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Automated geometric decomposition and semantic enrichment of shared wall boundary surfaces in LoD 2 CityGML models for urban building energy modelling

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Abstract

Urban Building Energy Modelling (UBEM) can be adapted to assess thermal comfort and climate resilience in dense urban cities. However, common modelling and simulation practices treat shared wall boundaries between adjacent buildings as adiabatic, de facto ignoring inter-building heat transfer, which can lead to deviations in energy and temperature simulations. To resolve this challenge, an automated framework is developed that identifies, geometrically decomposes, and semantically enriches shared wall boundaries within complex Level-of-Detail (LoD) 2 CityGML models. Application of the framework to a 1,429-building dataset in Antwerp, Belgium, successfully identified and decomposed 6,667 shared wall surfaces, maintaining topological validity for 1,404 of the 1,425 (98.53%) originally valid buildings prior to any external healing. For comparative analysis, both the original and the geometrically decomposed CityGML models were processed through a computational pipeline to generate simulation-ready epJSON files for EnergyPlus. This translation highlights a fundamental friction between the inherent geometric imperfections of sourced real-world, surveyed geospatial data in CityGML and the idealized geometries expected by EnergyPlus. Comparative urban simulations confirm that the modelling of explicit shared surface heat transfer, compared to adiabatic assumption, yields systematically higher heating demand projection (mean bias error (MBE) = +23.67 kWh/m^2, mean absolute error (MAE) = 24.14 kWh/m^2, root mean square deviation (RMSD) = 31.99 kWh/m^2) and lower indoor operative temperatures (MBE = $-0.216\,^{\circ}$C, MAE = $0.235\,^{\circ}$C, RMSD = $0.366\,^{\circ}$C). These findings emphasize the necessity of explicit shared-boundary modelling for accurate, actionable district-level energy and indoor thermal comfort assessments.

1. Introduction

The international open standard CityGML provides a semantically enriched and hierarchically structured data model that represents a first relevant step to move from semantic 3D city models to comprehensive urban simulations. In dense urban environments composed of multiple terraced housing or city blocks, buildings physically share boundary surfaces such as party walls. Standard LoD 2 generation processes often fail to capture this topological relationship, defining adjacent buildings separately without clear distinctions of shared surfaces in their exterior `bldg:WallSurface` geometries. Additionally, current UBEM workflows oversimplify these interfaces by applying either standard *Outdoor* or *Adiabatic* boundary conditions, both of which neglect inter-building heat transfer and varying thermal condition (Morales et al., 2025b). UBEM is evolving beyond traditional energy demand analysis to address climate change challenges like indoor thermal comfort and resilience to urban overheating (Pichardo-Velázquez et al., 2026). This shift requires high-fidelity simulations capable of predicting, for example, hourly indoor temperature, a task for which dynamic Building Performance Simulation (BPS) engines like EnergyPlus are essential.

EnergyPlus depends on explicitly partitioned 3D geometries that satisfy strict topological constraints, such as surface planarity, to model multi-zone heat transfers with precision. The challenge is compounded by the geometric reality of shared boundaries; they are rarely perfectly congruent. Discrepancies in building heights, setbacks, or footprints mean that a single party wall often comprises both internal shared segments and external sections exposed to ambient conditions. Imprecise partitioning of these shared boundary surfaces leads to a miscalculation of the building's thermal envelope.

Previous research has explored the detection and handling of shared wall surfaces in 3D city models. Early work by Iwaszczuk and Stilla (2010) focused on identifying occluded surfaces for visual texturing, establishing a precedent for adjacency detection. Kaden (2014) later demonstrated the use of 2D projection and Java Topology Suite to approximate shared walls for stationary energy demand calculations; however, such approaches are limited by their reliance on prismatic extrusion and 2D footprint analysis, which fail to preserve 3D geometric fidelity. Subsequent studies underscored that treating terraced houses as detached buildings leads to massive overestimations of wall area, resulting in inaccurate estimates of solar and transmission calculations (Braun et al., 2018). Similarly, Agugiaro et al. (2022) quantified the significant thermal impact of party walls in UBEM, demonstrating that ignoring them leads to substantial errors in energy demand calculations. Other efforts, such as the CityDPC library (Shamovich et al., 2024), offer foundational tools for processing 3D city models for energy simulation but do not present an end-to-end solution that resolves the specific geometric and semantic conflicts between CityGML's data structure and the strict requirements of dynamic BPS engines like EnergyPlus. Despite these advances, there is a lack of a formalized and robust workflow in a reliable and scalable decomposition of shared wall boundaries. Key challenges include geometric healing required to maintain model quality and the translation of these complex 3D CityGML geometries into the surface-matched format required by dynamic BPS engines. This forces practitioners to either rely on inaccurate adiabatic assumptions, use simplified projections that fail to capture true 3D geometric realities, or undertake laborious manual corrections.

To address these challenges, this paper makes the following primary contributions: (1) An automated pipeline for identifying, decomposing, and semantically enriching shared wall surfaces in LoD 2 CityGML models; (2) a multi-stage geometric healing algorithm that ensures the resulting 3D CityGML models remain topologically valid; (3) a CityGML-to-EnergyPlus translation pipeline for dynamic simulation of energy and indoor operative temperature, while also producing geometries that meet the strict surface-matching requirements of EnergyPlus; and (4) a quantitative analysis on a district-scale case study, demonstrating that the common adiabatic assumption leads to systematic deviations in both heating demand and indoor temperature simulations, thereby highlighting the impact of explicit shared wall modelling in UBEM.

