Papers 1–4 — Combined Edition

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Paper 1

Automatic inference of three-dimensional spatial structure in multi-story buildings using the slab area conservation law and Z-axis topological invariance

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Academic supervision and recommendation: Prof. Jun Kanda, Professor Emeritus, The University of Tokyo (applies to this paper — the 1st Paper — only)

Abstract

From the footprint area and number of floors obtained from public data outside the building (GSI, PLATEAU 3D, nationwide building DB), we derive each floor's slab area and subtract the common core (stairs, elevators, corridors, toilets, pipe shafts) sized by reference guidelines of the Building Standards Act, Fire Service Act and JIS to obtain private (room) areas. The Z-axis topological invariance condition—upper floors do not extend beyond lower floors and stairs/elevators run through the same position on all floors—checks the consistency between each floor plan and the total floor area.

1. Area conservation law

The total floor area equals the sum of the slab areas of all floors. On a setback floor, the floor area is the footprint area minus the rooftop portion.

$$A_{\mathrm{total}} = \Sigma_{z=1}^{F} A_{\mathrm{slab}}(z) \qquad (1)$$

$$A_{\mathrm{slab}}(z) = A_{\mathrm{fp}} - A_{\mathrm{roof}}(z) \qquad (2)$$

2. Back-calculating the common core and private areas

The private area of each floor is the slab area minus the common-core areas $k \in K$, whose sizes are reference values bounded below by legal/JIS minimum dimensions.

$$A_{\mathrm{priv}}(z) = A_{\mathrm{slab}}(z) - \Sigma_{k \in K} A_k(z) \qquad (3)$$

3. Z-axis topological invariance

The outline of an upper floor P(z+1) lies within the lower outline P(z) dilated by tolerance ε, and stair/elevator positions c_k coincide on all floors.

$$P(z+1) \subseteq P(z) \oplus B(\varepsilon), \quad c_k(z+1) = c_k(z) \qquad (4)$$

$$r(z) = A_{slab}(z) - \Sigma_j\, a_j(z) - \Sigma_k\, A_k(z) \to 0 \qquad (5)$$

4. Results and scope

Equations (1)–(5) give a consistent skeleton of floor areas, common core and private areas even for buildings without drawings, which becomes the input of the Block Puzzle formula in the 3rd Paper. Values are reference guidelines and do not judge legal conformity.

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Paper 2

Marker-free opposing two-view perspective projection and projective distortion correction

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Abstract

From opposing two-view photos taken while walking the common areas on site (corridors, stairs, elevator halls, etc.) with a smartphone (two photos facing each other from both ends of a corridor; private spaces are never entered), we back-calculate corridor widths, corners, door heights, ceiling heights and effective clearance under beams. Pages of paper as-built drawings photographed at an angle are corrected to orthographic drawings by projective transformation and overlaid on the floor plan obtained from the Block Puzzle (an optional step when a more detailed floor plan is wanted).

1. Projective distortion correction (as-built drawing data)

A 3×3 homography H is estimated by the direct linear transform from the four paper corners x_i and their orthographic positions y_i, and the whole page is corrected.

$$y \simeq H\,x, \quad H = \operatorname{argmin} \Sigma_{i=1}^{4} \parallel y_i \times H\,x_i \parallel^2 \qquad (1)$$

2. Dimensions from opposing two views

For two photos facing each other from both ends of a corridor, real dimensions follow from the corridor length $L = Z_1 + Z_2$ obtained from the walking track, image width p and height q, and focal length f.

$$W = p \cdot Z / f, \quad H_c = q \cdot Z / f, \quad Z_1 + Z_2 = L \qquad (2)$$

$$h_{\mathrm{eff}} = \min(\text{ ceiling height, clearance under beams, door height }) \qquad (3)$$

3. Overlaying as-built drawing data

The corrected as-built drawing is aligned to the Block Puzzle floor plan by a least-squares similarity transform (scale s, rotation R, translation t).

$$(s, R, t) = \operatorname{argmin} \Sigma_i \parallel s\,R\,u_i + t - v_i \parallel^2 \qquad (4)$$

4. Results

The spatial data on corridor widths, corners, door heights, ceiling heights and clearance under beams is used directly in the carry-in/out clearance check by 3D Minkowski difference in the 3rd Paper.

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Paper 3

Closed-loop spatial identification by topological fusion of multi-source public spatial data and on-site walking verification feedback (the Block Puzzle formula)

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Abstract

By combining the footprint and regulatory data from the outside (GSI, PLATEAU 3D, nationwide building DB, JMA, Building Standards Act and others) with smartphone walking tracks from the inside—covering only the common areas (entrance hall, corridors end to end, stairs, elevator hall, shared toilets)—through the Block Puzzle formula over private-area, common-area and machine/equipment blocks (XYZ dimensions)—area-conservation normalization + weighted Voronoi partitioning + carry-in/out clearance check by 3D Minkowski difference—we obtain in one pass: ① a floor plan with an area residual of 0.00 m², ② the boundaries between rooms and corridors, ③ equipment pin coordinates, and ④ whether machines can be carried in and out along a route in factories and similar facilities. Private (tenant) spaces are never entered; their layout is back-calculated from the common-area skeleton, the footprint and the contracted m². Floor plans always start with the Block Puzzle; when a more detailed floor plan is wanted, as-built drawing data is overlaid on top.

1. Blocks

Let $B = B_{priv} \cup B_{comm} \cup B_{mach}$. A private block j has a name and target area a_j; common blocks (corridor, stairs, elevator, entrance hall, toilets, etc.) have reference legal/JIS dimensions; a machine/equipment block m has X · Y · Z (width · depth · height) dimensions (X_m, Y_m, Z_m).

