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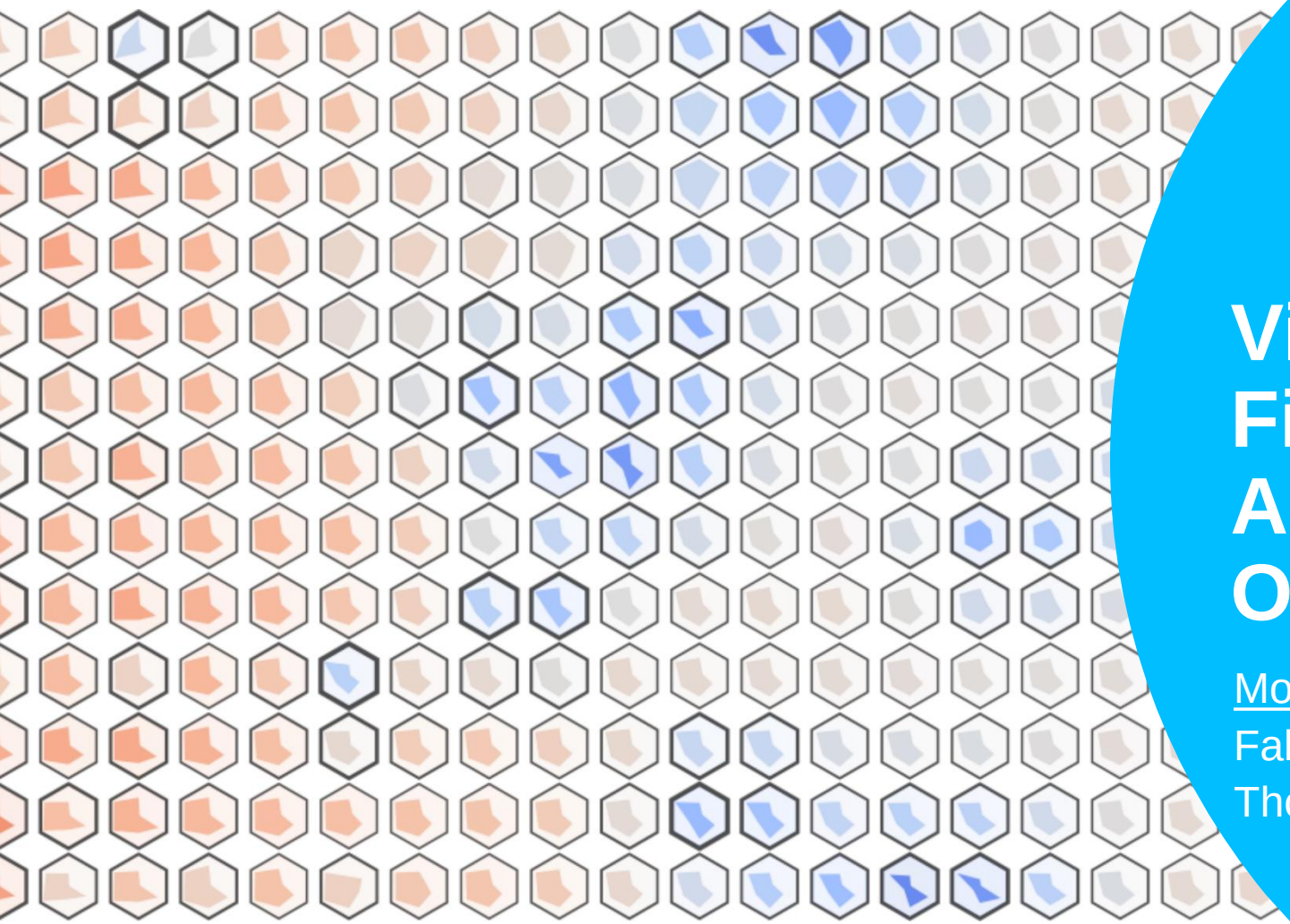
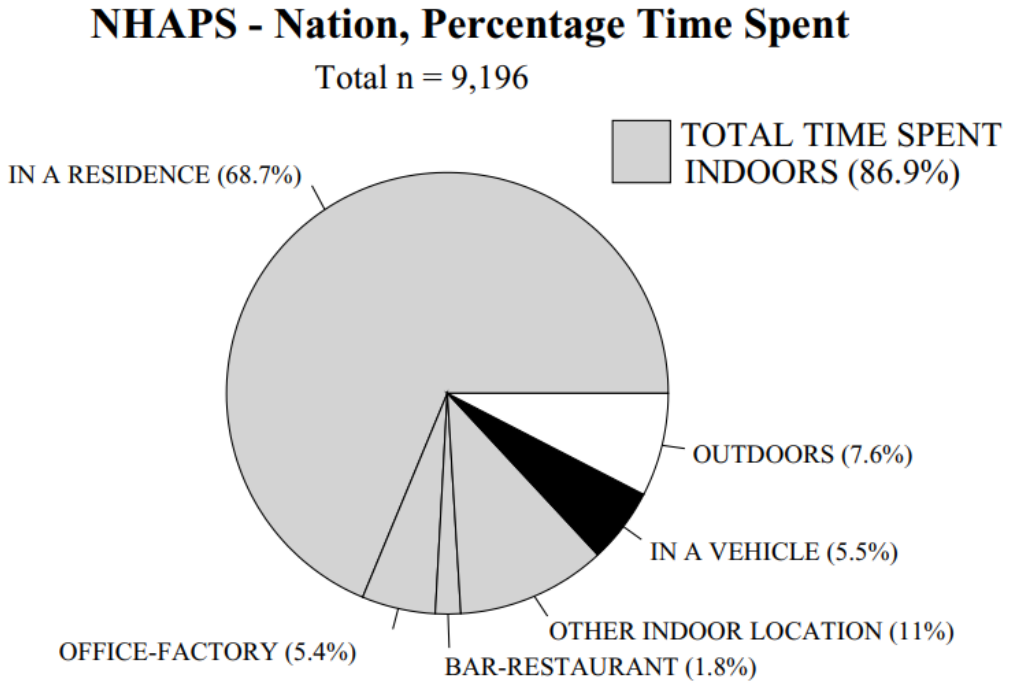


Visual Analysis of Fitness Landscapes in Architectural Design Optimization

Moataz Abdelaal, Marcel Galuschka, Max Zorn,
Fabian Kannenberg, Achim Menges,
Thomas Wortmann, Daniel Weiskopf, Kuno Kurzhals

CGI2024
IntCDC CLUSTER OF EXCELLENCE
ICD Institute for Computational Design and Construction
VISUS Visualization Research Center University of Stuttgart

Architecture

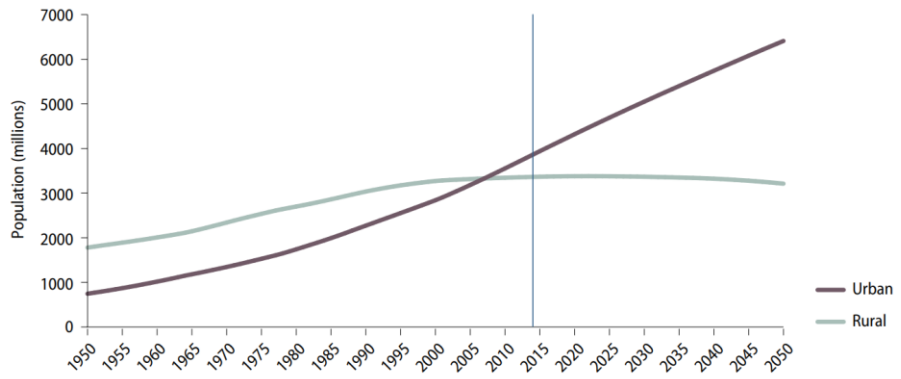


Klepeis, Neil E., et al. "The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants." Journal of Exposure Science & Environmental Epidemiology 11.3 (2001): 231-252.

Architecture, Engineering, and Construction (AEC)

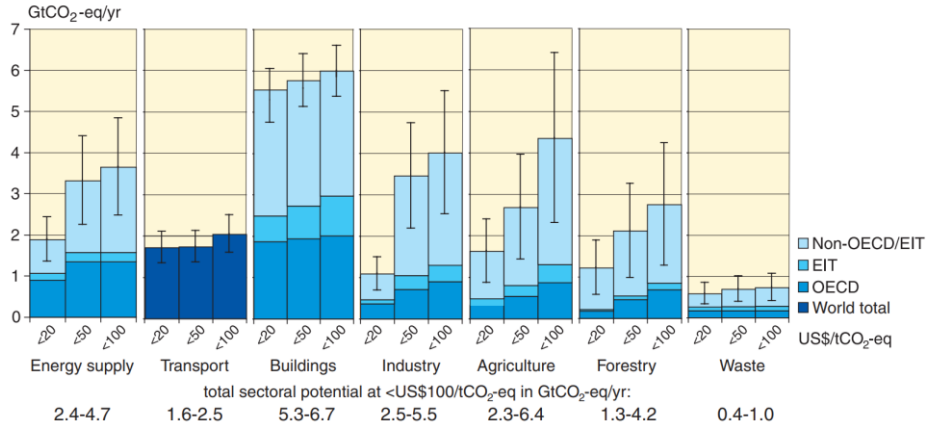
Demand, Productivity and Climate Change

Urban and rural population of the world, 1950–2050



United Nations, Department of Economic and Social Affairs, Population Division (2015). World Urbanization Prospects: The 2014 Revision.