2. Methodology

The methodology introduces a whole pipeline, from the geometric decomposition of shared walls and their semantic enrichment within the CityGML framework, to translating these enhanced models to EnergyPlus input files for dynamic simulation of heating energy demand and thermal comfort at the neighbourhood scale.

2.1 CityGML City Shared Walls Decomposition

The framework is developed via a modular Python pipeline that directly interfaces with a *3DCityDB* instance (Yao et al., 2018) by default, while maintaining a fallback capability to parse standalone CityGML files when a database is unavailable.

2.1.1 Case Study of Sint-Andries, Antwerp City, Belgium: A neighbourhood-scale case study was conducted using the Sint-Andries district in Antwerp, Belgium. The raw dataset comprises 1,473 LoD 2 CityGML buildings. Sint Andries is characterized by dense, historic urban morphology with a high prevalence of terraced housing and complex city blocks, making it an ideal testing ground for shared wall detection and UBEM applications.

The CityGML dataset originally acquired from the municipality contained several structural and semantic inconsistencies that required pre-processing. While an external healing tool, CityDoctor2 (Betz and Riegel, 2021), was used to improve compliance with CityGML modelling standards (Wagner et al., 2013), many buildings remained invalid. Data validation revealed that numerous invalid CityGML artifacts labeled as 'buildings' represented structures with a total height below 1.5 m (e.g., garden storage), rendering them irrelevant for energy assessments. Also, a large number of `bldg:Polygon` composing a `bldg:Solid` were not referenced by a corresponding geometry associated with a thematic surface. Therefore, a custom pre-processing was developed to target these

Figure 1. LoD 2 CityGML model of Sint-Andries, Antwerp

specific issues. A spatial filtering routine evaluated the absolute heights, derived from the maximum and minimum vertex Z-coordinates, systematically removing solids that fall below the height of 1.5 m (threshold that defines non-habitable space). This reduced the number of buildings down to 1,429. Also, `Polygon` not associated with a thematic surface were automatically assigned into thematic boundaries (`bldg:RoofSurface`, `bldg:WallSurface`, and `bldg:GroundSurface`) based on their true outward-facing normal vectors calculated using Newell's algorithm.

2.1.2 Adjacency Detection: Candidate building pairs are identified using a spatial index to avoid a brute-force $O(n^2)$ comparison across the entire dataset. A 2D spatial join is performed on 2D bounding boxes of `bldg:GroundSurface` geometries, expanded by a 10 cm buffer to account for minor planimetric inaccuracies in the source data where adjacent buildings might be slightly separated or overlapping.

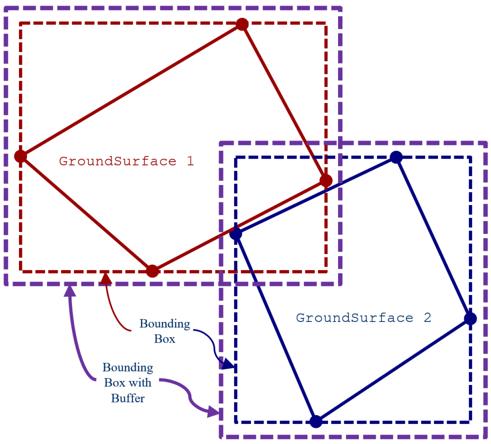

Figure 2. Adjacency detection of bounding boxes at `bldg:GroundSurface`

For each identified candidate building pair, `bldg:WallSurface` geometries are extracted, and their true normal vector, centroid, inclination, and azimuth are calculated. Pairs of wall surfaces are considered potential shared boundaries if they are logically coplanar (anti-parallel) and in contact with each other. Accounting for minor 3D geometric inaccuracies, an angular deviation between normal vectors of no more than 5° and a 3D distance between geometries of under 10 cm were utilized as thresholds. Furthermore, to filter out negligible overlaps, intersection areas must exceed a minimum of 0.1 m^2.

2.1.3 Geometric Decomposition: The wall pairs identified to have shared boundaries are then geometrically decomposed. For each pair, one wall is designated as the *subject*, and a local transformation matrix to 2D is derived from its normal vector and centroid. Both the subject wall and its adjacent counterpart(s) are then translated using the same matrix. Within this 2D space, the Python Shapely library (Gillies et al., 2025) is utilized to compute the intersection and difference.

The pipeline employs exact geometric constraints to resolve complex cases where one *subject* wall shares boundaries with multiple adjacent walls. The partition is computed as follows:

1. Sequential Intersection: Intersections are computed sequentially for each adjacent wall, processed from closest to farthest, based on the spatial distance calculated in the adjacency detection step (Section 2.1.2). To handle cases where one wall borders multiple others, any area already claimed by a closer neighbor is subtracted from subsequent intersections. This priority-based approach ensures each portion of the wall is unambiguously assigned to a single shared boundary. The final exterior portion (the difference) is then calculated in a single step by subtracting the total intersection areas from the original wall.

