Soundscape Perception Indices (SPI)

A unified framework for defining context-dependent single value indices

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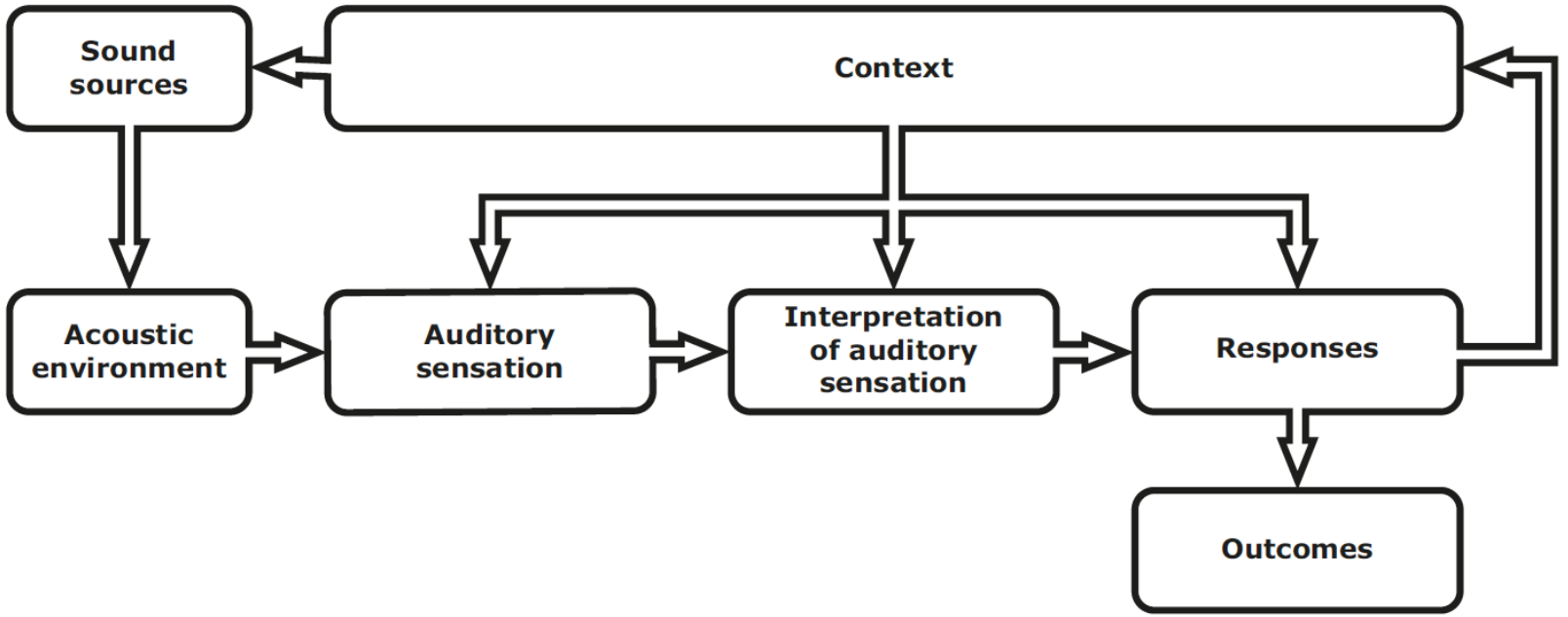
The Soundscape Approach

ISO 12913 Part 1:

The acoustic environment as perceived or experienced and/or understood by a person or people, in context



The Soundscape Approach

When applied to urban sound and specifically to noise pollution, the soundscape approach introduces three key considerations beyond traditional noise control:

1. Considering all aspects of the environment which may influence perception, **not just sound level and spectral content**

2. An increased and integrated consideration of the varying impacts which different sound sources have on perception

3. A consideration of **both the positive and negative** dimensions of soundscape perception.

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The Soundscape Approach

- Soundscape **descriptors** are measures of how people perceive the acoustic environment – e.g. perceptual attributes
- Soundscape **indicators** are measures used to predict the value of a soundscape descriptor – e.g. *LAeq, Loudness,* etc.
- Soundscape **Indices** are single value scales derived from either descriptors or indicators that allow for comparison across soundscapes.

Aletta, F., Kang, J., Axelsson, Ö. (2016, July). Soundscape descriptors and a conceptual framework for developing predictive soundscape models. *Landscape and Urban Planning.* 149:65-74.

