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# Building Corner Geometry and Sustainable Pedestrian Space Design: Acoustic Modeling and Listening-Based Comparisons

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**Abstract**

The geometry of building corners affects pedestrian acoustic conditions, but its design relevance depends on the functions of adjacent urban space. This study investigates how controlled acoustic and perceptual comparisons can inform preliminary sustainability-oriented decisions without predicting real-site exposure. Five corner types were simulated in a street canyon 10 m wide and 12 m high, using a stationary source screened by the corner. Forty adults compared auralized stimuli in paired listening trials. Additional existing analyses examined source-position sensitivity and one-third-octave stimulus spectra. At the sidewalk receiver, a 5 m chamfer increased the A-weighted sound-strength indicator by 6.72 dB relative to the right-angled reference under the screened-source condition and was judged louder and more annoying. Rounded and projecting-bay variants also increased the energetic indicator but were perceived as less loud and less annoying; spectral differences were observed without establishing their causal contribution. Comparisons with an alternative source position showed that the effect of chamfering can reverse. Three Poznań intersections illustrate design questions rather than site-specific acoustic validation. The contribution is a function-sensitive preliminary decision sequence linking acoustic shielding, perception, and pedestrian accessibility, subject to case-specific verification.

**Keywords:** building-corner geometry; pedestrian soundscape; sustainable urban design; urban acoustics; auralization; source-position sensitivity; acoustic comfort; public-space functions

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## 1. Introduction

The corner of a building is a relatively small element of urban form, yet it simultaneously affects two adjoining streets. For pedestrians, it may mark a change of direction, an approach to a shopfront, a place to wait at an entrance, or a brief stopping point. The same architectural form can provide shielding from sound originating on a cross street while also restricting acoustic contact with the surroundings. Its evaluation therefore depends on the intended use of the adjacent space.

Conventional noise-control practice focuses primarily on sound levels, emission sources, and mitigation measures. A soundscape-based approach complements these considerations by accounting for perception and the context of use [1–3]. The activity performed in a place thus becomes relevant to its assessment. Shielding may be particularly

important where people rest, whereas orientation and a legible connection to an adjoining street may be priorities along a pedestrian route.

The geometry of dense urban development can modify sound propagation through reflections between facades, scattering, and edge diffraction [4,5]. Although street width, building height, and facade configuration have received considerable attention in previous research, the practical selection of a single building-corner form often lacks an explicit link between measurable changes in the sound field, their auditory evaluation, and the function of a particular urban space. This link is the focus of the present study.

The five corner geometries are examined through a controlled screened-source model, complemented by already available comparisons with an alternative source position. Three intersections in Poznań provide a separate interpretive stage: they illustrate functional and spatial questions for sustainable pedestrian design, without assigning model-derived sound levels to real locations or claiming field validation. The present work does not quantify energy use, health outcomes, or broader sustainability performance.

The research question is whether local corner geometry, assessed by both energetic and listening-based measures, can inform early decisions about pedestrian movement and brief stationary use of space. Its academic contribution is not a new universal soundscape metric, but an explicit comparison of five local geometries under common acoustic conditions, the identification of disagreements between energetic and perceived responses, and a transparent decision sequence for exposing trade-offs before geometry is fixed. Sustainable urban design is addressed here through pedestrian-oriented acoustic quality and the coordination of environmental and accessibility considerations, not through a claim of measured sustainability benefits.

For operational purposes, movement denotes the planned function of continuous pedestrian passage or turning at a corner, whereas stopping or staying denotes a programmed opportunity for waiting, conversation, sitting, or a similar stationary activity. The distinction is based on the use envisaged for an area, not a numerical dwell-time threshold; pedestrian counts, dwell times, and accessibility scores were not measured. For the former function, unobstructed passage and legible connections are considered first, with potential changes in acoustic exposure treated as a design trade-off. For the latter, acoustic shielding and relative annoyance receive greater attention, while access and safety remain non-negotiable constraints. These qualitative categories are design inputs, not validated exposure classes.

## 2. State of the Art and Interpretive Framework

### *2.1. Built Geometry and the Local Redistribution of Sound Energy*

Echevarría Sánchez et al. [4] demonstrated numerically that even relatively modest changes to street cross-sections and facade geometry can produce substantial differences in pedestrians' exposure to traffic noise. The parametric study by Forssén et al. [5] likewise showed that urban layout influences the extent to which sound reaches sheltered locations via indirect propagation paths. Both studies point to the importance of the relationship among spatial geometry, source direction, and receiver location. A facade modification is not, in itself, a noise-control measure of fixed effectiveness.

Yilmaz et al. [6] investigated how auditory and visual stimuli, presented separately and together, influence perceptions of enclosure in street canyons with different height-to-width ratios. Thus, the proportions of the street are relevant not only to its physical configuration but also to its perceived spatial character. Separately, field measurements of aircraft noise in experimental courtyard arrangements showed that shielding and the geometry of reflective building surfaces can produce substantial local differences in sound levels [7]. Because that study concerned aircraft rather than road traffic noise, its results

are treated here as evidence of geometric sensitivity, not as a quantitative prediction for the present source configuration.

Of particular interest is a configuration in which a building corner separates the receiver from the sound source. Sound then reaches the area beyond the edge through diffracted and reflected components. The results presented below were selected for this screened-source configuration, enabling comparison of how different corner forms shape acoustically sheltered pedestrian space.

The acoustic importance of a screened building edge is consistent with established diffraction research on barriers and corners, including the work of Maekawa [8], Pierce [9], and Svensson et al. [10]. Those studies clarify propagation mechanisms rather than supply transferable numerical corrections for the particular geometric variants considered here. The use of an approximate diffraction implementation in the present geometrical-acoustics model is therefore an explicit source of uncertainty, especially for the detailed spectral and temporal structure of the synthesized signals.

### *2.2. From Physical Indicators to Perceptual Assessment*

Brown and Muhar [1] argue that acoustic design of outdoor space should begin by defining the desired conditions of use. Aletta, Kang, and Axelsson [2] distinguish descriptors of auditory experience from indicators intended to predict that experience. An energetic measure alone cannot, therefore, account for the full perceptual response. This position is supported by research on the relationship between soundscape evaluations and user activities [11], as well as by approaches to designing soundscape interventions [3].

ISO 12913-1 defines soundscape as the acoustic environment as perceived, experienced, or understood by people in context [12]; ISO/TS 12913-2 specifies data collection and reporting requirements for soundscape studies [13]. In situ assessments and laboratory comparisons of auralizations provide different but complementary types of information. The present study uses laboratory ratings of relative loudness, annoyance, and perceived shielding, and considers their relevance to specified functions of urban space. It is not presented as a full in situ soundscape assessment.

Fraisse, Tarlao, and Guastavino [14] compared four temporary sound installations in the same public space and found both shared and installation-specific benefits, influenced by contextual factors and design objectives. This supports the view that the effect of an acoustic intervention must be interpreted in relation to its setting and purpose. The present study examines a different design variable: building-corner geometry, which alters propagation paths rather than introducing a new sound installation.