Economic mitigation potentials by sector in 2030 estimated from bottom-up studies

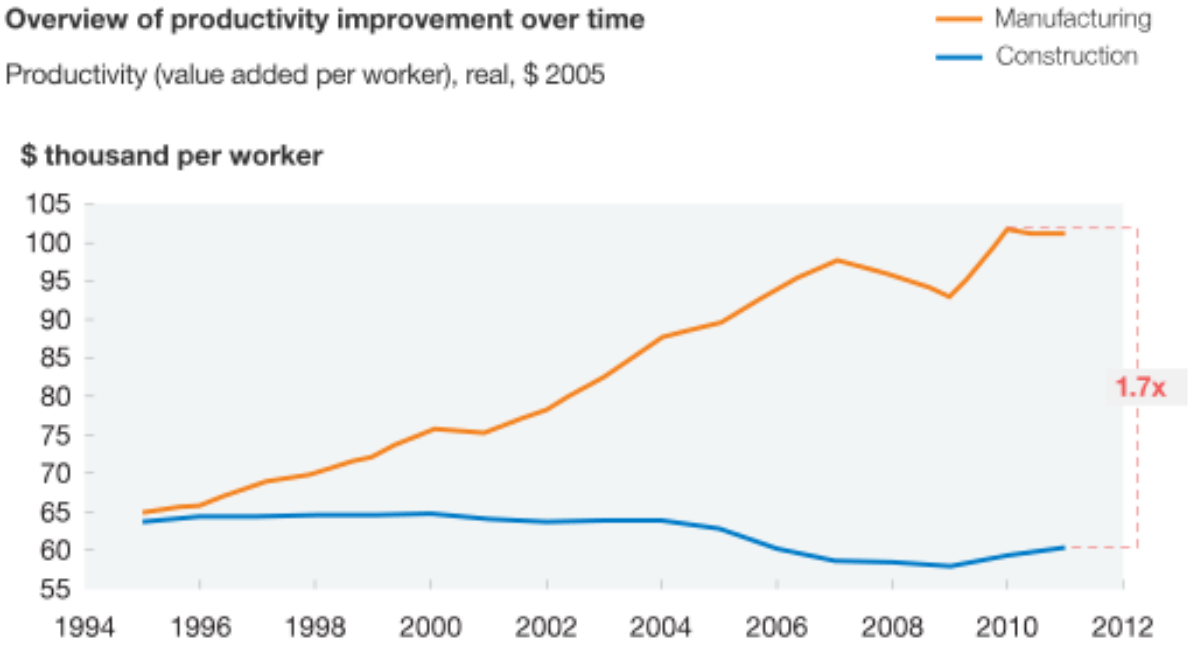


IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Productivity in manufacturing has nearly doubled, whereas in construction it has remained flat.

Overview of productivity improvement over time

Productivity (value added per worker), real, $ 2005



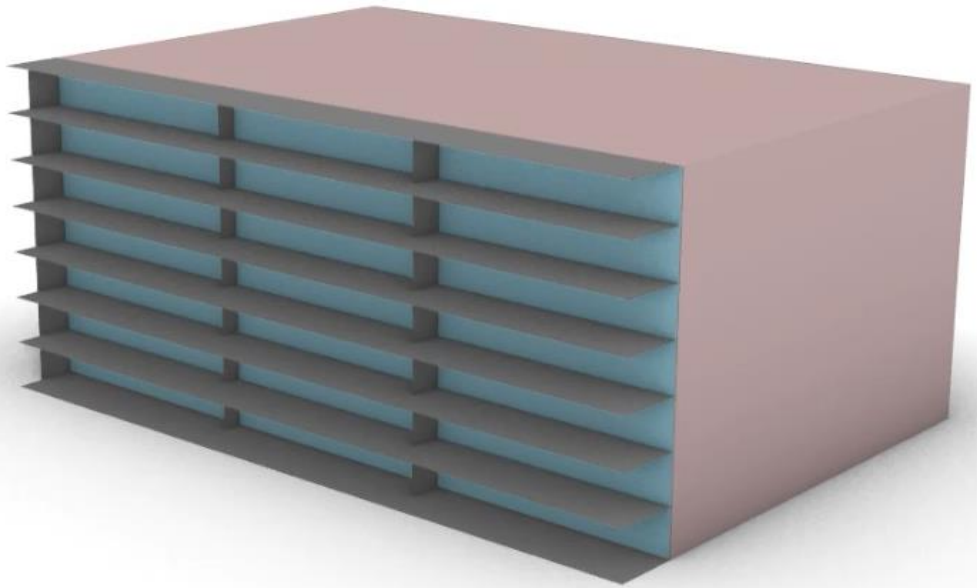
Source: Expert interviews; IHS Global Insight (Belgium, France, Germany, Italy, Spain, United Kingdom, United States); World Input-Output Database

McKinsey&Company

S. Changali, A. Mohammad, and M. Van Nieuwland, "The construction productivity imperative," McKinsey & Company, New York, NY, USA, Tech. Rep., 2015

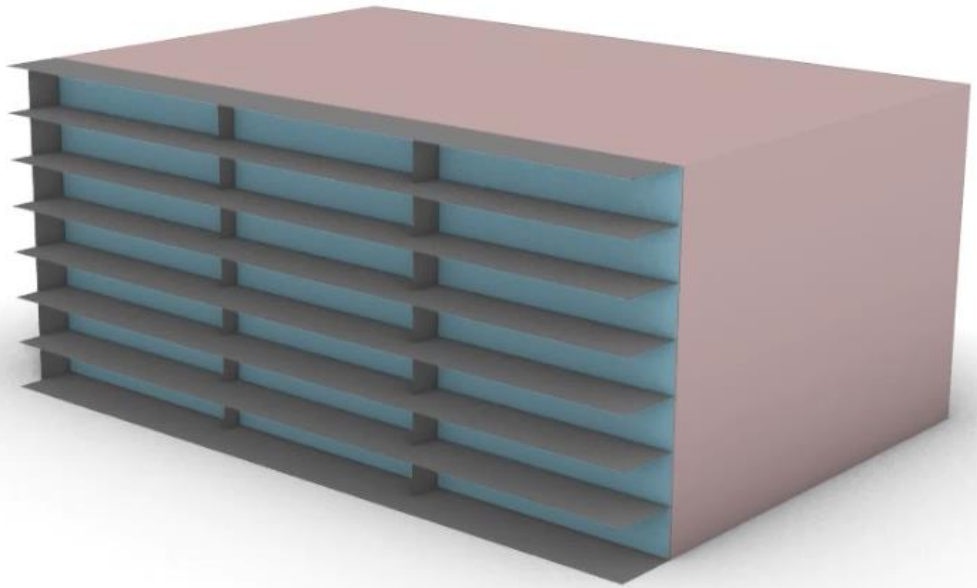
Design Optimization

Computational optimization methods have *great potential*



Design Optimization

Computational optimization methods have *great potential* but have had *limited impact* on architectural design so far



