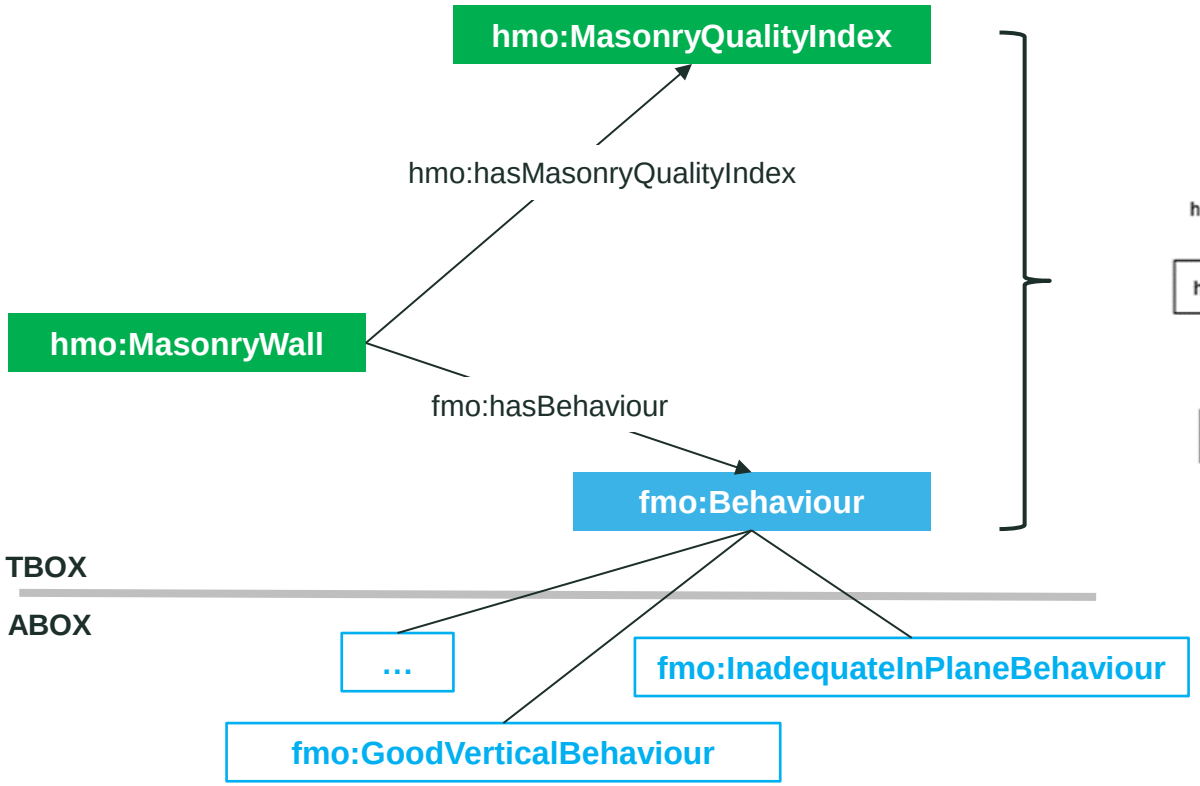
Scope:

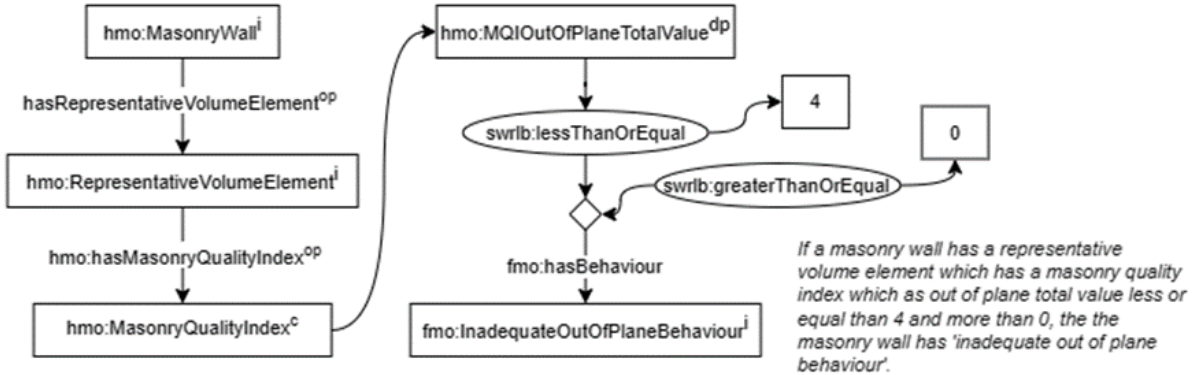
"Define the most plausible failure mechanism of a wall by analyzing its morphological features."