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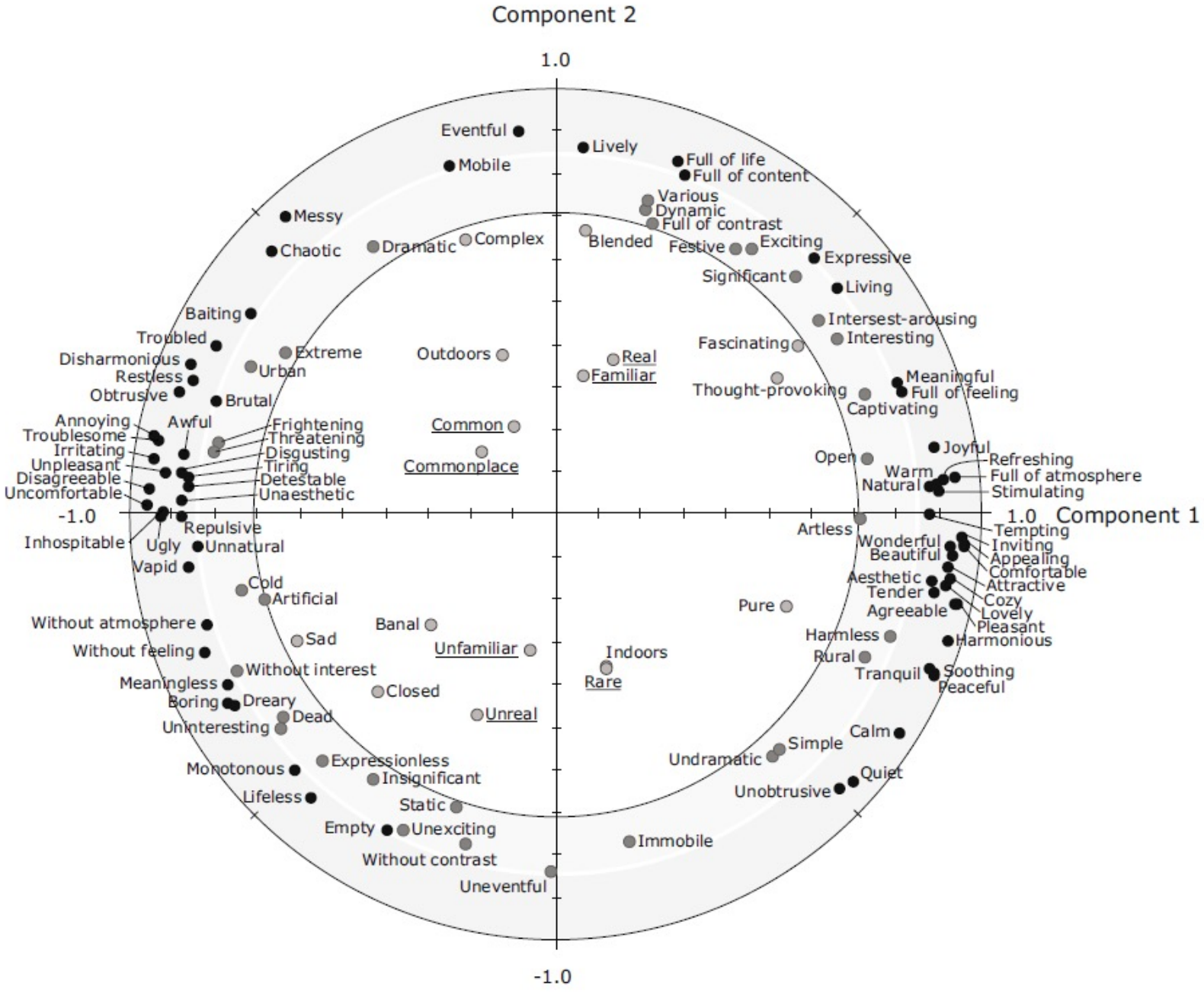
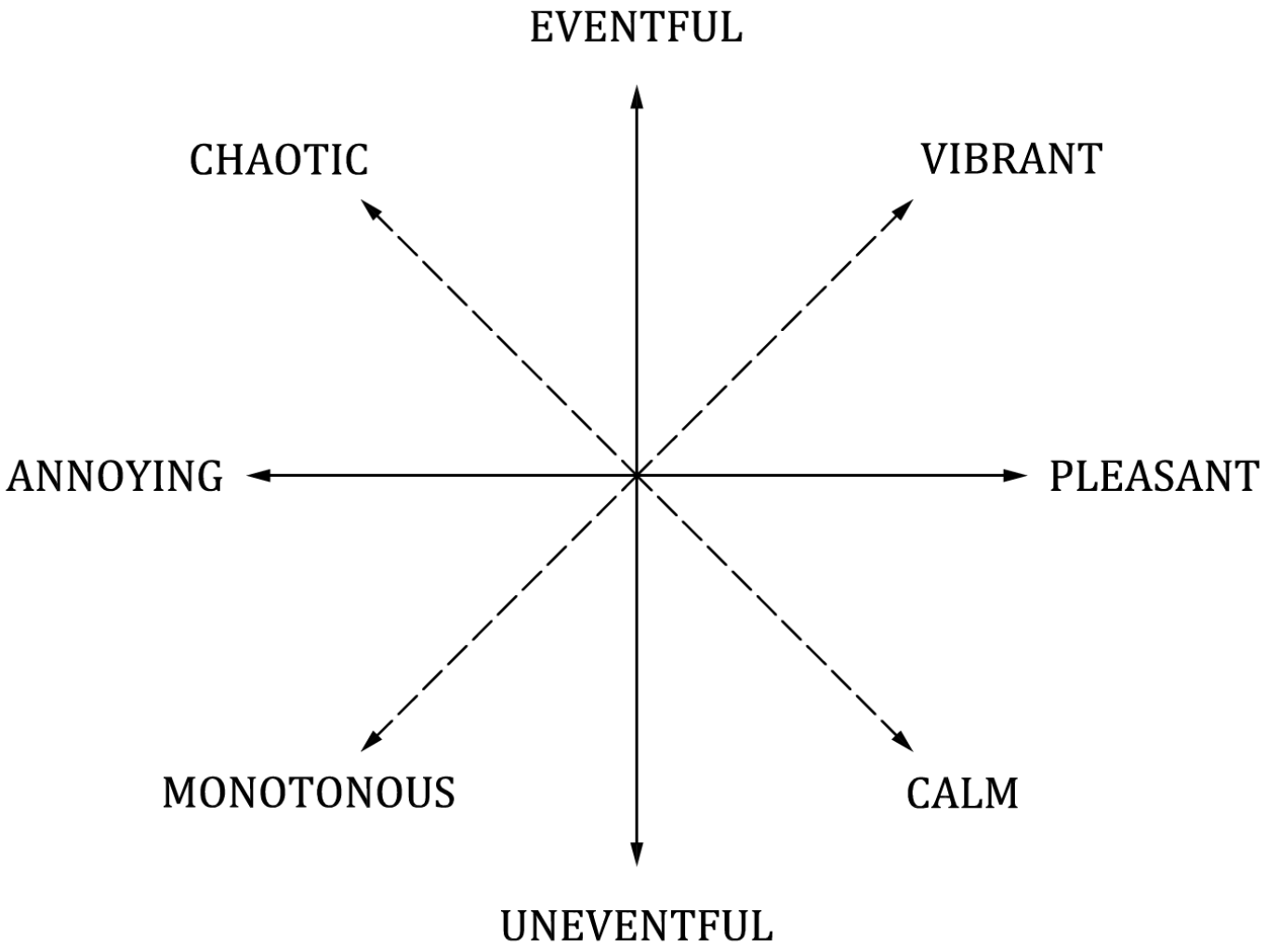
The Circumplex Model of Soundscape Perception



Axelsson, O., Nilsson, M.E., & Berglund, B. (2010). A principal components model of soundscape perception. *The Journal of the Acoustical Society of America, 128*(5), 2836-2846. doi.org/10.1121/1.3493436

