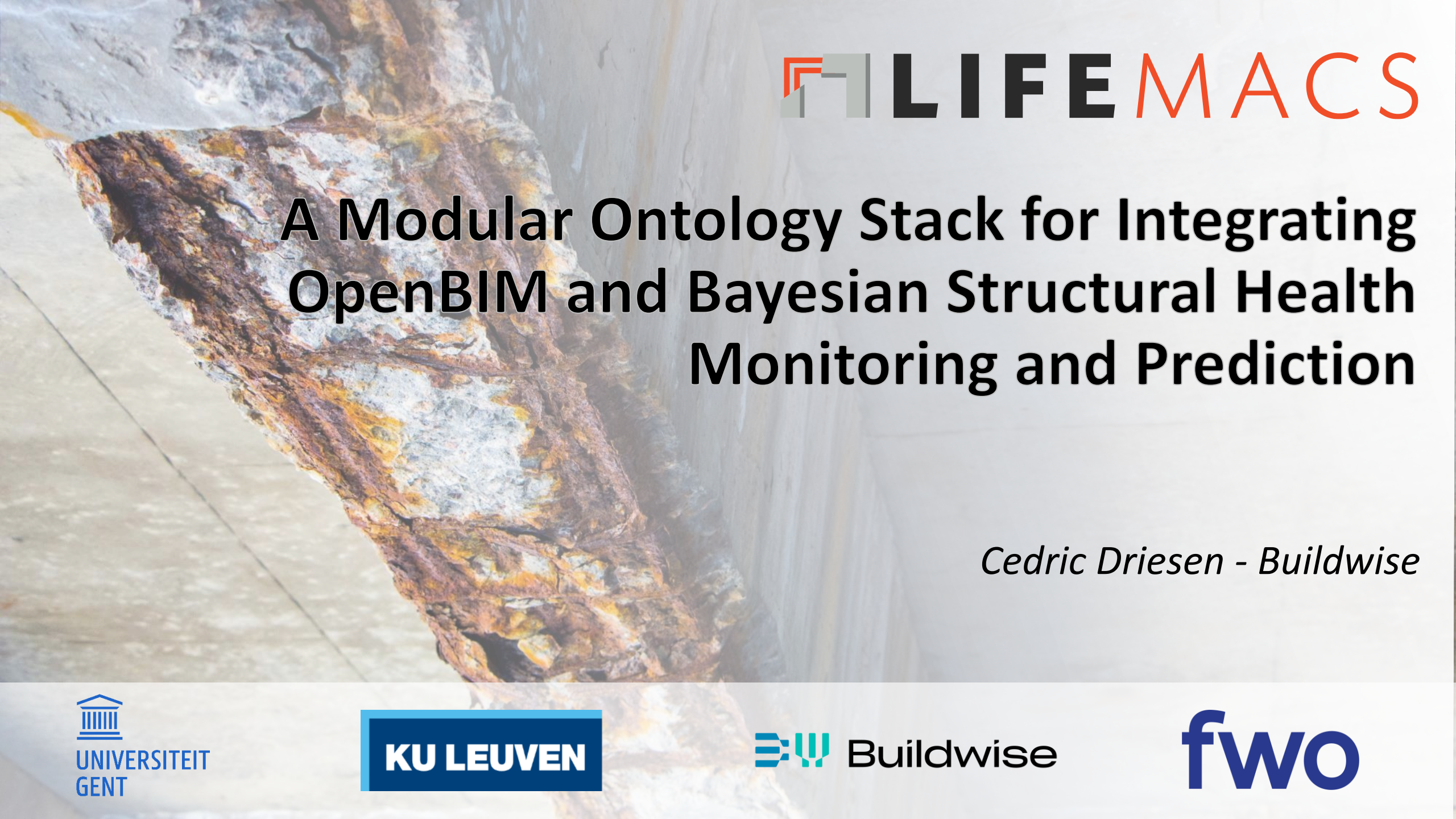

LIFEMACS

A Modular Ontology Stack for Integrating OpenBIM and Bayesian Structural Health Monitoring and Prediction