2. Sliver Polygon Reassignment: The decomposition process can create thin slivers of area that lie along the boundary of a shared (intersection) polygon. From an EnergyPlus perspective, modelling and simulating such slivers is highly undesirable. These high-aspect-ratio "micro-surfaces" add unnecessary complexity to the model for negligible thermodynamic impact. Therefore, these slivers are identified using erosion (negative buffer) followed by a dilation (positive buffer) of a configured sliver width of 5 cm. Once identified, these slivers are geometrically *unioned* with the bigger intersection polygon, as visualized in Figure 3. This reassignment simplifies the geometry for surface matching in EnergyPlus, and avoids the creation of problematic micro-surfaces, all while preserving the total area of the original wall.

3. Re-noding and Winding: All surface boundaries are re-noded together in a single pass, ensuring that every shared edge is coordinate-identical and free of T-junctions. Also, the winding order of each new surface is enforced to match the original wall's orientation, guaranteeing that all 3D normals remain consistent.

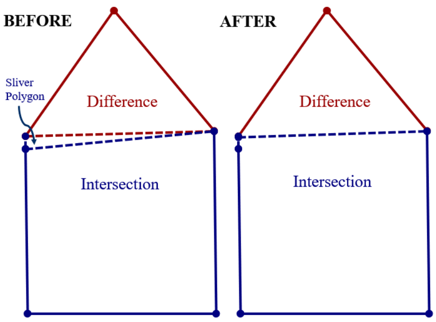

Figure 3. Sliver polygon reassignment

2.1.4 Precise 3D Reconstruction: To ensure the decomposed 2D pieces fit together perfectly back into 3D without creating gaps or overlaps, a precise 3D reconstruction method is used. The 3D coordinates for every vertex of a new surface are calculated based on its relationship to the original 3D wall geometry. This method follows a strict set of rules depending on the vertex type (refer to Figure 4):

- **Original Vertices:** Vertices that existed on the original wall retain their exact 3D coordinates, preventing any distortion of the building's original form.
- **Polygon Boundary Vertices:** New vertices created on the wall's boundary are mathematically interpolated as a parameter along the original 3D edge they fall upon. This guarantees collinearity within the line shared with adjacent surfaces (e.g., roofs, ground).
- **Surface Interior Vertices:** New vertices created inside the wall (i.e., not on a boundary) are lifted back to 3D using the wall-plane's inverse transformation matrix.

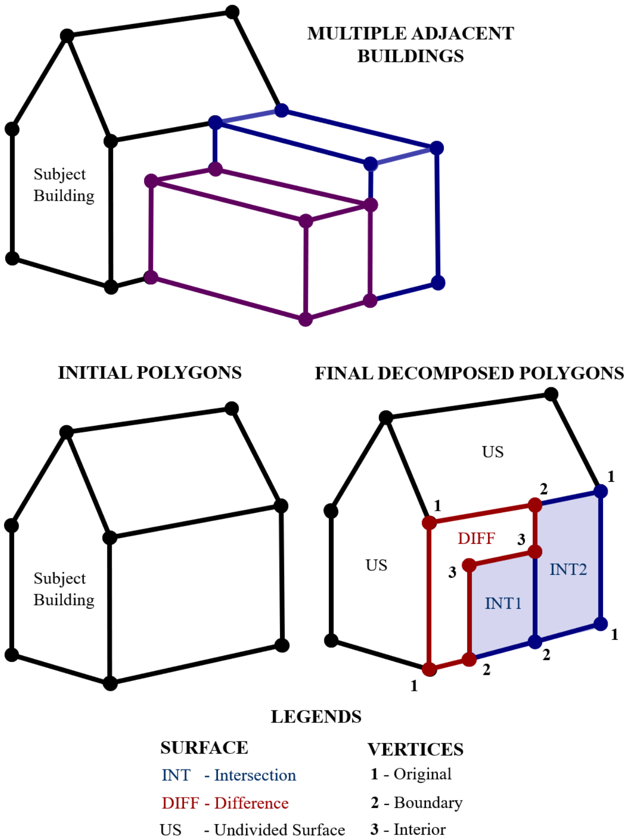

Figure 4. Decomposition of a wall with multiple shared boundaries.

2.1.5 Geometric Healing and Shell Closure: The vertices created from geometric decomposition must be integrated into the rest of the building to maintain a watertight shell. This is achieved through a building-wide healing process:

1. Vertex Unification: When two adjacent walls of a building are decomposed independently, the new vertices created on their shared physical boundary can have slightly different coordinates due to snap-rounding, creating micro-gaps. To ensure a watertight shell, these vertices must be unified. The algorithm clusters all new vertices across the building by 3D proximity, using a tolerance of 0.5 mm. This tolerance is set to be larger than the maximum expected numerical drift from independent snap-rounding operations (up to 0.2 mm), ensuring that vertices representing the same physical junction are reliably clustered and treated as duplicates. For each cluster, it determines a single canonical coordinate. To preserve the original building footprint, it prioritizes snapping to a nearby original vertex of the building if one exists within this same tolerance of 0.5 mm. Otherwise, the points in the cluster are merged to a single representative coordinate. This canonical coordinate then replaces all the original points in the cluster, guaranteeing that all surfaces meet perfectly at that junction and preventing topological errors (open edges) that would invalidate the CityGML `Solid`.

