Testing and Enhancing the Scenario ADE in the Context of Building Energy Performance Simulations

Energy ADE workshop

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TU Delft

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Contents

Motivation - From City Model to Chaos

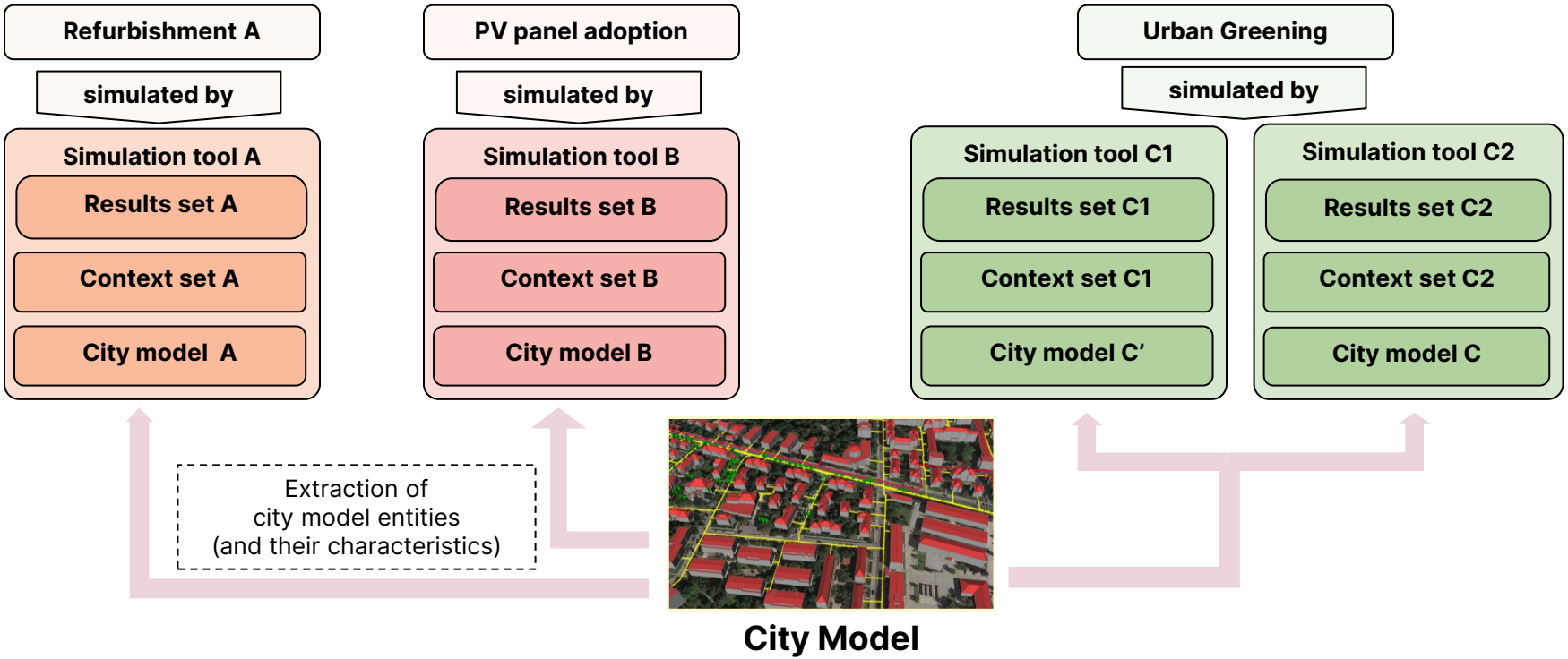
Real City

City Model

"digital twin"

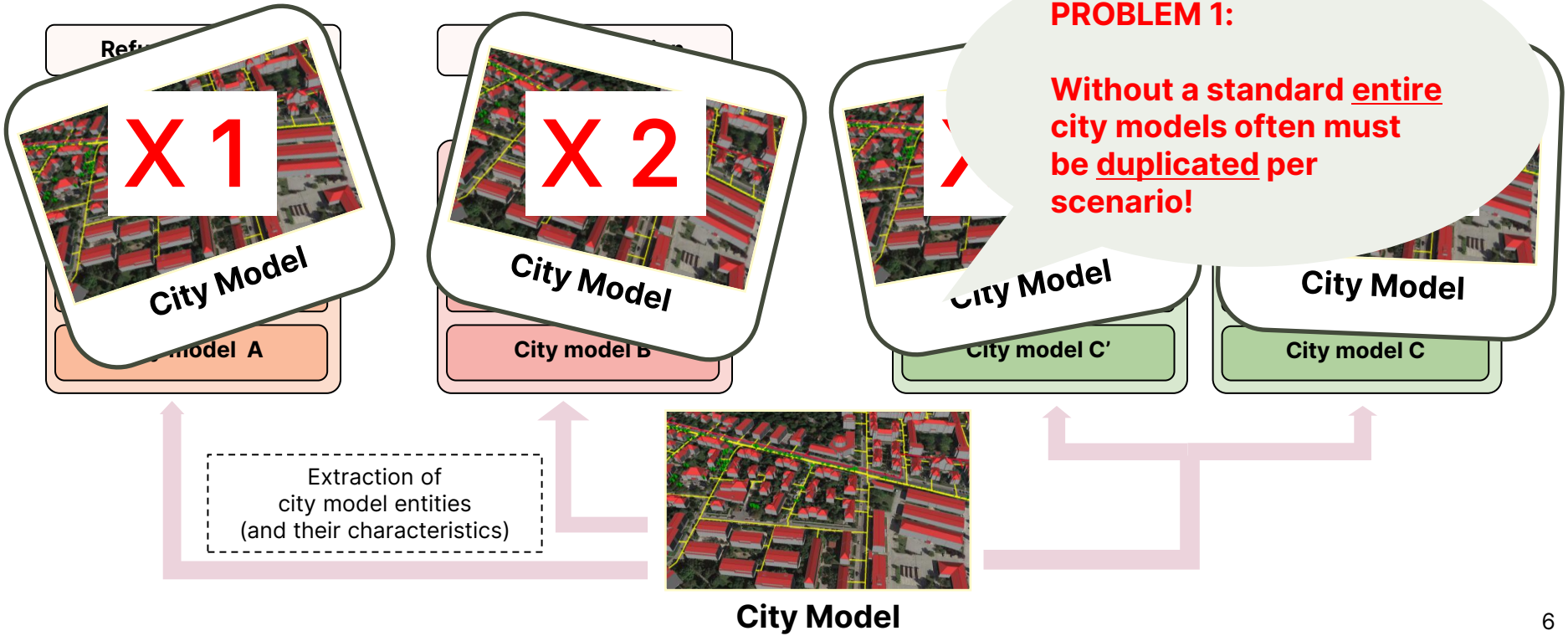
Motivation - From City Model to Chaos

Urban energy planning requires evaluating multiple “what if” futures of the city model (refurbishment, PV adoption, climate change)



Motivation - From City Model to Chaos

Urban energy planning requires evaluating multiple “what if” futures of the city model (refurbishment, PV adoption, climate change)



Motivation - From City Model to Chaos

PROBLEM 2:

Which set of results is "better“ ?