Cedric Driesen - Buildwise

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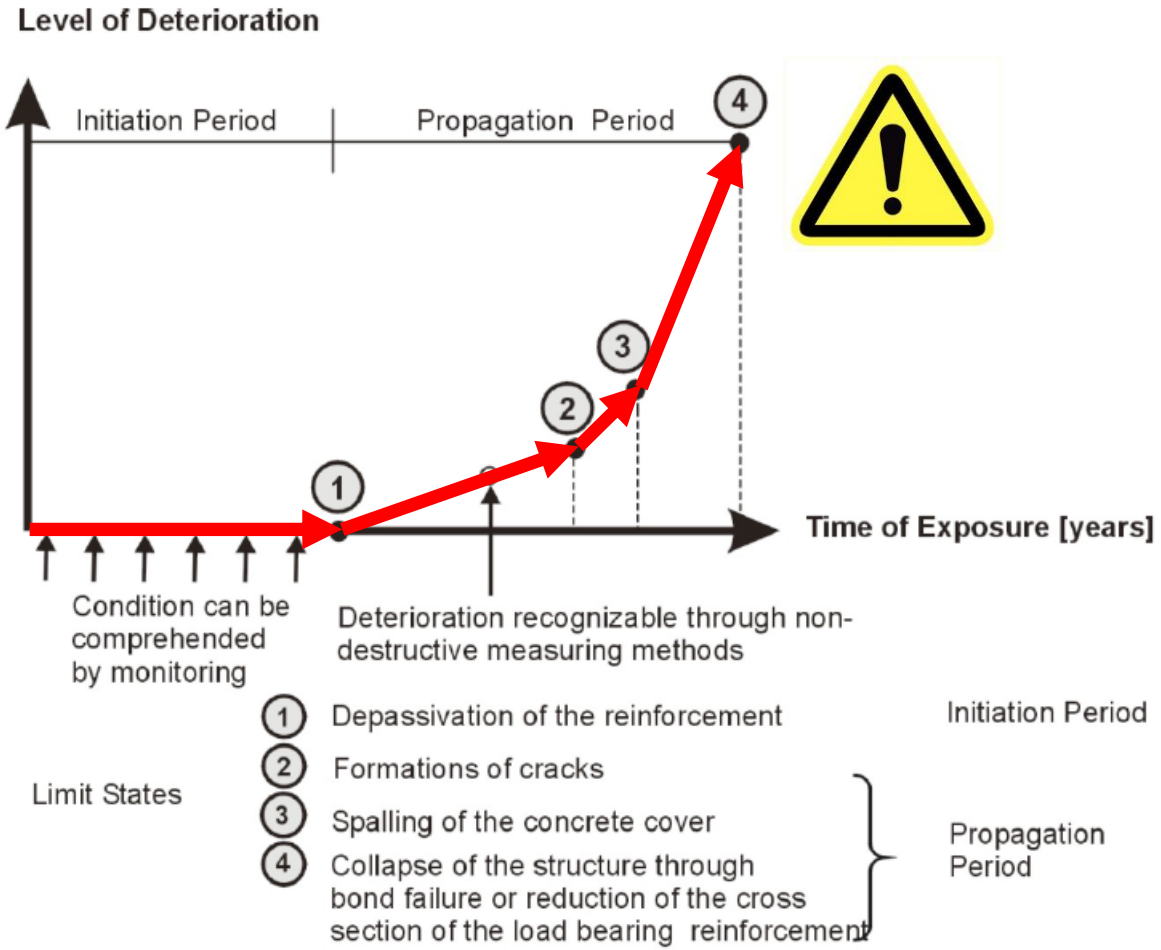
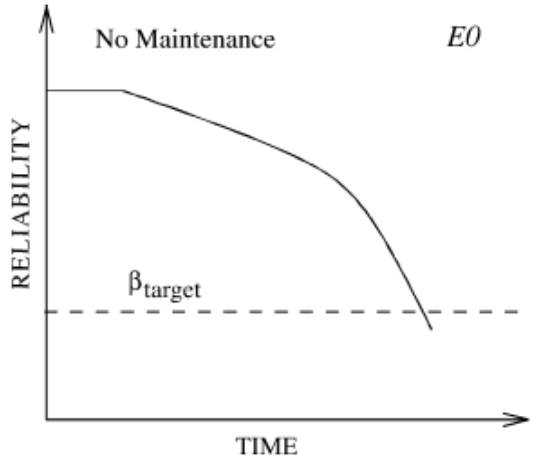
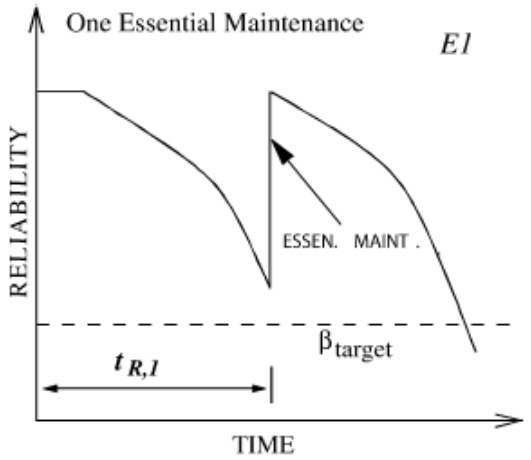
LifeMACS project summary

