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Between Sacred Tradition and Urban Form: An OpenStreetMap-Based Analysis of Church Orientation Patterns in Milan

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Abstract

The orientation of Christian churches has long attracted attention in liturgical studies, architectural history, and archaeoastronomy. In the Catholic tradition, churches are often associated with an eastward-facing sanctuary and a westward-facing entrance, but in urban settings their realized orientation is also shaped by streets, neighbouring buildings, plot geometry, topography, and rebuilding campaigns. This paper investigates 114 church buildings in Milan using open geospatial data derived primarily from OpenStreetMap (OSM). A web-based analysis tool built with MapLibre GL JS and Turf.js was used to measure the azimuth from the building centroid to the selected entrance for each church. Entrance bearings were analysed with circular statistics and visualized with a rose diagram. The strongest concentration lies in the western and west-southwestern sectors. The mean direction is 245.4°, the mean resultant length is 0.283, and a Rayleigh test rejects circular uniformity ($z = 9.101$, $p < 0.001$). The result is stable for the 99 Catholic-tagged buildings, but an entrance-tag sensitivity analysis shows that the concentration is carried mainly by the 82 records explicitly tagged entrance=main. The findings reveal a statistically detectable but measurement-sensitive westward tendency, consistent with partial persistence of the traditional east–west liturgical axis alongside adaptation to urban form.

1. Introduction

The orientation of Christian churches has long been understood as both an architectural and a symbolic issue. In the Catholic tradition, church buildings are frequently described through a directional logic in which the sanctuary or altar is located toward the east and the principal entrance toward the west. This arrangement has been associated with theological meanings linked to sunrise, resurrection, sacred cosmology, and eschatological expectation. The east–west axis is therefore not merely a technical matter of layout but a spatial expression of doctrine, ritual order, and collective memory.

At the same time, church buildings are never created in a vacuum. They are inserted into specific plots, along existing streets, within urban blocks, and among neighbouring structures that themselves change over time. In cities, the final orientation of a sacred building often emerges from negotiation between symbolic ideals and the material conditions of urban space. A church may preserve a canonical east–west axis, but it may also adapt to a pre-existing street grid, a constrained parcel, a prominent square, a sloping site, or later rebuilding campaigns. The resulting orientation is therefore not only a liturgical trace but also an urban one.

This tension between sacred principle and urban form makes church orientation a productive topic across multiple disciplines. Liturgical studies and religious history emphasize symbolic and doctrinal meanings; architectural history examines plans, styles, and design conventions; archaeoastronomy explores alignments with sunrise, solstices, and feast days; and urban studies highlight relationships with streets, parcels, and city growth. Yet city-scale analyses remain comparatively limited, especially those based on open geospatial data and reproducible digital workflows.

This study focuses on Milan, Italy. Milan is a particularly suitable case because it is a historic Catholic city with continuous ecclesiastical development across Roman, medieval, early modern, and modern periods. Its church buildings are embedded in a dense and layered urban fabric that reflects long-term transformations in land subdivision, infrastructure, rebuilding, and public space. This makes Milan an ideal site for examining whether the orientation of churches still reflects the traditional east–west liturgical logic, or whether urban constraints and historical change have produced more complex patterns.

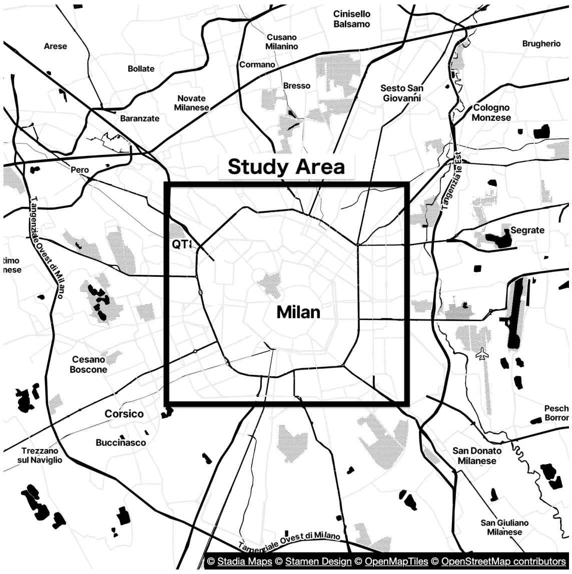

Figure 1. Study Area

The study asks three main questions. First, do church entrances in Milan display a statistically visible directional pattern? Second, does that pattern suggest the persistence of the traditional east–west liturgical axis? Third, how can directional variation be interpreted in relation to urban morphology and spatial constraints? In answering these questions, the paper also demonstrates how open geospatial infrastructures can support a form of spatial humanities research that remains analytically rigorous while being transparent and reproducible.

