The Urban Toolkit: A Grammar-based Framework for Urban Visual Analytics

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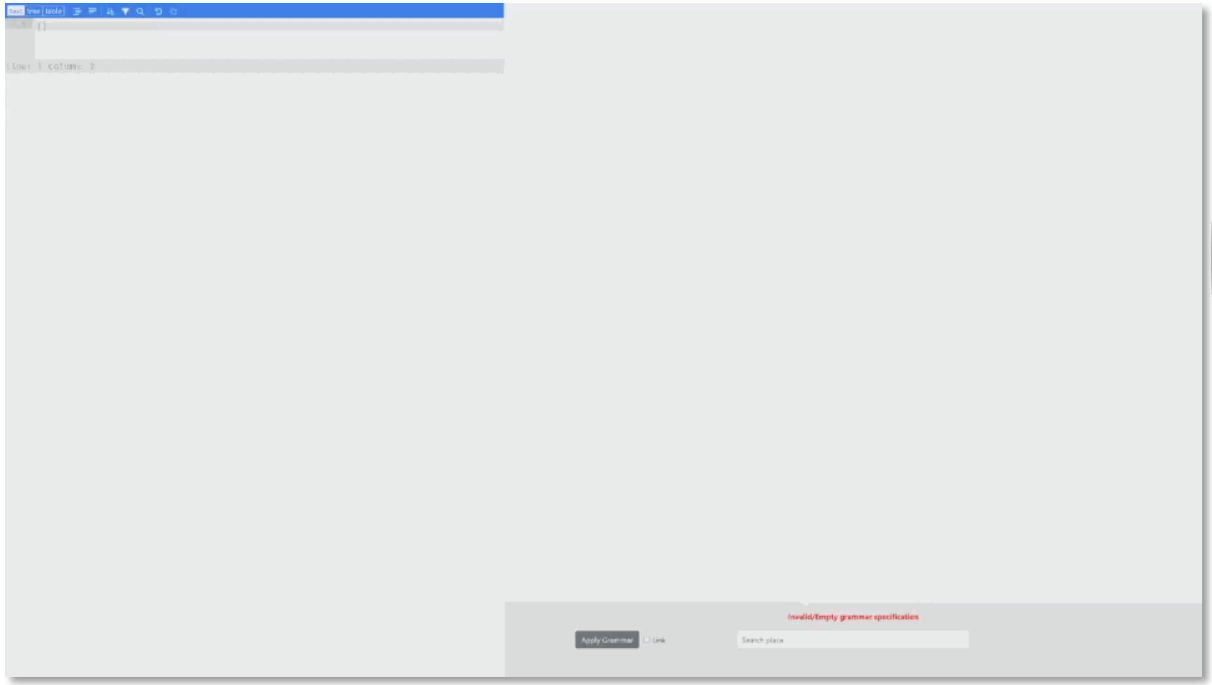
VIRTUS IMPAVIDA

The Urban Toolkit



UrbanTK

Diverse data

Diverse data

Diverse data

Diverse data

Occupational therapists

Urban noise experts

Transportation engineers

Public health experts

Environmental scientists

Architects

Urban planners

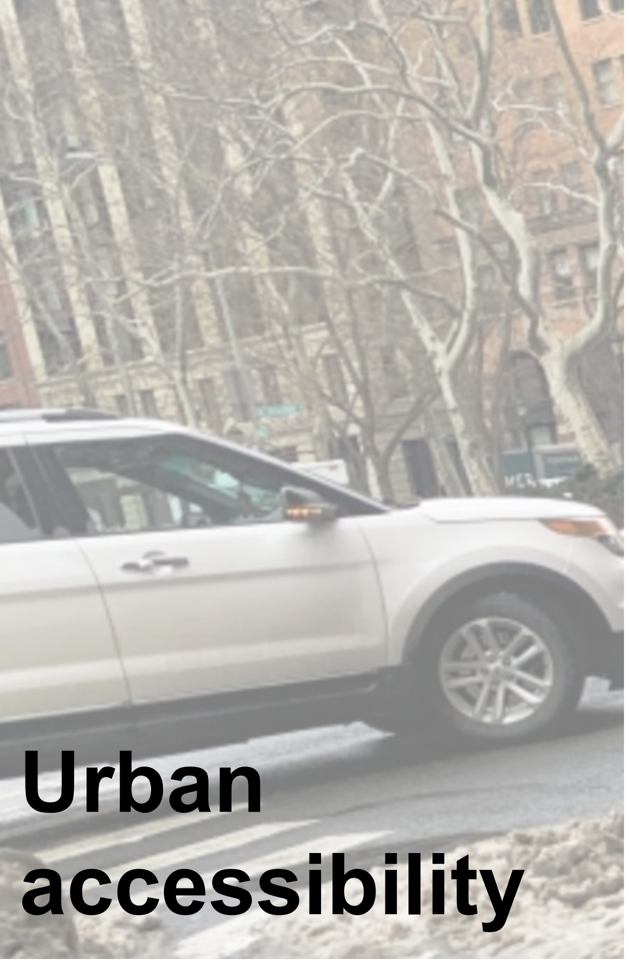
Diverse users

Diverse data

Diverse users

Diverse data

Diverse problems



Diverse problems

Diverse users

Diverse data

UIC COMPUTER SCIENCE


Visual Analysis of Uncertainty in Trajectories [Lu et al., 2014]
TrajGraph [Huang et al., 2015]
SemanticTraj [Al-Dohuki et al., 2016]
Spatiotemporal Statistical Data [Kim et al., 2017]
Forecasting Road Traffic Congestion [Lee et al., 2019]
A study of new york city taxi trips [Ferreira et al., 2013]
MaraVis [Li et al., 2020]
SEEVis [Li et al., 2020]
Air Pollution Problem in Hong Kong [Qu et al., 2007]
Air Temperature [Gautier et al., 2020]
Urban Mosaic [Miranda et al., 2020]
Location2vec [Zhu et al., 2019]
A correlative analysis process in a visual analytics environment [Malik et al., 2012]
HydroQual [Accorsi et al., 2014]
Shadow accrual maps [Miranda et al., 2018]
Urban Pulse [Miranda et al., 2016]