Clua, Llorca-Bofí, and Psarra [15] demonstrated the relevance of relating spatial configuration, outdoor acoustics, and patterns of use in public space. Cortesão and Lenzholzer [16] discussed the methodological need for rigorous testing when transferring research-through-design concepts into practice. Together, these perspectives motivate a cautious, function-sensitive interpretation of model findings rather than a direct transfer of numerical results to unmodeled urban locations.

Beyond acoustics, research on perceived urban design across different urban typologies indicates that experience and spatial form need to be interpreted in their local context [17]. Work on the sensory atmosphere of historic public space likewise highlights the importance of user experience alongside the visible urban fabric [18]. These studies do not validate the acoustic behavior of a building corner; they support a contextual interpretation of pedestrian-space quality. The present contribution remains a controlled comparison between local corner geometry, energetic indicators, and responses to auralized stimuli.

## 3. Materials and Methods

### *3.1. Scope and Analytical Procedure*

The study combines a controlled comparison of acoustic simulations and paired listening judgments with a separate, document-based interpretation of three Poznań intersections. Two supplementary analyses from the same experimental dataset are reported to evaluate the limitations of the principal comparisons: a change in source position (S0 versus S1) and a comparison of one-third-octave spectra of listening stimuli. These data were generated using the original modeling and auralization procedures; no additional participant recruitment or field measurement was undertaken for this revision.

The numerical stage addresses sound propagation around a building corner at the intersection of two perpendicular streets. The design-oriented stage considers how the space is used and where users are located relative to the corner and the sound source. This approach allows findings from the simplified model to be discussed in relation to specific situations encountered in urban space.

Two functional categories were used to structure preliminary interpretation:

- Pedestrian movement, meaning passage through or around the corner;
- Stopping or staying, including waiting, conversation, and rest near an entrance or seating area.

These categories were assigned from spatial use and urban documentation rather than observed dwell times. They specify different questions for design assessment rather than different numerical sound limits. The relevant receiver locations were considered relative to the facade, the sidewalk centreline, and vertically near the first floor.

### *3.2. Reference Model and Corner Variants*

The reference model represented a conventional four-way intersection within a continuous urban street frontage. The facade-to-facade width of each street was W = 10 m, the building height was H = 12 m, and H/W = 1.2. The carriageway was 6 m wide, with 2 m sidewalks on either side. The modeling domain covered 80 × 80 m. The reference case had a right-angled (90°) corner. The remaining variants involved local changes to the corner edge or building volume, while the source characteristics, materials, and surrounding buildings were held constant.

Five corner forms were selected: right-angled, chamfered with a 5 m setback measured along both facades, rounded with a radius of 3 m, ground-floor recessed, and with a projecting bay. The ground-floor recess extended 6 m along the building frontage, with a depth of 3 m and a height of 3.5 m; the bay was a projection above ground-floor level. All other parameters were unchanged. Figure 1 illustrates the form types schematically rather than reproducing the exact scale of the numerical models.

The main results concern the screened-source configuration S1, in which a stationary omnidirectional point source was placed on the cross street, behind the building corner under investigation. In local coordinates (x, y, z), source S1 was positioned at (−5, −5, 0.3) m. Receiver R1 (pedestrian near the facade) was at (5, 0.4, 1.5) m, R2 (sidewalk centreline) at (5, 1.0, 1.5) m, and R3 (near the facade at first-floor height) at (5, 0.2, 4.0) m. R2 was the primary receiver for comparisons with the listening experiment. An additional existing series placed the same stationary source at S0 = (−5, 5, 0.3) m while retaining the source spectrum, the modeled corner forms, the receivers, and the numerical settings. S0 provides a limited source-position comparison, not a model of moving traffic.

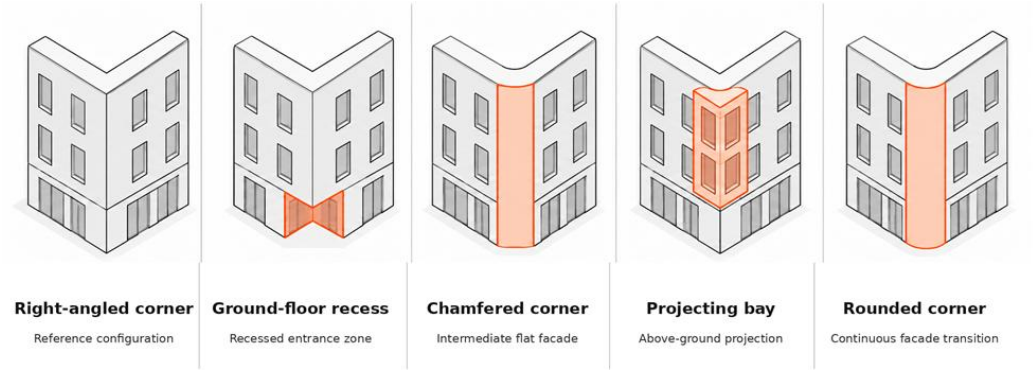



**Figure 1.** Schematic comparison of the five corner types investigated: right-angled (reference), recessed, chamfered, projecting bay, and rounded. Orange identifies the geometric change relative to the reference corner. The drawings are illustrative and do not reproduce the dimensions of the numerical models. Source: author's own illustration.

The simulations used an omnidirectional point source (DIRECTIVITY = "omni") as a simplified representation of the sound from a single passenger car. The source height was 0.3 m, and $L_{p}$,1 m(f) in the octave bands centered at 125, 250, 500, 1000, 2000, and 4000 Hz was set to 73, 77, 80, 82, 78, and 74 dB, respectively. The source level, spectrum, directivity, and position were identical in all five geometric variants. The findings therefore concern one controlled source–receiver propagation configuration, rather than actual vehicle traffic varying over time.

The source-position sensitivity check compared A-weighted modeled sound-pressure-level differences, ΔSPL(A), between each modified geometry and the right-angled reference at R2 within each source scenario. It is reported separately from the broadband A-weighted sound-strength indicator $\Delta G_a$ used for the main S1 results; the two indicators should not be conflated. A further pre-existing five-emitter calculation was available for the right-angled reference geometry only, with point sources at (−5, −13, 0.3), (−5, −9, 0.3), (−5, −5, 0.3), (−5, −1, 0.3), and (−5, 3, 0.3) m. This limited additional configuration demonstrates the importance of concurrent source positions but cannot verify a five-geometry ranking under simultaneous traffic sources.