Design

often described as a wicked problem with ill-defined tasks and incomplete data

Optimization

requires a well-defined problem with clear constraints and objective functions

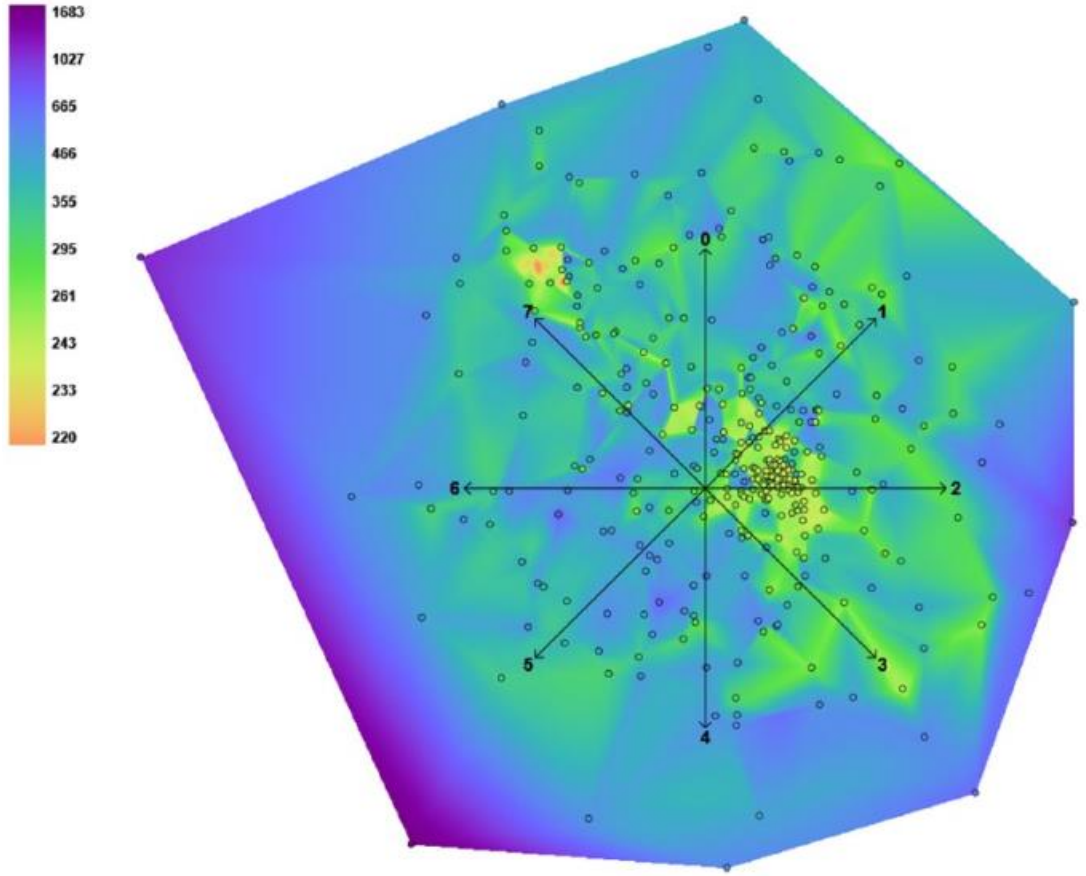
Design

Optimization

Human-in-the-loop

Fitness Landscape

Visualizes the design space parameters in relation to one or more objective functions



Wortmann, Thomas. "Surveying design spaces with performance maps: A multivariate visualization method for parametric design and architectural design optimization." International Journal of Architectural Computing 15.1 (2017): 38-53.

Requirements

- R1: A diverse landscape with a wide array of solutions
- R2: A 2D spatial embedding of the design space
- R3: A visual representation revealing relationships between the design parameters and performance

Research Questions

- Q1: How to design and build a visual analytics tool to fulfill these requirements?

- Q2: How to assess the usability and usefulness of such tool?

Research Questions

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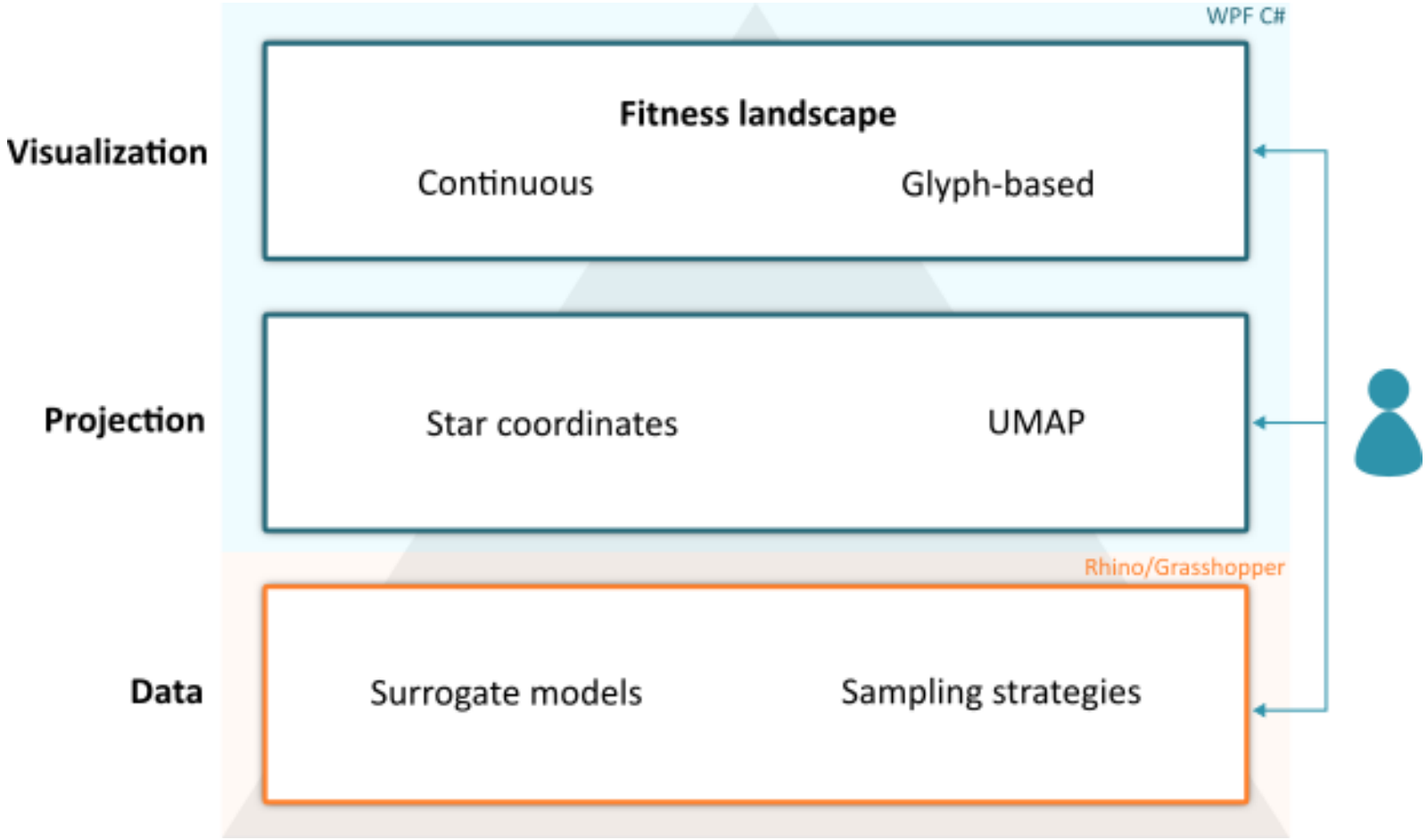
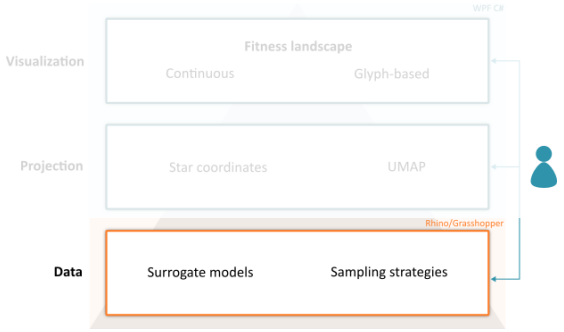
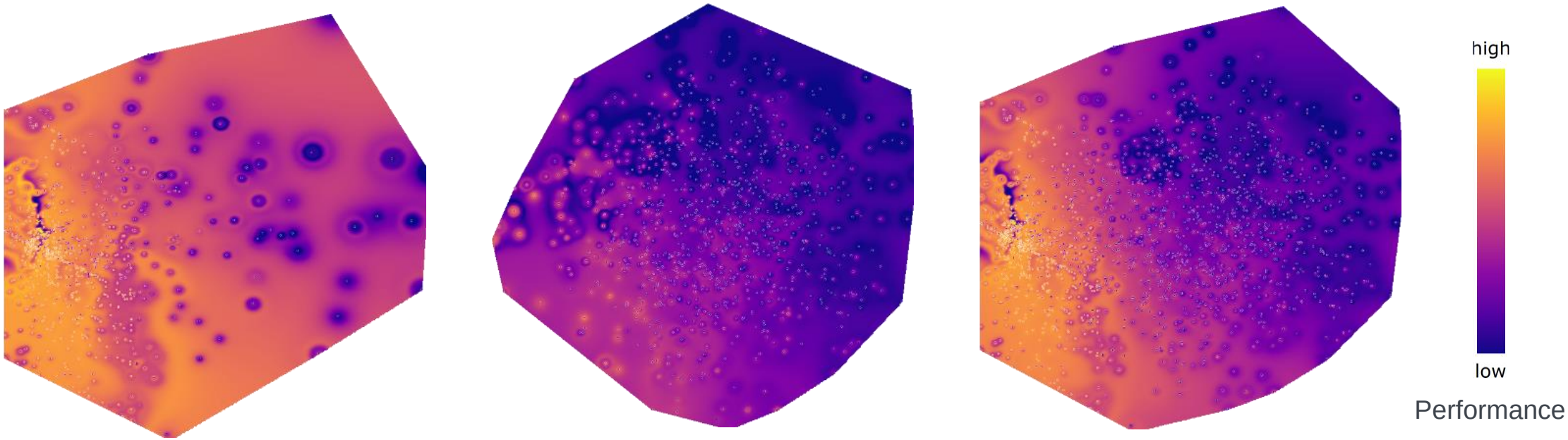
A Holistic Framework





R1: How to obtain diverse fitness landscapes with a wide array of solutions?