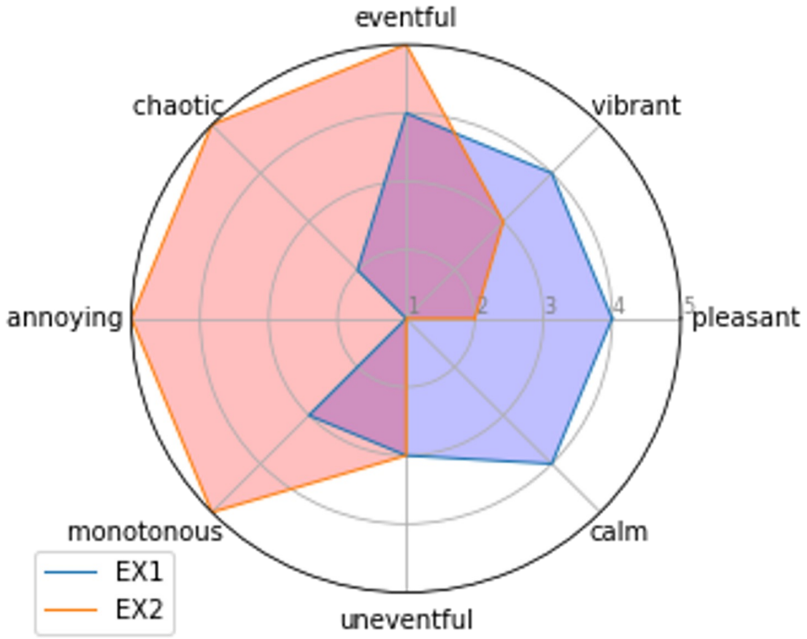
The Circumplex Model of Soundscape Perception



ISO/*TS 12913-3:2019 Acoustics - Soundscape - Part 3: Data analysis*

Soundscape Circumplex Model (SCM)

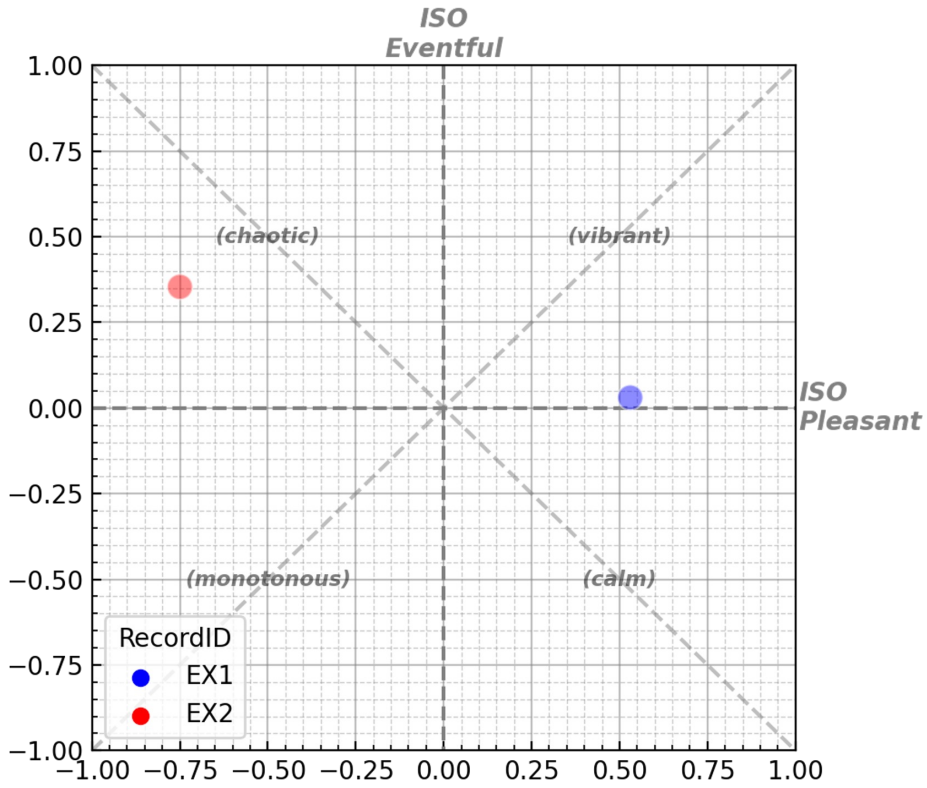
Likert scale PA responses



$$P_{ISO} = \frac{1}{\lambda}\sum_{i=1}^{8} \cos\theta_i \cdot \sigma_i$$

$$E_{ISO} = \frac{1}{\lambda}\sum_{i=1}^{8} \sin\theta_i \cdot \sigma_i$$

Soundscape Scatter Plot



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Perceived Affective Quality (PAQs)

For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is...

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
Pleasant	○	○	○	○	○
Chaotic	○	○	○	○	○
Vibrant	○	○	○	○	○
Uneventful	○	○	○	○	○
Calm	○	○	○	○	○
Annoying	○	○	○	○	○
Eventful	○	○	○	○	○
Monotonous	○	○	○	○	○

Sound Sources

To what extent do you presently hear the following four types of sounds?

	Not at all	A little	Moderately	A lot	Dominates completely
Traffic noise (e.g. cars, buses, trains, airplanes)	○	○	○	○	○
Other noise (e.g. sirens, construction, industry, loading of goods)	○	○	○	○	○
Sounds from human beings (e.g. conversation, laughter, children at play, footsteps)	○	○	○	○	○
Natural sounds (e.g. singing birds, flowing water, wind in vegetation)	○	○	○	○	○

Overall soundscape

Overall, how would you describe the present surrounding sound environment?

- ○ Very good
- ○ Good
- ○ Neither bad nor good
- ○ Bad
- ○ Very bad

Overall, to what extent is the present surrounding sound environment appropriate to the present place?

- ○ Not at all
- ○ Slightly
- ○ Moderately
- ○ Very
- ○ Perfectly

How loud would you say the sound environment is?