### *3.3. Calculations and Comparative Indicators*

Simulations were performed in CATT-Acoustic v9.1e (build 1.02) using image-source and ray-tracing methods with edge diffraction enabled (mode "d"). Identical calculation settings were applied to all five corner configurations: 497,062 rays/cones, a 5000 ms impulse-response length, an air temperature of 20 °C, and 50% relative humidity. The acoustic properties of the road, sidewalk, and façade surfaces remained unchanged across the variants, with the surface scattering coefficient set to 0.10. Octave-band sound-strength values G(f) and impulse responses were obtained from the simulation reports and the TUCT module. The calculations covered six octave bands with centre frequencies ranging from 125 to 4000 Hz.

The principal comparative measure was the broadband A-weighted sound-strength indicator ($G_a$), expressed in decibels. It was calculated by energetically combining the octave-band sound-strength values G(f), taking into account the source spectrum and the corresponding A-weighting adjustments. The source-spectrum values were identical for all geometric variants, as described in Section 3.2. The A-weighting adjustments applied to the octave bands centred at 125, 250, 500, 1000, 2000, and 4000 Hz were −16.1, −8.6, −3.2, 0.0, +1.2, and +1.0 dB, respectively. The broadband indicator was obtained by weighting the sound-strength contribution of each frequency band according to its share in the A-

weighted source energy and combining these contributions on an energetic rather than arithmetic basis.

For each receiver position, the influence of corner geometry was expressed as the difference in $G_a$ between the modified configuration and the right-angled reference corner. Positive differences indicate an increase in the calculated indicator relative to the reference geometry, whereas negative differences indicate a decrease. The indicator describes relative changes in sound propagation under the adopted modelling conditions and should not be equated with the absolute equivalent A-weighted sound pressure level ($L_a$,eq) or with perceived loudness.

Three receiver positions were considered to examine differences in the sound field associated with distance from the façade and receiver height. The results were used to compare the acoustic effects of corner geometry within pedestrian space and at first-floor level. Particular attention was given to the receiver located along the sidewalk centreline (R2), which served as the principal reference point for comparing the energetic effects of the investigated corner modifications.

The calculations were used for comparative inference only; no site-specific field calibration or independent numerical convergence study with different ray counts was performed. Changes of approximately 0.5–1 dB were therefore not considered sufficient, on their own, for strong design recommendations. The modeled edge-diffraction and facade-scattering representations are approximations, and the findings depend on the fixed street geometry, materials, source spectra, and receiver definitions. A broader validation would require independent calculations or measurements across source trajectories, traffic conditions, and street aspect ratios.

### *3.4. Auralization and Listening Experiment*

Auralizations were generated using impulse responses for the S1 → R2 configuration. The common input was a segment of the monophonic car-pass-by recording "Vehicle_Car_Passby_Exterior_Mono.wav" (Nox_Sound, Freesound recording 522222, published in 2020 under CC0) [19]. The first 10.000 s were used, with brief fade-ins and fade-outs at the boundaries. Each variant was produced by convolving the same input x(t) with the impulse response h(t) corresponding to its geometry: $y(t) = x(t) * h(t)$. After convolution, all signals received the same +25 dB gain without variant-specific loudness normalization. The resulting files were 10.923 s long, in stereo WAV format at 48 kHz and 32-bit resolution. Although the input contained the temporal variation of a passing vehicle, the impulse response represented a fixed source–receiver configuration; actual source movement through space was not modeled.

Forty adults (24 women and 16 men; mean age 40.5 years, standard deviation 14.0 years; age range 18–64 years) participated in individual listening sessions. All participants reported normal hearing and no infection or auditory fatigue during the previous 24 h. These screening responses were self-reported, and no audiometric examination was performed. Participants were informed about the study and gave written consent before participation. Age and sex were summarized descriptively; no demographic subgroup comparisons were conducted. Each participant evaluated 11 stimulus pairs for relative loudness, annoyance, perceived shielding/muffling, and directness/reduced reverberance. Sessions were held in a quiet room using DT 770 Pro headphones (beyerdynamic GmbH & Co. KG, Heilbronn, Germany) and an Edirol UA-25 audio interface (Roland Corporation, Hamamatsu, Japan).Four versions of pair order and A/B assignment were used. Instructions and a practice trial preceded the approximately 20–25 min session, and a pair could be replayed once. Playback settings were identical across trials, but output was not calibrated to a known physical dB SPL at the ear; visual urban context was not presented.

Therefore, responses represent directional comparisons of synthesized recordings rather than absolute loudness, community annoyance, or in situ soundscape quality.

For each pair and criterion, the response options were A, B, 'equal', and 'difficult to judge'. No 'difficult to judge' responses occurred in the analyzed data matrix; 'equal' responses were excluded from tests of directional preference. A two-sided exact binomial test (null hypothesis $p = 0.5$), 95% Clopper–Pearson confidence intervals [20], and Holm's sequential multiple-testing correction [21] across the 11 pairwise comparisons were used separately for each criterion ($\alpha = 0.05$). Four comparisons with the reference variant are reported in the Results section..

The same complete WAV stimuli were also compared in one-third-octave bands (125–4000 Hz) using consistent analysis settings. The resulting values express band-level differences in digital stimulus energy relative to the right-angled reference, in decibels. Because the playback chain was not calibrated to an absolute sound-pressure reference, these values must not be read as physical outdoor sound-level changes, nor as independent proof of the psychoacoustic cause of a preference. The spectral differences most relevant to the observed discrepancy between the energetic indicator and listener judgments are discussed together with the listening results in Section 4.2. The complete set of one-third-octave results for all four modified corner geometries is provided in Table S1 (Supplementary Materials).

### *3.5. Selection and Assessment of the Poznań Case Studies*

Three intersections in Poznań were selected for the analysis: Woźna–Ślusarska, Jackowskiego–Wawrzyniaka, and Kwiatowa–Łąkowa (Table 1). Each represents a different design challenge. At the Woźna–Ślusarska intersection, a pedestrian zone adjoins a street carrying vehicular traffic. At the Jackowskiego–Wawrzyniaka intersection, the spatial character is shaped by a raised intersection, traffic-calming measures, an expanded pedestrian area, and the rounded corner of a historic tenement building. At the Kwiatowa–Łąkowa intersection, a distinctive feature is the presence of bay windows projecting beyond the main planes of the corner façades.

