Energy-related data integration using Semantic data models for energy efficient retrofitting projects

Álvaro Sicilia ascilia@salleurl.edu
FUNITEC, La Salle Architecture School, Ramon Llull University
Optimised Energy Efficient Design Platform For Refurbishment At District Level

Challenges:

- Provide innovative design tools
- Renovation of buildings as part of a global energy system
- Support the evaluation of retrofitting alternatives
- Ensure interoperability among tools
- Solutions adapted to collaborative multi-disciplinary work
Optimised Energy Efficient Design Platform For Refurbishment At District Level

Challenges:

- Provide innovative design tools
- Renovation of buildings as part of a global energy system
- Support the evaluation of retrofitting alternatives
- Ensure interoperability among tools
- Solutions adapted to collaborative multi-disciplinary work
Energy-related data integration using Semantic data models

1. BIM data
   - IFC models

2. GIS data
   - CityGML

3. Contextual data
   - Socio-economic data
   - Weather data
   - Energy prices
   - Users’ objectives
   - Monitoring data
   - CSV, SQL...
Energy-related data integration using Semantic data models

1. BIM data
   - IFC models

2. GIS data
   - CityGML

3. Contextual data
   - Socio-economic data
   - Weather data
   - Energy prices
   - Users' objectives
   - Monitoring data
   - CSV, SQL...

District Retrofitting design

ENERGY DPI’s
COMFORT DPI’s
ENVIRONMENTAL DPI’s
ECONOMIC DPI’s
SOCIAL DPI’s
URBAN DPI’s
GLOBAL DPI’s
Energy-related data integration using Semantic data models

Input Data

1. BIM data
   - IFC models

2. GIS data
   - CityGML

3. Contextual data
   - CSV, SQL...

OptEEmAL Platform
A web-based platform for district energy-efficient retrofitting design

Automating data integration task to enable optimisation process (>1000 simulations)

District Retrofitting design

Energy Plus
- ENERGY DPI's
- COMFORT DPI's

CitySim
- ENVIRONMENTAL DPI's
- ECONOMIC DPI's
- SOCIAL DPI's
- URBAN DPI's
- GLOBAL DPI's

NEST

Multiple data models, domains, formats...
Multiple tools, input formats...
Energy-related data integration using Semantic data models

**Input Data** ➔ **District Data Model** ➔ **Retrofitting design**

1. **BIM data**
   - IFC models
   - Socio-economic data
   - CSV, SQL, ...

2. **GIS data**
   - CityGML
   - Weather data

3. **Contextual data**
   - CSV, SQL...

**Multiple data models, domains, formats...**

**District Data Model**

- IFC model
- CityGML
- Energy prices
- Monitoring data

**Users’ objectives**

**Retrofitting design**

- **Energy Plus**
  - ENERGY DPI’s
- **CitySim**
  - COMFORT DPI’s
- **NEST**
  - ENVIRONMENTAL DPI’s
- **Multiple tools, input formats...**

**Multiple data models, domains, formats...**
Energy-related data integration using Semantic data models

Input Data → District Data Model → Retrofitting design

“Centralized” approach

Standard data model

Domain 1 → Domain 2 → Domain 3 → Domain 4

Centralized standard data models (e.g. CityGML, IFC)

“Decentralized” approach

Domain 1 → Domain 2 → Domain 3 → Domain 4

Decentralized and ad hoc solutions to interoperability

Multiple domains, formats... Input formats...
Energy-related data integration using Semantic data models

Input Data → District Data Model → Retrofitting design

1. Data Integration

Socio-economic data
CSV, SQL, ...

Weather data

Energy prices

Monitoring data

2. Data Interoperability

Multiple data models, domains, formats...

Energy Data Model

Energy Plus

CitySim

NEST

n Data Model

Economic Data Model

Users’ objectives

Simulation Data models

Multiple tools, input formats...

Semantic Web Technologies

OptEEmAL GA no. 680676 | Address Sustainable Places 2017 | Middlesbrough, UK
Energy-related data integration using Semantic data models

Input Data → District Data Model → Retrofitting design

1. Data Integration
   - CityGML RDF
   - IFC RDF

2. Data Interoperability
   - CityGML OWL
   - IFC OWL
   - SimModel OWL

Output Models:
- Energy Plus
- CitySim
- NEST
- Proprietary Format

DATA MODELS → SEMANTIC DATA MODELS → SIMULATION DATA MODELS → SIMULATION MODELS

Contextual Data

CityGML File
IFC File

Energy Data Model
Energy-related data integration using Semantic data models

Input Data → District Data Model → Retrofitting design

1. Data Integration

A) Finding relations (alignments) between CityGML OWL, ifcOWL and SimModelOWL
Ontology matching: LogMap, AML...