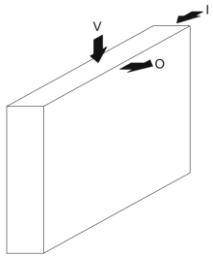
https://w3id.org/fmo#



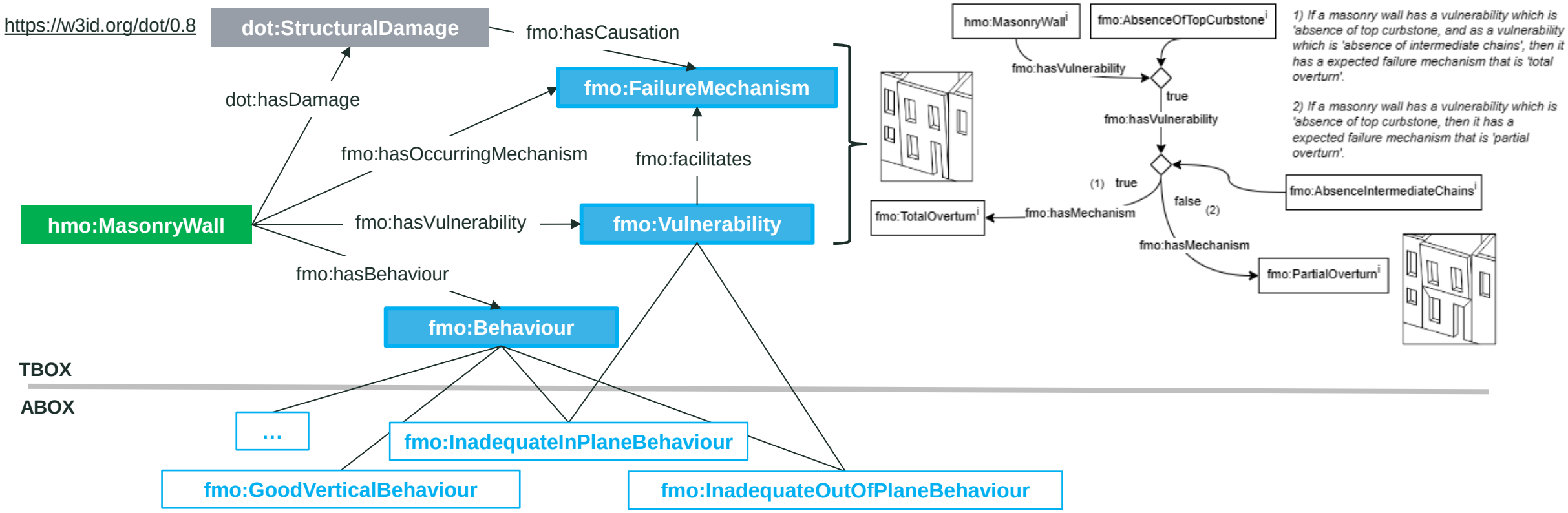
The Failure Mechanism Ontology (FMO)