Urban visual analytics surveys

Visual Analytics in Urban Computing: An Overview

Yixian Zheng, Wenchao Wu, Yuanzhe Chen, Huamin Qu, *Member, IEEE*, and Lionel M. Ni, *Fellow, IEEE*

Abstract—Nowadays, various data collected in urban context provide unprecedented opportunities for building a smarter city through urban computing. However, due to heterogeneity, high complexity and large volumes of these urban data, analyzing them is not an easy task, which often requires integrating human perception in analytical process, triggering a broad use of visualization. In this survey, we first summarize frequently used data types in urban visual analytics, and then elaborate on existing visualization techniques for time, locations and other properties of urban data. Furthermore, we discuss how visualization can be combined with automated analytical approaches. Existing work on urban visual analytics is categorized into two classes based on different outputs of such combinations: 1) For *data exploration and pattern interpretation*, we describe representative visual analytics tools designed for better insights of different types of urban data. 2) For *visual learning*, we discuss how visualization can help in three major steps of automated analytical approaches (i.e., cohort construction; feature selection & model construction; result evaluation & tuning) for a more effective machine learning or data mining process, leading to sort of artificial intelligence, such as a classifier, a predictor or a regression model. Finally, we outlook the future of urban visual analytics, and conclude the survey with potential research directions.

Index Terms—Urban computing, visual analytics, visualization, visual learning, spatio-temporal, multivariate

1 INTRODUCTION

WITH the development of science and technology, urbanization process has been accelerating worldwide, which on one hand improves people's life quality, on the other hand gives rise to serious problems, such as environmental pollution, traffic congestion and ever-increasing

quite a few issues which have not been addressed satisfactorily. Recently, Zheng et al. [3] presented a survey on urban computing, which introduced general framework, key research problems, methodologies, and applications mainly based on automated data mining approaches. However, as

> 150 papers (Zheng et al., 2016)

A survey of urban visual analytics: Advances and future directions

Zikun Deng[1], Di Weng[2] (✉), Shuhan Liu[1], Yuan Tian[1], Mingliang Xu[3,4], and Yingcai Wu[1] (✉)

Abstract Developing effective visual analytics systems demands care in characterization of domain problems and integration of visualization techniques and computational models. Urban visual analytics has already achieved remarkable success in tackling urban problems and providing fundamental services for smart cities. To promote further academic research and assist the development of industrial urban analytics systems, we comprehensively review urban visual analytics studies from four perspectives. In particular, we identify 8 urban domains and 22 types of popular visualization, analyze 7 types of computational method, and categorize existing systems into 4 types based

knowledge and expertise into the analysis loop. Thus, urban visual analytics [7] is used to empower urban experts using a combination of intuitive data visualization and fast computational methods, enabling experts to visually and interactively perceive, explore, manipulate, and reason about urban data [8].

When developing an urban visual analytics approach, practitioners like urban analysts and researchers may have the following four questions:

1. Which urban *domain problems* have been solved or remain unsolved by visual analytics?
2. What *visualization* techniques have been applied to visually interpret urban data?

> 200 papers (Deng et al., 2022)

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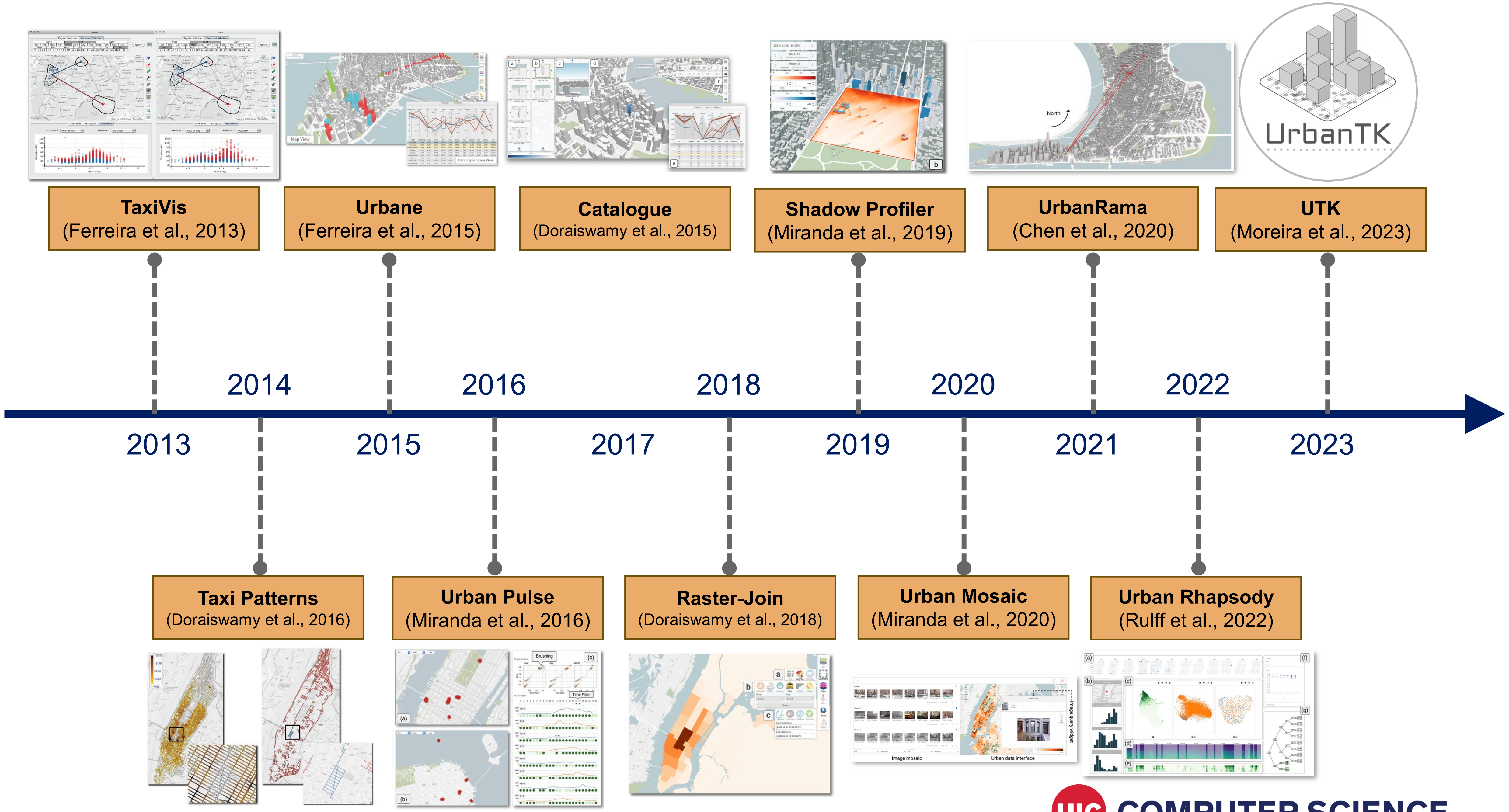