Storing "just" the results may not be enough!

anel adoption

ted by

n tool B

set B

text set B

City model B

Urban Greening

simulated by

Simulation tool C1

Results set C1

Context set C1

City model C’

Simulation tool C2

Results set C2

Context set C2

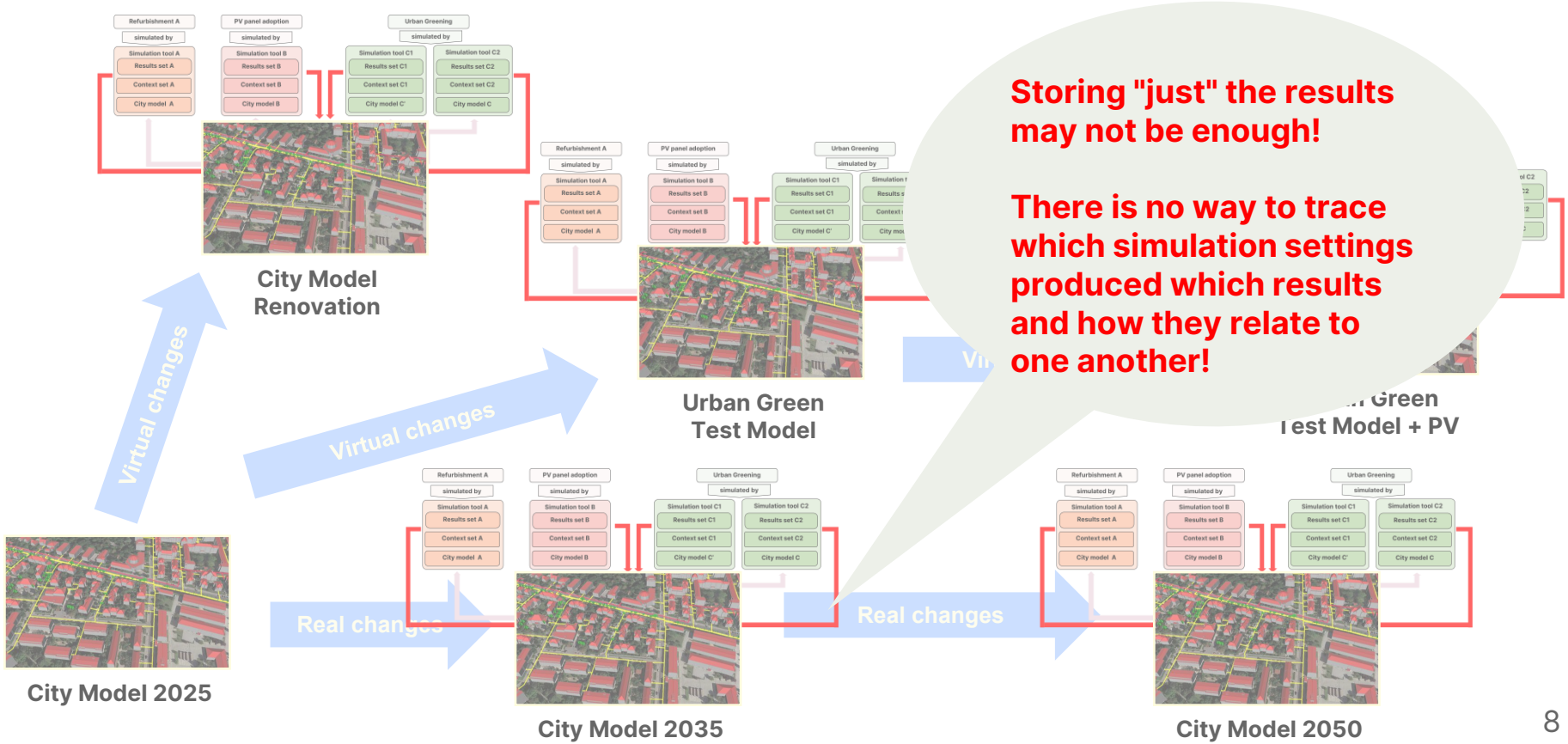
City model C

Extraction of
city model entities
(and their characteristics)

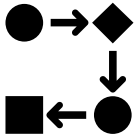
City Model

Import of Simulation Results

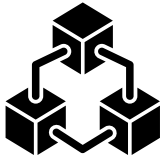
Motivation - From City Model to Chaos



Motivation - From need to objective



Track how city models **change** and **relate** to one another



Let **parallel "what if" alternatives** live in **one dataset**, without duplication the city model for each

Tie every **result** back **to the configuration** that produced it **and** the **city entities** it is related to

Objective: Test and enhance the Scenario ADE for CityGML 2.0 so it can hold several alternative futures of one neighborhood in a single dataset and link each future to the simulation that produced it.

Motivation - current tools can't do this yet

CityGML 2.0 + the ADE mechanism

- ADEs extend the schema for new domain data, but only describe the state — *not why or under what assumptions*

What today's tools track

- **CityGML 3.0 Versioning**: bitemporal model to track object lifecycles (Chaturverdi et al., 2017)
- **CityGML 3.0 Dynamizer**: Animates a single attribute over time
- **CityJSON**: Offers a git-based versioning file-level deltas (Ledoux et al., 2019)
- **Provenance Standards (ISO19115, PROV):** how data was created, *but no binding to changes, settings and assumptions*

The Limitation

- Currently none of the existing tools support 3D city models that captures not only ***what*** changed but also ***why*** and under ***which*** assumptions.