B) Transforming RDF data according to the ontologies and their alignments. RDF-To-RDF via SPARQL constructs: SPARQL Constructs, R2R
Energy-related data integration using Semantic data models

- Ontologies represent different domains (e.g., Construction, Energy Simulations...)
- Ontologies have structural and semantic differences

SEMANTIC DATA MODELS → SIMULATION DATA MODELS
Energy-related data integration using Semantic data models

Structural and conceptual mismatches between models:
- Different structures
Energy-related data integration using Semantic data models

SIMMODEL IFC RDF data

inst:IfcBuildingStorey_941 sim:BuildingStoryHeight "2699.99999999993".

IFC RDF data

inst:IfcLengthMeasure_919 rdf:type ifc:IfcLengthMeasure; inst:IfcLengthMeasure_919 express:hasDouble "2.69999999999993".

Structural and conceptual mismatches between models:
- Different structures
- Different Units
Energy-related data integration using Semantic data models

**CONSTRUCT** {
  ?storey rdf:type sim:SimBuildingStory_BuildingStory_Default ;
  ?storey sim:BuildingStoryHeight ?elevationInMM.
}

**WHERE** {
  ?storey rdf:type ifc:IfcBuildingStorey ;
  ?elevationStorey express:hasDouble ?elevationInMts.
  BIND (?elevationInMts*1000 AS ?elevationInMM).
}
Energy-related data integration using Semantic data models

Structural differences: from a list of linked items to a string with the items concatenated
Energy-related data integration using Semantic data models

CONSTRUCT {
    ?placement rdf:type simgeom:SimPlacement_Axis2Placement3D_Default ;
    simgeom:coordinates ?coordinates .
}

WHERE {
    ?placement ifc:location_IfcPlacement [ ifc:coordinates_IfcCartesianPoint ?item1 ].
    ?item1 list:hasContents [ express:hasDouble ?point1 ];
    list:hasNext ?item2 .
    ?item2 list:hasContents [ express:hasDouble ?point2 ];
    list:hasNext [ list:hasContents [ express:hasDouble ?point3 ] ].

    BIND (concat (STR(?point1), ', ', STR(?point2), ', ', STR(?point3)) AS ?coordinates ) .
}

Structural differences: from a list of linked items to a string with the items concatenated
Energy-related data integration using Semantic data models

```java
java -jar DataMapper.jar <input IFC file> <output SimModel file> <queries path>
```

<table>
<thead>
<tr>
<th></th>
<th>IFC - express</th>
<th>IFC CBIP-express</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Storey</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Slabs</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Walls</td>
<td>675</td>
<td>675</td>
</tr>
<tr>
<td>Spaces</td>
<td>262</td>
<td>262</td>
</tr>
<tr>
<td>SpaceBoundaries</td>
<td>0</td>
<td>6332</td>
</tr>
</tbody>
</table>
Energy-related data integration using Semantic data models

**OPTEEMAL - DataMapper (ETL2)**

**IFC input file:** UG1_Torre_Turina_18_BST.ttl

Invoking the following **sparql** CONSTRUCTS (18):