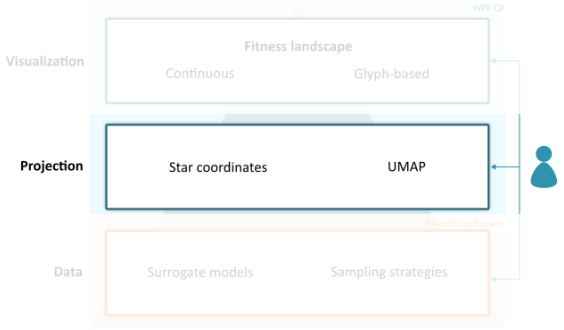


Optimization-based

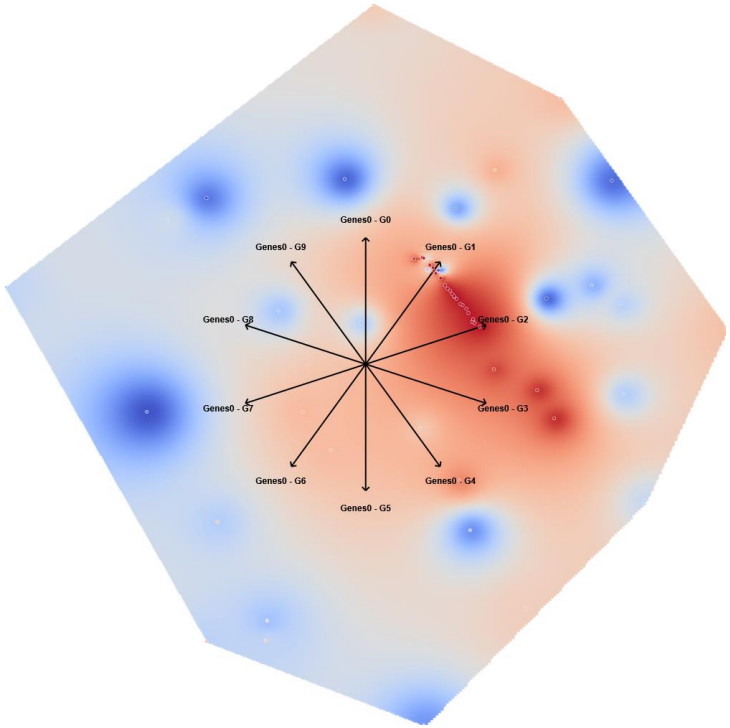
Latin Hypercube

Hybrid

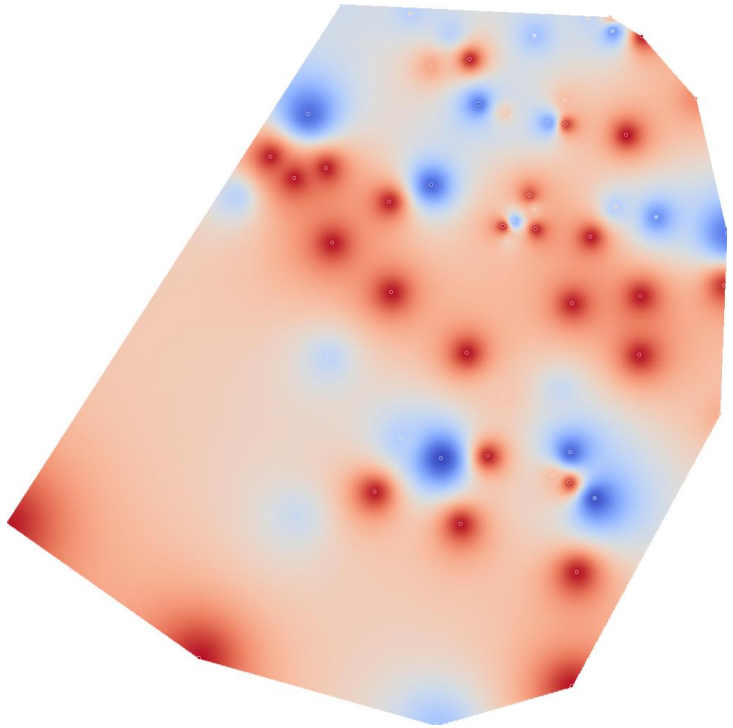
RBF fitness landscapes with 1000 samples using three sampling strategies



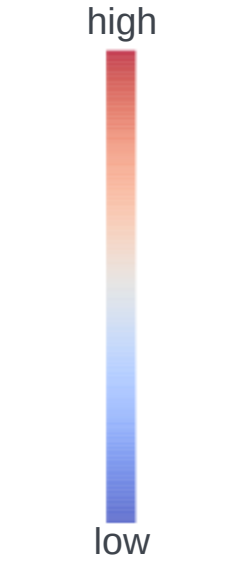
R2: How to obtain a spatial 2D embedding of the design space?

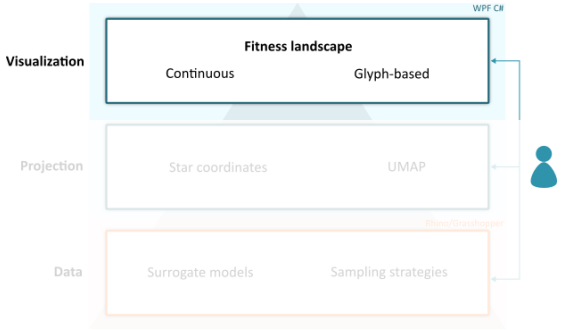


Star Coordinates (SC)