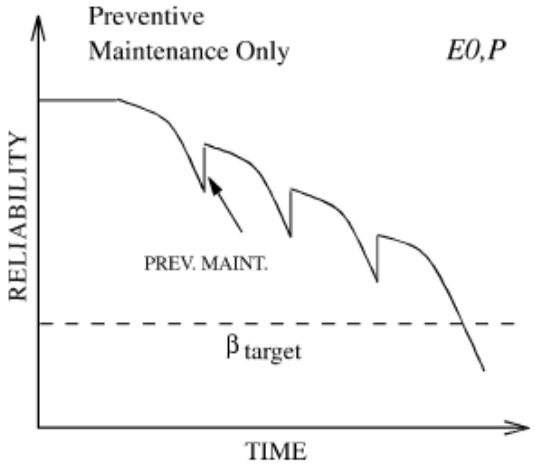
- Deterioration of concrete structures



Traditional repair strategies







LifeMACS: **optimize maintenance timing** & **strategies** using **Bayesian** methods

The work discussed today: **optimize** and facilitate **data storage**, **manipulation**, and **exchange**

Problem statement

Structural health monitoring is complex

Centralized data management?

Technology issues:

- Information is located in **data silos**
- Often **unstructured** e.g. reports on paper
- How to deal with **live** data (e.g. sensors)

Data issues:

- **Time-dependency** is crucial
- Bayesian data has complex **uncertainties**

BIM + databases can give structure and combine information sources

→ but the data issues still remain…

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Solution

Linked data:

- **Convert** centralized BIM model + external databases into one linked graph
- Find/create **ontologies** supporting our data needs
- Automate **queries** to get complicated data immediately

Required:

- BIM-to-LD
- Specific ontology stack
  - BIM support
  - Damage/sensors
  - Uncertainties
  - Time-dependence

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Ontology stack

Ontologies:

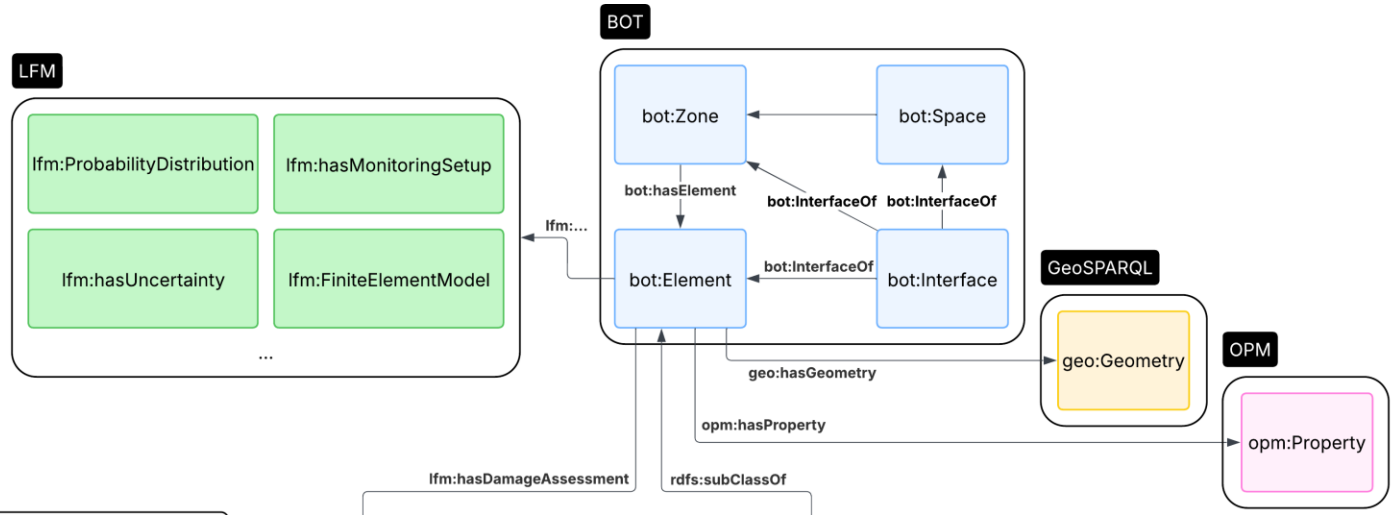
- BOT
- SSN/SOSA
- GeoSPARQL

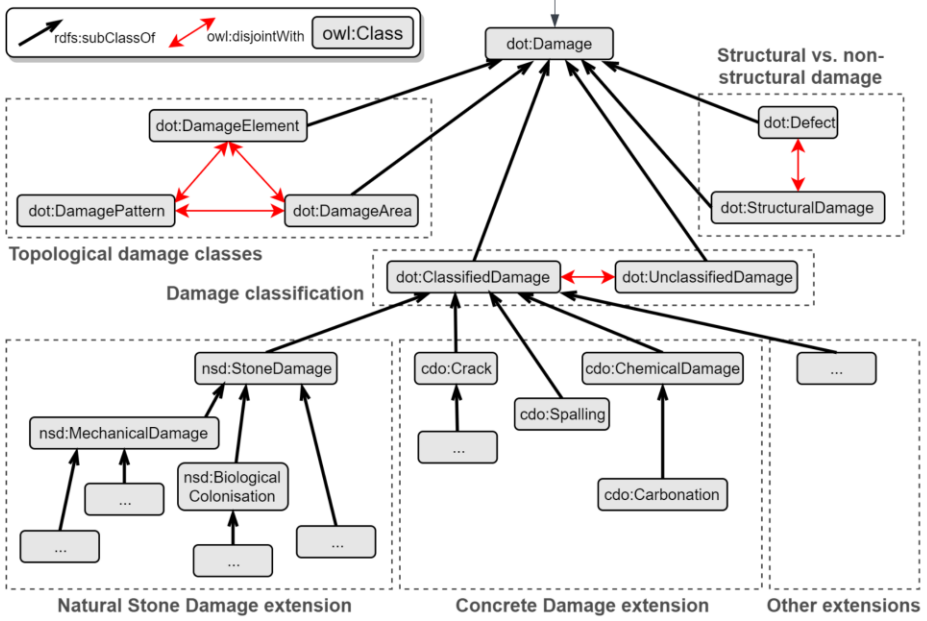
} Proposed in CEN 17632-2

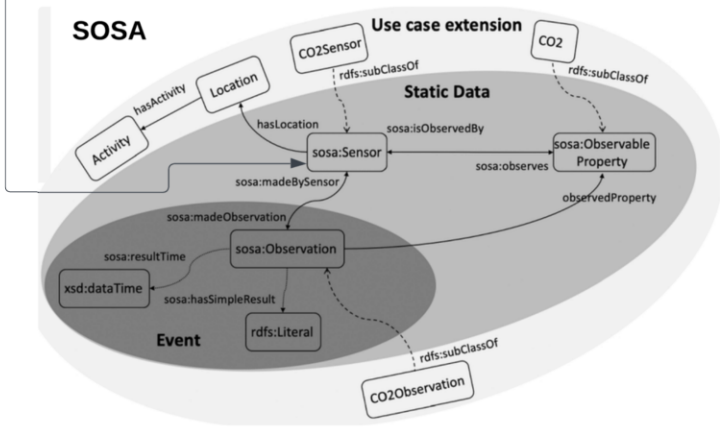
- DOT
- LFM – LifeMACS ontology
- …

- Link to bSDD

- Custom convertor
  - BIM-to-LD







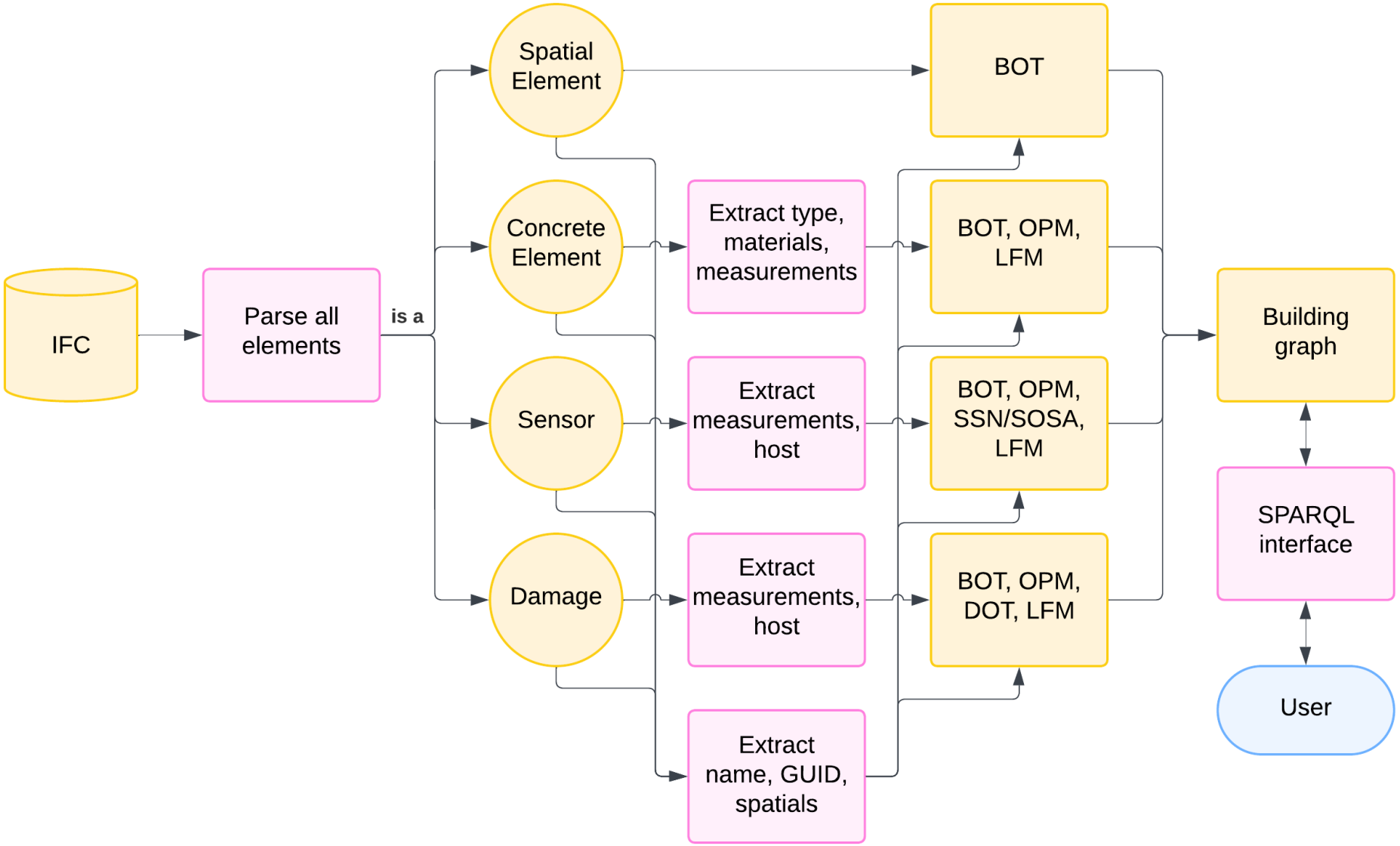
[LifeMACS_LD/LFM.ttl]

LFM Ontology

Name	Description
------	----------
****Classes****	
BayesianModel	A probabilistic model using Bayesian inference.
ProbabilityDistribution	Statistical distribution representing uncertainty in parameters.
Parameter	A parameter in a model or measurement.
ConcreteElement	A structural element made of concrete.
Reinforcement	Steel reinforcement in concrete elements.
CoreSample	A concrete core sample taken from a structure.
LoadTest	A structural load test performed on the structure.
FiniteElementModel	FE model for structural analysis.
DegradationModel	Model describing material degradation over time.
****Properties****	
hasProbabilityDistribution	has probability distribution
hasModelParameter	has model parameter
hasUncertainty	has uncertainty
hasReinforcement	has reinforcement
hasCorrosionLevel	has corrosion level
hasFiniteElementModel	has finite element model
hasDegradationModel	has degradation model
hasValidityPeriod	has validity period
hasDamageAssessment	Links a BOT element to its damage assessment in DOT.
hasMonitoringSetup	Links a BOT element to its sensor platform.
hasSensorNetwork	Links a BOT zone to its sensor network platform.
hasPropertyState	Links a BOT element to its property states in OPM.
hasDamageMonitoring	Links a damage assessment to its observations.
observationState	Links a sensor observation to its property state.
hasTimeInterval	Links any temporal entity to its time interval.
hasIfcRepresentation	Links to the corresponding IFC entity.
confidence	Confidence level in a measurement or prediction.
timestamp	Timestamp of a measurement or event.