- ○ Not at all
- ○ Slightly
- ○ Moderately
- ○ Very
- ○ Extremely

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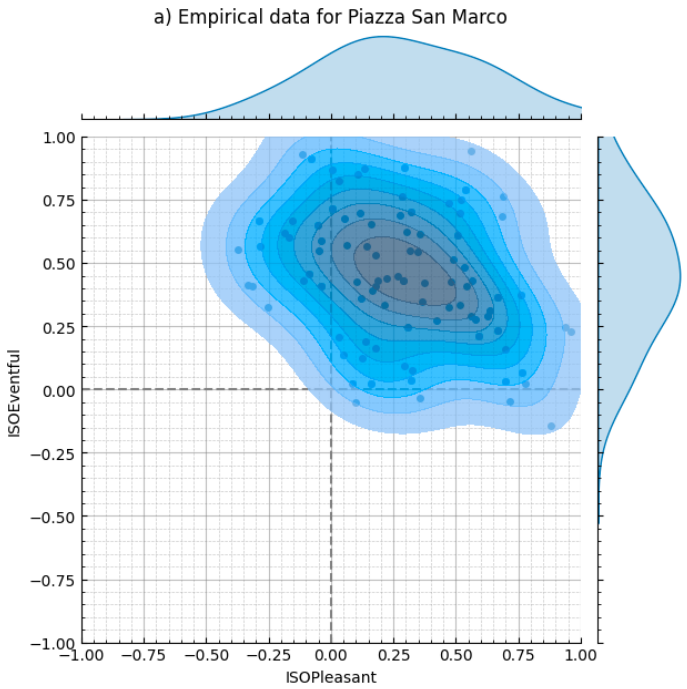
Soundscape Distributions

The **collective perception of a soundscape** can be described as the distribution of responses



This forms a **Multivariate Skew Normal Distribution (MSN)**

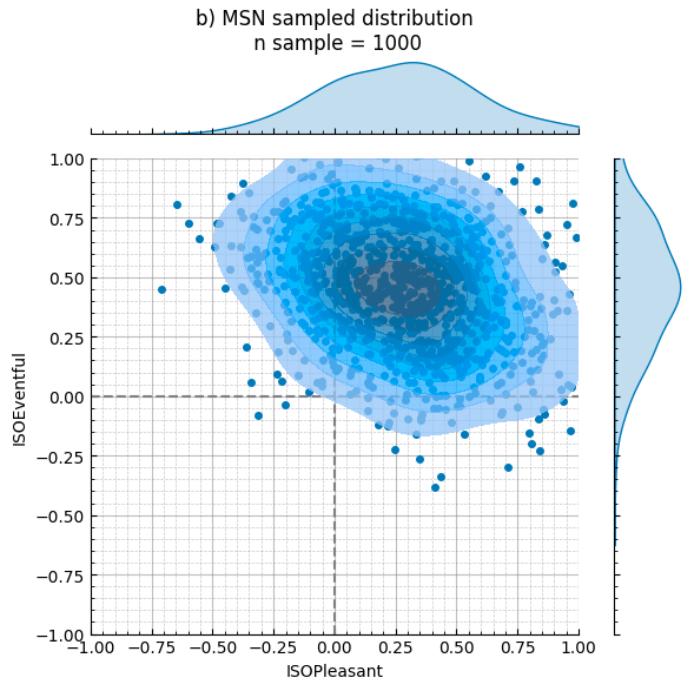
An MSN consists of three parameter vectors:

- Location (ξ)
- Covariance Matrix (Ω)
- Shape (α)

$$MSN(\xi, \Omega, \alpha)$$

These parameters can be estimated from empirical data and used to characterize the soundscape perception

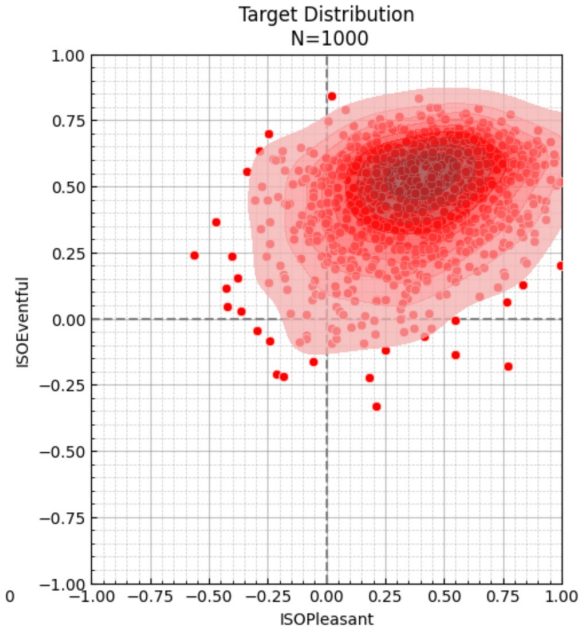
$$MSN = \begin{cases} \xi = [0.065, 0.629] \\ \Omega = \begin{bmatrix} 0.149 & -0.064 \\ -0.064 & 0.101 \end{bmatrix} \\ \alpha = [0{,}791, -0.767] \end{cases}$$

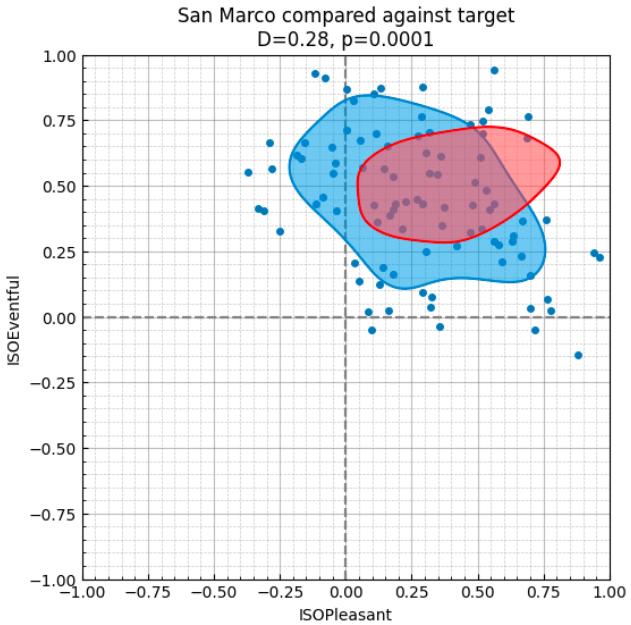


The Soundscape Perception Indices (SPI) method

Define target soundscape distribution → Sample target distribution → Compare test and target distributions → Calculate SPI

$$tgt_1 = \begin{cases} \xi = [0.5, 0.7] \\ \Omega = \begin{bmatrix} 0.1 & 0.05 \\ 0.05 & 0.1 \end{bmatrix} \\ \alpha = [0, -5] \end{cases}$$





$$SPI = 100 * (1 - KS\{test, target\})$$

$$\boldsymbol{SPI_1 = 72}$$

The SPI Framework

Bespoke and Archetypal Targets

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Bespoke Targets

Bespoke targets are **tailor-made for specific projects** or purposes.