Contents

Research Questions

MAIN RESEARCH QUESTION

How can a Scenario ADE for CityGML 2.0 be developed and implemented to support the structured management, analysis, and comparison of multi-temporal scenarios in urban applications, using urban energy simulations as the case study?

SUB-QUESTIONS

SQ 1 — What entities, properties, and relations must a Scenario ADE represent to model an urban scenario?

SQ 2 — How can an existing Scenario ADE schema be iteratively refined and evaluated against design principles derived from scenario theory and empirical evidence?

SQ 3 — To what extent can the operationalized Scenario ADE, in its physical encodings, support the management, analysis and comparison of urban energy scenarios?

Contents

Methodology — Sequential Phases

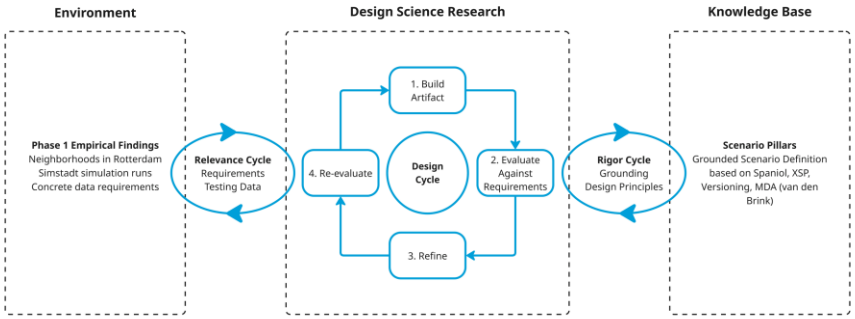
Exploratory Analysis

Empirical Requirement Evaluation

Theoretical Requirement Derivation

SQ 1

Conceptual Schema Development



Beta 3 — **Beta 4,5** — **Beta 6**

DSR iterative design cycle applied to the Scenario ADE (Hevner et al., 2004)