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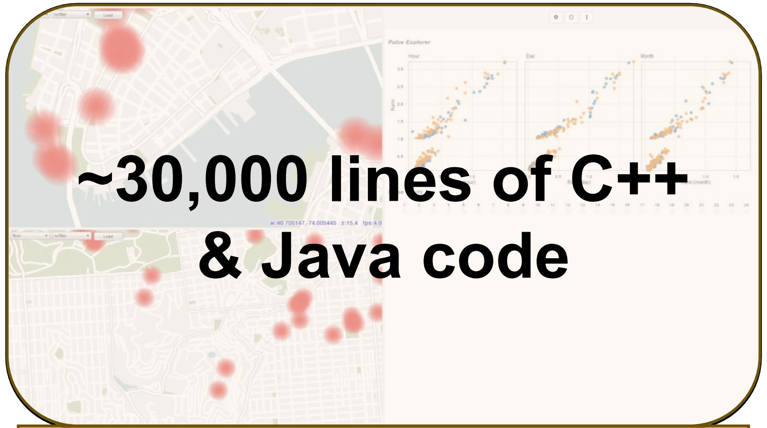
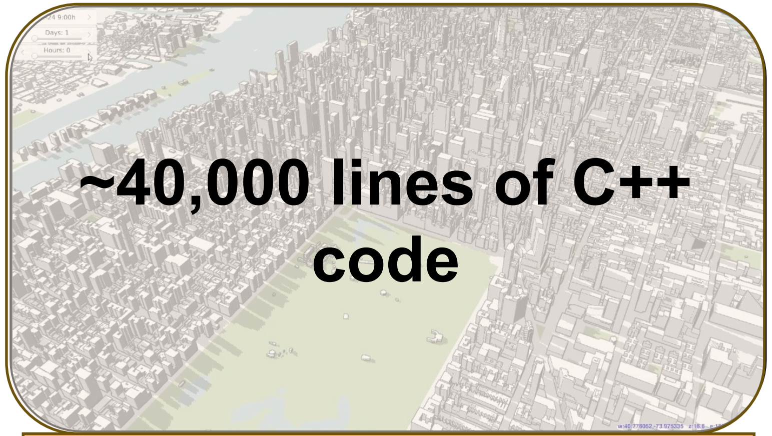
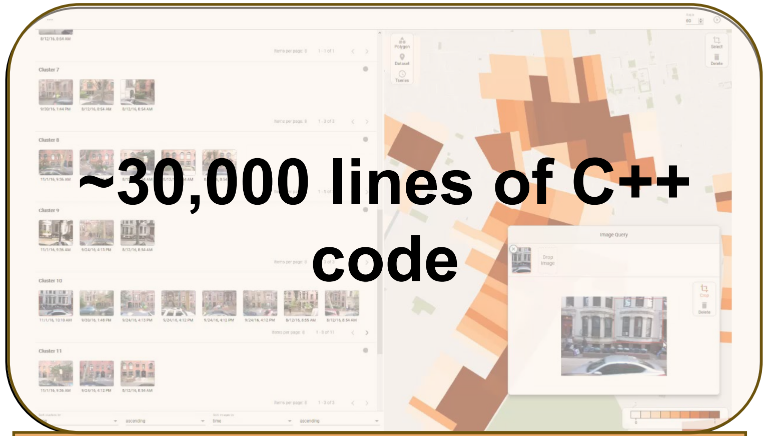


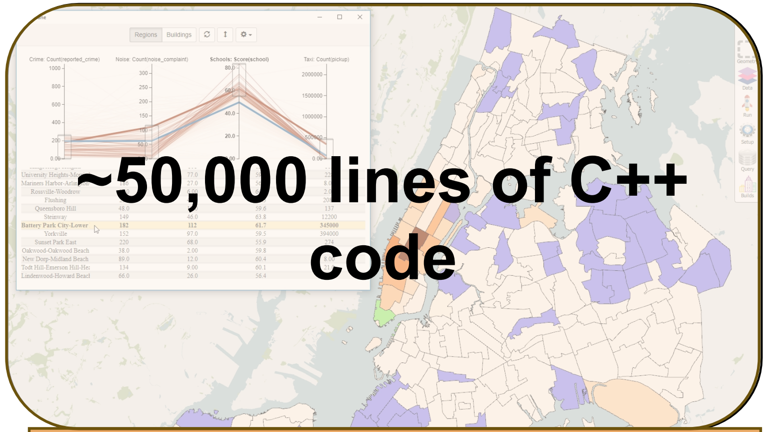
Urban Pulse:
Large-scale data mining of social media data



Shadow Profiler:
City-scale assessment of sunlight access



Urban Mosaic:
Interactive exploration of large imagery data



Urbane:
Interactive exploration of large data

Current state of urban tools

Lack of flexibility:
Tools and techniques are not translatable to other domains or regions
(Acuto et al., 2018)

Lack of extensibility:
Hard to add new functionalities needed for specific workflows
(Lobo et al., 2020)

Lack of reproducibility:
Results are rarely reproducible
(Ziegler and Chasins, 2023)

Lack of scalability:
Analyses are rarely interactive, limiting the number of hypothesis from the exploratory process
(Ziegler and Chasins, 2023)

Lack of accessibility:
Tools and techniques are often difficult to use, limiting stakeholders' ability to conduct large-scale analysis
(Kontokosta, 2021)

How to support (1) accessible, (2) flexible, (3) extensible, (4) reproducible and (5) scalable tools across domains and users?