**Table 1.** Characteristics of the three locations and the design issues considered in the analysis.

| Case | Documented Context | Corner Form and Street Cross-Section | Design Issue |
|---|---|---|---|
| Woźna–Ślusarska | Woźna: 9–10 m or 11–15 m street sections; a transition from a pedestrianized area to a one-way vehicular street [22]. | Continuous historic street frontages; assessment in relation to the right-angled and chamfered corner types. | Shielding a stopping place versus opening the connection between adjoining streets. |
| Jackowskiego–Wawrzyniaka | Raised intersection, 30 km/h zone, seating and planting; 8 m carriageway including parking bays [23,24]. | Tenement building at 21 Jackowskiego/32 Wawrzyniaka with a rounded corner and curved balconies [25]; wider street cross-section. | Assessing a rounded corner where pedestrians move or stop briefly on a traffic-calmed street. |
| Kwiatowa–Łąkowa | Tenement buildings with projecting bays at 8 Kwiatowa/15 Łąkowa and 7 Kwiatowa/16 Łąkowa [26]. | Articulated facades with elements projecting over pedestrian space; typological analogy with the projecting-bay variant. | Locating areas near entrances and considering the effect of projecting facade elements. |

The urban-context material comprised street descriptions and survey drawings issued by Poznań's Municipal Road Authority for Woźna [22], redevelopment documentation for Jackowskiego and its intersection with Wawrzyniaka [23,24], and publicly available photographs and descriptions of the corner buildings at 21 Jackowskiego Street/32 Wawrzyniaka Street [25] and 8 Kwiatowa Street/15 Łąkowa Street [26]. The Woźna documentation gives widths of 9–10 m or 11–15 m for different street sections [22]. At

Jackowskiego, the carriageway was reported to be 8 m wide, including parking bays, with sidewalks approximately 2.8–3.3 m wide. A green strip also separates pedestrian and vehicular areas on the northern side [24]. Carriageway width and the distance between opposite street frontages were treated as distinct geometric characteristics when comparing these locations with the reference model.

The case-study assessment considered intersection type, documented continuity of street frontage, corner geometry, sidewalk use, and the likely relation between source directions and receiver positions. Pedestrian movement and brief stopping or staying were distinguished as prospective design functions, not field-observed exposure categories. The three Poznań examples are typological illustrations based on available urban documentation; they provide neither field validation of the CATT-Acoustic model nor evidence that one form has superior acoustics at those locations. No site-specific acoustic measurements, traffic simulations, or listening surveys were performed for the three intersections. Transferring model magnitudes would require the actual site geometry, materials, source directions, traffic, and background conditions.

The cases were compared in the following sequence: (1) how the space is used; (2) possible directions of sound arrival; (3) corner geometry; (4) street width and the ratio between building height and street cross-section; and (5) the energetic and perceptual findings for the corresponding modeled variant. This sequence helps identify functions that a particular form may support and the parameters relevant to an architectural decision.

## 4. Results

### *4.1. Changes in the Energetic Indicator*

The investigated source scenario produced marked differences among the five corner forms. For the reference geometry, $G_a$ at the sidewalk receiver was −0.12 dB. The largest increase occurred for the chamfer (+6.72 dB), followed by the projecting bay (+3.03 dB), rounded corner (+2.36 dB), and ground-floor recess (+2.15 dB). Thus, modifying the corner geometry changed the amount of sound energy reaching the area screened by the building edge, with the magnitude of the change depending on the type of intervention (Figure 2).

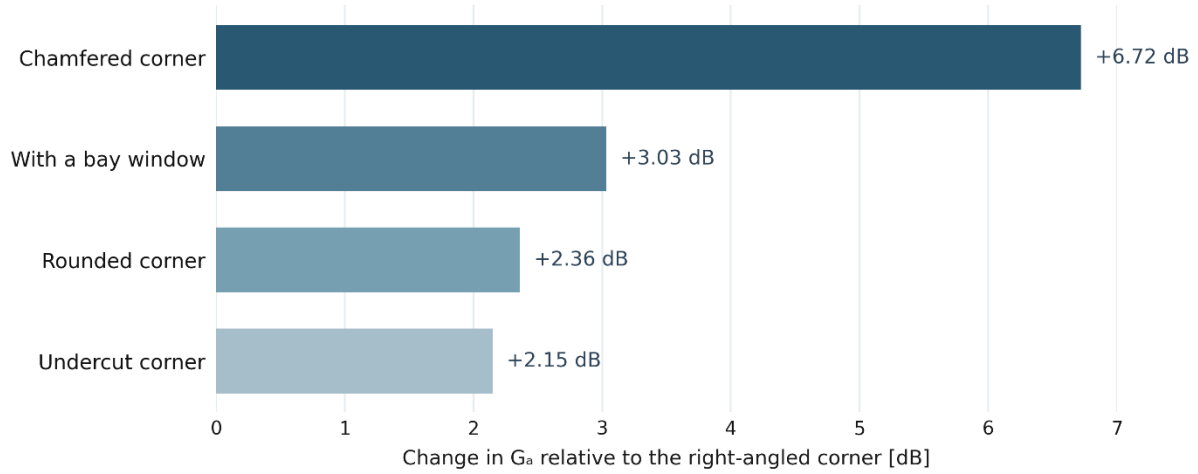



**Figure 2.** Changes in $\Delta G_a$ at the sidewalk receiver for four corner modifications relative to the right-angled reference configuration.

The corresponding values for all three receiver positions are presented in Table 2.

**Table 2.** $G_a$ at three receiver positions for the five corner forms. $\Delta G_a$ is the change at the sidewalk receiver relative to the right-angled reference corner.

| Corner Form | Receiver 1 [dB] | Receiver 2 [dB] | Receiver 3 [dB] | $\Delta G_a$ at Receiver 2 [dB] | Range Across Receivers 1–3 [dB] |
|---|---|---|---|---|---|
| Right-angled corner | −1.17 | −0.12 | −2.30 | 0.00 | 2.18 |
| Chamfered corner (5 m) | 6.13 | 6.60 | 4.70 | +6.72 | 1.90 |
| Rounded corner (3 m) | −0.68 | 2.24 | −1.81 | +2.36 | 4.05 |
| Recessed ground floor | 6.26 | 2.03 | −2.31 | +2.15 | 8.57 |
| Corner with projecting bay | 0.26 | 2.91 | 0.06 | +3.03 | 2.85 |

Variation across receiver positions was equally relevant. For the recessed ground-floor variant, $G_a$ was 6.26 dB near the facade at pedestrian height, 2.03 dB at the second receiver on the sidewalk, and −2.31 dB near the facade at first-floor height. The range across the three positions was 8.57 dB. For the chamfered corner, the corresponding values were 6.13, 6.60, and 4.70 dB, with a range of only 1.90 dB. These results show that the position of a short-stay area relative to a facade may matter considerably even when building geometry remains unchanged.

In functional terms, the comparison between the chamfer and ground-floor recess is especially informative. Both configurations increased energy at the sidewalk receiver relative to the reference, but the recess produced substantially greater variation between the near-facade receivers at pedestrian and first-floor heights. This suggests that pedestrian routes, entrances, and short-stay locations should be considered separately during design.

A source-position comparison using already available simulation outputs shows that the corner ranking is contingent on the sound-source configuration. Table 3 reports ΔSPL(A) at R2 relative to the right-angled reference, calculated separately for S0 and S1. In particular, the 5 m chamfer changed from −2.29 dB in S0 to +6.76 dB in S1, reversing the direction of the modeled difference. By contrast, rounding changed by +0.20 dB and +2.37 dB in the respective scenarios. These results provide a limited sensitivity check and do not imply general stability across arbitrary source trajectories or changing traffic intensities. The magnitude of the additional five-emitter result for the right-angled reference also illustrates the influence of source arrangement: modeled SPL(A) at R2 was 65.09 dB for S1 and 75.48 dB for the five-emitter configuration. Source count and position both changed, so these absolute scenario values cannot be used to rank the modified corners.