LifeMACS_LD/LFM.txt

BIM-to-LD



[LifeMACS_LD/IFCtoLD.py]

Case study: W20

- Bridge in Belgium
- > 60 years old
- Prestressed concrete
- Heavy degradation
  - Reinforcement corrosion
  - Concrete spalling
- Current actions
  - Monthly nighttime inspections
  - 300+ IoT sensors
- Monitoring next 4+ years

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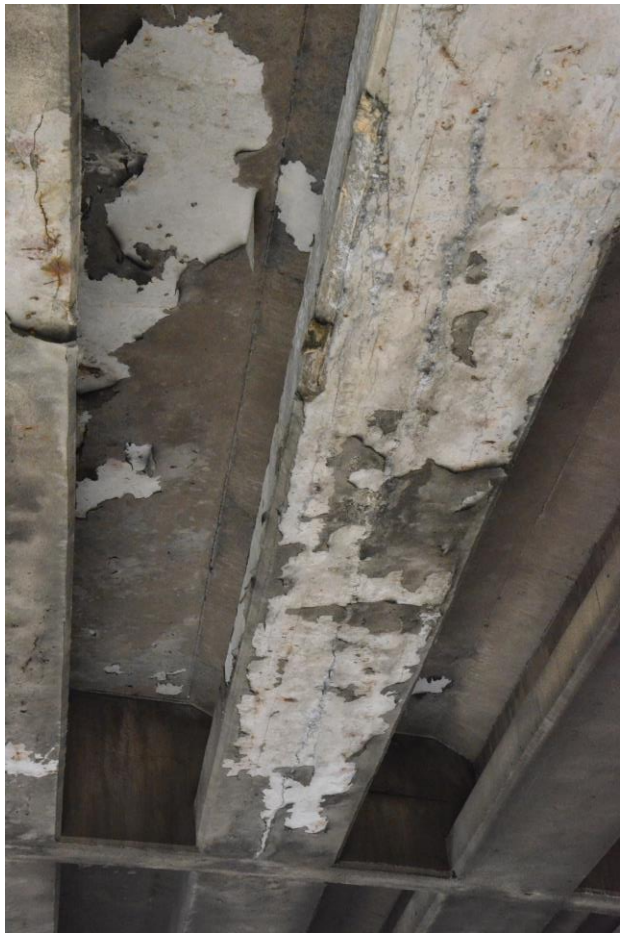
Case study



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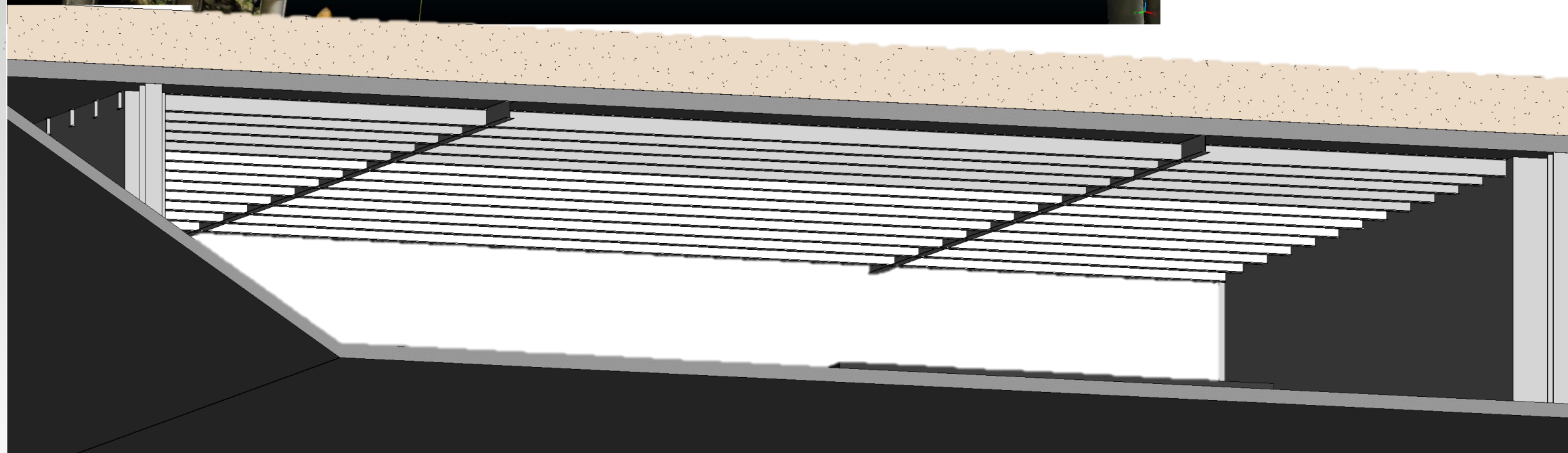
Scan-to-BIM