UrbanTK

```cpp
#include "UrbaneMapView.hpp"

#include <QApplication>
#include "../MapView/BuildingRenderingLayer.hpp"

#include "../MassingGeneration/massinggeneration.h"
#include "../Util/ColorMapDivergent.hpp"
#include "UrbaneManager.hpp"

#include <QElapsedTimer>
#include <QThread>
#include <QDir>

#include <vector>

UrbaneMapView::UrbaneMapView(const QString &filename, const QRectF &vp, QWidget *parent)
    : MapView(filename,vp,parent), graphLayer(NULL)
{
    initialized = false;
    skyExposureData = false;
    this->centerIndex = GridIndex(1024,1024);
    this->currentLayer = NULL;
    this->lotUpdate = true;
}

UrbaneMapView::~UrbaneMapView() {}

void UrbaneMapView::initializeGL() {
    if(!initialized) {
        MapView::initializeGL();
        this->buildingScore.initComputeShader();
        this->skyScore.initComputeShader();
    }
    initialized = true;
}

void UrbaneMapView::paintGL()
{
    this->showOsd(false);

    // Lot data initialization in manager
    // TODO Don't know of a better place to do this
    if(lotUpdate && this->parcelLayer->isDataReady()) {
        updateLotDataDB();
        lotUpdate = false;
    }

    UrbaneManager *manager = UrbaneManager::getInstance();
    QPair<RenderingOperation, UIOperation> state = manager->getState();

    RenderingOperation operation = state.first;
    UIOperation what = state.second;
    switch(operation) {
    case RenderingOperation::UpdateVis:
    {
        bool updateFunction = false;
```