<table>
<thead>
<tr>
<th>Triples</th>
<th>Time</th>
<th>Query</th>
</tr>
</thead>
<tbody>
<tr>
<td>166</td>
<td>1527 ms</td>
<td>SimBuildingStory_BuildingStory_Default.rq</td>
</tr>
<tr>
<td>29</td>
<td>35 ms</td>
<td>SimBuilding_Building_Default.rq</td>
</tr>
<tr>
<td>37993</td>
<td>446 ms</td>
<td>SimGeomCurve_CompositeCurve_Default.rq</td>
</tr>
<tr>
<td>18997</td>
<td>1424 ms</td>
<td>SimGeomCurve_Polyline_Default.rq</td>
</tr>
<tr>
<td>94981</td>
<td>903 ms</td>
<td>SimGeomSurface_BoundedSurface_CurveBoundedPlane.rq</td>
</tr>
<tr>
<td>685</td>
<td>10 ms</td>
<td>SimGeomVector_Vector_Direction.rq</td>
</tr>
<tr>
<td>8</td>
<td>238 ms</td>
<td>SimLocalPlacement_LocalPlacement_AbsolutePlacement.rq</td>
</tr>
<tr>
<td>25361</td>
<td>4353 ms</td>
<td>SimLocalPlacement_LocalPlacement_RelativePlacement.rq</td>
</tr>
<tr>
<td>84659</td>
<td>1461 ms</td>
<td>SimPlacement_Axis2Placement3D_Default.rq</td>
</tr>
<tr>
<td>92134</td>
<td>1311 ms</td>
<td>SimPlacement_Axis2Placement3D_Default_optional.rq</td>
</tr>
<tr>
<td>49</td>
<td>5463 ms</td>
<td>SimSlab_Floor_FloorOverEarth.rq</td>
</tr>
<tr>
<td>203</td>
<td>5935 ms</td>
<td>SimSlab_Floor_InterzoneFloor.rq</td>
</tr>
<tr>
<td>49</td>
<td>406 ms</td>
<td>SimSlab_RoofSlab_RoofUnderAir.rq</td>
</tr>
<tr>
<td>92277</td>
<td>1084 ms</td>
<td>SimSpaceBoundary_SecondLevel_SubTypeA.rq</td>
</tr>
<tr>
<td>0</td>
<td>63 ms</td>
<td>SimSpaceBoundary_SecondLevel_SubTypeB.rq</td>
</tr>
<tr>
<td>4717</td>
<td>34 ms</td>
<td>SimSpace_Occupied_Default.rq</td>
</tr>
<tr>
<td>2887</td>
<td>86 ms</td>
<td>SimWall_TypicalWall_ExteriorAboveGrade.rq</td>
</tr>
<tr>
<td>5136</td>
<td>189 ms</td>
<td>SimWall_TypicalWall_Interior.rq</td>
</tr>
</tbody>
</table>

Storing test_002_Torre_Turina_sparql.ttl model with a total of 611818 triples
Energy-related data integration using Semantic data models

Only slabs and walls attached to a thermal space are processed

<table>
<thead>
<tr>
<th></th>
<th>IFC - express</th>
<th>IFC CBIP- express</th>
<th>SimModel - RDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Storey</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Slabs</td>
<td>48</td>
<td>48</td>
<td>12</td>
</tr>
<tr>
<td>Walls</td>
<td>675</td>
<td>675</td>
<td>505</td>
</tr>
<tr>
<td>Spaces</td>
<td>262</td>
<td>262</td>
<td>262</td>
</tr>
<tr>
<td>SpaceBoundaries</td>
<td>0</td>
<td>6332</td>
<td>6332</td>
</tr>
</tbody>
</table>
Energy-related data integration using Semantic data models

2. Data Interoperability

Ad hoc connectors between Energy Data Models and particular simulation models.

All particular data needed by Simulation models have been integrated in the Simulation Data Models.
Example of a SPARQL query used in the simulation model generation process

```sparcql
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX simbldg: <http://www.lbl.gov/namespaces/Sim/BuildingModel#>
PREFIX simgeom: <http://www.lbl.gov/namespaces/Sim/ResourcesGeometry#>
PREFIX simres: <http://www.lbl.gov/namespaces/Sim/ResourcesGeneral#>

SELECT ?simSpace ?coordinates
WHERE
{
  ?simSpace rdf:type simres:SimSpaceBoundary_SecondLevel_SubTypeA .
  ?simSpace simres:refId ?refId .
  FILTER regex(?refId, "58")
  ?SimSpace_Occupied_Default rdf:type simbldg:SimSpace_Occupied_Default .
}
```
Conclusions

- **Solve interoperability** issues between data models and simulations tools is a hard task

- **Mappings** and **transformation** rules help to overcome the structural and semantic heterogeneity

- Currently, we are **integrating** IFC, climate, Energy Conservation measures data to calculate the baseline scenario and the refurbished scenarios.
THANK YOU FOR YOUR ATTENTION!

Álvaro Sicilia ascilia@salleurl.edu

FUNITEC, La Salle Architecture School, Ramon Llull University
Energy-related data integration using Semantic data models

Ontologies

ifcOWL (Pauwels & Terkaj) - [http://www.buildingsmart-tech.org/future/linked-data/ifcowl](http://www.buildingsmart-tech.org/future/linked-data/ifcowl)
- Is an ontology for IFC supported by BuildingSMART.
- Exploit the benefits of semantic web technologies in terms of data distribution, extensibility of the data model, querying, and reasoning.

CityGML Owl (Knowledge Engineering @ ISS UoG) - [http://cui.unige.ch/isi/icle-wiki/ontologies](http://cui.unige.ch/isi/icle-wiki/ontologies)
- A direct translation of the CityGML XMLSchema to OWL, manually tuned

- It is a data model with a domain that covers the domain of energy simulation of the entire building.
- This is implemented as a data model (.XSD) that is interoperable through XML.
- Is “geometrically compatible” with IFC among other formats.