SQ 2

Interacting with Scenario Data

Encoding UML

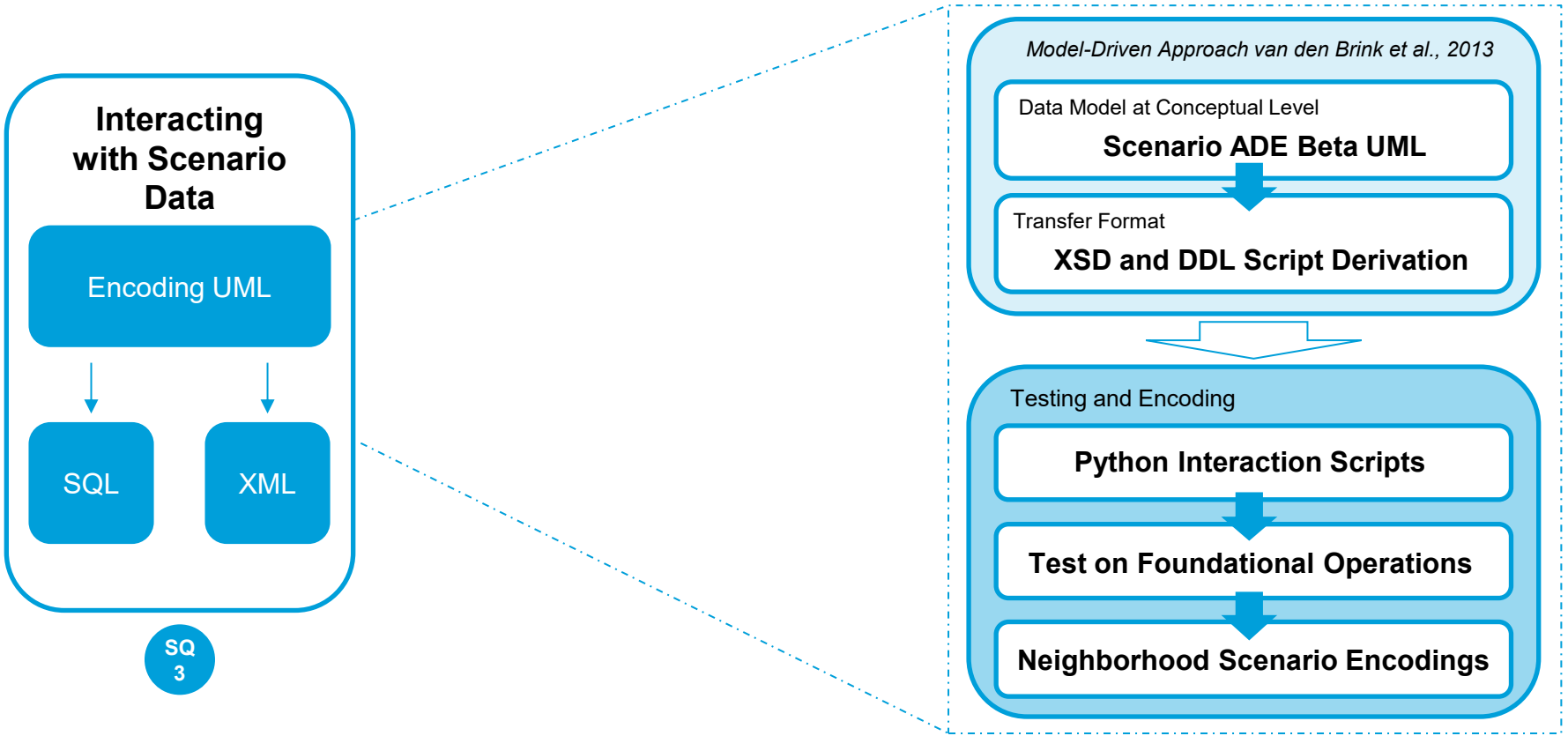
SQL

XML

Model-Driven Approach van den Brink et al., 2013

SQ 3

Methodology – Generating Final Encodings



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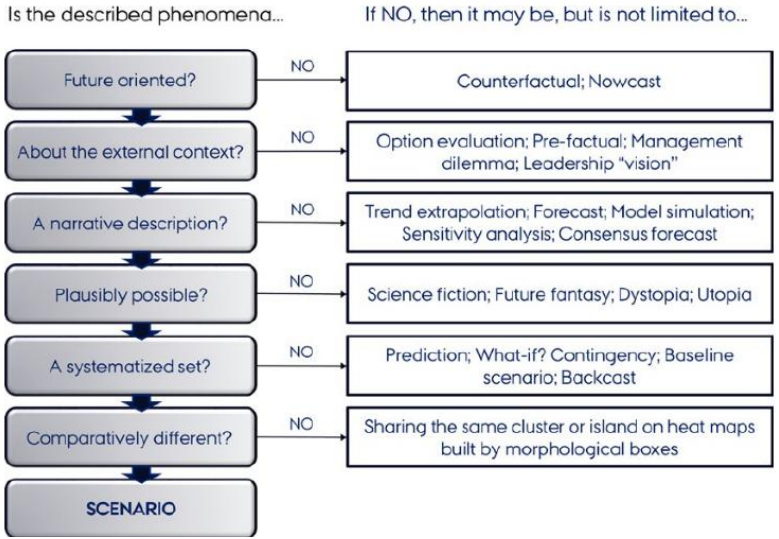
Schema Development - What “counts” as a Scenario?

The Definitional Chaos

- "Scenario" is used loosely; futures science has decades of “methodological chaos” (Bradfield et al. 2005)
- Spaniol & Rowland (2019) synthesized consensus from hundreds of definitions
- → **a scenario is about the external future context, not the actions you take**.
- But urban planners also need to test interventions (strategies)
- → **decouple the external context from the strategy / intervention (XSP, Abou Jaoude et al. 2022)**



Classifying a phenomenon as a scenario (Spaniol & Rowland, 2019)

Schema Development - Pillars of a Scenario

Context

What past, present or future conditions are we in?

- Climate projections (KNMI 2050)
- Socio-economic factors
- Grid constraints

e.g. KNMI 2050Hn weather file

Strategy

What intervention are we applying?

- Envelope modifications (U-values)
- PV panel deployment
- Building demolition /greening

e.g. Advanced TABULA retrofit

Configuration

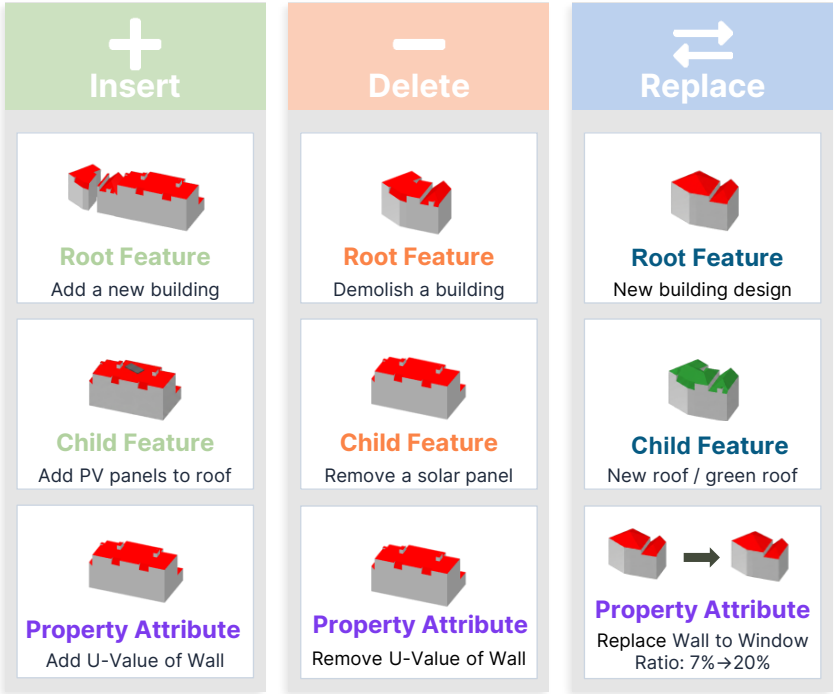
How were the results computed?

- Simulation engine & version
- Calculation standards (ISO)
- Temporal resolution

e.g. SimStadt + ISO 13790

Schema Development – The underlying operations a Scenario ADE needs to support

- Every scenario is built from the same **nine** operations
  - Three actions at three levels
- Covers the “what changed”
- *E.g., simulation result is inserted like any other change, but bound to the configuration that produced it*



Schema Development – What the simulation runs demanded

- **Store inputs**

  Simulation inputs must be stored and linked

- **Native Resolution**

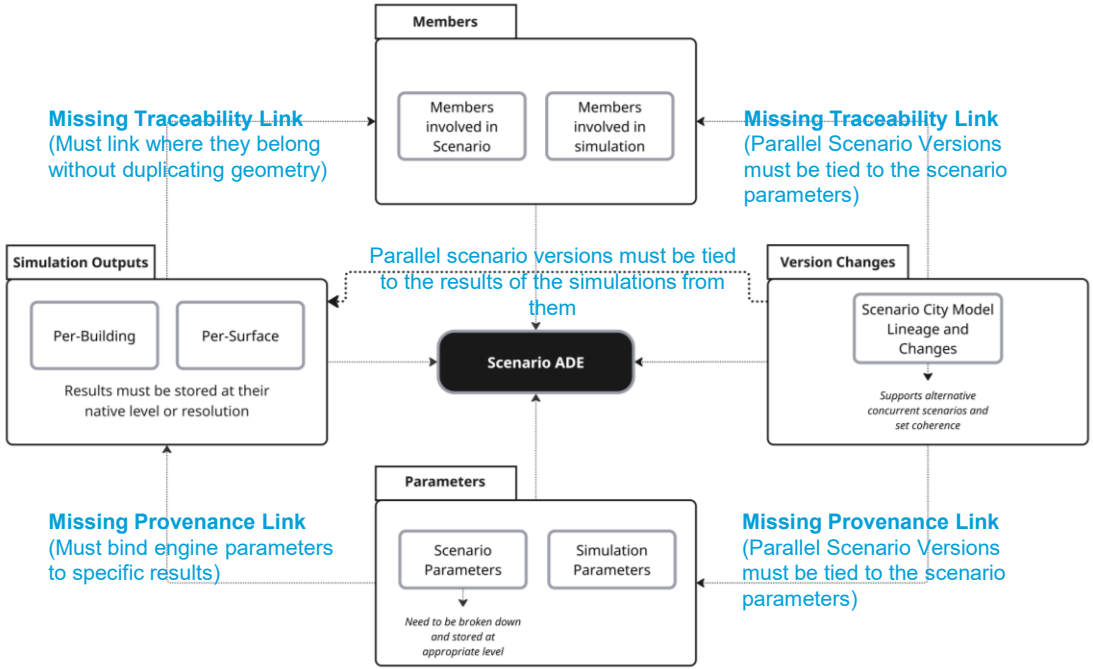
  Results must be stored at their native level of resolution