2. Neighbour Surface Densification: Every neighbouring surface that shares a divided edge is identified and corresponding matching vertices from the newly decomposed surfaces are added into that neighbor's vertex list. It does not change the neighbor's shape, area, or planarity, but it densifies its boundary to match the new vertices on the decomposed wall, thus preventing T-junctions and ensuring a watertight solid (Figure 5).

3. Edge Collapse: As a final cleanup step, two types of edge degeneracies are resolved. First, zero-width spikes (A→B→A backtracks) are removed from polygon rings. Second, a building-wide merge of consecutive ring vertices closer than 0.15 mm is performed. This value matches the minimum vertex distance flagged by validation tools. At this sub-millimeter scale, such vertices are considered functionally degenerate and can create invalid self-intersections. The merge uses a canonical mapping where original vertices are never moved, ensuring all surfaces are modified consistently, and the shell remains closed without distorting the building's original footprint.

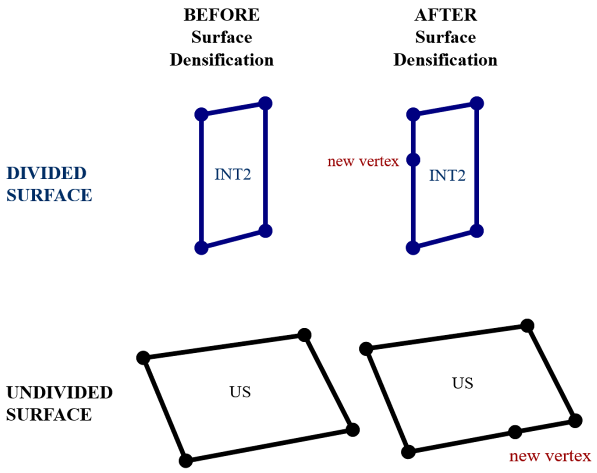

Figure 5. Vertex densification of neighbour polygon surfaces. (1) Adjacent intersection (divided) surface and (2) adjacent undivided roof surface, preserving the building's watertight shell. See Figure 4 for the reference solid.

2.2 CityGML-to-EnergyPlus Simulation pipeline

The conversion of CityGML buildings into executable EnergyPlus (epJSON) simulations is achieved through a multistage workflow adapted from prior work (Morales et al., 2025a).

The LoD 2 CityGML data is parsed using the building's solid as the geometric source of truth, and the projected coordinates (EPSG:31370) are transformed into a local, per-building system. Total floor area is estimated by slicing the solid at 3.5 m intervals and integrating the resulting areas. Thermal properties are assigned by linking each building via its `gml:id` to an archetype from the Belgian TABULA database (Cyx et al., 2011), with construction assemblies (U-values) derived from construction years. Shared walls receive a specific two-layer construction reflecting the properties of adjacent archetypes. Windows are parametrically generated on exterior walls with a 31% window-to-wall ratio (WWR) based on statistical data, creating `FenestrationSurface:Detailed` objects for each 3.5 m floor-height segment.

Internal conditions and systems are then defined. Gains and thermal mass are based on the building's total floor area, with mass modeled via interior partitions and interstory floor slabs. Standardized 8760-hour schedules govern occupancy (40 m^2/person), lighting (5.0 W/m^2), and equipment (2.0 W/m^2). An idealized HVAC system (`HVACTemplate:Zone:IdealLoadsAirSystem`) maintains a 20°C heating setpoint during occupied hours, with no mechanical cooling modelled. This homogenization of internal conditions provides the theoretical basis for the widespread use of adiabatic boundary conditions, an assumption this study explicitly tests. To manage computational load while retaining shading accuracy, the urban model is simulated on a block-by-block basis, including surrounding buildings within a 50-meter radius as simplified `Shading:Site:Detailed` objects (see Figure 6).

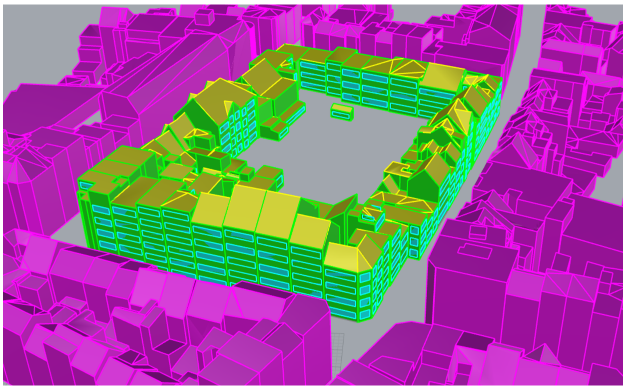

Figure 6. Block-level EnergyPlus simulation

2.2.1 Simulation Scenarios and Semantic Enrichment

To assess and quantify the impact of shared-wall modelling, this pipeline generates two simulation scenarios:

- **Adiabatic Scenario (Baseline):** The original, undivided wall surfaces identified as adjacent to another building are assigned a single `Adiabatic` outside boundary condition. This represents the common UBEM simplification, where the entire wall is assumed to be a party wall with no heat transfer.
- **Surface-to-Surface Scenario:** The decomposed wall geometries are used. The shared portions are assigned a `Surface` outside boundary condition, with the `"outside_boundary_condition_object"` field pointing to the corresponding adjacent wall. The exterior (difference) portions are assigned a standard `Outdoor` boundary condition, exposing them to ambient weather.

