General Indicator Modelling Framework for Decision Support

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ISO TC 211 Seminar “Standards in Action”, 4 June 2021
Measuring Landscape / City Performance

Evaluation is typically based on indicators, the most relevant are called Key Performance Indicators (KPIs)

- Energy Indicators
- Ecological Indicators
- Mobility Indicators
- Financial Indicators
- Social Indicators

Source: shutterstock.com
Indicators

- Energy Indicators
- Mobility Indicators
- Ecological Indicators
- Social Indicators
- Financial Indicators

Geo(base) data

- CityGML Data
- ALKIS Data
- ATKIS Data
- INSPIRE Data
- BIM Data
Observations

1. Geobase data are available for entire countries and can be used for computing indicator values
   - (however, typically additional domain specific data are required)

2. All these geospatial information are based on standardized semantic data models / ontologies

3. So far, indicators are typically not formally modelled using a standardized framework

4. Furthermore, no systematic model exists yet for linking indicators and geobase data
Model Driven Engineering (MDE)

- … is a software engineering paradigm which began to evolve in the 1980s

- MDE puts the “model” in the form of formal specifications in the centre of software analysis and design
  - Application relevant structures are represented by formal data models (e.g. using Unified Modeling Language, UML)
  - Model Driven Architecture (MDA) is considered a part of MDE
  - Program code is automatically derived from models

- MDE also addresses the linking of different models
  - This is called Model Weaving
  - Different models are linked by a weaving model which takes care of data transformation across the models
This is the general schema which all geospatial data models follow (e.g. CityGML, INSPIRE, LADM, national cadaster & topogr. models)

This is the data model of the 3D city model (here: CityGML)
It defines the structures of all possible 3D city models

3D city model data, e.g. the objects of the 3D city model of Berlin
General Indicator Modeling Framework for Decision Support

**Indicator Modelling**

Domain specific indicators follow a General Ind. Model

These are the indicator models from different application domains

Concrete indicators for concrete city / landscape objects

**General Feature Model**
ISO 19109

**CityGML Application Schema**

**General Indicator Model**

**Energy Related KPIs Application Schema**

**Climate Related KPIs Application Schema**

**M1: Model**

**M2: Metamodel**

**M0: Instance**

KPI A Building Y

KPI B Building Z

X Y Z
Requirements for Indicator Models

► **Different types of indicators** need to be distinguished (i.e. numerical, textual, categorical indicators)

► **Complex indicators** can be composed & computed from
  - attribute values from associated city / landscape model objects
  - constants
  - mathematical expressions (unary / binary arithmetic operations) on other indicators

► **Indicator value aggregation** (e.g. summation, average, maximum, etc.) of other indicators

► Augment indicator values with **meta information** like accuracy, lineage / source etc.
  - allowing for **automatic sensitivity analysis**
Domain Specific Indicator Modelling (I)

Domain of the stakeholder/application specialist

Energy Planner
Domain Specific Indicator Modelling (II)

Many of the reference objects in the context of urban & landscape indicators are spatial objects.

Energy Planner
Linking Geospatial and Indicator Models

- **Geospatial Application Model (e.g. CityGML)**
  - CityObject
  - CityObject Group
  - Building
  - Solid

- **Weaving Model**
  - District Connector
  - Building Connector
  - OCL Rule 1

- **Reference Model**
  - District
  - Building
  - OCL Rule 2

- **Object Related Domain Indicators**
  - DistrictHeat EnergyDemand
  - BuildingHeat EnergyDemand
  - HeatDemand

- **Domain Indicators**

- **General Indicator Model**
  - Numeric Indicator
    - + value

**Domain of the geodata provider**

**Domain of the stakeholder/application specialist**

City Modeler

Energy Planner
Rules in Object Constraint Language (OCL) - 1

Reference Objects

- District [refDistrict]
- Building [refBuilding, refBuildingHeat]

Object Related Domain Indicators

- DistrictHeatEnergyDemand
- BuildingHeatEnergyDemand [+ compute()]

Domain Indicators

- HeatDemand

General Indicator Model

- Numeric Indicator
  - + value

context BuildingHeatEnergyDemand inv:
  self.value = refBuilding.volume * 0.97

context DistrictHeatEnergyDemand inv:
  self.value = Sum(refDistrict.refBuilding.refBuildingHeatEnergyDemand.value)
Rules in Object Constraint Language (OCL) - 2

context BuildingConnector inv: refBuilding.volume = refCityGMLBuilding.volume
General Indicator Modeling Framework

► Each **Indicator Application Model** is defined purely from the viewpoint and requirements of the domain specialist
  - data is modeled and structured according to application domain needs only – and not according to a given geospatial data model

► The **data model** is separated into **5 consecutive sections**
  1. Abstract Indicator classes (e.g. numeric indicator)
  2. Domain specific indicators (e.g. heat demand)
  3. Object-related domain specific indicators (e.g. building heat demand)
  4. Reference Objects for the indicators (e.g. building)