**Table 3.** Sensitivity of modeled ΔSPL(A) to source position at sidewalk receiver R2. Values represent differences relative to the right-angled reference geometry within each source scenario (S0 = (−5, 5, 0.3) m; S1 = (−5, −5, 0.3) m).

| Corner Geometry | ΔSPL(A), S0 [dB] | ΔSPL(A), S1 [dB] | S1 Minus S0 [dB] |
|---|---|---|---|
| Right-angled reference | 0.00 | 0.00 | 0.00 |
| Chamfer, 5 m | −2.29 | +6.76 | +9.05 |
| Rounded, 3 m | +0.20 | +2.37 | +2.17 |
| Recessed ground floor | −0.64 | +2.17 | +2.81 |
| Projecting bay | +0.10 | +3.02 | +2.92 |

### *4.2. Listening Results and Discrepancies Between Perception and Energy*

The listening results complement the energetic comparison. In the reference-versus-chamfer pair, all participants judged the chamfered variant to be louder and more annoying. The ground-floor recess was evaluated similarly. By contrast, preferences regarding greater perceived shielding in the reference-versus-recess pair were equally divided. This

indicates that a spatially recessed ground floor can yield an auditory impression different from what its appearance alone might suggest.

The largest mismatch between a broadband energetic difference and listener judgments occurred for the rounded and projecting-bay conditions. At R2, the rounded corner increased $G_a$ by 2.36 dB relative to the right-angled reference, although 38 of 40 listeners judged the reference auralization louder and all 40 judged it more annoying. The projecting-bay case increased $G_a$ by 3.03 dB, while all 40 listeners judged the reference louder and 36 found it more annoying. A further analysis of the same audio stimuli found non-uniform one-third-octave differences (Figure 3; Supplementary Table S1). At 315 Hz the rounded and projecting-bay stimuli exceeded the reference by 18.37 and 15.71 dB, respectively, whereas at 630 Hz the rounded stimulus was 19.94 dB below the reference and at 1250 Hz the bay stimulus was 25.92 dB below it. These are local contrasts in a spectrum, not changes in overall calibrated exposure. Their presence indicates that equal broadband descriptors need not imply identical spectral composition; it does not establish which spectral or temporal features caused the listeners' choices.

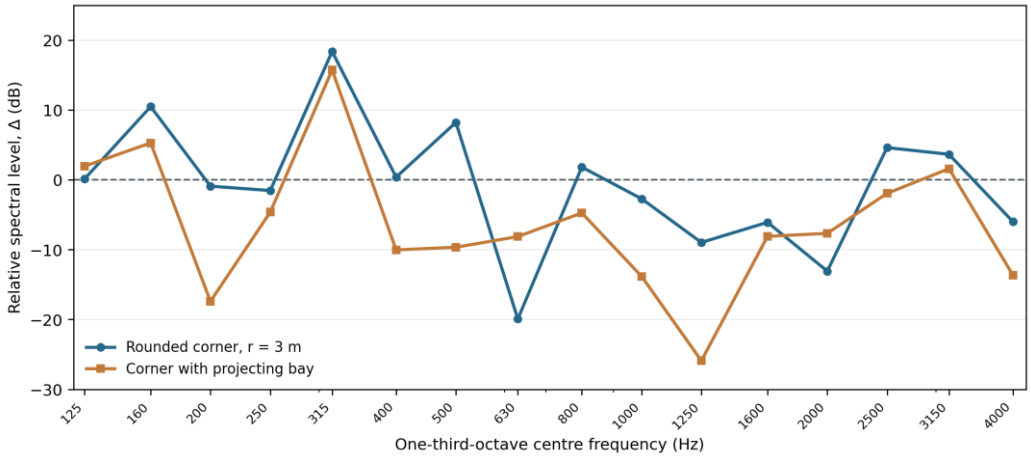



**Figure 3.** One-third-octave differences in the digital auralization stimuli relative to the right-angled reference (S1 → R2), measured across the complete signals using consistent processing settings. The values are not calibrated outdoor sound-pressure levels; they do not identify a causal psychoacoustic mechanism.

The four comparisons involving the right-angled reference corner were selected from the 11 pairs evaluated in the full listening experiment. All four comparisons of perceived loudness and annoyance remained statistically significant after applying the Holm correction ($p_{holm} < 0.0001$). For perceived acoustic shielding, statistically significant differences were found for the chamfered corner ($p_{holm} = 0.0005$), the rounded corner, and the corner with a projecting bay window ($p_{holm} < 0.0001$ for both). In contrast, the corner with a recessed ground floor produced an equal distribution of responses (20 participants for each variant), indicating no directional preference ($p_{holm} = 1.0000$). Assessments of greater acoustic shielding refer to the participants' subjective auditory impressions rather than directly measured sound attenuation.

All four reference comparisons in Table 4 remained significant after Holm correction for the directional judgments of loudness and annoyance (adjusted $p < 0.0001$). For perceived shielding, the chamfer comparison yielded $p = 0.0005$, the rounded and projecting-bay comparisons yielded adjusted $p < 0.0001$, and the recess comparison yielded $p = 1.0000$. These tests concern directional preferences within a fixed presentation setup; they do not estimate calibrated loudness, annoyance in real streets, or population-representative effects.

**Table 4.** Results of four auralization comparisons against the right-angled reference corner: number of selections for the indicated variant among 40 decisive responses (N = 40). These pairs are a subset of the 11 comparisons in the full experiment.

| Comparison | Stimulus Judged Louder (*n*/40) | Stimulus Judged More Annoying (*n*/40) | Stimulus Judged More Shielded (*n*/40) |
|---|---|---|---|
| Reference vs. chamfer | Chamfer: 40/40 | Chamfer: 40/40 | Right-angled: 32/40 |
| Reference vs. recess | Recess: 40/40 | Recess: 40/40 | 20/40 each (no preference) |
| Reference vs. rounded | Right-angled: 38/40 | Right-angled: 40/40 | Rounded: 40/40 |
| Reference vs. projecting bay | Right-angled: 40/40 | Right-angled: 36/40 | Projecting bay: 34/40 |

### *4.3. Functional Interpretation: From Modeled Differences to Design Decisions*

The function of a proposed pedestrian space provides a starting point, but not a validated acoustic threshold, for evaluating corner design. Where waiting, conversation, or rest is intended, shielding from a dominant cross-street sound source is a reasonable priority to investigate. In the tested S1 configuration the reference corner had a lower $G_a$ than the chamfered alternative. This makes retention of a defined building edge a hypothesis worth checking for shelter-oriented designs, not a universally effective rule.