They reflect the **desired soundscape perception** for a particular application.

These targets can be defined by **stakeholders, designers, policymakers, or decision-makers** based on their unique requirements, objectives, and constraints.

They could be co-created with other stakeholders or space users, based on trying to match the soundscape of a previous project, **or they can be defined arbitrarily.**

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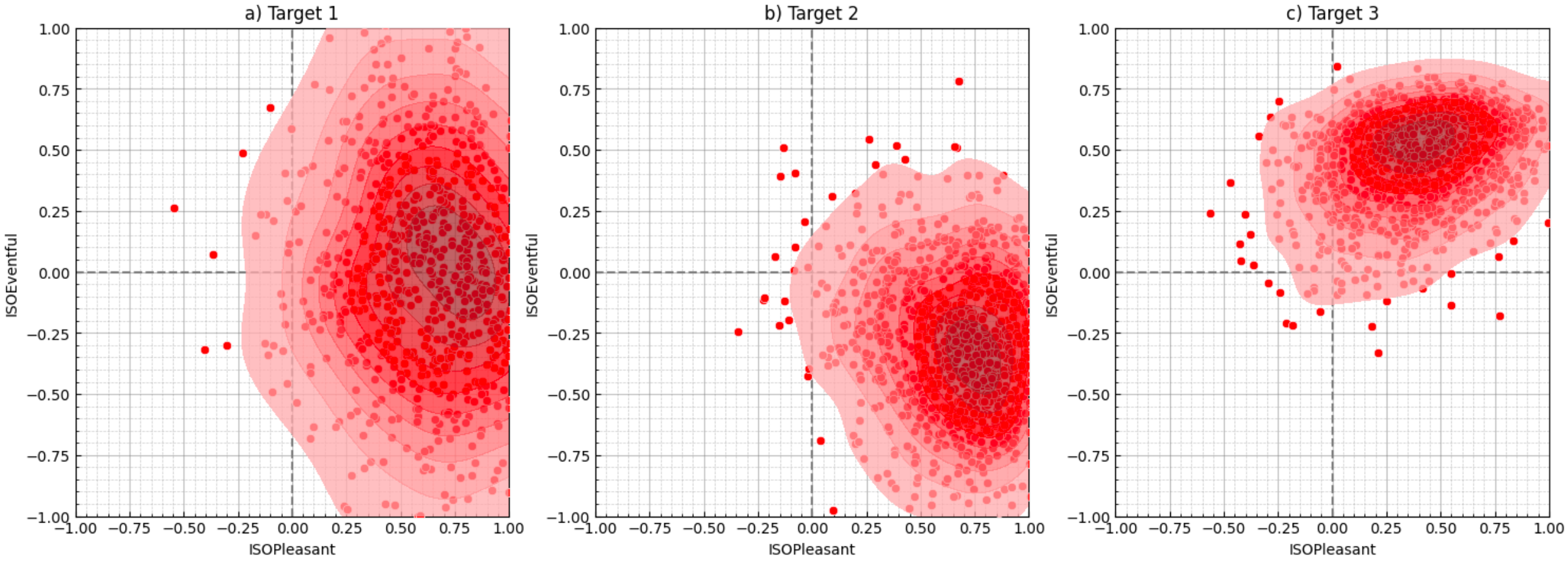
Bespoke Targets



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Bespoke Targets - Ranking

The ISD comprises soundscape surveys collected in 18 locations.

By scoring these locations against each of our 3 targets separately, **we produce SPI scores and a ranking** for each target.

Each SPI_{tgt} thus represents its own **unique index, all defined within a unified framework.**

Ranking	SPI_1 (pleasant)	SPI_2 (calm)	SPI_3 (vibrant)
1	72 CarloV	64 CampoPrincipe	72 SanMarco
2	70 RegentsParkFields	54 CarloV	62 TateModern
3	64 CampoPrincipe	51 RegentsParkFields	60 StPaulsCross
4	64 RegentsParkJapan	50 PlazaBibRambla	59 Noorderplantsoen
5	63 PlazaBibRambla	46 MarchmontGarden	54 PancrasLock
6	62 RussellSq	44 MonumentoGaribaldi	54 TorringtonSq
7	62 MarchmontGarden	41 RussellSq	47 StPaulsRow
8	61 PancrasLock	40 PancrasLock	47 RussellSq
9	61 MonumentoGaribaldi	39 RegentsParkJapan	46 MiradorSanNicolas
10	55 StPaulsCross	32 StPaulsCross	42 CamdenTown
11	50 TateModern	32 MiradorSanNicolas	40 CarloV
12	50 StPaulsRow	31 TateModern	36 MonumentoGaribaldi
13	46 MiradorSanNicolas	30 TorringtonSq	34 MarchmontGarden
14	41 Noorderplantsoen	29 StPaulsRow	33 PlazaBibRambla
15	39 TorringtonSq	17 SanMarco	32 CampoPrincipe
16	35 SanMarco	16 Noorderplantsoen	31 EustonTap
17	22 CamdenTown	14 EustonTap	27 RegentsParkFields
18	17 EustonTap	14 CamdenTown	27 RegentsParkJapan

Archetypal Targets

In contrast to bespoke targets, archetypal targets represent **generalized, widely recognized soundscape archetypes** which transcend specific applications or projects.

These archetypes serve as **reference points** and **enable comparisons across different domains** and use cases.

Essentially an archetypal target is a target that has been **empirically defined to encapsulate the ideal of a particular type of soundscape**.