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BIM-to-LD

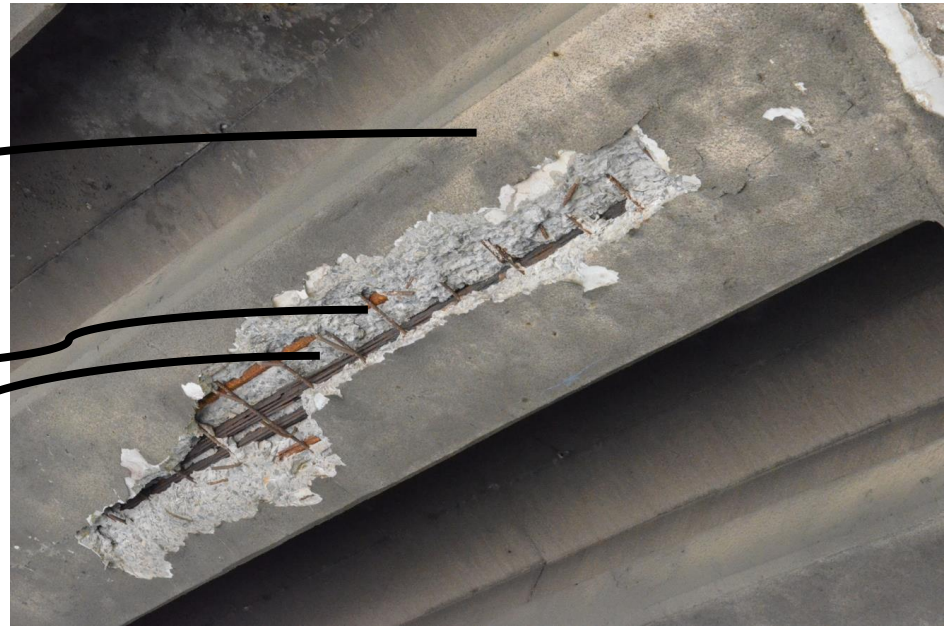
W20 BIM to Linked Data graph (excerpt):

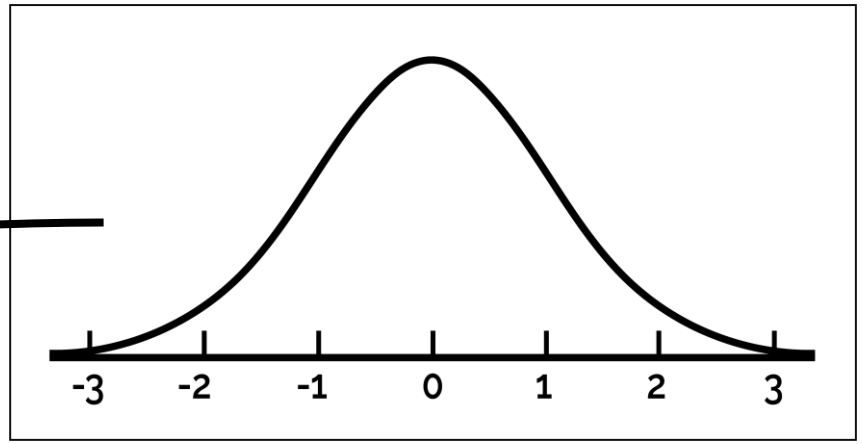
```
# Concrete element hosting a damage
ex:element_b9a2457e-24dd-4abc-b91d-50767b1560bc
   a lfm:ConcreteElement ;
   lfm:hasIfcRepresentation ifc:IfcBeam ;
   lfm:hasIfcGlobalId "0VwJW5Qw3E2uMg8ZhXPz5A" ;
   # Indicate that this element has a damage instance (crack)
   lfm:hasDamageAssessment ex:damage_3f1dac7a-6a5b-471b-b72e-a847716a2301 .

# Damage instance
ex:damage_3f1dac7a-6a5b-471b-b72e-a847716a2301
   a dot:Damage ;
   rdfs:label " crack_1" ;
   lfm:hasIfcGlobalId "1FsUCh_1n6AAe2OZ$QBHTi" ;
   # Instead of a single numeric crack length, we store a property state referencing a probability distribution
   lfm:hasPropertyState ex:property_state_9e5d8ba6-87cc-49f2-a719-5e35c315f711 .

# Property state holding the distribution info
ex:property_state_9e5d8ba6-87cc-49f2-a719-5e35c315f711
   a opm:PropertyState ;
   opm:propertyName "Crack Length" ;
   prov:generatedAtTime "2024-07-23T12:00:00Z"^^xsd:dateTime
   # We link to a NormalDistribution instance
   lfm:hasProbabilityDistribution ex:normalDist_32c68ab0-2f14-4c94-9d3f-0aef47b10f06 .

# The NormalDistribution instance
ex:normalDist_32c68ab0-2f14-4c94-9d3f-0aef47b10f06
   a lfm:NormalDistribution ;
   lfm:mean "17.2"^^xsd:float ;
   lfm:standardDeviation "1.2"^^xsd:float .
```