This direct topological link in the second scenario allows EnergyPlus to calculate explicit, bi-directional heat transfer between coupled multi-zone interfaces. Comparing the results of the two scenarios, *ceteris paribus*, will quantify the error due to the adiabatic assumption.

3. Results and Discussion

During the processing of the healed and pre-processed dataset (1,429 LoD 2 buildings), the pipeline successfully isolated shared boundary surfaces, as shown in Figure 7. Both original input data and the decomposed versions were later translated for EnergyPlus simulation for comparison.

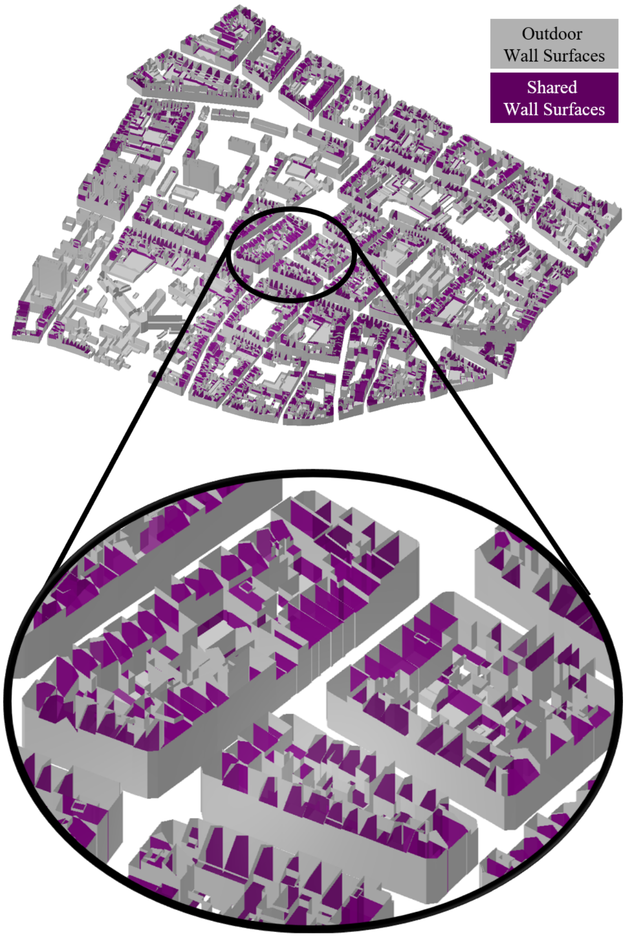

Figure 7. Decomposition of shared wall boundary surfaces

3.1 Geometric Decomposition Results

During geometric decomposition, the pipeline continuously checks for area preservation, ensuring that the sum of the areas of the decomposed sub-geometries equals the area of the original wall. The execution of the pipeline on the Sint-Andries dataset provided detailed metrics on the geometric transformations at each stage, summarized in Table 1.

Geometric Processing Metrics	Value
Initial Wall Surfaces	17,001
Candidate Wall Pairs (Spatial Index)	14,644
– Zero Intersection Wall Pairs	8,560
– Walls Decomposed	6,084
Intersection (Shared) Surfaces	6,667
Difference (Exterior) Surfaces	5,724
Dropped Degenerate Surfaces	2
Total Decomposed Surfaces	**12,393**

Table 1. Key metrics from the geometric processing

Starting with 17,001 initial `bldg:WallSurface` geometries across 1,429 buildings, the adjacency analysis identified 14,644 candidate *subject-adjacent* wall pairs for intersection (where pair A-B is distinct from B-A). Of these, 8,560 pairs (approximately 58%) were discarded because their intersection area was below the 0.1 m^2 threshold, indicating that they were either not truly touching or their overlap was negligible. The final output for the modified walls consists of 6,667 surfaces reclassified as shared, accounting for a total area of 445,993 m^2, and 5,724 exterior `bldg:WallSurface` geometries, covering a remaining exposed area of 88,895 m^2.

Decomposed geometries are preserved as `bldg:WallSurface` geometries. The portion of the surfaces with shared boundary is semantically enriched with a generic integer attribute `isShared` as 1 and another *generic URI attribute* `adjacentWallSurface` pointing to the `WallSurface` `gml:id` of the adjacent shared surface (Figure 8).

```
<bldg:WallSurface gml:id="UUID_de94b429-e4b1-49b3-9c97-16c7d8215192">
  <gen:intAttribute name="isShared">
    <gen:value>1</gen:value>
  </gen:intAttribute>
  <gen:uriAttribute name="adjacentWallSurface">
    <gen:value>#UUID_7ec3c5d7-ce92-4d35-a938-e2828ff600e7</gen:value>
  </gen:uriAttribute>
```

Figure 8. Semantic enrichment for shared wall surfaces

3.1.1 Validation:

The decomposed CityGML models were validated using CityDoctor2 (Table 2). Of the 1,429 input buildings, 1,425 were initially valid (99.72%). Because the pipeline strictly processes valid geometries, the four originally invalid buildings remained so throughout. On the 1,425 eligible buildings, the decomposition maintained validity for 1,404, achieving a **98.53% net performance** prior to external healing. While this complex geometric decomposition inherently introduced topological errors, causing the validity to drop to 98.25%, subsequent healing with CityDoctor2 recovered many of these, improving validity to 99.65%.