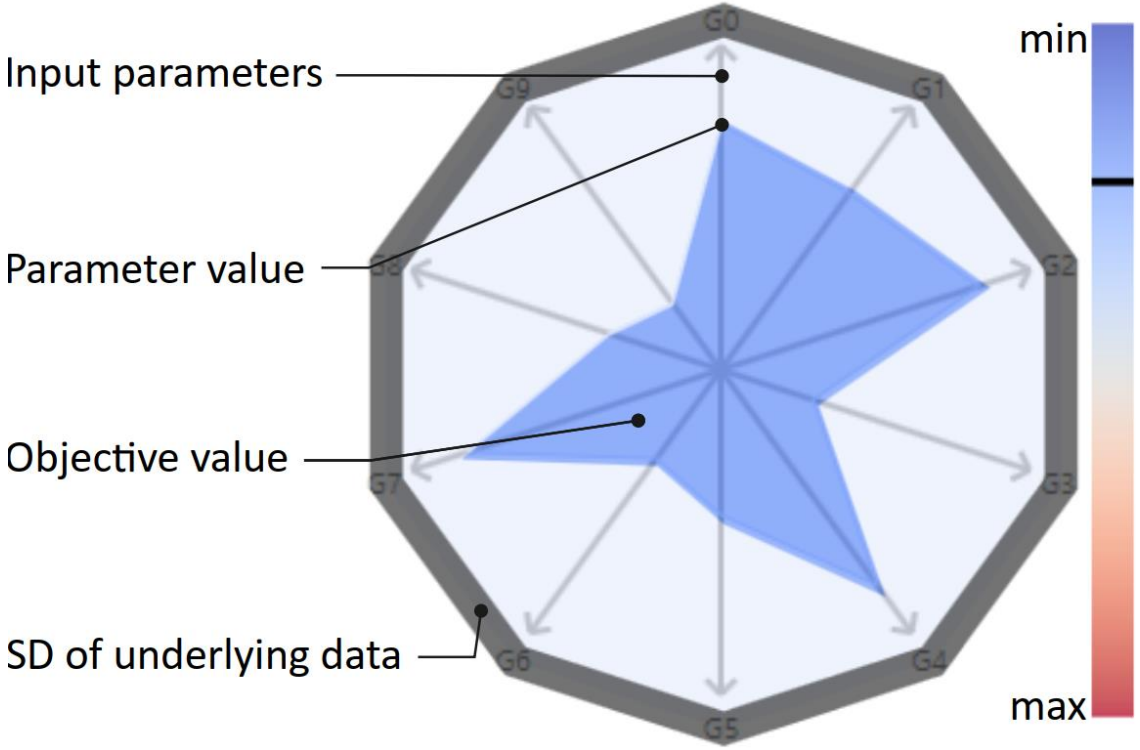


UMAP

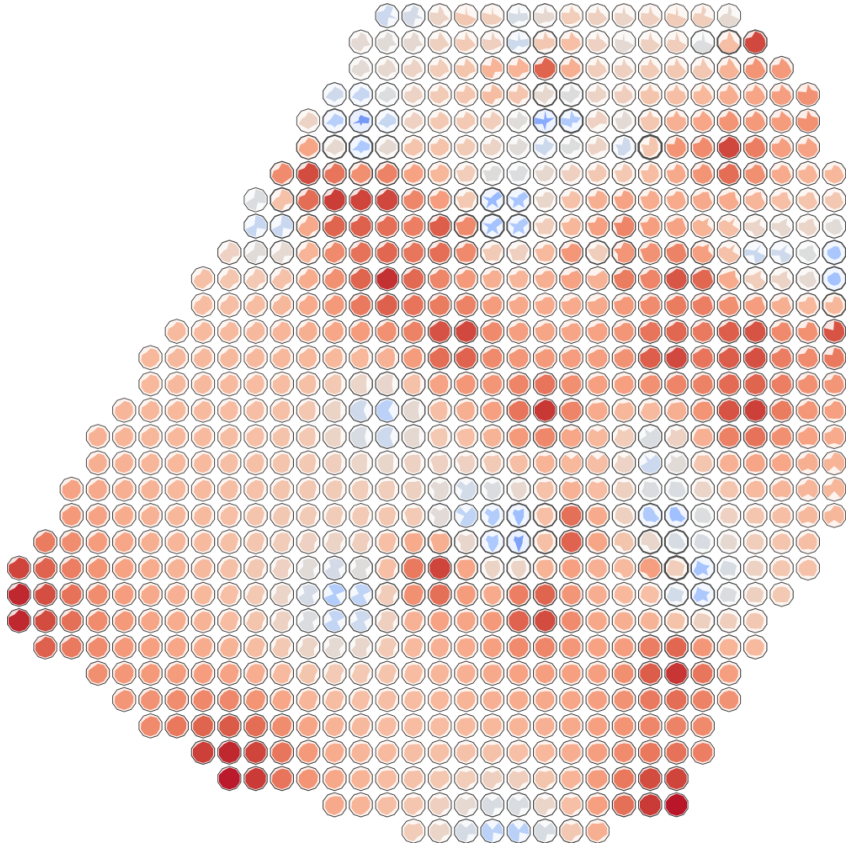




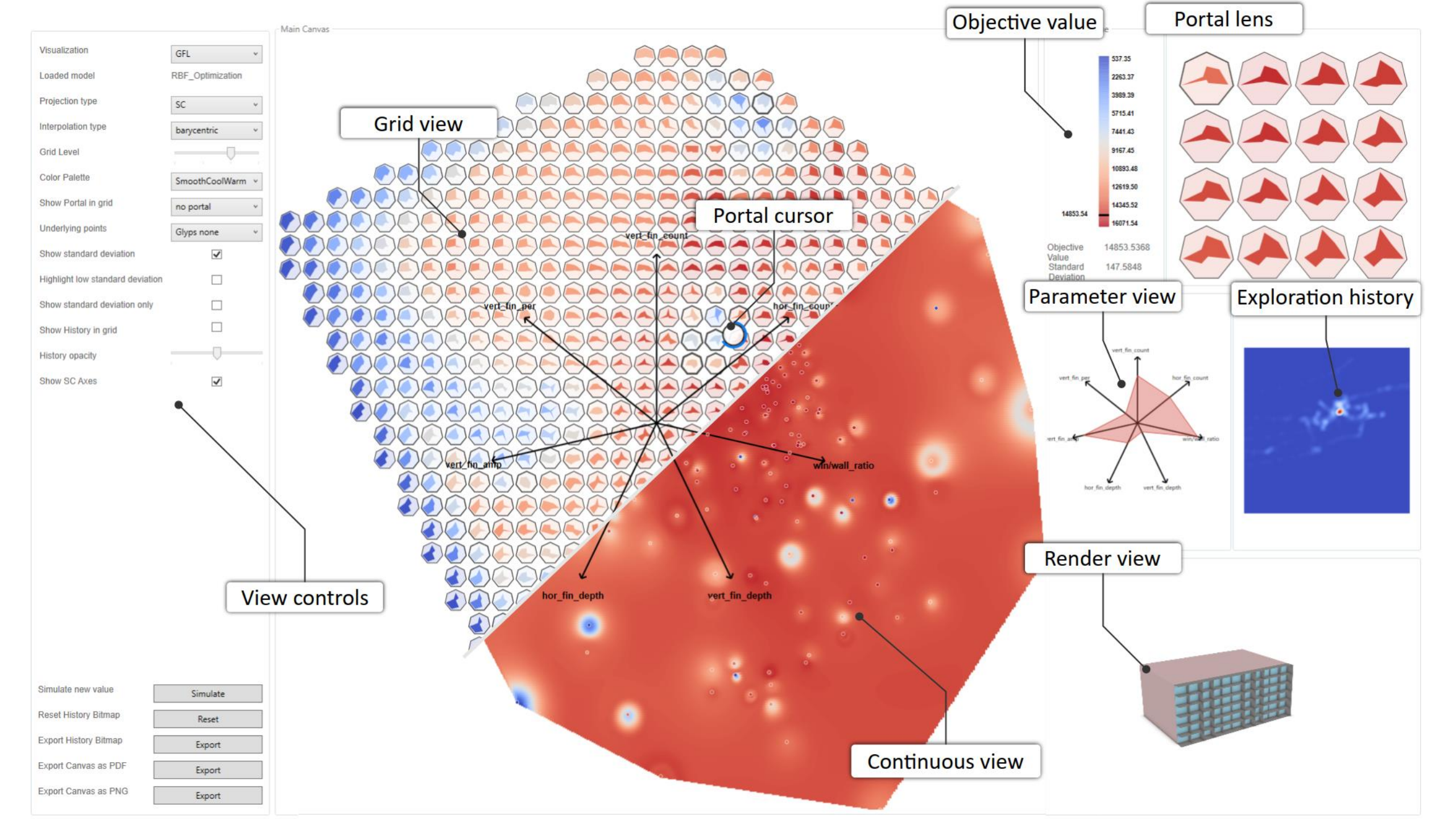
R3: How to visually uncover relationships between the design parameters and performance?



Star Glyph



Continuous Fitness Landscape (CFL)