How would we empirically derive an SPI target?

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Archetypal Targets
Deriving a target distribution

Begin with a given ranking. This could be defined through a number of methods, e.g. paired comparison experiments or using an independent metric such as health or business outcomes.

Treat it as an optimization task with two objectives – to derive an SPI target which will **(1) reproduce the given ranking** and **(2) score the top ranked soundscapes highly.**

Use multi-objective optimization to **learn the MSN parameters** using the 2 objectives as **loss functions**.

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Archetypal Targets
MSN multi-objective optimization

MSN parameters (with constraints) to search through:

$\xi = (\xi_x, \xi_y)$

- $-1 \leq \xi \leq 1$

$$\Omega = \begin{bmatrix} var(x) & cov(x,y) \\ cov(y,x) & var(y) \end{bmatrix}$$

- $0 \leq var(\quad) \leq 1$
- $-1 \leq cov() \leq 1$
- Must be positive definite

$\alpha = (\alpha_x, \alpha_y)$

Objective functions:

$$f_1 = -r(ranks_{given}, ranks_{tgt})$$

$$f_2 = -\frac{1}{n}\sum_{i=1}^{n} SPI_{tgt}(X_i))$$

Multi-objective Optimization Algorithm:

NSGA-II: Non-dominated Sorting Genetic Algorithm

Population size: 150

Max Generations: 50

Given ranking of parks:

Rank	Location
1	RegentsParkJapan
2	RegentsParkFields
3	CampoPrincipe
4	MonumentoGaribaldi
5	RussellSq
6	MiradorSanNicolas
7	StPaulsCross
8	Noorderplantsoen

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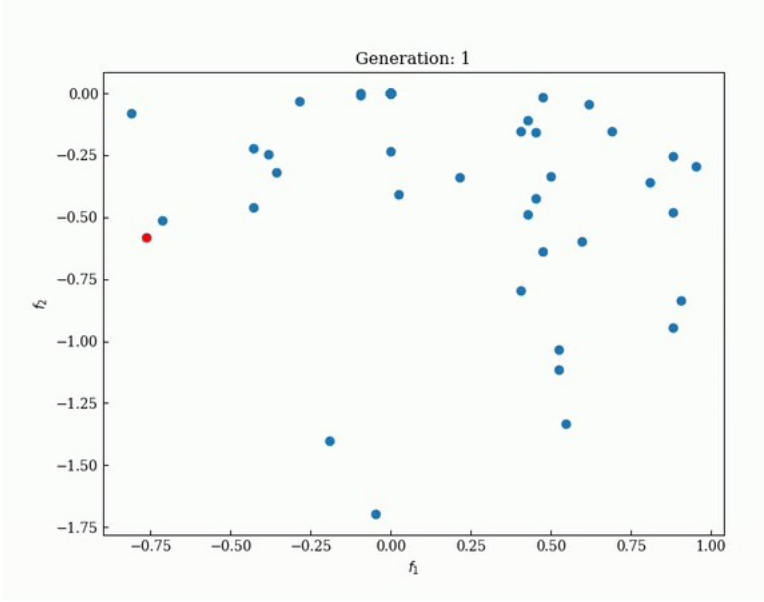
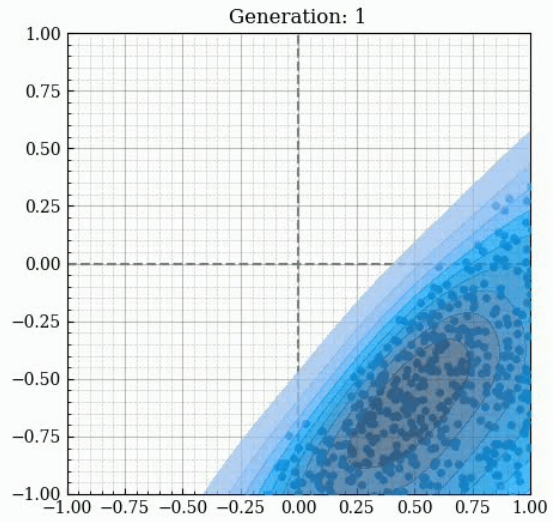
Archetypal Targets
Optimized Target

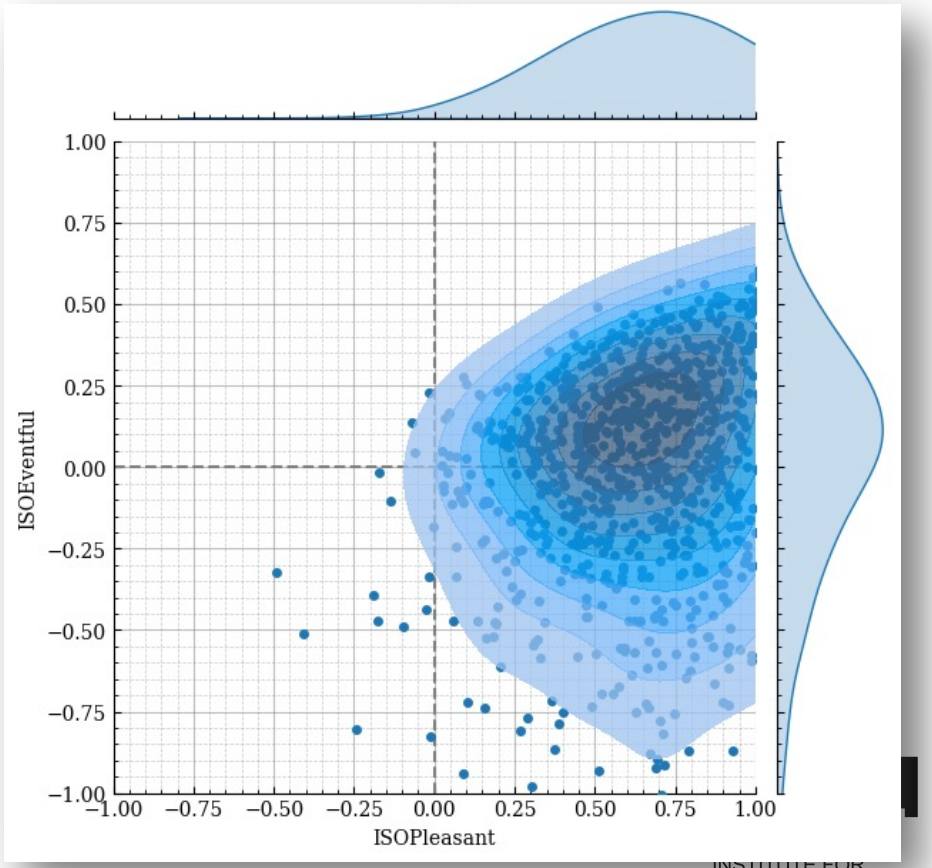
$$tgt_{parks} = \begin{cases} \xi = [0.621, 0.423] \\ \Omega = \begin{bmatrix} 0.117 & -0.01 \\ -0.01 & 0.298 \end{bmatrix} \\ \alpha = [2.4, -9.2] \end{cases}$$