- **Bind every result**

  Each results must be linked to what produced it

- **Trace enrichment**

  Data must be traceable to specific features



Schema Development – The intentions and the conceptual requirements

Intentions

Foundational Intentions

F1 Domain agnostic layer over any CityGML module

F2 Scenario set coherence

F3 Forward compatible with CityGML 3.0

Context

External Boundary Condition

C1 Boundaries remain independently retrievable

C2 Horizons & narratives travel with parameters

C3 Parameters carry role metadata (input vs. result)

Strategy

Intervention

ST1 Interventions without duplicating base geometry

ST2 Attribute changes point unambiguously to target

Configuration

Simulation + Reproducibility

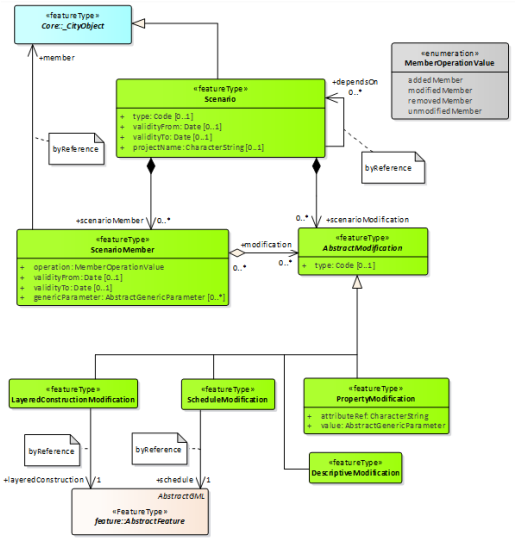
CF1 Simulation settings separable & reusable

CF2 Results traceable to object + run

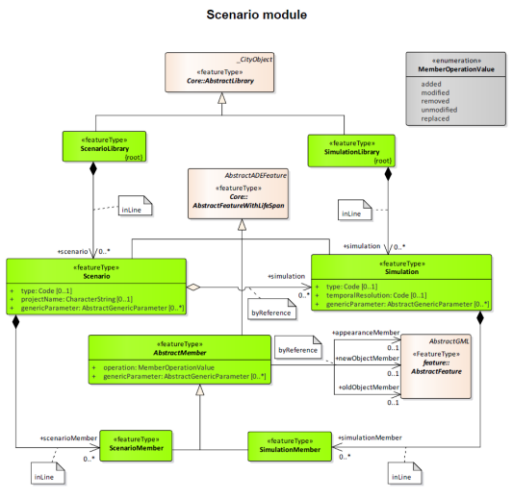
CF3 Multiple result types structurally distinguishable

Schema Development – Iterative progression

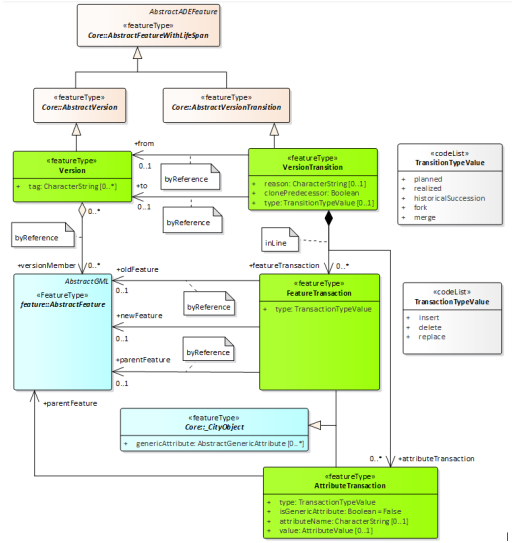
Beta 3



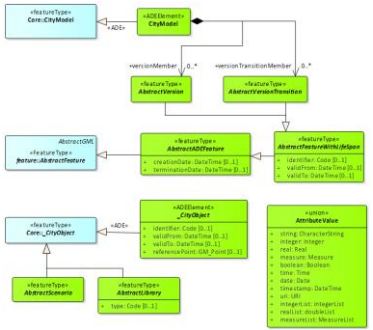
Beta 5

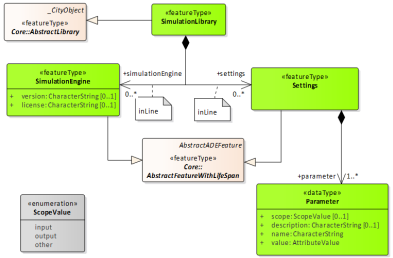


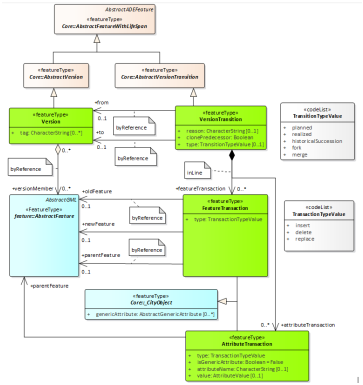
Beta 6

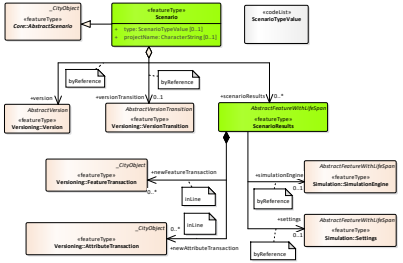


Schema Development – The Scenario ADE Beta 6 modules









Core Module

- Anchors the extension to CityGML and provides the shared abstract types for feature and cityobject versioning

Simulation Module

- Captures how the results were produced. Representing the configuration pillar.