Where pedestrian flows are intensive, chamfering may open up a corner, create additional room for movement, or strengthen the spatial connection between two streets. These benefits arise from urban form, but the acoustic comparison indicates a trade-off: more energy reached the screened part of the sidewalk, and the chamfered auralization was judged more annoying. The design assessment must therefore weigh movement needs against the role of nearby stopping places.

Rounded corners and projecting bays add another consideration: how sound is perceived. Their auralizations were rated less loud and less annoying than the reference, although $G_a$ was higher at receiver R2. This underscores the value of perceptual evidence as an additional design input, particularly in pedestrian environments. At the same time, the findings require a cautious distinction: listening judgments of a stimulus and energetic exposure metrics describe different aspects of the acoustic environment.

In the simulated recess, $G_a$ varied by 8.57 dB across R1–R3: 6.26 dB at the near-facade pedestrian receiver R1, 2.03 dB at the sidewalk-centre receiver R2, and −2.31 dB at the first-floor receiver R3. The differences are not a direct map of the entire recessed space; R3 is above the ground-floor recess. Nevertheless, the result shows why a bench, entrance queue, and passing route should not be represented by one receiver position. Recess depth (3 m), longitudinal extent (6 m), and height (3.5 m) were fixed, so the present dataset cannot identify optimal recess proportions.

Corner selection can consequently be guided by three questions: Where do people move or stop? From which direction does the dominant sound arrive? And is the quality of the space primarily determined by energetic shielding, or also by the auditory character of the stimulus? These questions provide the basis for considering the Poznań examples below (Table 5).

**Table 5.** Implications of the acoustic findings for selecting corner geometry under different uses of urban space.

| Use of Space | Corner Form | Research Finding | Design Implication |
|---|---|---|---|
| Brief stops or staying in a shielded zone | Right-angled | In the tested configuration, the right-angled corner limited sound-energy transmission from the cross street more effectively than the chamfer. | Retaining a distinct building edge may benefit spaces where shielding from sound is a priority. |

| | | | |
|---|---|---|---|
| Pedestrian movement between adjoining streets | Chamfered | Chamfering increased $G_a$ at the sidewalk receiver by 6.72 dB relative to the right-angled corner and was judged louder and more annoying in the listening test. | Opening the corner may improve pedestrian passage and connections between streets, but the accompanying increase in acoustic exposure must be considered. |
| Movement and brief stops near a corner | Rounded | $G_a$ at the sidewalk receiver increased by 2.36 dB, while the rounded auralization was judged less loud and less annoying than the reference. | Both energetic change and auditory perception should inform assessment; these criteria may lead to different evaluations. |
| Waiting or walking beneath a recessed ground floor | Recessed | The $G_a$ range across receivers 1–3 was large (8.57 dB), and the auralization was judged more annoying than the right-angled reference. | Receiver location, the depth of the recess, and the height of the setback require particular attention. |
| Movement or staying adjacent to a projecting bay | Projecting bay | $G_a$ at the sidewalk receiver increased by 3.03 dB, although the bay auralization was rated less loud and less annoying than the reference. | When locating places to stay, account for the amount of projection, its height, and its position relative to users. |

The reported $G_a$ results apply to the tested configuration in which the corner screens the source. Perceptual ratings come from a controlled comparative listening experiment.

### *4.4. Application Case Study I: Woźna–Ślusarska*

The intersection of Woźna and Ślusarska combines two modes of street use. Near the Old Market Square, Woźna is pedestrian-oriented; farther along, it accommodates one-way vehicle traffic. Municipal documentation reports street sections 9–10 m and 11–15 m wide [22]. Continuous historic frontages and well-defined building edges make this an appropriate example for examining the relationship between shielding from a cross street and opening the corner to facilitate pedestrian movement.

The first design situation concerns a brief stop on the quieter side of the street. The shielding provided by the building mass is then relevant. In the numerical comparison, the right-angled corner produced a lower $G_a$ at the sidewalk receiver than the chamfered corner, whose auralization was judged louder and more annoying. Preserving a compact corner is therefore worth considering where the quality of short stays takes priority.

The second situation prioritizes pedestrian passage and the connection between adjoining streets. Chamfering can enlarge the space at the intersection edge and change the visibility of the adjoining street. At the same time, the modeled results indicate the acoustic consequences of this opening for receivers in the screened zone. Comparing the two forms thus highlights two competing priorities that should be considered when the building footprint is being designed.

The Woźna example suggests that the key issue is not the intrinsic appeal of a chamfer or sharp corner, but rather how the adjacent sidewalk is used. Shielding becomes more important at a stopping place, while a pedestrian route calls for clear spatial connections between streets. Acoustic analysis provides one criterion for balancing these objectives.

### *4.5. Application Case Study II: Jackowskiego–Wawrzyniaka*

The intersection of Jackowskiego and Wawrzyniaka in the Jeżyce district combines pedestrian movement, local vehicle traffic, and areas for short stays. The redevelopment of Jackowskiego included a raised intersection, a 30 km/h speed limit, reorganized parking, new sidewalks, planting, and seating [23]. Project documentation specifies an 8 m carriageway including parking lanes and sidewalks approximately 2.8–3.3 m wide. On the northern side, a planted strip also separates the sidewalk from the carriageway [24].

The resulting street gives pedestrian functions greater prominence while accommodating slower local traffic.

At 21 Jackowskiego Street/32 Wawrzyniaka Street, on the northern frontage, there is a corner tenement building documented in a local architectural photographic survey [25]. The rounded portion of the corner, as interpreted from architectural documentation, provides a typological point of reference for the rounded-corner variant. The actual building is taller and geometrically more complex than the numerical models.

In the model, rounding increased $G_a$ at the sidewalk receiver by 2.36 dB relative to the right-angled corner. At the same time, 95% of participants judged the right-angled auralization to be louder, and 100% judged it more annoying than the rounded variant. Both considerations are relevant at Jackowskiego: pedestrians cross the raised intersection, but may also stop near entrances, planting, or benches. The example illustrates how rounding can be considered in terms of both the legibility of building form and the perception of sound.

The proportions of the street cross-section are particularly pertinent here. Jackowskiego comprises an 8 m carriageway (including parking lanes), sidewalks, and a local planted strip. The overall street-space width is therefore greater than that of the carriageway alone. Architectural interpretation must distinguish between the geometric corner type, which motivates comparison with the rounded model, and the scale of the surrounding urban space, which determines the context in which model results might be applied. Short-stay locations call for attention to both shielding and perceived annoyance, while crossing routes also require a coherent connection between the streets.

### *4.6. Application Case Study III: Kwiatowa–Łąkowa*

The intersection of Kwiatowa and Łąkowa exhibits varied corner-facade detailing. The building at 8 Kwiatowa Street/15 Łąkowa Street has a rounded projecting bay; another, at 7 Kwiatowa Street/16 Łąkowa Street, has several bays, including an element that connects the two facades [26]. Unlike a fully rounded corner extending from ground level, these forms alter the building mass primarily at selected heights. They therefore provide examples for considering the findings for a corner with a projecting bay.