Pareto front

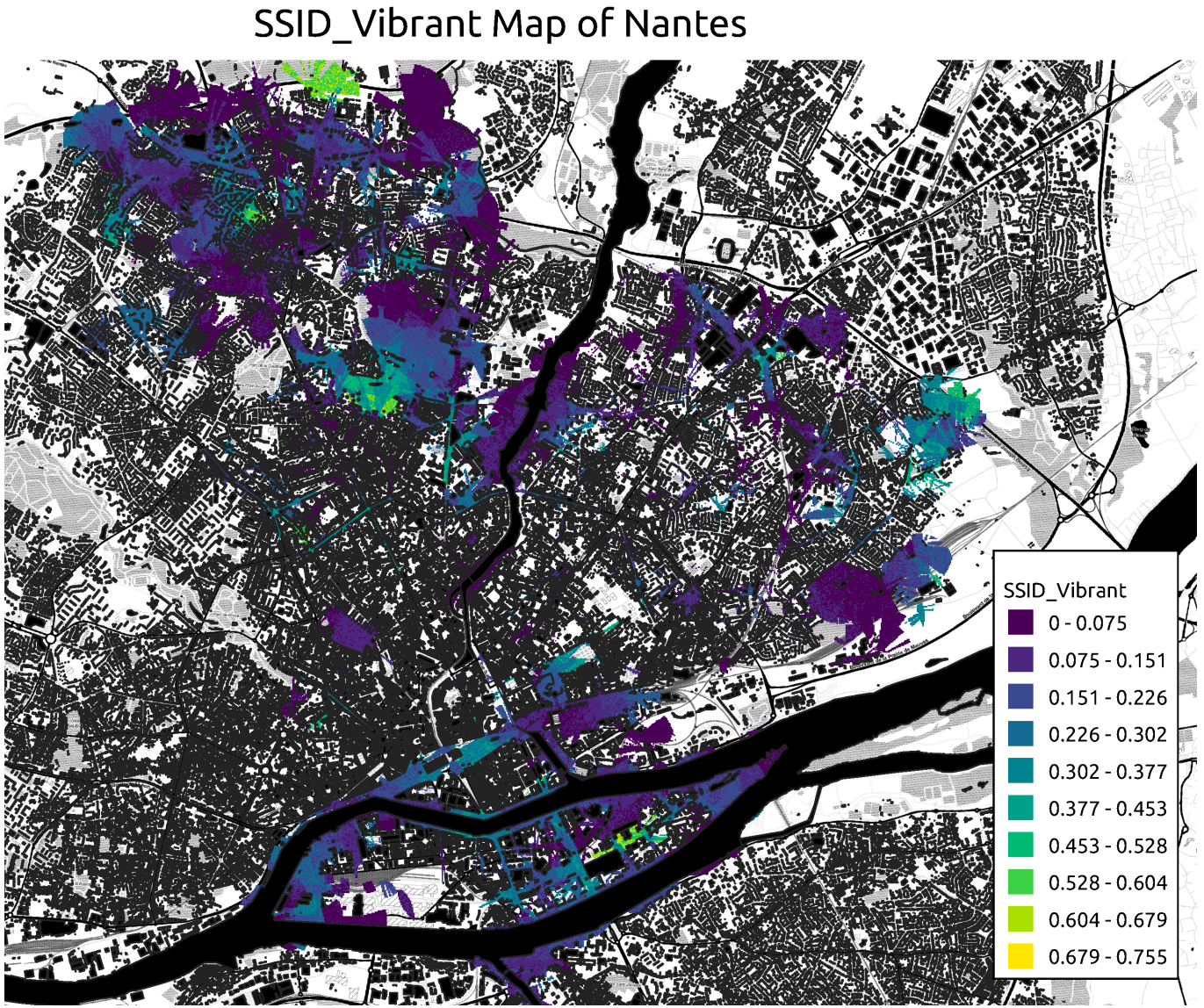


Optimal target per generation





Soundscape Indices for Mapping & Monitoring



- A preliminary example of SPI mapping.
- Mapping soundscape vibrancy based on PAQs from surveys collected in Nantes.