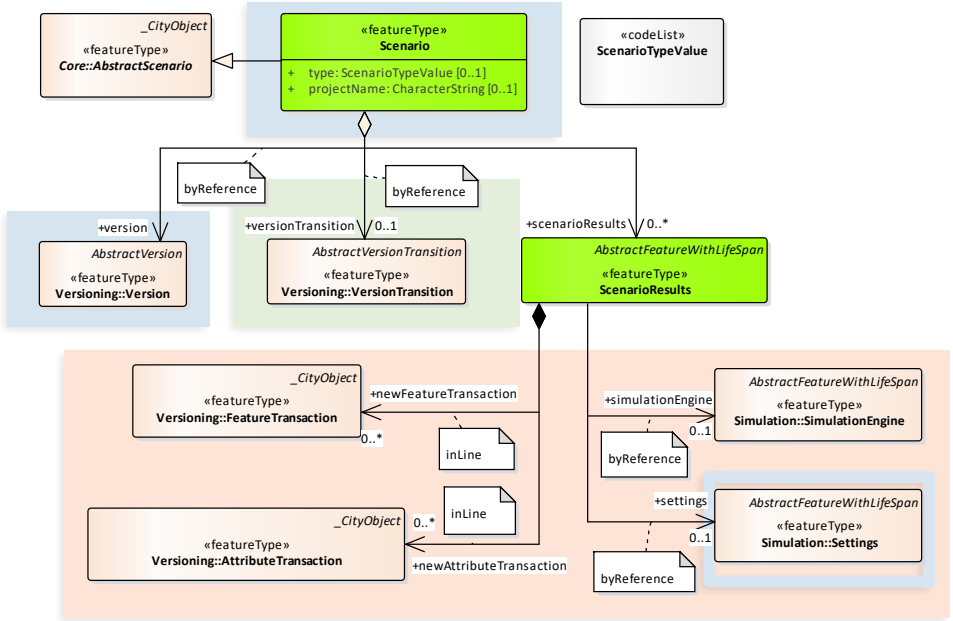
Versioning Module

- Manages the logic for all the nine underlying operations.

Scenario Module

- Binds the Scenario to its context, strategy and sets of unique simulation runs

Schema Development – Scenario Module



The Scenario Module reflects all the scenario components:

Context

Different contextual elements are stored amongst different classes.

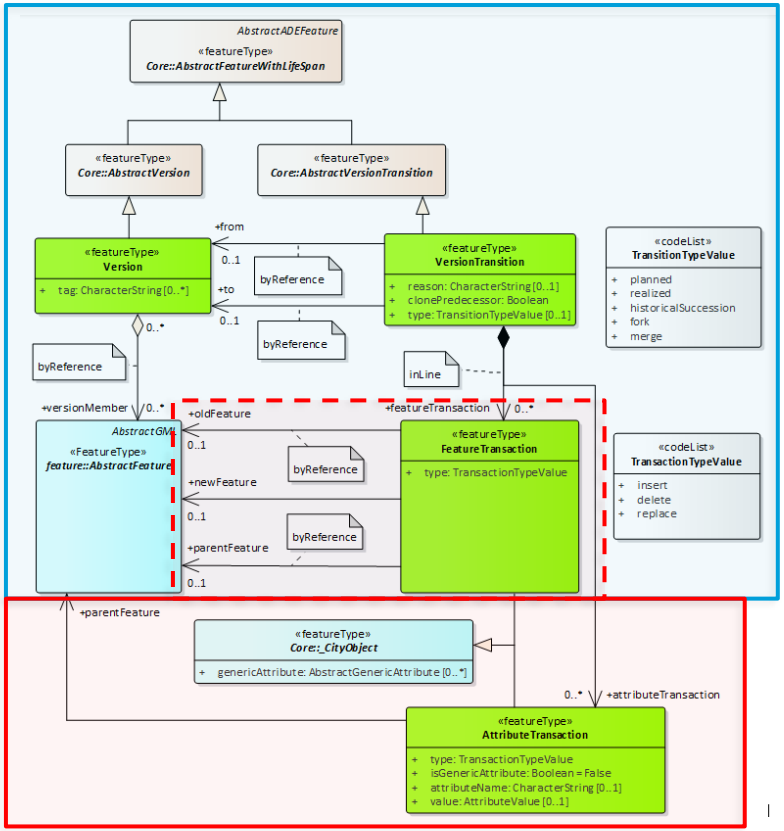
Strategy

Represented by the **VersionTransition** holding all strategy changes required to arrive at the **Version** of the Scenario

Configuration

Represented by the **ScenarioResults** which holds a unique combination of a **SimulationEngine, Settings** and **Transactions** to insert results tied to scenariomembers

Schema Development – Versioning Module



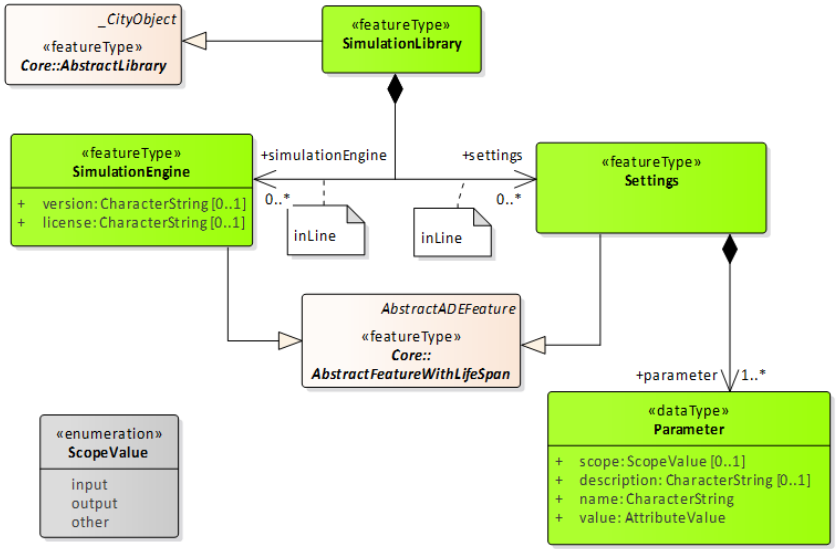
Backported from CityGML 3.0 Versioning Module

- **Version, VersionTransition and Transaction**

Beta 6 added functionality

- **AttributeTransaction**
  - Supports Attribute Modifications for root and child features.
- **FeatureTransaction**
  - Additionally allows storing features inside Scenario Container