The projecting-bay model produced an increase in $G_a$ of 3.03 dB at the sidewalk receiver relative to the reference, although the associated auralization was rated less loud and less annoying. At Kwiatowa, the relationship between the projected building volume and the sidewalk area near entrances is of particular interest. Users occupy space below elements that may alter sound reflections and the local character of a stimulus. This highlights the importance of the receiver's position relative to the facade surfaces in a functional assessment.

When locating a bench, outdoor cafe seating, or a larger waiting area, the height and projection of the bay and its relationship to other reflecting surfaces become relevant. These features can be identified in plan, section, and elevation before decisions are made about street furnishings. The model findings therefore provide a rationale for considering the three-dimensional articulation of the facade when determining how the sidewalk should be used.

Kwiatowa–Łąkowa complements the preceding cases by shifting attention from the corner edge itself to elements that extend over pedestrian space. It illustrates why the facade geometry above head height may also matter when choosing locations for brief stays.

### *4.7. Comparative Synthesis of the Case Studies*

The three examples approach building-corner selection from different perspectives. Woźna–Ślusarska illustrates the choice between retaining shielding and opening the spatial connection between streets. Jackowskiego–Wawrzyniaka highlights rounded

geometry in an area used for pedestrian movement and short stays on a traffic-calmed street. Kwiatowa–Łąkowa introduces projecting bays and the position of users relative to elevated facade surfaces. Each case therefore represents a different relationship between building form and the use of its immediate surroundings.

Taken together, these cases clarify two connected design decisions. The first concerns the way space is used—movement versus stopping or staying—and users' positions relative to the corner, entrances, and facade elements. The second concerns selecting geometry in view of its known energetic and perceptual characteristics. Examining the street cross-section and building mass allows model findings to be related cautiously to the features of a specific location.

Table 6 summarizes how the findings from the acoustic simulations and listening experiment can inform corner-geometry selection in three urban locations in Poznań, taking into account the function of each space and the resulting design implications.

**Table 6.** Poznań examples illustrating how model findings can inform corner-geometry selection. $\Delta G_a$ values concern a source located on the screened side of the corner.

| Location | Function of Place | Design Consideration | Model Finding | Design Implication |
|---|---|---|---|---|
| Woźna–Ślusarska | Brief stop | Preserve shielding from a distinct corner edge | Chamfer: +6.72 dB at the sidewalk receiver relative to the right-angled corner | Prioritize a quieter area for staying. |
| Woźna–Ślusarska | Movement between streets | Consider opening the corner | Chamfer was judged louder and more annoying | Balance spatial openness against acoustic exposure. |
| Jackowskiego–Wawrzyniaka | Pedestrian movement around a rounded corner | Use rounded geometry as a comparison case | Rounding: +2.36 dB at the sidewalk receiver | Consider both spatial legibility and sound energy. |
| Jackowskiego–Wawrzyniaka | Brief waiting | Include perceptual evaluation | The reference was judged louder than the rounded variant in 95% of responses | Consider annoyance at stopping places. |
| Kwiatowa–Łąkowa | Walking beside the facade | Consider projecting building volumes | Projecting bay: +3.03 dB at the sidewalk receiver | Account for reflecting surfaces and user positions. |
| Kwiatowa–Łąkowa | Waiting/sitting | Locate seating in relation to the bay | The bay received more favorable listening ratings than the reference | Consider both horizontal and vertical facade articulation. |

## 5. Discussion

### *5.1. Why Is There No Universal Ranking of Corner Geometries?*

The results show that the evaluation of a corner depends on the criterion used. A large chamfer increased sound energy and perceived annoyance within the screened zone. Yet such a form may be selected for spatial reasons, for example to accommodate pedestrian passage or connect two streets. Evaluating a variant should therefore consider both the intended use of the place and the resulting change in acoustic conditions.

These findings are consistent with the broader observation that the shape of street cross-sections and facades can alter pedestrians' acoustic exposure [4,5]. The present experiment, however, isolates the effect of a local modification to a single building corner. Combining simulation results with listener evaluations extends the analysis beyond a single energetic indicator and reflects the distinction between measured sound fields and perceived acoustic environments [1,2,11]. Nevertheless, laboratory listening does not constitute a complete soundscape assessment as defined in ISO 12913 [12,13].

The rounded and projecting-bay variants show why acoustic energy and perceived judgments cannot be ranked using a single broadband indicator. Although both raised $G_a$ at R2 for S1, their auralizations were judged less loud and less annoying than the right-angled reference. In the complete set of eleven listening pairs, the direction of $G_a$ change agreed with the louder-stimulus judgment in six cases. The supplementary one-third-octave results show strong positive and negative band differences within both stimuli (Figure 3; Supplementary Table S1). Possible contributors include spectral balance, the distribution of early and late energy, and features of the convolved vehicle transient. None was experimentally isolated or statistically linked to individual responses, so a specific psychoacoustic explanation cannot be established from these data. The result is an empirical disagreement between descriptors under a controlled stimulus set, not evidence that increased $G_a$ generally produces lower perceived loudness.

Source position is an especially important boundary condition. In the supplementary model comparisons at R2, the 5 m chamfer reduced ΔSPL(A) relative to the reference by 2.29 dB under S0 but raised it by 6.76 dB under S1 (Table 3). The sign reversal shows that a geometry ranking obtained for a screened source cannot be transferred to traffic arriving from a different direction. Additional changes in street height-to-width ratio, moving vehicles, several simultaneous sources, background conditions, or surface absorption may also alter differences and preferences, but cross-geometry reversals under these other conditions have not been quantified here.

### *5.2. The Role of Function and Duration of Use*

For the present design interpretation, movement denotes a sidewalk segment programmed primarily for pedestrian passage or turning, and short stay denotes a place designed to accommodate waiting, sitting, or conversation. These are operational land-use distinctions rather than measured behavioral classes or fixed thresholds of residence time. Movement-oriented designs must preserve the accessible pedestrian route, clear sightlines, and safety; acoustic comparisons then reveal potential trade-offs. Short-stay designs may place greater emphasis on shelter from intrusive cross-street sound and on the character of sounds reaching the user. However, the listening ratings do not establish acceptable exposure limits or the actual duration of use at any proposed site.

It is therefore meaningful to describe a location as ‘more favorable’ only after specifying the criterion: reducing sound energy, lowering perceived annoyance, or maintaining acoustic contact with the adjoining street. Corner selection remains a multicriteria decision. Accessibility, visibility, safety, and conservation of historic building form may also affect the final design, even when a configuration performs distinctly better in an acoustic comparison.

The Poznań examples illustrate the relevance of contextual use. At Woźna, shielding in pedestrian areas must be balanced against connections between streets. At Jackowskiego–Wawrzyniaka, a rounded building corner coincides with a raised intersection, planting, and places for short stays. At Kwiatowa–Łąkowa, attention shifts to pedestrian space beneath projecting bays. The same set of modeling results can inform questions in all three locations, but each raises a different design priority.