Decomposition Metrics	Input	Initial Output	Healed Output
Buildings	1,429	1,429	1,429
Valid	1,425	1,404	1,424
% Valid	99.72%	98.25%	99.65%
WallSurface (outdoor)	17,001	16,641	16,638
WallSurface (shared)	0	6,667	6,666

Table 2. Validation Results of the decomposed building dataset

A visual inspection of the results also revealed the pipeline's capability to handle complex topological edge cases, demonstrating its applicability in real-world urban scenarios (see Figure 9):

- **Staggered Heights and Setbacks:** In terraced housing with varying rooflines or rear extensions, the algorithm cleanly isolated the exposed upper and lateral walls, preserving them as exterior surfaces while perfectly matching the internal interface with the adjacent, lower building.
- **T-Junctions and Multi-Wall Collisions:** For buildings at block corners or internal courtyards intersecting multiple neighbours, the pipeline successfully executed successive decompositions, carving out distinct `adjacentWallSurface` references for each neighbouring structure without compromising watertightness.
- **Complex Footprints and Overhangs:** The framework correctly processes non-trivial vertical adjacencies, such as where an upper-story cantilever or overhang of one

building touches the wall of its neighbour. The 3D intersection logic identifies these shared surfaces even when the ground footprints are not contiguous.

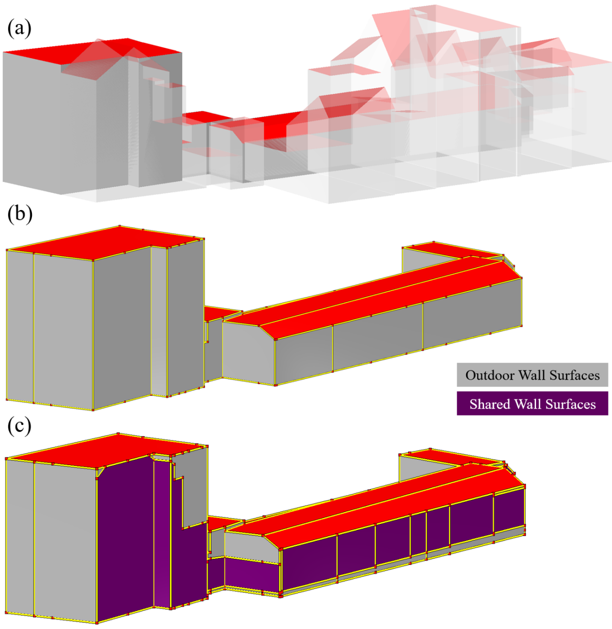

Figure 9. Decomposition of staggered terraced houses, isolating exposed walls from the shared boundary, including multiple boundary-sharing cases. (a) The subject building with multiple adjacent buildings. (b) Initial wall surfaces. (c) Decomposed wall surfacesg.

3.2 CityGML to EnergyPlus

3.2.1 Syntax transformation from CityGML to epJSON format: The transition from CityGML to EnergyPlus requires a deliberate semantic enrichment process to ensure that decomposed shared geometries are accurately parameterized for surface boundary conditions. During the translation into the EnergyPlus epJSON syntax, this enriched metadata dictates the exact configuration of the thermal boundary. Assigning the value of `"Surface"` to the `"outside_boundary_condition"` key shifts the engine's heat transfer calculation from adiabatic to an inter-zone thermal exchange. To complete this bidirectional thermal link, the targeted adjacent UUID is mapped directly into the `"outside_boundary_condition_object"` key. Furthermore, to accurately reflect the physical reality of an internal party wall, all external environmental interactions are programmatically disabled within the epJSON by setting `"sun_exposure"` to `"NoSun"` and `"wind_exposure"` to `"NoWind"`.

3.2.2 Geometric and Data Quality Requirements (CityGML vs EnergyPlus): The translation from 3D CityGML models to EnergyPlus models requires navigating distinct geometric requirements stemming from the inherent quality of data versus the idealized constraints of simulation engines.

On one hand, **CityGML** rely on GML (Geography Markup Language) for its geometric foundation. Because urban-scale CityGML models are predominantly derived from surveyed geospatial data (e.g., LiDAR, photogrammetry), their raw geometries inherently contain noise, minor deviations, and physical imperfections. The governing standards for 3D primitive solids such as ISO 19107 balances topological strictness and geometric tolerance. Topologically, standards demand the creation of valid, perfectly watertight GML solids with no gaps. Geometrically, however, it is tolerant, allowing polygons to be slightly non-planar to reflect the reality of surveyed source data.

The topological strictness dictates the first phase of the methodology. When buildings with shared wall boundaries are geometrically decomposed, their original boundaries are broken. Healing and artifact-deletion algorithms were applied to achieve topologically watertight GML solids. This ensures the enriched models remain standard-compliant, highly valuable digital assets applicable for wide array of urban analyses beyond energy simulation, such as computational fluid dynamics, noise propagation, or daylight simulation.