Abstracts low-level functionalities

Easy access to data analytics

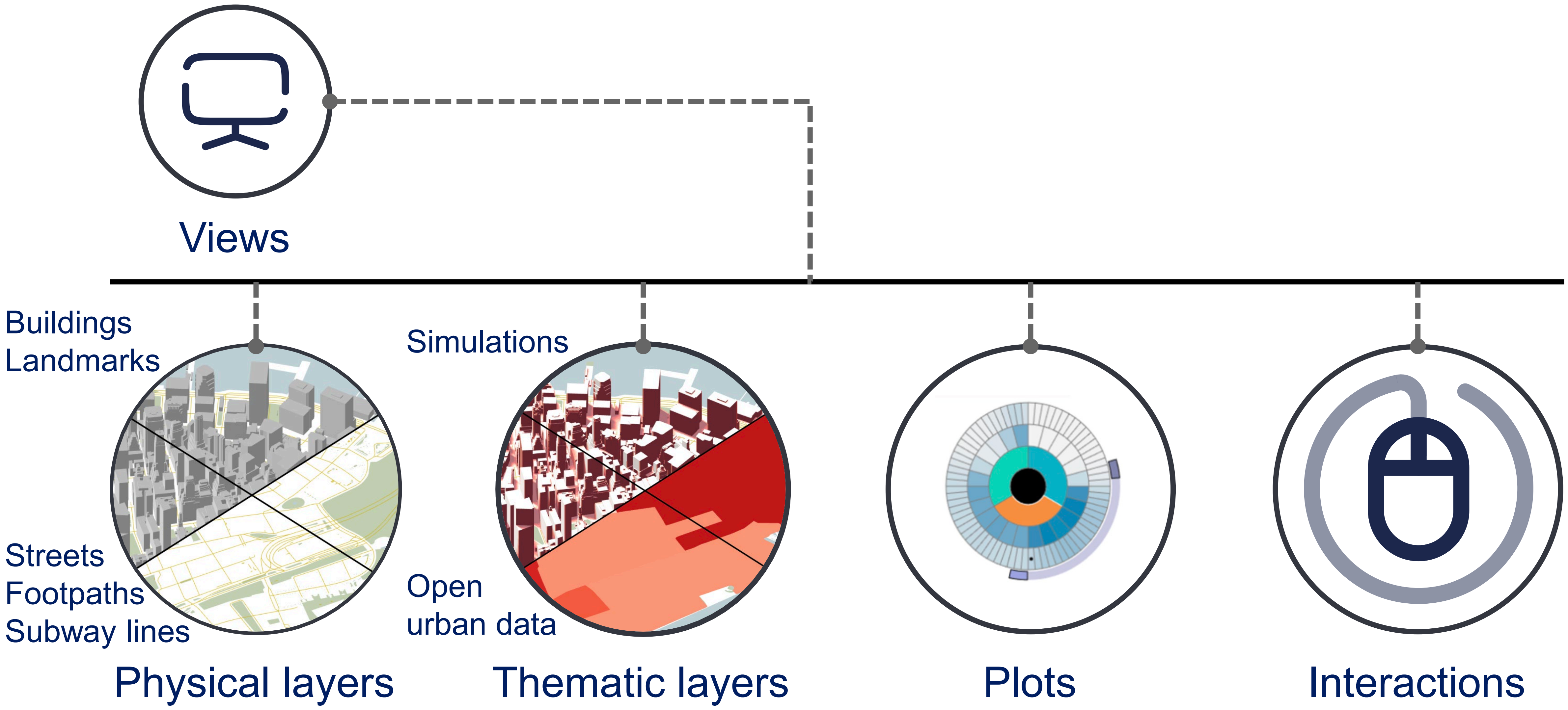
Self-contained & sharable JSON file

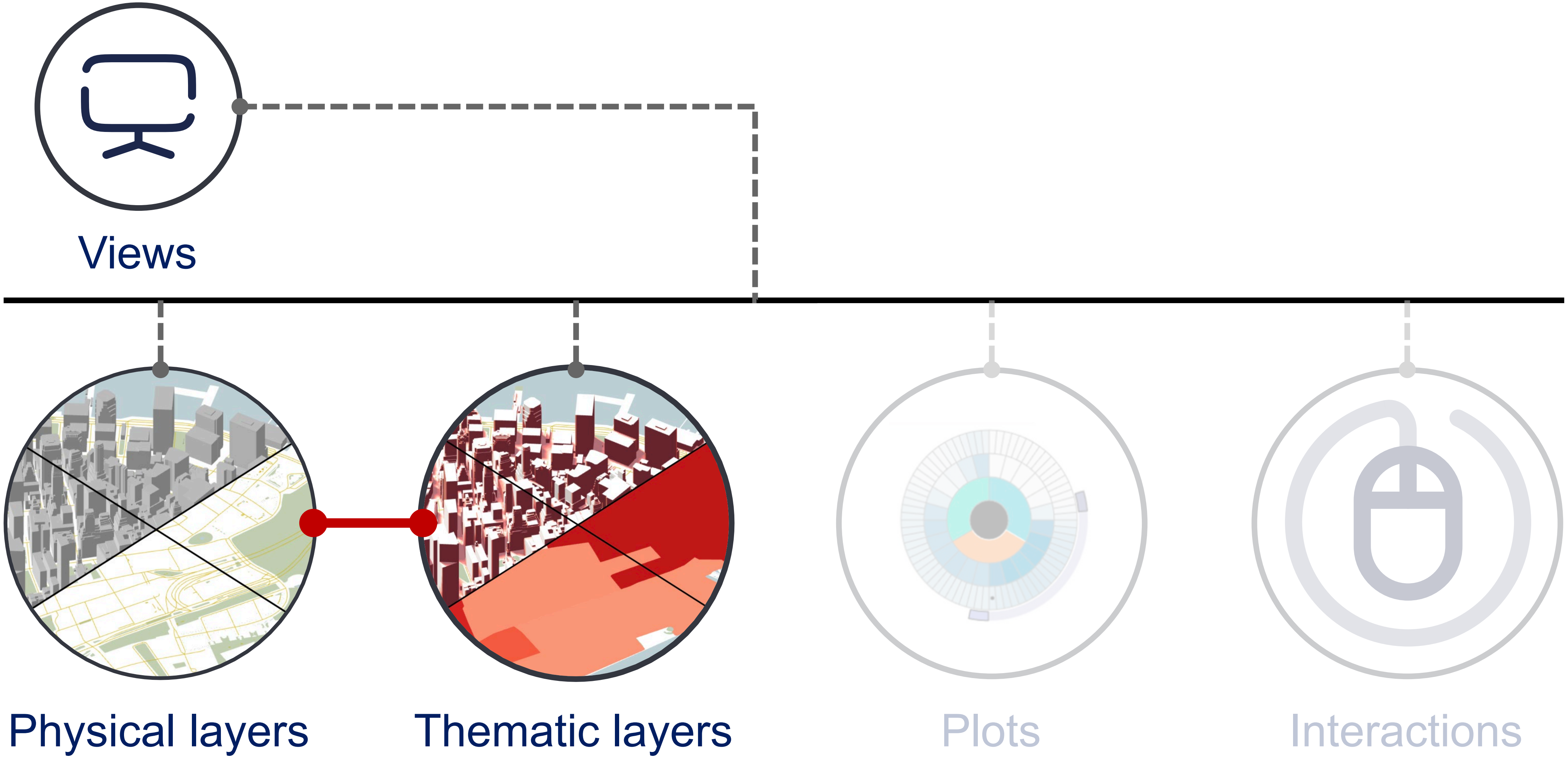
Lower the barrier for the construction of urban tools & systems

Views

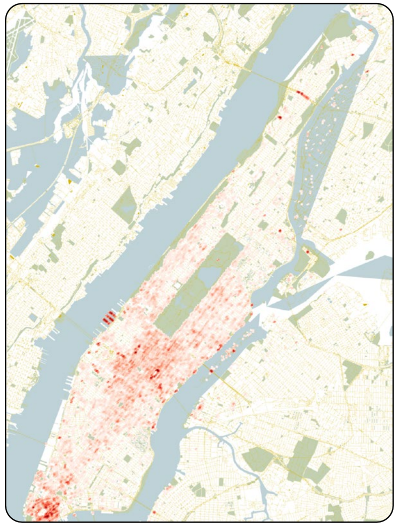
```
{
  “views": [
    {
      "map": {
        "camera": {
          "position": […],
          "direction": {…}
        },
        …
      },
      "plots": […],
      "knots": […]
    }
  ]
}
```

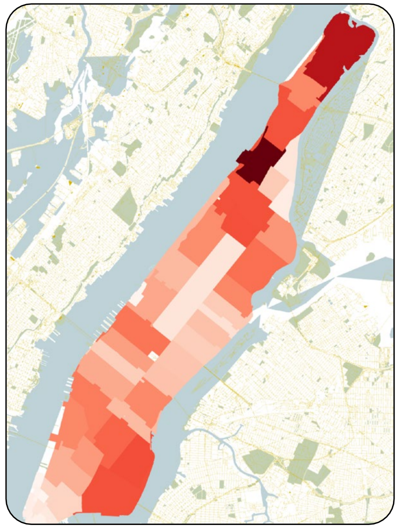
JSON


Views
Buildings
Landmarks
Streets
Footpaths
Subway lines
Physical layers
Simulations
Open
urban data
Thematic layers
Plots
Interactions