Schema Development – Simulation Module



Allows for the storing of scenario configurations

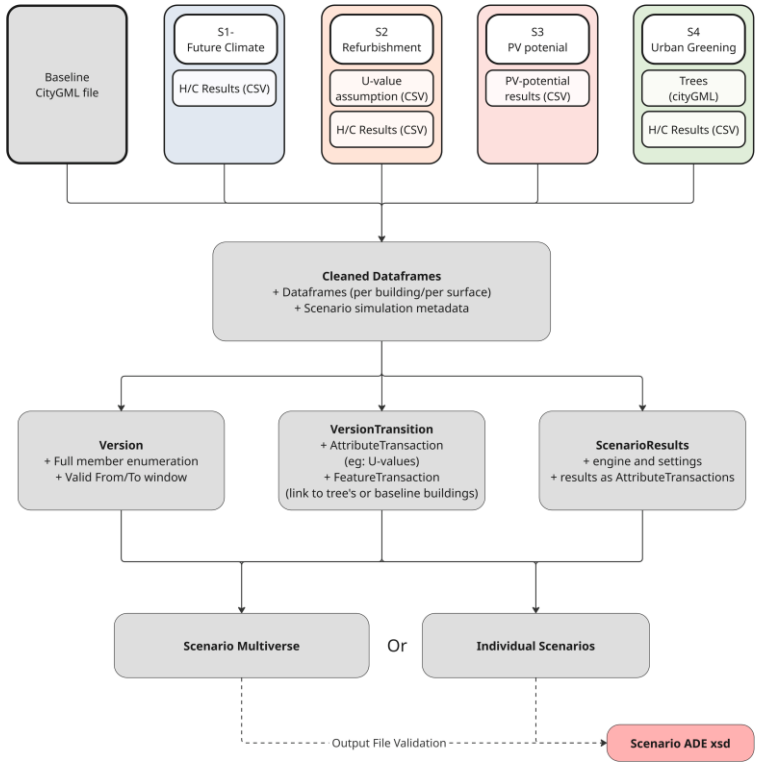
SimulationLibrary

- Holds all **SimulationEngine** and **Settings**
- **Settings** is composed of Parameters that can be:
  - Input, outputs or other

Schema Development – Generating the XML and SQL Encoding

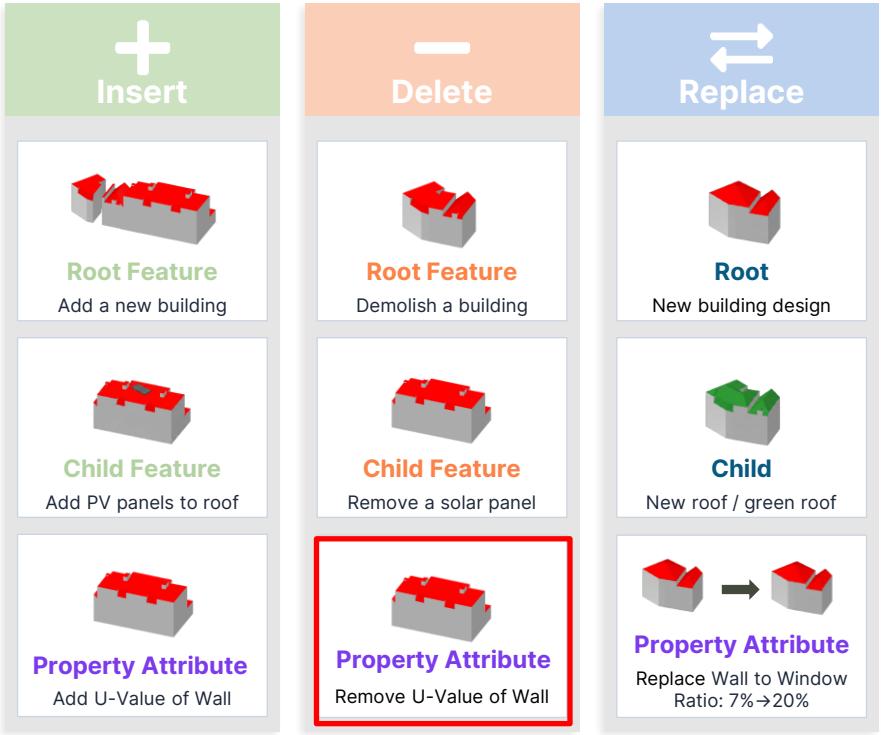
- The 4 case scenarios were encoded for Feyenoord using the following:
- **XML:** First test on foundational operations, then neighborhood scale
- **SQL:** First for 10 buildings in Feyenoord, then neighborhood scale

The 4 scenarios are:



Contents

Results – Operation encoding example in XML




```
<scn:Scenario gml:id="id_scenario_case8">
  <gml:description>U-value attribute removed after facade replacement</gml:description>
  <scn:identifier>id_scenario_case8</scn:identifier>
  <scn:validFrom>2026-06-01T00:00:00</scn:validFrom>
  <scn:validTo>2030-12-31T23:59:59</scn:validTo>
  <scn:type codeSpace="http://.../1.0/codelists/ScenarioType.xml">explorative</scn:type>
  <scn:projectName>ScenarioADE Beta6 – Test Suite</scn:projectName>
  <scn:version xlink:href="#id_version_case8_v2"/>
  <scn:versionTransition xlink:href="#id_vt_case8"/>
</scn:Scenario>
```
Scenario

```
<scn:VersionTransition gml:id="id_vt_case8">
  <gml:description>Stale wall U-value attribute deleted</gml:description>
  <scn:reason>Facade replaced – pre-renovation U-value no longer valid, pending new measurement</scn:reason>
  <scn:clonePredecessor>true</scn:clonePredecessor>
  <scn:type codeSpace="http://.../codelists/VersionTransitionType.xml">planned</scn:type>
  <scn:from xlink:href="#id_version_case8_v1"/>
  <scn:to xlink:href="#id_version_case8_v2"/>
  <scn:attributeTransaction>
    <scn:AttributeTransaction gml:id="id_at_case8_delete">
      <gml:description>Delete stale wallUValue_W_m2K generic attribute after facade replacement</gml:description>
      <scn:type codeSpace="http://.../codelists/AttributeTransactionType.xml">delete</scn:type>
      <scn:parentFeature xlink:href="#BAG_0599100000654922"/>
      <scn:attributeType>cityGMLGenericAttribute</scn:attributeType>
      <scn:attributeName>wallUValue_W_m2K</scn:attributeName>
    </scn:AttributeTransaction>
  </scn:attributeTransaction>
</scn:VersionTransition>
```
AttributeTransaction