On the other hand, **EnergyPlus** operates on an idealized, surface-based mathematical paradigm. It is designed around the expectation of mathematically perfect, non-surveyed geometry (e.g., manually drafted in CAD or procedurally generated), and it rejects the geometric tolerances required to handle surveyed data. The primary constraints for EnergyPlus are not volumetric but surface-specific:

- *Surface Planarity and Matching:* EnergyPlus demands absolute surface planarity. The simulation engine's calculations are highly sensitive: vertex deviations from the surface plane by as little as four decimal places (e.g., 0.0001) will trigger warnings, whereas deviations at a two-decimal threshold (e.g., 0.01) generate severe errors that can compromise or terminate the simulation. For shared walls, it requires that adjacent surfaces are geometrically identical, possessing the exact same number of vertices and area, but with reversed vertex orientations to enable correct heat transfer calculations.

- *Computational Efficiency:* EnergyPlus is sensitive to the number of surfaces in a model. Each surface is a unit of calculation in the heat-balance equations, so minimizing their count is preferable for creating computationally tractable simulations, especially at the urban scale. While techniques like triangulation can enforce geometric validity by creating many small, planar triangles, this approach is counterproductive for EnergyPlus as it drastically increases simulation complexity for negligible gains in thermal accuracy.

The supplementary vertices and micro-adjustments to heal decomposed geometries and to create a valid, watertight GML solid frequently violate EnergyPlus' strict vertex matching and planarity rules. The simultaneous pursuit of perfect planarity, exact surface matching, and minimal surface count makes maintaining a true topologically watertight solid practically impossible in very complex LoD 2 models. A single geometric representation cannot satisfy both geospatial standards and simulation engines. This necessitates a dual, decoupled workflow presented in this study.

First, following geometric decomposition, we generate a high-fidelity, standard-compliant CityGML model composed of healed, valid GML solids, preserving it as the authoritative source of truth for the city. Second, we generate a *derived*, simulation-specific geometry for EnergyPlus. This involves a targeted synchronization step that reduces vertex counts on shared boundaries to meet exact matching criteria, and adjusts surface planarity. While this simplification may introduce micro-gaps, sacrificing strict topological watertightness according to CityGML validation standards, the geometry remains logically and conceptually enclosed. Furthermore, this loss of strict mathematical watertightness does not compromise the simulation. Traditionally, EnergyPlus relies on a perfectly enclosed shell to autocalculate internal zone volumes. However, because the engine allows these volumes to be manually overridden, this geometric limitation can be bypassed entirely. By calculating the exact volume from the valid CityGML solid and supplying it to EnergyPlus as a parameter, the simplified, surface-matched geometry is used purely for heat transfer. This approach successfully produces both reusable 3D digital models and efficient urban building energy models, bridging the gap between the two paradigms without compromising either.

3.3 EnergyPlus Simulation Results (UBEM)

The geometric resolution of shared walls was systematically tested against baseline models utilizing adiabatic simplifications. EnergyPlus simulations were executed to track variations in energy demands and indoor temperatures.

3.3.1 Heating Demand: Analysis of the normalized annual heating energy or the energy use intensity (EUI) reveals a clear difference in simulation results of heating demand. As shown in Figure 10, modelling actual inter-zone heat transfer yields higher simulated results compared to simplifying shared boundaries as adiabatic. Across the building stock, the median EUI difference (Shared – Adiabatic) is +18.48 kWh/m^2 (+8.1%), indicating a consistent rightward shift of the shared-boundary distribution. This is reflected in the aggregated error metrics (Shared vs. Adiabatic): MBE = +23.17 kWh/m^2, MAE = 23.75 kWh/m^2, RMSD = 31.96 kWh/m^2, and coefficient of variation of the root mean square deviation (CV(RMSD)) = 13.1%.

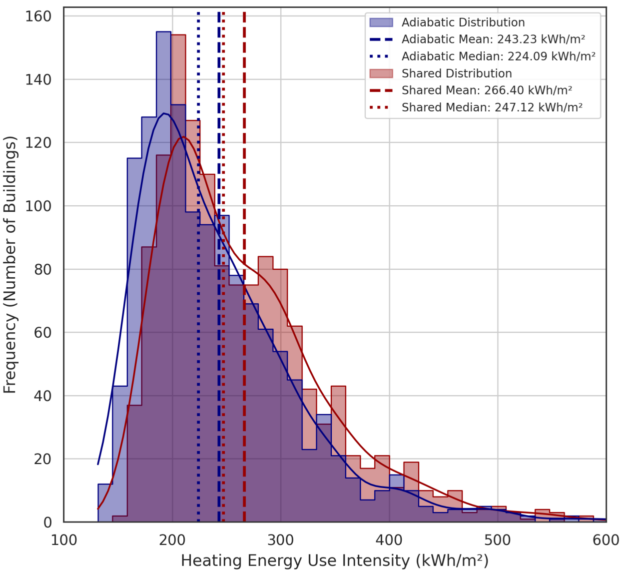

Figure 10. Frequency distribution of normalized annual heating energy (EUI) of Sint-Andries, Antwerp

It is important to note that these results are based on a uniform heating setpoint of 20°C across all buildings. In reality, variations in occupant behaviour, thermostat settings, and building vacancy would lead to greater temperature differences between adjacent units, likely increasing inter-building heat transfer. Therefore, the deviations reported here, while significant, may represent a conservative estimate of the deviations introduced by the adiabatic assumption in real-world scenarios.