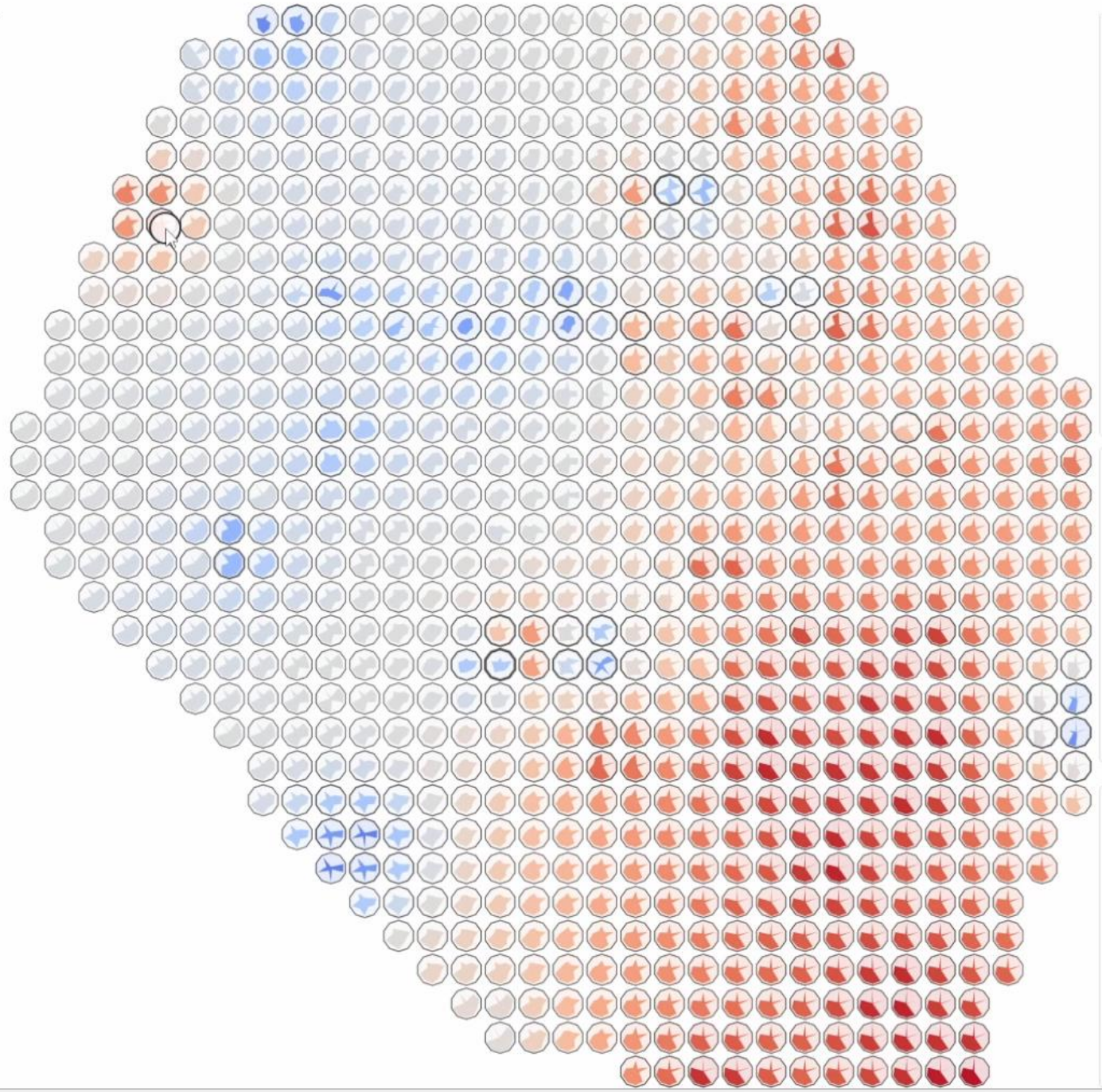

Main Canvas
Visualization
GFL
Loaded model
RBF_Optimization
Projection type
SC
Interpolation type
barycentric
Grid Level
Color Palette
SmoothCoolWarm
Show Portal in grid
no portal
Underlying points
Glyps none
Show standard deviation
Highlight low standard deviation
Show standard deviation only
Show History in grid
History opacity
Show SC Axes
Simulate new value
Simulate
Reset History Bitmap
Reset
Export History Bitmap
Export
Export Canvas as PDF
Export
Export Canvas as PNG
Export
Grid view
Portal cursor
Objective value
Portal lens
537.35
2263.37
3989.39
5715.41
7441.43
9167.45
10893.48
12619.50
14345.52
14853.54
16071.54
Objective Value 14853.5368
Standard Deviation 147.5848
Parameter view
Exploration history
vert_fin_count
vert_fin_per
hor_fin_count
vert_fin_amp
win/wall_ratio
hor_fin_depth
vert_fin_depth
View controls
Render view
Continuous view

Opossum Performance Explorer

Data representation: GridView
Loaded model: RBF_Optimization
Projection type: UMAP
Interpolation type: shepard
Shepard power: 2
Grid Level
Color Palette: SmoothCoolWarm
Show Portal in grid: no portal
Underlying points: Glyps none
Show standard deviation
Highlight low standard deviation
Show standard deviation only

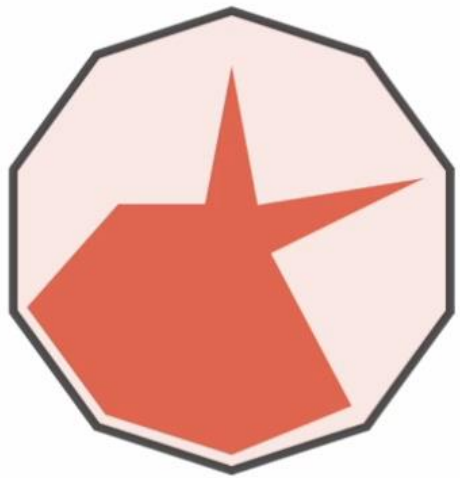
Show History in grid
History opacity
Reset History Bitmap: Reset
Export History Bitmap: Export
Simulate new value: Simulate
Export Canvas as PDF: Export

Objective Value: 8696.4998
Standard Deviation: 656.5565

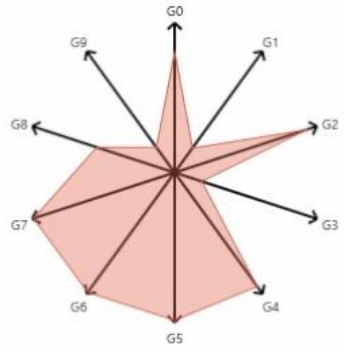


Objective Value

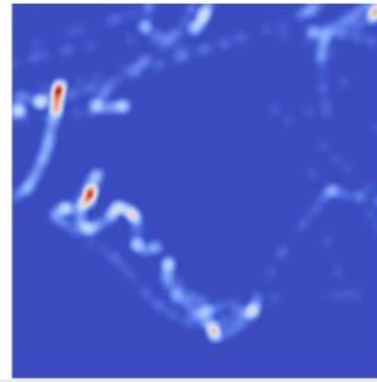
Portal



Param View



Exploration History



Render View

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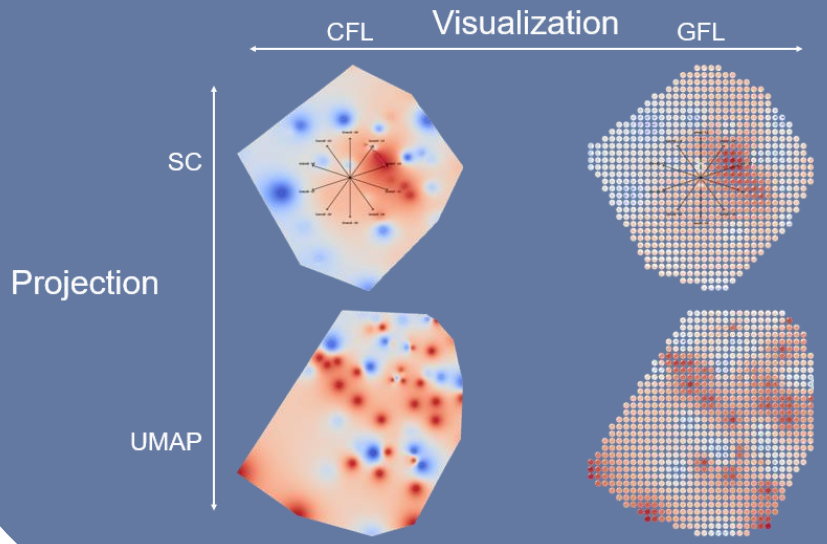
- Q2: How to assess the usability and usefulness of such tool?

Variables



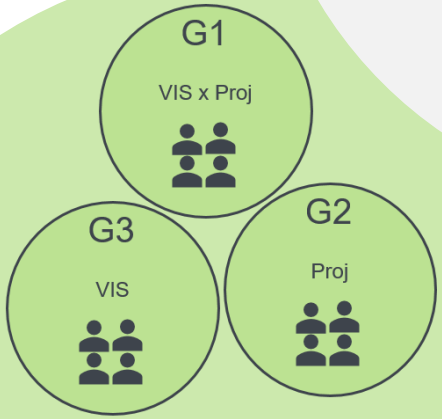
Measures

- Task Difficulty
- Subjective Preferences
- Mouse Trajectories

User Study

Procedure

N=12



Mixed Design

Tasks

T1: Projection Mental Map
Approximate where a solution is located on the map, given parameter values

T2: Design Alternatives
Find two design alternatives that achieve relatively high performance but differ in their parameter configurations

T3: Significant Parameters
Identify parameters that have a significant impact on the performance and identify the impact type (positive or negative)?