2. Related work

Previous scholarship has proposed several explanatory frameworks for church orientation. The first and most enduring emphasizes alignment toward geographic East as a symbolic and liturgical norm. Empirical studies in England and continental Europe nevertheless show substantial variation around that ideal and have tested astronomical, calendrical, magnetic, and site-specific explanations (Ali and Cunich, 2001; Dallas, 2015; Spinazzè, 2016). Church orientation is therefore best approached as a directional tendency whose strength and dispersion must be measured rather than assumed.

A second line of interpretation proposes that church alignment may correspond not simply to true East but to the sunrise azimuth on the feast day of the patron saint (Ali and Cunich, 2001; Spinazzè, 2016). A third interpretation suggests that deviations from true East may reflect the historical use of magnetic compasses during construction (Abrahamsen, 1992). These explanations are not mutually exclusive at the scale of individual buildings, but they imply different aggregate patterns and require comparison with construction dates, patronal calendars, horizon conditions, and historical magnetic declination.

A major contribution to this debate is provided by Arneitz, Draxler, Rauch, and Leonhardt (2014), who reassessed these competing explanations through a statistical analysis of medieval churches in Lower Austria and northern Germany. Their study compared deviations from geographic East, magnetic East, and sunrise azimuths associated with patrons' feast days. The smallest mean deviations were found relative to geographic East, whereas deviations from magnetic East were substantially larger. On this basis, they rejected the compass hypothesis statistically. They also found that the patron-saint sunrise model showed greater scatter and only limited explanatory value overall.

Equally important is the interpretive argument advanced by Arneitz et al. (2014). They stress that deviations from East should not automatically be read as evidence of alternative symbolic rules. Church orientation may be affected by neighbouring buildings, pre-existing streets, foundation conditions, vegetation, topography, and horizon effects, especially in urban settings. This shift is crucial because it suggests that church orientation should be understood not as the outcome of a single rule, but as the result of interaction between sacred principles and material-spatial constraints.

Other strands of scholarship reinforce this plural understanding of church alignment. Archaeoastronomical studies have tested solar and calendrical alignments in different regional contexts (Dallas, 2015; Spinazzè, 2016), while architectural and urban interpretations emphasize plots, streets, approaches, and rebuilding histories. Taken together, the literature suggests that no single framework is sufficient. Church orientation should instead be read as a layered spatial phenomenon in which liturgical convention, astronomical imagination, construction practice, and urban form overlap.

This framework is especially useful for Milan. If church orientation in the city is neither fully eastward nor randomly distributed, then the most plausible reading is likely to involve layered interactions among liturgical tradition, urban morphology, and historical transformation. The question is therefore not whether Milan's churches are religious or urban in their orientation, but how those dimensions are negotiated spatially.

3. Materials and Methods

3.1 Study area

Milan is one of the most historically significant Catholic cities in Europe. Its ecclesiastical landscape includes early foundations, medieval parish churches, monastic complexes, Baroque rebuilding, nineteenth-century transformations, and modern insertions. The street network, block structure, and parcel pattern likewise reflect multiple historical phases. Church buildings in Milan are therefore embedded in a stratified urban fabric rather than a single, uniform plan.

The city is particularly suitable for the present study because it combines long-term ecclesiastical continuity with strong urban morphological diversity. Churches may front medieval lanes, Baroque squares, nineteenth-century boulevards, or modern redevelopment areas. Such diversity makes Milan an ideal case for examining whether directional tendencies remain legible despite urban change and whether some parts of the city exhibit greater conformity to canonical orientation than others.

3.2 Dataset

The source table contained 148 candidate building features compiled from OpenStreetMap data extracted on 25 October 2025 (OpenStreetMap contributors, 2025). Candidate records represented mapped church or place-of-worship buildings within the Milan study area. A feature was retained when a polygonal building footprint was available and a principal entrance could be assigned in the web interface. Of the 148 candidates, 114 had a usable entrance bearing and formed the analytical sample; 34 records without a usable bearing were excluded. This rule prioritizes measurement consistency, although it may under-represent buildings with complex footprints or ambiguous access arrangements.