3.3.2 Indoor Operative Temperature: Similarly, the modelling approach strongly influenced thermal comfort predictions. Across the full year, the explicit shared-wall model simulated systematically lower zone operative temperatures than the adiabatic simplification in every month. This is confirmed by the indoor temperature difference (Shared – Adiabatic) at the monthly aggregation level, with MBE = $-0.216\,^{\circ}$C, MAE = $0.235\,^{\circ}$C, and RMSD = $0.366\,^{\circ}$C. A per-building assessment further indicates that the discrepancy remains bounded across the stock, with 100% of buildings showing RMSD $< 2\,^{\circ}$C and median per-building RMSD of $0.29\,^{\circ}$C.

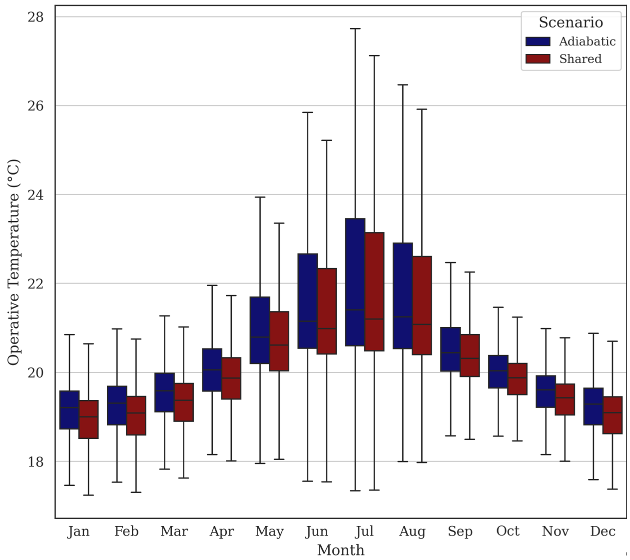

Figure 11. Monthly distribution of mean indoor operative temperature of Sint-Andries, Antwerp

As with heating demand, this analysis assumes uniform internal conditions between adjacent buildings. Real-world heterogeneity in occupancy and behaviour would create more pronounced temperature differentials between adjacent buildings, suggesting that the adiabatic assumption's impact on indoor temperature could be even more significant than what is quantified here.

4. Conclusions and Future Work

This paper presented a comprehensive, automated framework designed to overcome the limitations of the conventional adiabatic assumption in UBEM. By identifying, geometrically decomposing, and semantically enriching shared wall boundaries in LoD 2 CityGML models, the developed pipeline bridges the critical gap between geospatial data standards and the stringent geometric requirements of EnergyPlus.

At the **CityGML level**, this research presents a methodology for identifying adjacent buildings, projecting their walls into a 2D plane for stable geometric operations, and decomposing them into discrete shared and exterior segments. The integrated healing algorithms, specifically sliver reassignments, neighbour surface vertex densification, and edge collapse fixing, proved effective in preserving topological integrity, ensuring the final, enriched CityGML models remain valid, watertight GML solids suitable for a wide range of urban applications beyond energy modelling.

During the translation to the **EnergyPlus level**, the work highlights the geometric challenges stemming from inherent data quality and origin. While GML, the geometric foundation of CityGML, permits solid geometries containing polygons typical of surveyed geospatial data, EnergyPlus enforces strict planar surface-matching constraints. To reconcile this, the methodology employs a decoupled translation pipeline. It retains standard-compliant, topologically valid geometries as the authoritative CityGML asset, while simultaneously extracting a targeted, surface-matched representation tailored for EnergyPlus.

The comparative analysis in EnergyPlus simulations between the explicit surface-to-surface model and the conventional adiabatic baseline confirms that simplifying shared boundaries introduces significant, systematic simulation differences. The explicit modelling of surface heat transfer in shared walls, as compared to an adiabatic assumption, was shown to substantially predict higher heating demand (8.1% median EUI difference) and lower indoor operative temperatures (median per-building RMSD of $0.29\,^{\circ}\mathrm{C}$).

In conclusion, this research provides not only a functional and scalable tool for UBEM but also a clear methodological blueprint for enriching 3D city models while preserving their integrity for broader geospatial use cases. By decoupling the geometric processing for CityGML validity from the optimization for BPS, it offers a path to more accurate urban-scale energy simulations without sacrificing the long-term value of the underlying city model.

Future work will focus on enhancing the framework's robustness to diverse data quality and expanding its applicability to different urban contexts. The pipeline will be tested against datasets from other cities and countries, featuring different urban morphologies and data quality levels, to validate its scalability and adaptability. A key area for future research will be to move beyond simulation of single-zone buildings to multiple thermal zones to further analyze more complex inter-zone heat transfer. Also, a sensitivity analysis exploring the impact of variable indoor conditions, such as vacant adjacent units or differing temperature setpoints, would provide a more realistic quantification of the errors associated with the adiabatic assumption and further strengthen the case for explicit shared-wall modelling. Furthermore, a full integration of external validation and healing tools directly into the automated workflow will improve the pipeline. This would create a self-correcting loop, further minimizing the need for manual intervention and ensuring a higher degree of compliance and validity in the final outputs.

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