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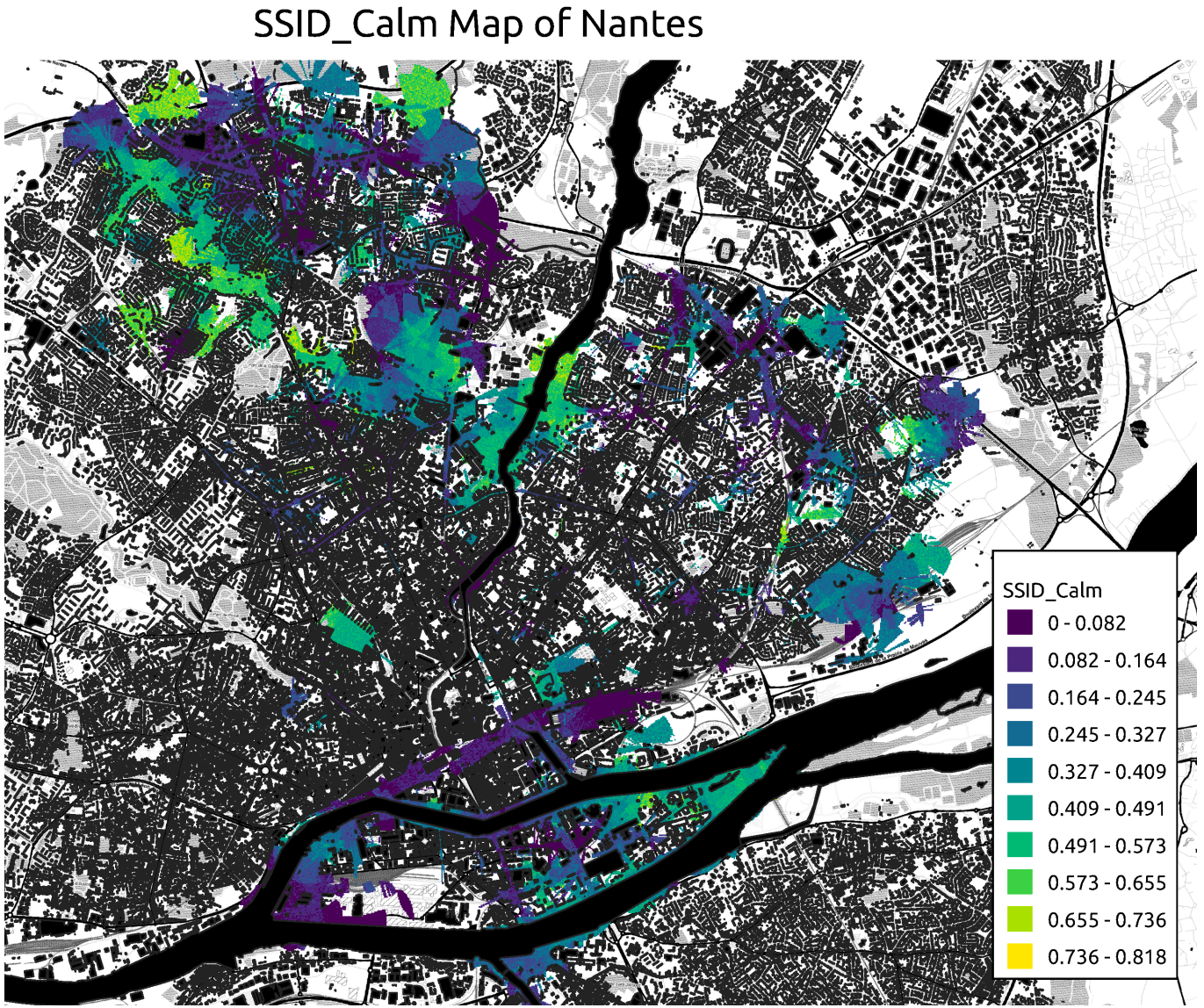
Soundscape Indices for Mapping & Monitoring



- A preliminary example of SPI mapping.
- Mapping soundscape calmness based on PAQs from surveys collected in Nantes.

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Putting it all together

Audio analysis

Psychoacoustics, environmental acoustics, bioacoustics, etc.

```
]: metric = "loudness_zwtv"
   stats = (5, 50, 'avg', 'max')
   func_args = {
       'field_type': 'free'
   }

   b.mosqito_metric(metric, statistics=stats, as_df=True
```

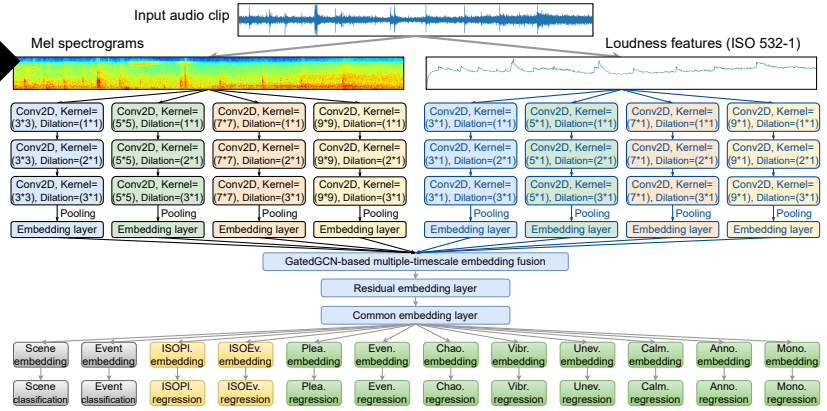
```
- Calculating MoSQITo metric: loudness_zwtv
```

]:

Recording	Channel	N_5	N_50	N_avg	N_m
CT101	Left	28.834482	23.164299	22.669519	36.1608
	Right	30.834215	23.939352	23.774119	37.7623

Predictive Modelling

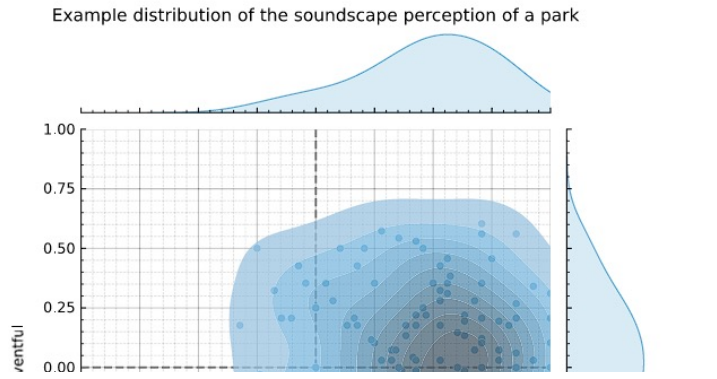
Multi-level Linear Regression
Probabilistic Predictions
Joint Source-Perception Modelling



Visualisation & Scoring

Soundscape Density Plots
Soundscape Perception Indices

```
jo = ssid.isd.filter_location_ids(['RussellSq']).isd.circumplex_jointplot_density(
    title='Example distribution of the soundscape perception of a park',
    marginal_kind = 'kde', hue = 'LocationID', legend = True, alpha=0.75, incl_scatter = True, joint_kwargs={'s': 30})
```



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Thank you for listening

Paper to be submitted to JASA Special Issue on Soundscapes.

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For more on me and my work, visit:

These slides can be found at my website:
https://drandrewmitchell.com

And my software packages:

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