OSM denomination tags were retained as descriptive metadata rather than used as an initial inclusion filter. Among the 114 analysed buildings, 75 were tagged catholic, 24 roman_catholic, nine with other Christian denominations, and six without a denomination value. Because the historical interpretation focuses on the Catholic east–west tradition, the full-sample analysis was supplemented by a sensitivity analysis restricted to the 99 buildings explicitly tagged catholic or roman_catholic. This comparison tests whether the aggregate result is driven by the smaller set of other or unspecified denominations.

For each retained church, entrance orientation was identified using a dedicated web-based tool developed with MapLibre GL JS, an open-source browser mapping library (MapLibre contributors, 2026), and Turf.js, a modular JavaScript library for geospatial analysis (Turf contributors, 2026). The tool calculates the initial bearing from the building centroid toward the selected principal entrance and exports the result in tabular form. The software is released under a CC0-1.0 license (mapconcierge, 2025), making the measurement workflow inspectable and reusable.

3.3 Measurement definition

Entrance direction was defined as the azimuth from the building centroid toward the principal entrance. This measure does not directly capture altar orientation or the full liturgical axis. However, it provides a practical and scalable proxy for analysing the public-facing directionality of church buildings within the urban fabric. For a city-scale study based on open building footprints, it offers a coherent compromise between interpretive richness and operational consistency.

This operational definition also aligns with an urban perspective on church architecture. The main entrance is the interface through which a church addresses public space, receives congregants, and forms a visual and functional relationship with adjacent streets and squares. Even when the liturgical axis is not directly observed, entrance direction offers a meaningful indicator of how sacred architecture is exposed to and negotiated with the city.

For irregular, multi-part, or asymmetrical footprints, the centroid-to-entrance bearing may differ from the longitudinal nave axis. The measure should therefore be interpreted as entrance-facing direction, not as a direct observation of altar orientation or architectural axis. The same operational rule was applied across the sample. The dataset records 82 entrances explicitly classified as main and 32 mapped with the more general entrance=yes value; this difference is another source of measurement uncertainty considered in the interpretation.

3.4 Analytical procedure

The analysis proceeded in four steps. First, entrance azimuths were compiled for all 114 churches. Second, the values were summarized through circular statistics following standard directional methods (Mardia and Jupp, 2000). The circular mean indicates the dominant angular tendency, while the mean resultant length (R) measures concentration on a scale from 0 to 1. Values near 0 indicate strong dispersion; values near 1 indicate close clustering around a common direction.

Third, the azimuths were grouped into 16 equal directional sectors of 22.5° and visualized using a rose diagram. The sector containing 0° was centred on North, with the remaining labels progressing clockwise. This grouping supports an interpretable overview of western, eastern, and southwestern concentrations without treating small angular differences as substantively distinct.

Fourth, a Rayleigh test was applied to the ungrouped bearings to evaluate the null hypothesis of circular uniformity (Mardia and Jupp, 2000). The test is most sensitive to a unimodal departure from uniformity, so its result was interpreted together with the rose diagram and R rather than as proof of a single deterministic axis. The complete analysis was then repeated for the 99 buildings tagged catholic or roman_catholic as a denomination-based sensitivity check.

The workflow was intentionally designed to remain lightweight and reproducible. Rather than relying on proprietary GIS environments, it combines open building geometries, a small open-source web tool, and standard circular analysis. The approach is transferable to other cities where church inventories and building footprints are available. At the same time, the study recognizes the limitations of entrance-based azimuths. Entrance direction is an urban-facing proxy, not a direct substitute for sanctuary orientation, construction chronology, or doctrinal intention.

3.5 Data quality and reproducibility

The workflow separates source geometry, the manually selected entrance, and derived statistics. OSM identifiers were retained so that every measurement can be traced back to its mapped feature. The source table also preserved centroid coordinates, the computed bearing, and the entrance tag used in selection. This structure makes it possible to rerun the circular calculations without repeating the visual inspection and to revisit individual choices when the underlying map changes.

The most consequential manual decision is the identification of the public-facing principal entrance. In the analytical table, 82 selected entrances were explicitly tagged entrance=main, whereas 32 were represented by the less specific entrance=yes. The latter tag confirms an entrance but does not itself establish that it is the historically or functionally principal one. An entrance-tag sensitivity analysis was therefore added alongside the denomination check: circular statistics and the Rayleigh test were calculated separately for these two groups.

Reproducibility in this context does not mean eliminating interpretive judgement. It means exposing the judgement as a reviewable data field and keeping derived values separate from source attributes. A future release should archive the exact OSM extract, the entrance-selection table, tool version, analysis script, and a confidence or evidence note for each entrance. This would allow reviewers to distinguish disagreements about the selected entrance from disagreements about the statistical procedure.