► The 5\textsuperscript{th} section addresses linking of the indicator model with a geospatial application schema (like CityGML or INSPIRE)
  - Weaving Classes relate Reference Objects with Feature Types from the geospatial application schema
Linking Geospatial and Indicator Models

Geospatial Application Model (e.g. CityGML)

- CityObject
  - Building
    - geometry

Weaving Model

- District Connector
  - District
    - volume

Reference Objects

- Building
  - EnergyDemand
    - compute()

Object Related Domain Indicators

- DistrictHeat
  - EnergyDemand
    - num
    - value

Domain Indicators

- HeatDemand

General Indicator Model

- Numeric Indicator
  - + value

OCL Rule 1

- «Aggregation»

Domain of the geodata provider

Domain of the stakeholder/application specialist

City Modeler

Energy Planner

04.06.2021

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General Indicator Modeling Framework for Decision Support
General Indicator Model (Meta Model Level)

From ISO 19109

Class M2

«metaclass» GI_FeatureType
+ typeName: LocalName [0..1]
+ definition: CharacterString
+ isAbstract: Boolean

«metaclass» GI_InheritanceRelation
+ subtype
1
+ supertype
0..*

«metaclass» GI_IndicatorType
+ definition: CharacterString

«metaclass» GI_WeavingClassType

«metaclass» GI_FeatureType_WeavingClassType_AssociationType
+ constrainedBy 0..*

«metaclass» GI_Constraint
+ definition: CharacterString

«metaclass» GI_IndicatorComputationRule
+ definition: CharacterString

«metaclass» GI_ReferenceFeatureType
+ constrainedBy 0..*

«metaclass» GI_WeavingClassType_ReferenceFeatureType_AssociationType
+ includes 1..*

«metaclass» GI_PropertyType
+ memberName: LocalName [0..1]
+ definition: CharacterString

«metaclass» GI_AttributeType
+ valueType: TypeName
+ domainOfValues: CharacterString
+ cardinality: Multiplicity

«metaclass» GI_AssociationRole
+ roleName 1..*
+ constrainedBy 0..*
+ carrierOfCharacteristics 0..*

«metaclass» GI_AssociationType
+ roleName 0..*
+ linkBetween 0..*

«metaclass» GI_AggregationType
+ cardinality: Multiplicity

«metaclass» GI_TemporalAssociationType

«metaclass» GI_SpatialAssociationType

«metaclass» GI_DomainIndicatorType

«metaclass» GI_ObjectRelatedDomainIndicatorType

«metaclass» GI_ObjectRelated

04.06.2021

General Indicator Modeling Framework for Decision Support
Linking of an Indicator Model to different Geospatial Application Models and BIM

Domains of the geodata / BIM providers

Model Weavings

Domain of the stakeholder/application specialist

- CityGML
- Weaving Classes 1
- Reference Object Classes
- Object Related Indicators Domain A
- General Indicator Model

Domain of the stakeholder/application specialist

What can we do with our data?

Where do I get the data from?
Linking of an Indicator Model to different Geospatial Application Models and BIM

CityGML

Weaving Classes 1

INSPIRE

Weaving Classes 2

BIM / IFC

Weaving Classes 3

Reference Object Classes

Object Related Indicators Domain A

General Indicator Model

Domains of the geodata / BIM providers

Model Weavings

Domain of the stakeholder/application specialist

We can analyze & compare how good / easy an indicator model fits to a specific geospatial application model!
Example: Flood Damage Assessment à la HAZUS

Geospatial Application Schema (here: CityGML)

Weaving Class Types

Reference Feature Types

Object Related Domain Indicator Types

Domain Indicator Types

General Indicator Model

Ph.D. Work by Mostafa El Fouly (TU Munich) & Anna Labetzki (TU Delft):
Flood Damage Cost Estimation in 3D based on an Indicator Modelling Framework,
IJGI, 11(1), 2020  https://doi.org/10.1080/19475705.2020.1777213

04.06.2021 General Indicator Modeling Framework for Decision Support 19
Cracking Data Silos by Connecting Domain Data via CityGML
Semantic 3D City Model as Integration Platform
Information Integration within the 3D City Model

**Energy**
- Heat energy demand
- Energy demand for warm water
- Electric power demand

**Noise immission**
- Noise levels on the facade
- Number of inhabitants

**Economy**
- Assessed real estate value
- Provided support for rents
Standardized Access to Semantic City Models

Mapping the state of a city at time $t_i$

Virtually carrying out planned actions by changing the city model accordingly

Energy Demand & Production Estimation
Noise Immission Simulation & Mapping
Real Estate Management & Urban FM
Vulnerability Analysis & Disaster Management
Conclusions

► General Indicator Model: new framework for model based representation and automated computation of indicators

● Indicators for different domains are specified in a standardized and interoperable way using UML class diagrams and OCL rules
  ● analogous to ISO 19109 and geospatial application schemas

● Indicator models are linked to geobase data models using model weaving

► The framework facilitates

● systematic analysis of (also very complex) indicators and their relationships to digital landscape and city models & BIM

● representing and explaining key performance indicators for evaluation of city & landscape (aspects) represented by 3D models

● automatic derivation of programs to compute indicator values