T4: Parameters Correlations
Identify correlations between parameter pairs and the performance

T1: Projection Mental Map

Approximate where a solution is located on the map, given parameter values

T2: Design Alternatives

Find two design alternatives that achieve relatively high performance but differ in their parameter configurations

T3: Significant Parameters

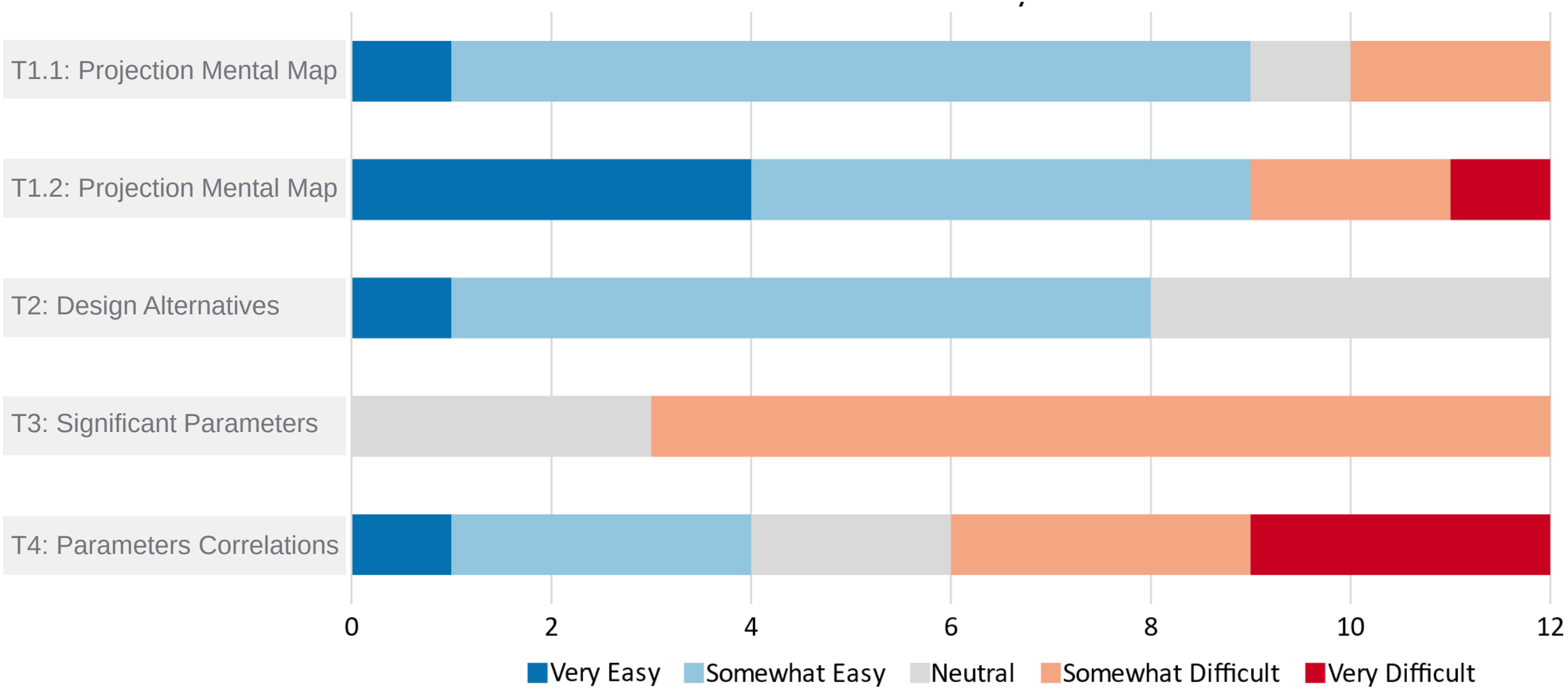
Identify parameters that have a significant impact on the performance and identify the impact type (positive or negative)?

T4: Parameters Correlations

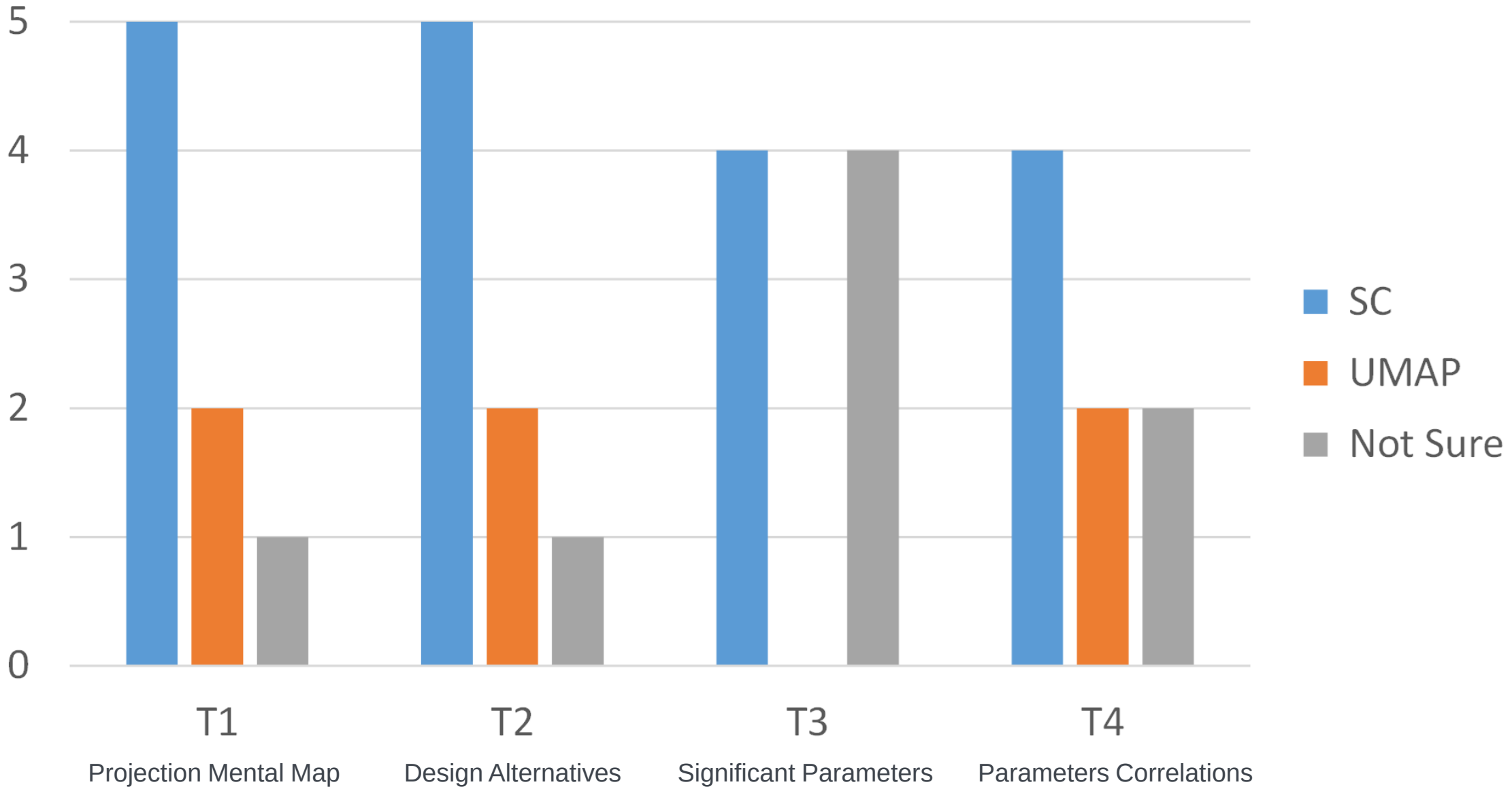
Identify correlations between parameter pairs and the performance