4. Results

The entrance bearings are dispersed across all 16 sectors but exhibit a clear western concentration. As summarized in Table 1 and visualized in Figure 2, the two most frequent classes are W and WSW, each with 19 cases (16.7%). Together these sectors account for 38 of the 114 observations (33.3%). A secondary concentration appears in E with 12 cases (10.5%), followed by SW with 11 cases (9.6%).

The circular mean for the full sample is 245.4°, corresponding to a west-southwestern tendency, and R is 0.283. The Rayleigh statistic is $z = 9.101$ with $p = 0.000096$, rejecting circular uniformity at the 0.001 level. The low R nevertheless shows that the statistically detectable tendency is weak relative to the overall dispersion. Thus, the data support a non-uniform aggregate pattern, but not a claim that Milanese churches follow one tightly defined bearing.

Metric	Value
Num. of churches	114
1st peak sector	W (19; 16.7%)
2nd peak sector	WSW (19; 16.7%)
W + WSW	38 (33.3%)
Circ. mean dir.	245.4°
Mean resultant length (R)	0.283
Catholic-tagged subset	n = 99; mean = 244.9°; R = 0.306
Explicit main entrances	n = 82; mean = 250.4°; R = 0.382
General entrance=yes	n = 32; mean = 175.8°; R = 0.091

Table 1. Church entrance orientation in Milan.

The denomination-restricted analysis confirms that this result is not driven by the smaller group of other or unspecified denominations. For the 99 buildings tagged catholic or roman_catholic, the mean direction is 244.9°, R is 0.306, and the Rayleigh test remains significant ($z = 9.259$, $p = 0.000080$). These estimates are close to the full-sample values and strengthen the interpretation of a dispersed westward entrance tendency within the Catholic-tagged subset.

4.1 Entrance-tag sensitivity

The entrance-tag split produces a more substantial difference. The 82 records explicitly tagged entrance=main have a mean direction of 250.4° and R of 0.382; the Rayleigh test strongly rejects uniformity ($z = 11.954$, $p = 0.000004$). By contrast, the 32 records represented by entrance=yes have a mean direction of 175.8°, R of 0.091, and no detectable departure from uniformity ($z = 0.268$, $p = 0.768$). The stronger full-sample westward pattern is therefore concentrated in the explicit-main subset.

This contrast has two possible, non-exclusive interpretations. Explicit entrance=main tags may identify principal façades more reliably, giving a closer proxy for the intended public-facing axis. Alternatively, mapping completeness may be associated with church prominence, age, location, or building form, so the explicit-main group may not be representative of all churches. The analysis cannot distinguish these mechanisms, but the split demonstrates that entrance classification is analytically consequential and should not be treated as incidental metadata.

Across all 16 sectors, counts were N 6, NNE 3, NE 4, ENE 5, E 12, ESE 3, SE 4, SSE 4, S 4, SSW 8, SW 11, WSW 19, W 19, WNW 4, NW 5, and NNW 3. Reporting the complete distribution prevents the western peaks from obscuring the broad dispersion visible elsewhere and provides a compact benchmark for replication or comparison with other cities.

In substantive terms, the result indicates that the city preserves directional traces of the traditional arrangement in which the entrance faces west, and the sanctuary faces east. Yet the data also show that this arrangement has not been implemented uniformly. The presence of eastern entrances and southwestward groupings suggests that churches have responded to different site conditions and urban situations, producing a morphology that is patterned but not rigid.

4.2 Summary of dominant sectors

The four most frequent directional sectors are W (19 cases, 16.7%), WSW (19 cases, 16.7%), E (12 cases, 10.5%), and SW (11 cases, 9.6%). These values indicate that directional preference exists, but that it is distributed across more than one urban and symbolic logic. The western cluster is dominant, yet the eastern and southwestern clusters remain too large to be dismissed as mere noise.