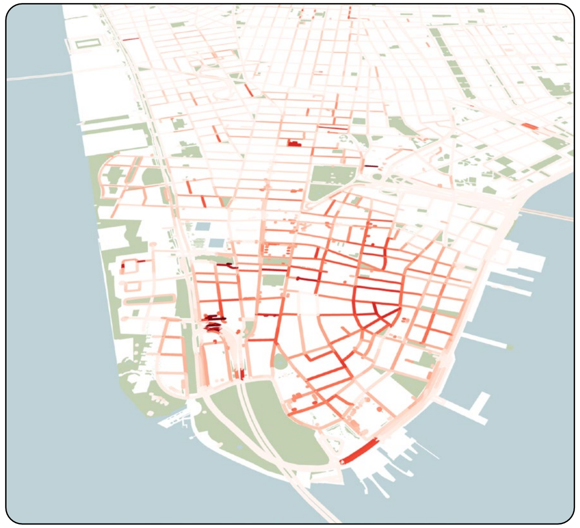

Views
Physical layers
Thematic layers
Plots
Interactions

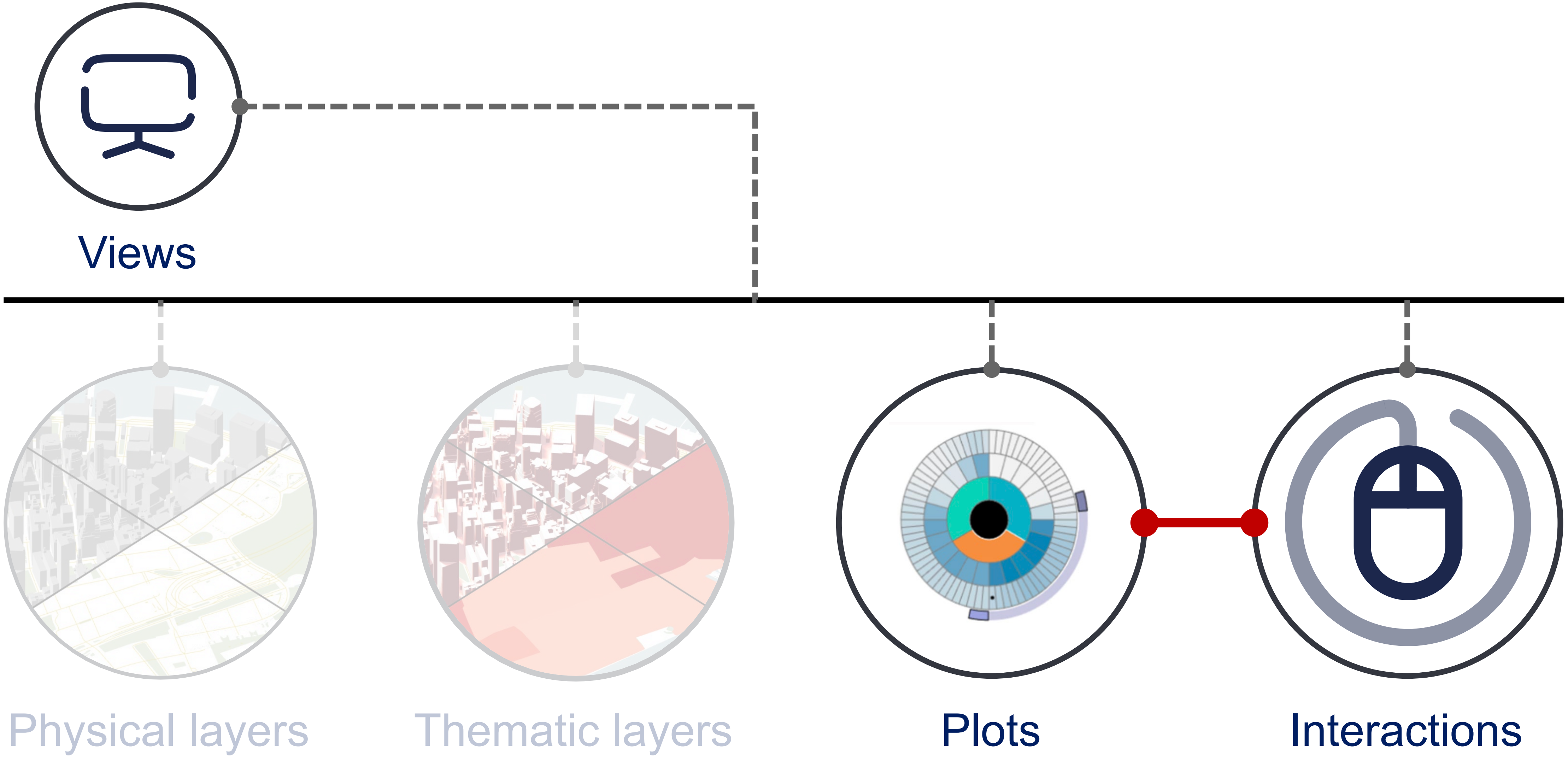
Views


Grid

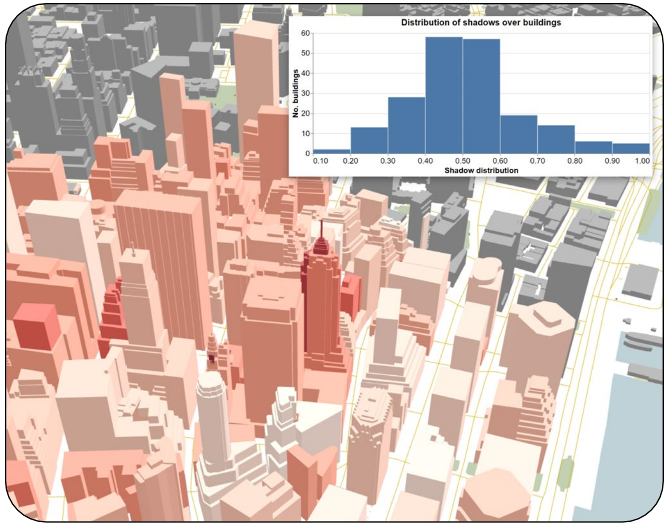

Areas


Buildings

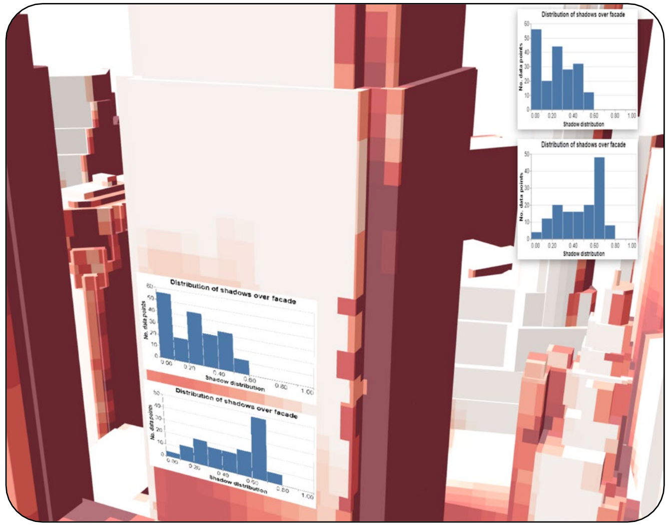

Networks


Views
Physical layers
Thematic layers
Plots
Interactions

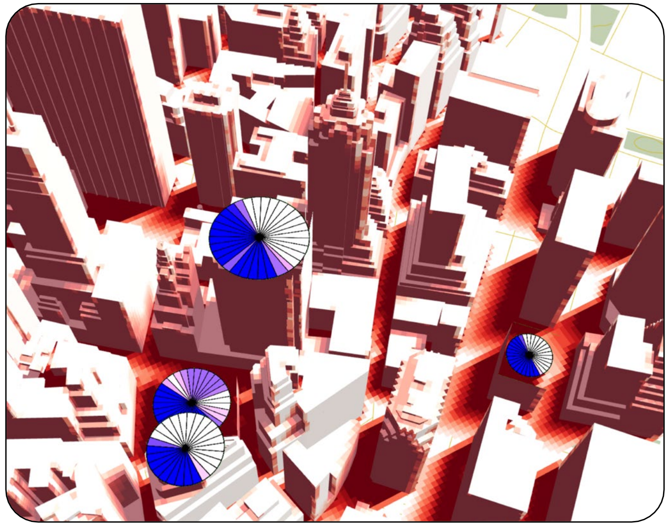
Views



Juxtaposed



Embedded (surface)

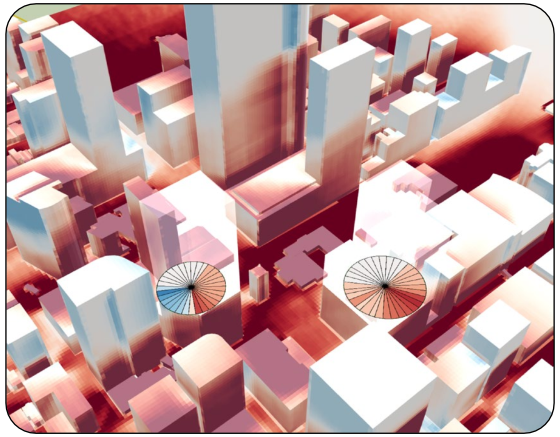


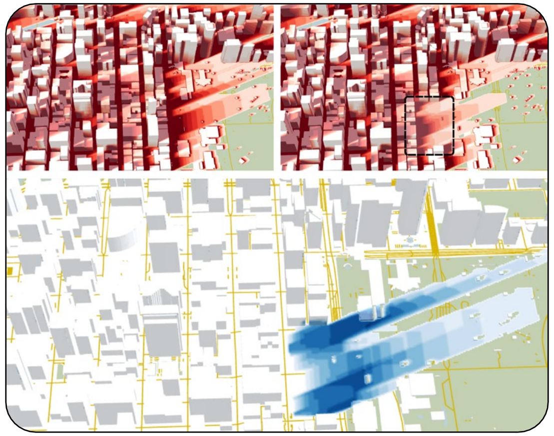
Embedded (crosscut)

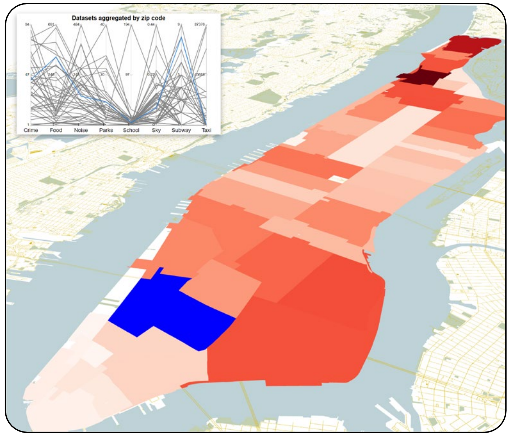
Taxonomy by Mota et al. (VIS 2022)

Operating with layers