VersionTransition

```
<scn:Version gml:id="id_version_case8_v1">
  <gml:description>Building with pre-renovation wallUValue_W_m2K attribute</gml:description>
  <scn:validFrom>2026-01-01T00:00:00</scn:validFrom>
  <scn:tag>baseline</scn:tag>
  <scn:versionMember xlink:href="#BAG_0599100000654922"/>
</scn:Version>
```
Version 1 (baseline)

```
<scn:Version gml:id="id_version_case8_v2">
  <gml:description>Building with stale wall U-value attribute deleted after facade replacement</gml:description>
  <scn:validFrom>2026-06-01T00:00:00</scn:validFrom>
  <scn:tag>scenario</scn:tag>
  <scn:versionMember xlink:href="#BAG_0599100000654922"/>
</scn:Version>
```
Version 2 (scenario)

Results – Neighbourhood Scale Encoding in XML

Category	File	Lines	Bytes	Smaller vs. sum (%)
Individual	Future Climate (S1)	120,626	6,380,915	–
Individual	PV Adoption (S2)	86,391	4,310,510	–
Individual	Refurbishment (S3)	133,775	7,462,885	–
Individual	Urban Greening (S4)	169,699	9,178,187	–
Sum of individual	(4 files combined)	510,491	27,332,497	–
Multiverse	Scenario Multiverse	332,836	19,490,515	–
Savings (multiverse vs. sum)		177,655	7,841,982	28.7%

Results – Tracking Scenario Lineage in SQL

#	depth	version_gmlid	via_transition_gmlid	scenario_gmlid	scenario_project
1	0	v_baseline	–	–	–
2	1	ver_scn_future_climate	vt_scn_future_climate	scn_future_climate	Feijenoord Future Climate DIN18599 H+C demand under projected climate
3	2	ver_scn_pv_adoption	vt_scn_pv_adoption	scn_pv_adoption	Feijenoord PV Adoption per-surface PV yield + irradiance
4	2	ver_scn_refurbishment	vt_scn_refurbishment	scn_refurbishment	Feijenoord Tabula AdvancedRefurbishment surface U-values + post-refurb H/C demand
5	2	ver_scn_urban_greening	vt_scn_urban_greening	scn_urban_greening	Feijenoord Urban Greening trees + post-greening H/C and PV results

Results – Comparing Scenario Results

#	target_class	target_gmlid	attr_name	uom	Refurbishment_Scenario_2050	Future_Climate_Scenario_2050	delta	pct_change
1	Building	BAG_0599100000618980	yearlyCoolingDemand	kWh/a	4026	5314	1288	32
2	Building	BAG_0599100000618982	yearlyCoolingDemand	kWh/a	9623	10042	419	4
3	Building	BAG_0599100000618983	yearlyCoolingDemand	kWh/a	2792	3607	815	29
4	Building	BAG_0599100000618984	yearlyCoolingDemand	kWh/a	21220	25322	4102	19
5	Building	BAG_0599100000654922	yearlyCoolingDemand	kWh/a	23625	34791	11166	47

Results – did the schema meet its intentions?

Trajectory

- From mostly unmet in Beta 3 to 8 out of 11 met in Beta 6

Three remain partial:

- **C1** context stored by naming, not structure
- **C2** narrative on inherited description
- **ST2** generic-attribute targeting

Design principle	Beta 3	Beta 5	Beta 6
F1 Domain agnosticism	*unmet*	*met*	*met*
F2 Scenario set coherence	*partial*	*unmet*	*met*
F3 Forward compatibility	*unmet*	*met*	*met*
C1 Context independently retrievable	*unmet*	*partial*	*partial*
C2 Horizons & narratives travel	*partial*	*partial*	*partial*
C3 Parameter role (input vs result)	*partial*	*partial*	*met*
ST1 No base-geometry duplication	*partial*	*deferred*	*met*
ST2 Attribute change targets feature	*met*	*deferred*	*partial*
CF1 Reusable simulation settings	*unmet*	*partial*	*met*
CF2 Results traceable to object & run	*unmet*	*unmet*	*met*
CF3 Result types distinguishable	*unmet*	*unmet*	*met*

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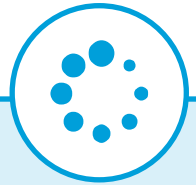
Discussion

Implications

- A new standard to store and deal with scenarios
- Build on established versioning
- Introduces new functionality to CityGML 2.0



Interpretation

- From scenario theory to scenario data components
- Conflation of context and configuration
- Domain agnosticism versus semantic rigidity
- Geometric changes

Limitations

- Validation in one domain (energy, SimStadt)
- Residual schema gaps
- Simulation derived configuration class

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Conclusion – Main research question

How can a Scenario ADE for CityGML 2.0 be **developed** and **implemented** to support the **structured management**, **analysis**, and **comparison** of multi-temporal **scenarios** in urban applications, using urban energy simulations as the case study?

- **Current Beta 6:** a working Scenario ADE for CityGML 2.0
- Holds several alternative futures of one neighbourhood in a single dataset
- Binds each result back to the run that produced it
- Validated in energy simulations; some principles C1, C2, ST2 still partial

***Contribution**: A way to store a scenario as structured, comparable data, where every change and every result is bound to the decision, the run, and the assumptions behind it.*

Future Work

Direct Schema recommendations

- Addressing requirement gaps through:
    - Context scope, Narrative slot, Codelists, attributes carry their namespaces

Future Work

- Apply and test the schema on a non-energy domain (flood / mobility / policy)
    - Is the schema really domain agnostic?
- Test generalizing configuration pillars to a generalized provenance standard (ISO19115 / W3C PROV)
- Migrate to next city model standard (CityGML 3.0), possible additional CityJSON encoding
- Build an application layer / GUI for end users to interact with the schema

Thank you!

Link to thesis repository: https://repository.tudelft.nl/record/uuid:42e6250f-7dfb-49e2-bfc1-3277b915bdcb

References

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