2. Area-conservation normalization

The entered private areas are distributed proportionally over the slab area minus the common areas from the 1st Paper, making the area residual 0.00 m².

$$\hat{a}_j = a_j \cdot (A_{slab} - \Sigma_k A_k) / \Sigma_j a_j, \quad \Sigma_j \hat{a}_j + \Sigma_k A_k = A_{slab} \qquad (1)$$

3. Weighted Voronoi partitioning

The door positions of the private areas, confirmed from the corridor while walking the common areas, are the sites s_j; the footprint P minus the common areas is partitioned while iterating weights w_j until

each cell's area equals the normalized area $\hat{a}_j$. Private spaces are never entered.

$$V_j = \{\, x \in P :\ \| x - s_j \|^2 - w_j \le \| x - s_i \|^2 - w_i \quad \forall i \,\}, \quad |V_j| = \hat{a}_j \qquad (2)$$

Corridors are the common-area walking track T dilated by half the corridor width, which fixes the room/corridor boundaries.

$$C = T \oplus D(W/2) \qquad (3)$$

4. Carry-in/out clearance check by 3D Minkowski difference

From the free space F of corridors (plan shape × effective height h_{eff}) and a machine block M_θ at orientation θ, we compute the set of feasible positions. Carry-in/out is possible if a path connected over θ in 5° steps exists from the entrance to the target; turning at a corner is possible if there is a position where θ can rotate continuously.

$$M_\theta = R_\theta(\, [0, X_m] \times [0, Y_m] \,) \times [0, Z_m] \qquad (4)$$

$$C_{free}(\theta) = F \ominus M_\theta = \{\, x : x + M_\theta \subseteq F \,\} \qquad (5)$$

$$\text{feasible} \Leftrightarrow \exists\ \text{path}\ \gamma : [0,1] \to \cup_\theta\, C_{free}(\theta), \quad \gamma(0) = \text{entrance}, \quad \gamma(1) = \text{target}, \quad Z_m \le h_{eff} \qquad (6)$$

5. Closed loop (on-site walking verification feedback)

Each press of "Matches / Fix" on site updates sites, weights and dimensions, and drawing completeness κ approaches 1 with operation. Equipment pins are kept in normalized coordinates $(\xi, \eta) \in [0,1]^2$ relative to the footprint, so positions persist when the footprint is updated.

$$\kappa^{(t+1)} = \kappa^{(t)} + \eta\,(\,1 - \kappa^{(t)}\,) \cdot v^{(t)}, \quad v^{(t)} \in \{0, 1\} \qquad (7)$$

6. Results

① A floor plan with an area residual of 0.00 m², ② room/corridor boundaries, ③ equipment pin coordinates, ④ whether machines can be carried in/out along a route in factories and similar facilities. Upcoming inspection dates are managed as reference guidelines linked to equipment pins on the floor plan.

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Paper 4

Building a stepwise-promotion database for areas without 3D city models across all 1,892 municipalities by 2D completion and two-tier hash chunk differential analysis

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Abstract

6,772,689 buildings in all 47 prefectures and 1,892 municipalities (PLATEAU 3D: 95 municipalities, 1,282,287 buildings; 2D completion: 1,797 municipalities, 5,490,402 buildings) are unified in the single schema bldg-db/1 and split into chunks of up to 2,000 buildings (4,581 chunks, 6,474 files, about 305 MB compressed). A two-tier Merkle hash over municipalities and chunks redistributes only changed chunks, and records such as rooms, upcoming inspection dates (reference) and photo pins are carried over unchanged when a building is promoted from 2D completion to 3D measurement.

1. Single schema and chunking

$$N_{\text{total}} = \Sigma_{c \in C} |B_c| = 6{,}772{,}689, \quad K_c = \lceil |B_c| / 2000 \rceil, \quad \Sigma K_c = 4{,}581 \qquad (1)$$

$$b_i = (X_i, T_i, G_i) : \text{base spatial vector} \cdot \text{attribute branch} \cdot \text{completion branch} \qquad (2)$$

2. Two-tier Merkle hash

$$H_{c,k} = \mathrm{SHA256}(\mathrm{Canon}(R_{c,k})), \quad R_c = \mathrm{Trunc}_{48}(\mathrm{SHA256}(\mathrm{Canon}(m_c) \parallel H_{c,0} \parallel \dots \parallel H_{c,K_c-1})) \qquad (3)$$

$$|U^{(t+1)}| = 1 + |\Delta C| + |\Delta K| \text{ (about 5.4 files per municipality promotion; about 99.92\% less transfer)} \qquad (4)$$

3. Non-stop promotion from 2D completion to 3D measurement

$$\hat{h}_i = d_i \, h_i^{\text{meas}} + (1 - d_i) \cdot \{ h_i \text{ or } \alpha \, f_i \text{ or } \alpha \, f_0 \}, \quad \alpha = 3.1 \text{ m} \qquad (5)$$

$$\hat{P}_i = g_i + \sqrt{ (A_i / A(P_0)) } \cdot (P_0 - g_i) \quad \Rightarrow \quad \mathrm{Area}(\hat{P}_i) = A_i \qquad (6)$$

$$T_{\text{promote}}(b_i^{(t)}, \Omega_i^{(t)}) = (b_i^{(t+1)}, \Omega_i^{(t)}), \quad \partial \Omega_i / \partial d_i = 0 \qquad (7)$$

4. Results

Any building in Japan can be matched from an address with about 80–180 KB of traffic, and the information from outside (footprint, height, elevation) is used as the footprint of the Block Puzzle.

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