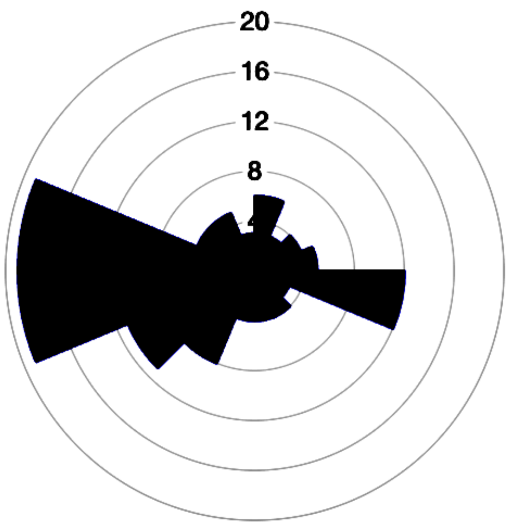

Figure 2. Entrance Direction in Milan (Rose diagram)

5. Discussion

The western concentration is consistent with the traditional Catholic arrangement in which the entrance faces west and the sanctuary faces east. Because this study measures entrance-facing direction rather than altar position or nave axis, the interpretation must remain cautious. Nevertheless, the significant Rayleigh result and the similar Catholic-tagged sensitivity estimate show that the westward tendency is not simply an artefact of grouping the observations into sectors.

At the same time, R values of 0.283 for the full sample and 0.306 for the Catholic-tagged subset indicate substantial dispersion. The observed distribution is therefore compatible with partial persistence of a liturgical orientation convention, but it does not demonstrate that convention as the cause of every bearing. Eastern, southwestern, and other orientations may reflect different combinations of architectural history, street frontage, parcel geometry, public-space access, and later alterations.

This interpretation aligns closely with the implications of Arneitz et al. (2014). Their study argues that church orientation is best understood not through a forced choice between symbolic and practical explanations, but through the interaction of sacred principles and spatial-material constraints. Milan offers a strong urban case for this view. The directional pattern is sufficiently structured to reject a purely incidental reading, yet sufficiently dispersed to reject a single deterministic explanation.

From the perspective of urban morphology, entrance bearings provide a reproducible starting point for examining how sacred architecture addresses streets and public space. However, the present analysis does not directly measure street bearings, parcel axes, construction periods, or rebuilding events. These factors should therefore be treated as hypotheses explaining the observed dispersion rather than as demonstrated causes. A causal assessment would require building-level comparison between entrance direction, architectural axis, adjacent street orientation, chronology, and historical plans.

The study also demonstrates the value of open geospatial workflows for spatial humanities research. By combining OpenStreetMap, a small open-source measurement tool, spreadsheet-based data management, and circular statistics, the analysis moves beyond isolated case studies toward a city-scale understanding of church orientation. This is significant for FOSS4G-related scholarship because it shows that open mapping ecosystems can support not only technical geospatial research, but also historically and culturally informed urban analysis.

5.1 Robustness of the directional pattern

The denomination-based sensitivity analysis provides one robustness check. Removing the 15 buildings not explicitly tagged catholic or roman_catholic changes the mean direction by only 0.5° and increases R by 0.023. The western tendency is therefore stable under this restriction. This check does not resolve uncertainty in denomination tagging or entrance identification, but it makes the scope of the religious interpretation more explicit.

The entrance-tag analysis, however, shows that robustness depends on measurement metadata. The strong concentration among explicit main entrances and its absence among general entrance=yes records mean that the full-sample result should not be generalized uncritically to every church in the candidate inventory. The explicit-main result is consistent with a meaningful public-facing axis, while the general-entrance group requires additional validation before it can support the same interpretation.

This finding also identifies a practical contribution for volunteered-geographic-information research. Attribute completeness is not only a documentation issue; it can stratify the evidential quality of derived measurements. Publishing the analysis with entrance classes, excluded records, and sensitivity results allows later work to update the sample as OSM tagging improves rather than treating the present dataset as a fixed authoritative inventory.

5.2 Limitations and future work

Several limitations should be acknowledged. First, centroid-to-entrance azimuth is a proxy for entrance-facing direction and not a direct measurement of altar orientation or nave axis. Second, 34 of 148 candidate records lacked a usable entrance bearing; if ambiguity is spatially systematic, their exclusion may affect the result. Third, entrance classifications combine explicit entrance=main and general entrance=yes values, and present-day access may differ from the historical principal entrance. Fourth, OSM denomination tags are incomplete and do not substitute for a historical church inventory. Finally, the Rayleigh test detects a unimodal departure from uniformity and does not by itself explain the secondary peaks visible in the rose diagram.

Future work should validate entrance choices against field observations or authoritative architectural plans, derive nave and sanctuary axes, compare bearings with adjacent streets and parcel geometry, and stratify churches by construction and rebuilding period. Mixture models or omnibus circular tests such as Kuiper's test could examine the secondary peaks without assuming a single mode. Comparative studies across other Catholic and non-Catholic cities would help determine whether Milan's mixed morphology is typical or distinctive. Versioned entrance points, confidence classes, and archived data snapshots would further improve reproducibility.