Arithmetic operations	Logical operations	What-if analyses	Data exploration
+ -	> ?	x	, ,







text tree table

Line: 1 Column: 2

Editing the JSON specification

Visualization

Invalid/Empty grammar specification

Apply Grammar Link

Search place

Data functionalities

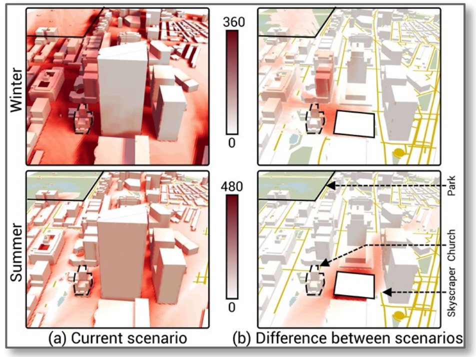
- Converting data: Pandas' DataFrame, GeoJSON, shapefile, CSV and Protocolbuffer Binary Format (PBF).
- Loading data: OpenStreetMap (OSM).
- Generating data: Sunlight access simulation (Miranda et al., TVCG 2018).

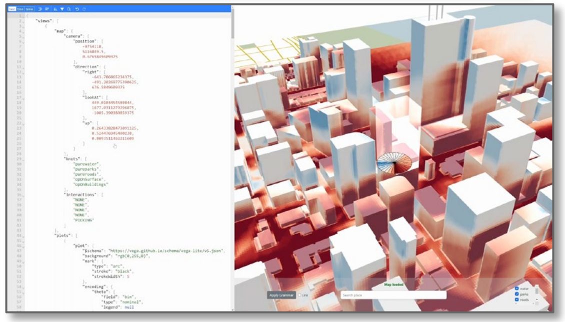
```
import utk
uc = utk.OSM.load('Chicago,USA', layers=['buildings'])
uc.save('chicago')
uc.view()
```