[LifeMACS_LD/W20.ttl]

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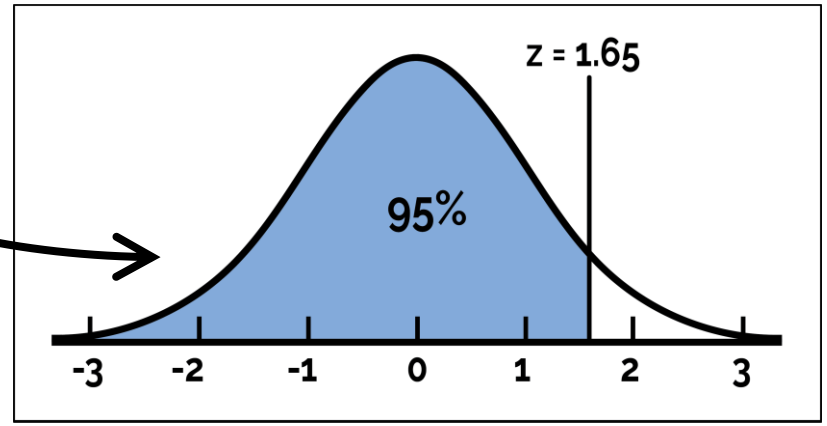
Damage query

- Can be queried using SPARQL query language
- This query gets all damages longer than 15 mm at p < 0.05, their hosts and other properties:

```
SELECT ?element ?elementGuid ?damage ?damageGuid ?meanValue ?stdValue ?lower95
WHERE {
 ?element a lfm:ConcreteElement ;
        lfm:hasIfcGlobalId ?elementGuid ;
        lfm:hasDamageAssessment ?damage .

 ?damage a dot:Damage ;
       lfm:hasIfcGlobalId ?damageGuid ;
       lfm:hasPropertyState ?ps .

 ?ps a opm:PropertyState ;
    opm:propertyName "Crack Length" ;
    lfm:hasProbabilityDistribution ?dist .

 ?dist a lfm:NormalDistribution ;
      lfm:mean ?meanValue ;
      lfm:standardDeviation ?stdValue .

 # Calculate 95% lower bound for damage length = mean - 1.645 * std
 BIND(xsd:float(?meanValue) - 1.645 * xsd:float(?stdValue) AS ?lower95)

 # Filter to return only those cracks whose lower 95% bound is > 15 mm
 FILTER(?lower95 > 15)
}
```



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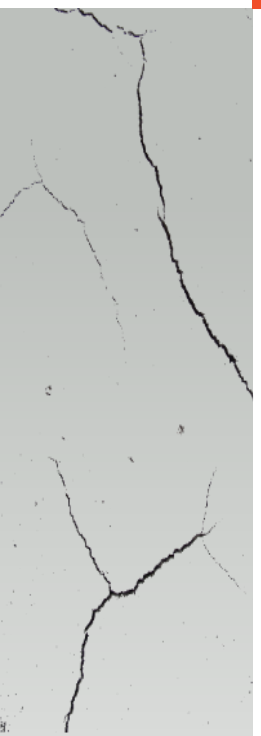
Sensor query

- Retrieve all latest sensor measurements along with their structural element hosts:

```
SELECT ?structuralElement ?elementType ?sensorId ?observation ?value ?unit ?timestamp
WHERE {
  # Get structural elements with sensors
  ?structuralElement a lfm:ConcreteElement ;
                     rdf:type ?elementType ;
                     lfm:hasSensor ?sensor .

  # Get sensor details
  ?sensor sosa:hasId ?sensorId ;
          sosa:observes ?measurementType ;
          sosa:madeObservation ?observation .

  # Get the observation data
  ?observation sosa:hasResult ?result ;
               sosa:resultTime ?timestamp .

  ?result sosa:hasSimpleValue ?value ;
          sosa:hasUnit ?unit .

  # Subquery to get only the latest measurement for each sensor
  {
    SELECT ?sensor (MAX(?time) as ?timestamp)
    WHERE {
      ?sensor sosa:madeObservation ?obs .
      ?obs sosa:resultTime ?time .
    }
    GROUP BY ?sensor
  }
}
ORDER BY ?structuralElement ?measurementType
```

E.g. spatial coordinates, material properties, uncertainty values… could be fed to a FEM-tool.



Questions?

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