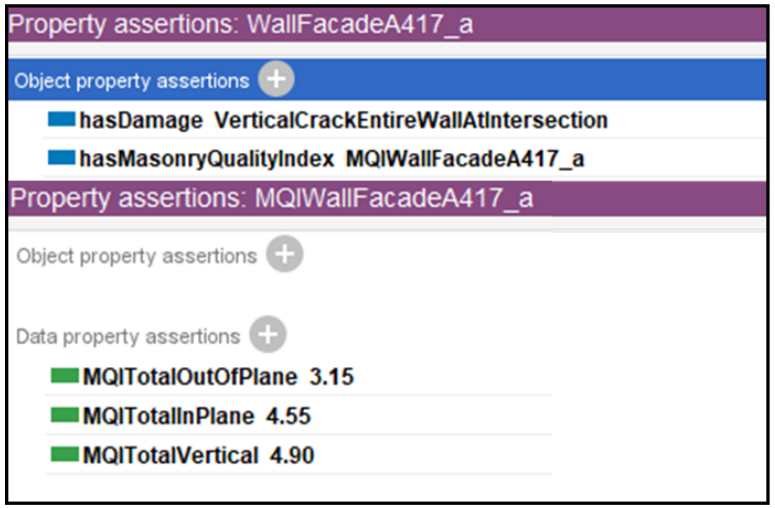


The Failure Mechanism Ontology (FMO)

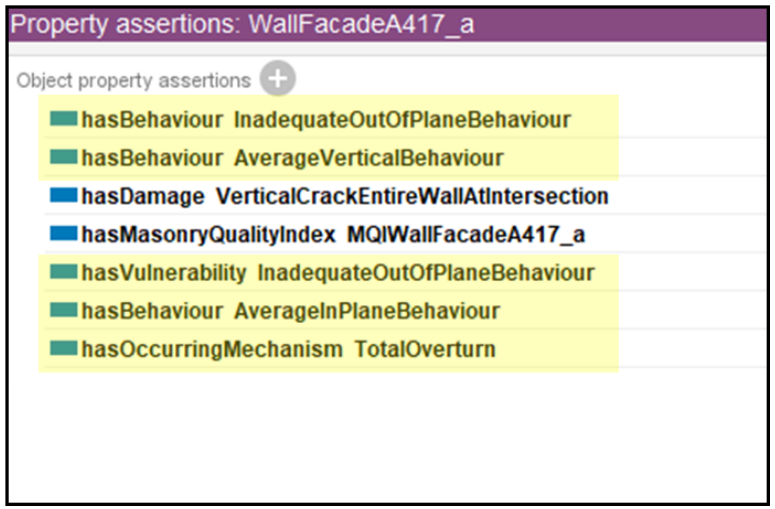


Example of FMO application

Asserted Properties



Inferred Properties



Conclusions and future work

Universidade do Minho

Work timeline – what was done

BIM TO FEM framework

HMO ontology
FMO ontology
HSO ontology

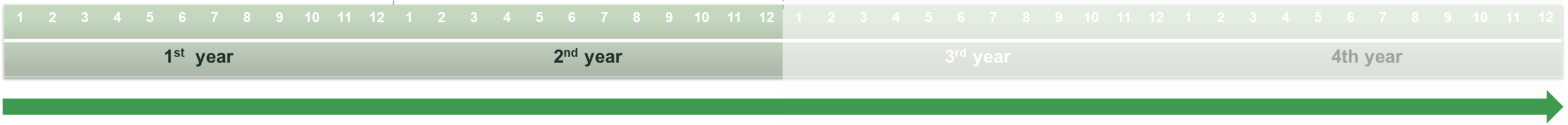
Historic Analysis
In situ survey

Timber-wall connections

Pushover analysis

Ontology rules

Code parallelisation



Work timeline – what to do now

BIM TO FEM framework

HMO ontology
FMO ontology
HSO ontology

Historic Analysis
In situ survey

Timber-wall connections

Pushover analysis

Ontology rules

Code parallelisation

Framework Improvement (complex multimaterial elements)

Cycling testing

Dynamic analyses

Implementation of javascript platform

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

Thanks! Questions?

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Universidade do Minho