6. Conclusions

This paper examined entrance-facing directions for 114 church buildings in Milan using OpenStreetMap-derived geometries, a custom open-source measurement tool, and circular statistics. The mean direction is 245.4°, R is 0.283, and a Rayleigh test rejects circular uniformity ($p < 0.001$). A sensitivity analysis of 99 Catholic- or Roman-Catholic-tagged buildings yields a closely matching result. An entrance-tag analysis shows, however, that the concentration is strong among 82 explicit main entrances and absent among 32 general entrance=yes records.

These findings identify a statistically detectable but measurement-sensitive westward entrance tendency that is consistent with partial persistence of the traditional Catholic east–west arrangement. They do not establish liturgical convention as the sole cause of individual orientations. Instead, the secondary peaks, overall dispersion, and entrance-tag contrast indicate a heterogeneous pattern whose relationship to architectural axes, streets, parcels, chronology, and mapping completeness remains to be tested directly.

The study contributes in two ways. Substantively, it offers new evidence that church orientation in Milan reflects both religious convention and urban form. Methodologically, it demonstrates that OpenStreetMap-based analysis and openly released tools can extend church orientation research toward reproducible, city-scale spatial humanities. More broadly, it shows that open geospatial ecosystems can support interdisciplinary research connecting religion, architecture, urban history, and geospatial science.

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Appendix. Replication workflow

This appendix documents the open workflow used in the study. OpenStreetMap building features for the Milan study area were extracted on 25 October 2025 and assembled into a 148-record candidate table. Each candidate was inspected in the browser interface. A centroid-to-entrance bearing was exported when a principal entrance could be assigned; 114 records contained a usable bearing and 34 were excluded from directional analysis. The retained table included the OSM identifier, available church attributes, centroid coordinates, entrance bearing, and entrance classification.

The 114 ungrouped bearings were converted to radians for circular calculations. Sine and cosine components were summed to obtain the circular mean and mean resultant length. Counts for the rose diagram used 16 sectors of 22.5°. Rayleigh's z was calculated as nR^2, with the finite-sample approximation used for the p-value. The same calculations were repeated after retaining only catholic and roman_catholic denomination tags. These steps reproduce the statistics reported in Table 1 from the exported bearing column.

For reuse, the entrance-selection interface and source code are available in the cited repository. A complete archival package should additionally preserve the precise OSM extract, the 148-record candidate table, the 114-record analytical table, software versions, and a confidence field explaining each entrance choice. These additions would allow later researchers to distinguish changes in OSM data from changes in interpretation and to rerun the analysis for other cities. The following quality-control sequence is recommended for replication. First, retain every candidate feature, including excluded records, and assign a stable identifier and exclusion reason. Second, record whether the selected point is explicitly tagged as a main entrance, inferred from another entrance tag, or identified only through visual interpretation. Third, inspect centroid locations for footprints with courtyards, detached components, or strongly concave geometry, since a geometric centroid may fall outside the functional nave or even outside the visible building mass. Fourth, review bearings close to sector boundaries using their continuous values rather than relying only on the displayed sector label. Fifth, recompute the full sample and all pre-specified sensitivity subsets from the same bearing column. These checks reduce the risk that manual selection, changing map data, or categorical binning will be mistaken for a stable historical pattern.

The exported table should also carry provenance at field level. Source attributes copied from OSM should remain distinguishable from analyst-created fields such as selected entrance, confidence, exclusion reason, and inferred sanctuary direction. Derived fields should document units and direction conventions: bearings in this study are degrees clockwise from geographic North in the range from 0° to less than 360°. Sector labels should record the boundary rule used for values exactly halfway between named directions. Explicit conventions are essential because reversing an entrance bearing to approximate sanctuary direction adds 180°, while treating a building axis as axial rather than directional data changes the statistical problem.

Finally, future releases should report changes between data versions. New or corrected entrance tags may move records from the general entrance=yes group into the explicit-main group, while building-footprint edits can change centroid positions and therefore calculated bearings. A version comparison should identify added, removed, and modified OSM features; list entrance choices that changed; and report the effect on the circular mean, R, sector counts, and test results. This update-oriented design is well suited to FOSS4G research because it treats the open map not as a static source but as a living dataset whose analytical consequences can be measured transparently.