### *5.3. Scope and Limits of Applying Model Results*

This work provides controlled estimates of relative model differences and laboratory judgments of corresponding auralizations; its three Poznań examples illustrate a way to structure design questions, not effectiveness demonstrated in the field. The $\Delta G_a$ results of Table 2 apply only to S1, one street cross-section (H/W = 1.2), fixed surfaces, and the defined receivers. A second stationary source position changes even the sign of the chamfer

effect in ΔSPL(A) (Table 3). Thus neither the absolute changes nor the rank ordering should be transferred to real intersections without additional site-specific analysis.

The contextual assessment draws on documented characteristics of the streets and buildings: the historic street frontage at Woźna, the rounded building corner at Jackowskiego, and projecting bays at Kwiatowa. Differences in scale and facade articulation indicate which features of the models may matter most for an architectural decision. Table 2 quantifies changes obtained under controlled model conditions; the urban descriptions provide a basis for interpreting their potential design implications.

The geometrical-acoustics modeling accounted for reflections and approximate diffraction over the 125–4000 Hz octave bands. Interpretation emphasizes the larger energetic differences, particularly the chamfered versus reference corner, and considers these alongside the listening judgments. Using the same calculation settings and indicator definition across all variants facilitates an assessment of the effects associated with corner geometry itself.

The 40 adult volunteers (24 women, 16 men; ages 18–64 years) compared headphone auralizations without accompanying visual context. Although age and sex were recorded, this sample does not establish the representativeness of the responses for a wider pedestrian population, and no demographic subgroup tests were conducted. Playback was not calibrated to an absolute dB SPL at the ear, and hearing status was assessed by self-report without objective audiometric screening. The nominal pass-by recording was convolved with static impulse responses rather than a time-varying moving-source propagation model. Consequently, the judgments describe relative differences between the specific files at constant playback settings, not absolute perceived loudness, real-world exposure, or a complete ISO 12913 soundscape appraisal. The simplified geometrical-acoustics treatment of diffraction also restricts the certainty of detailed spectral and temporal predictions. Independent in situ observations and scenario-specific modeling will be needed before these comparisons can support final urban design decisions.

### *5.4. A Procedure for Design Decision-Making*

We propose a four-stage sequence for preliminary, sustainability-oriented corner design:

(1) Identify the intended activity and the required accessible pedestrian route;
(2) Specify competing objectives, such as sound shielding at a waiting point, passage continuity, visibility, and the desired auditory character;
(3) Consider comparative energetic and listening-based evidence under the actual dominant source directions;
(4) Test candidate geometries in a site-specific model, with appropriate pedestrian and safety checks, before selecting a solution (Figure 4).

The sequence makes the decision criteria explicit, but it is not a calibrated optimization model or a predictive sustainability index.

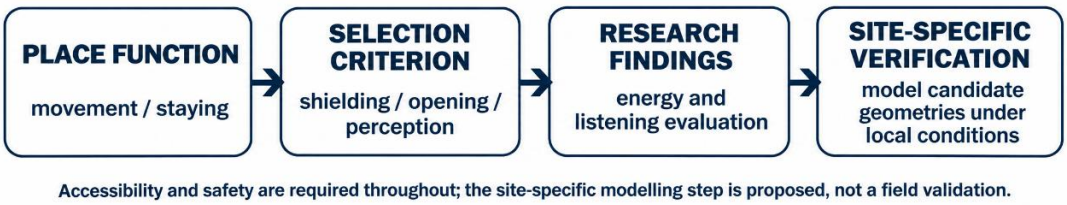



**Figure 4.** Stages in selecting building-corner geometry: from place function and the chosen evaluation criterion, through interpretation of acoustic and perceptual findings, to preliminary appraisal of the form within a specific urban context. Source: author's own illustration.

The sequence is applied as a non-compensatory screening process rather than a numerical weighted sum. Compliance with relevant pedestrian accessibility and safety requirements is assessed first; forms that fail these constraints are not justified by a favorable acoustic indicator. Among feasible forms, the priorities of stationary occupation and movement can then be compared with their acoustic trade-offs. No universal weights, minimum acceptable $\Delta G_a$, or annoyance thresholds are inferred from the present data, and no optimization or user-based validation of the decision sequence has been conducted. Its contribution beyond established soundscape frameworks is the explicit inclusion of local corner modifications, contrasting energetic/perceptual evidence, source-position dependence, and site-function constraints in a single auditable early-design procedure. Additional stakeholder and field studies would be needed to operationalize weighting.

## 6. Conclusions

1. Within the screened-source S1 configuration (W = 10 m, H = 12 m), the 5 m chamfer raised $G_a$ by 6.72 dB at sidewalk receiver R2 relative to the right-angled reference and was perceived as louder and more annoying in the paired auralization experiment. This result supports testing the preservation of a defined corner edge when shielding is a design objective, but does not establish its superiority for other source positions or street proportions.

2. In the same scenario, rounded and projecting-bay configurations increased $G_a$ yet received lower relative loudness and annoyance ratings than the right-angled reference. One-third-octave differences confirm that the listening stimuli also differed spectrally, but the causal contribution of spectral versus temporal cues was not tested.

3. The ground-floor recess produced the largest variation in $G_a$ among the three receiver positions. This highlights the importance of user location relative to a recessed ground floor and differences in receiver height. The three-dimensional arrangement of the building mass should be considered around entrances, recessed passages, and waiting areas.

4. For sustainability-oriented pedestrian design, the value of the analysis lies in identifying acoustic trade-offs at the time of choosing local geometry, alongside accessibility, safety, and the intended duration and nature of use. Neither measured sustainability improvements nor universal acoustic acceptability thresholds are claimed.

5. The Woźna–Ślusarska, Jackowskiego–Wawrzyniaka, and Kwiatowa–Łąkowa intersections illustrate how functional criteria can be posed for different local forms. No acoustic simulations, measurements, or perceptual tests at these three locations were performed, and they do not establish the effectiveness of any specific intervention.

6. The proposed four-stage procedure is a transparent preliminary deliberation framework, not a validated predictive or weighted decision model. The additional S0/S1 comparison demonstrates the sensitivity of the chamfer effect to source position. Final decisions require site-specific verification across relevant sound directions and levels, street proportions, and pedestrian requirements.

**Supplementary Materials:** The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su182211558/s1. Table S1, One-third-octave differences of listening stimuli; Table S2, Source-position sensitivity at sidewalk receiver R2.

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**Informed Consent Statement:** Written informed consent was obtained from all 40 participants before the listening experiment.

**Data Availability Statement:** The comparative data underlying the primary figures and tables are presented in the article and its Supplementary Materials. Additional simulation outputs and anonymized response data may be obtained from the corresponding author on reasonable request, subject to participants' consent, privacy protections, and applicable data-protection requirements. The original public-domain source audio is identified in Reference [19].

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