Results

Task Difficulty

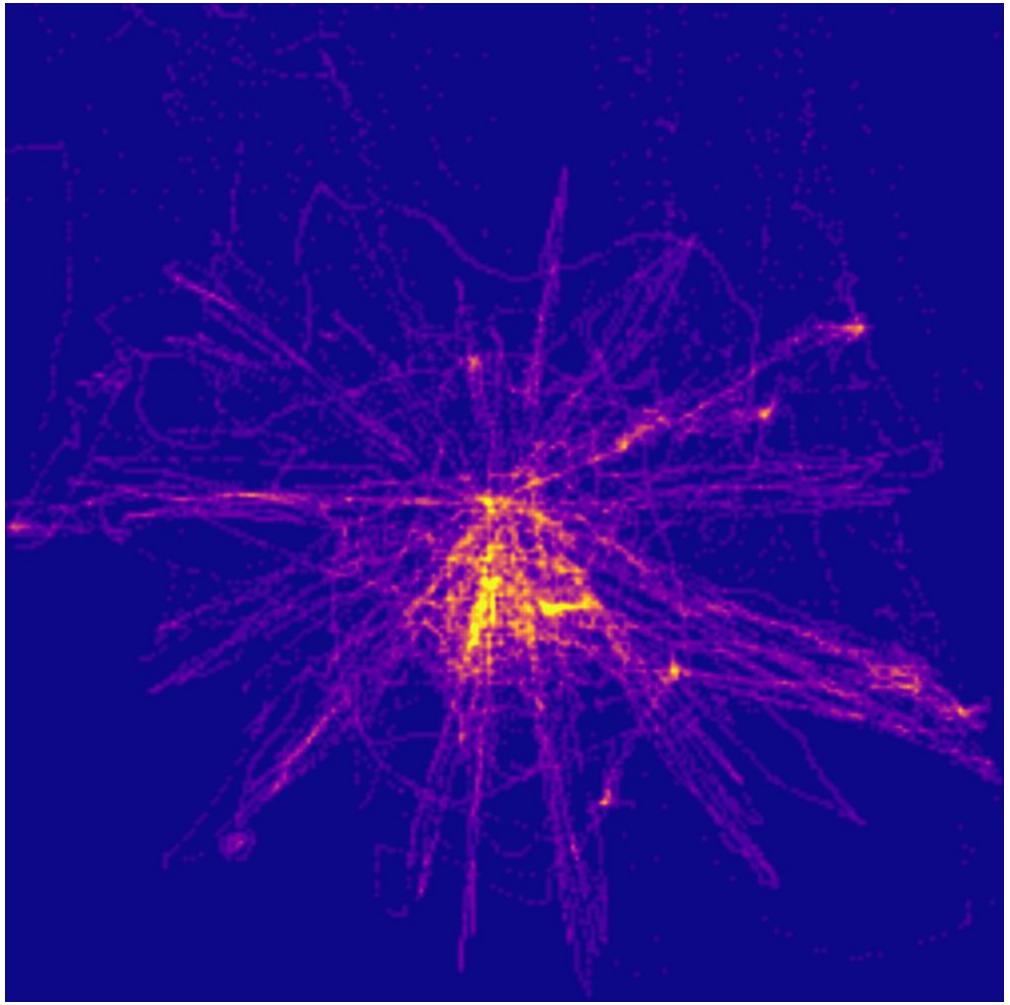


Preferred Projection per Task

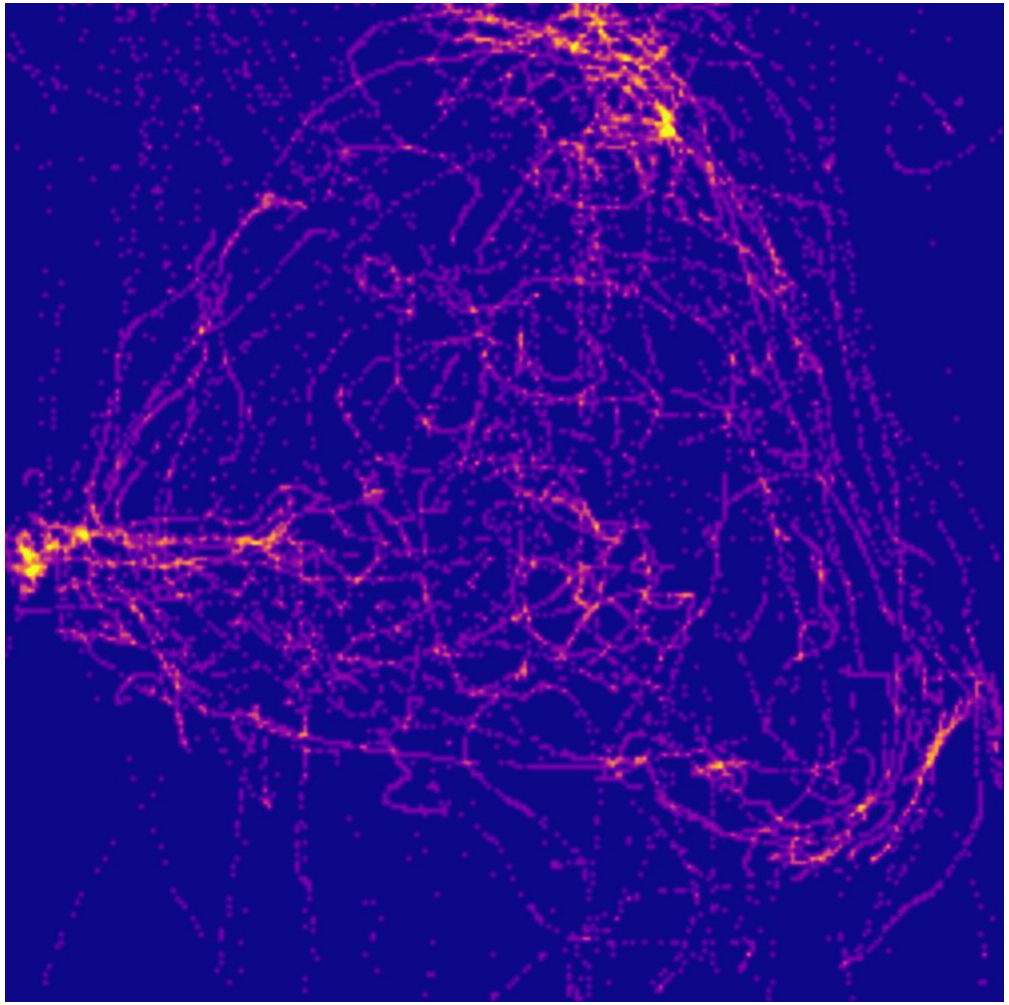


Participants Comments

Mouse Trajectories

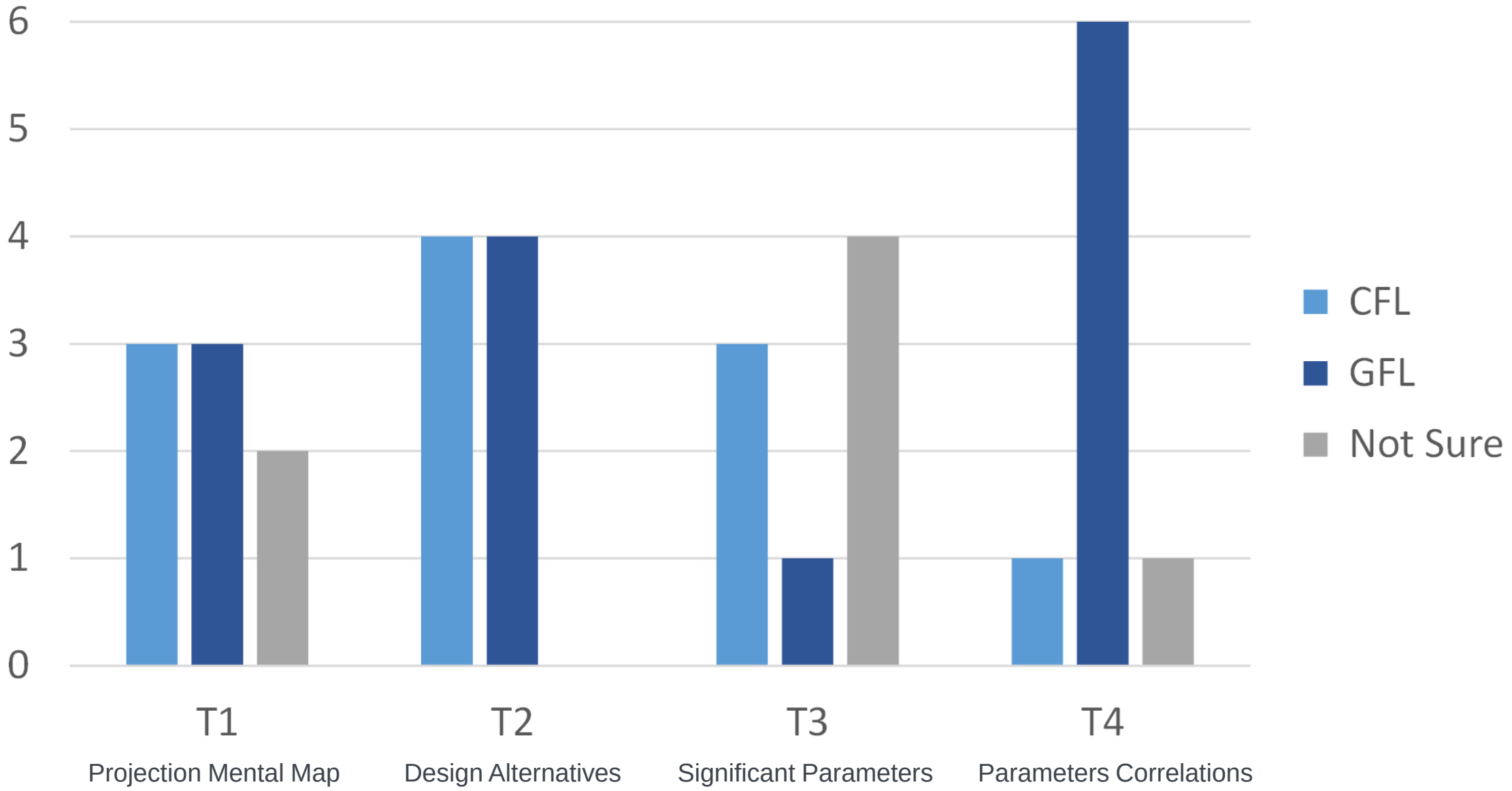


(a) Axes Following



(b) Random Search

Preferred Visualization per Task



Participants Comments

Conclusion

- A holistic framework for exploring fitness landscapes that span across data, projection, and visualization layers
- The three layers pose a challenge not only to design and build visualization tools but also to use them
- Abstract data visualizations offer high-level design space insights, but architects seek to "see" and "inspect" the 3D structure

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Thank you for your attention!


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