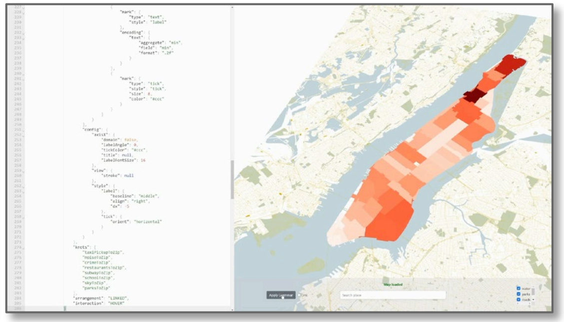
Evaluation

Case studies

- Motivated by real-world problems
- Inspired by previous collaborations

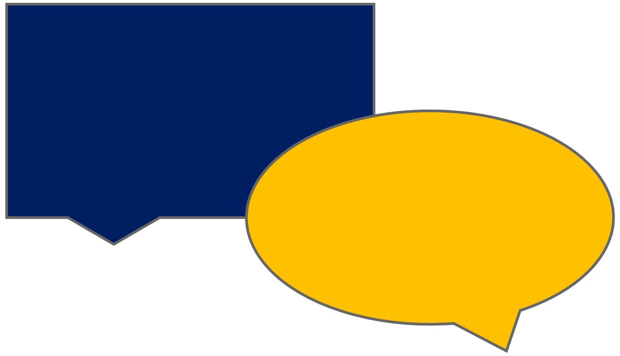






Experts' feedback

- One-hour semi-structured interviews
- Their perspectives on UTK's usability, limitations and needed features



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                            }
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                            }
                        }
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                    }
                }
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            "noiseToZip",
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            "restaurantsToZip",
            "subwayToZip",
            "schoolToZip",
            "skyToZip",
            "parksToZip"
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        "interaction": "HOVER"
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],
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        "linkingScheme": [
            {
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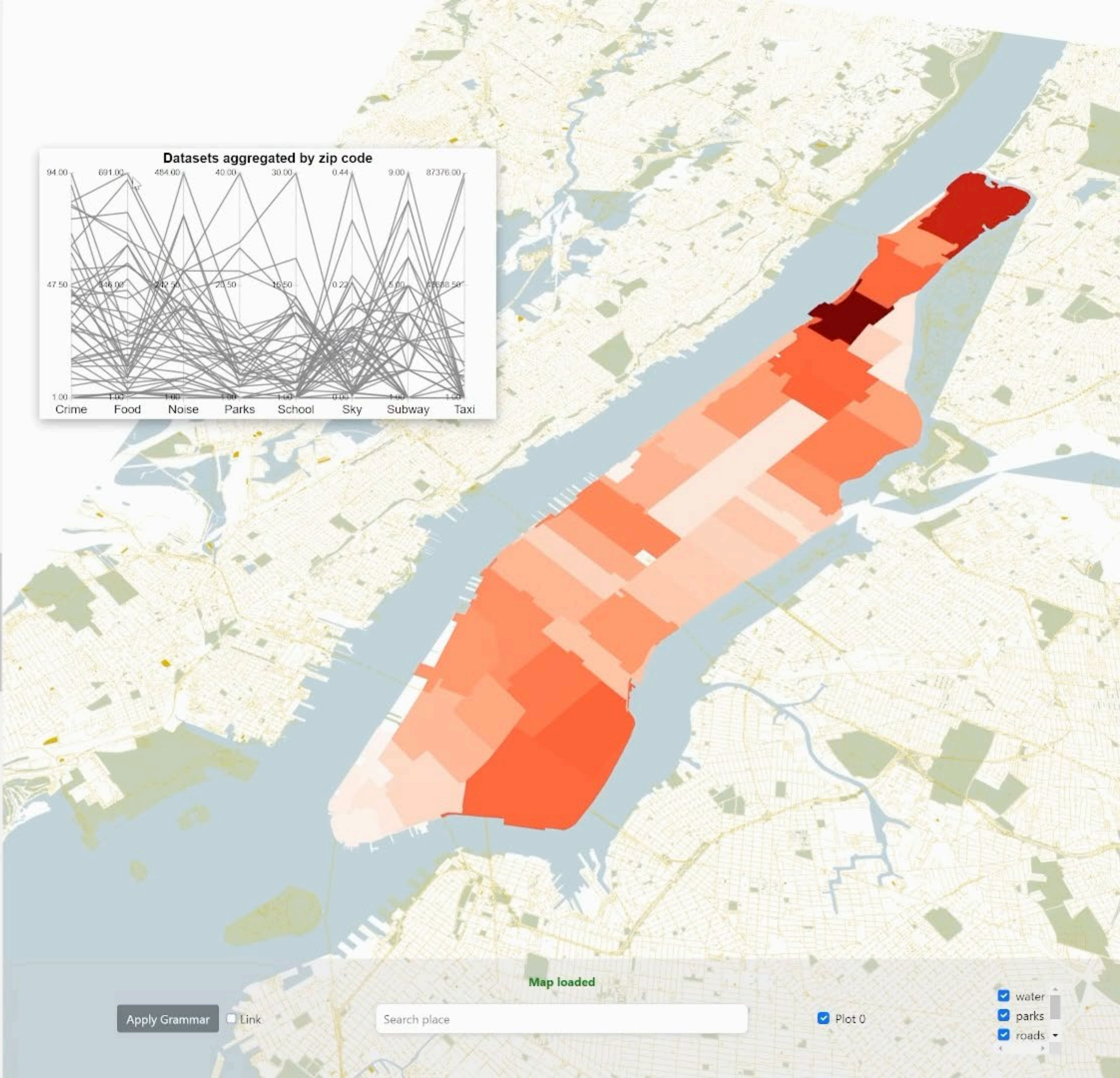
```



text tree table


```
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                        5116849.5,
                        0.6765849609375
                    ],
                    "direction": {
                        "right": [
                            -643.786865234375,
                            -491.20269775390625,
                            676.5849609375
                        ],
                        "lookAt": [
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                            1677.0311279296875,
                            -1085.390380859375
                        ],
                        "up": [
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                            0.524476945400238,
                            0.8093511462211609
                        ]
                    }
                },
                "knots": [
                    "purewater",
                    "pureparks",
                    "pureroads",
                    "opOnSurface",
                    "opOnBuildings"
                ],
                "interactions": [
                    "NONE",
                    "NONE",
                    "NONE",
                    "NONE",
                    "PICKING"
                ]
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```


Experts' feedback

"… facilitates engagement not only across disciplines, but also across urban communities" (Weather scientist)

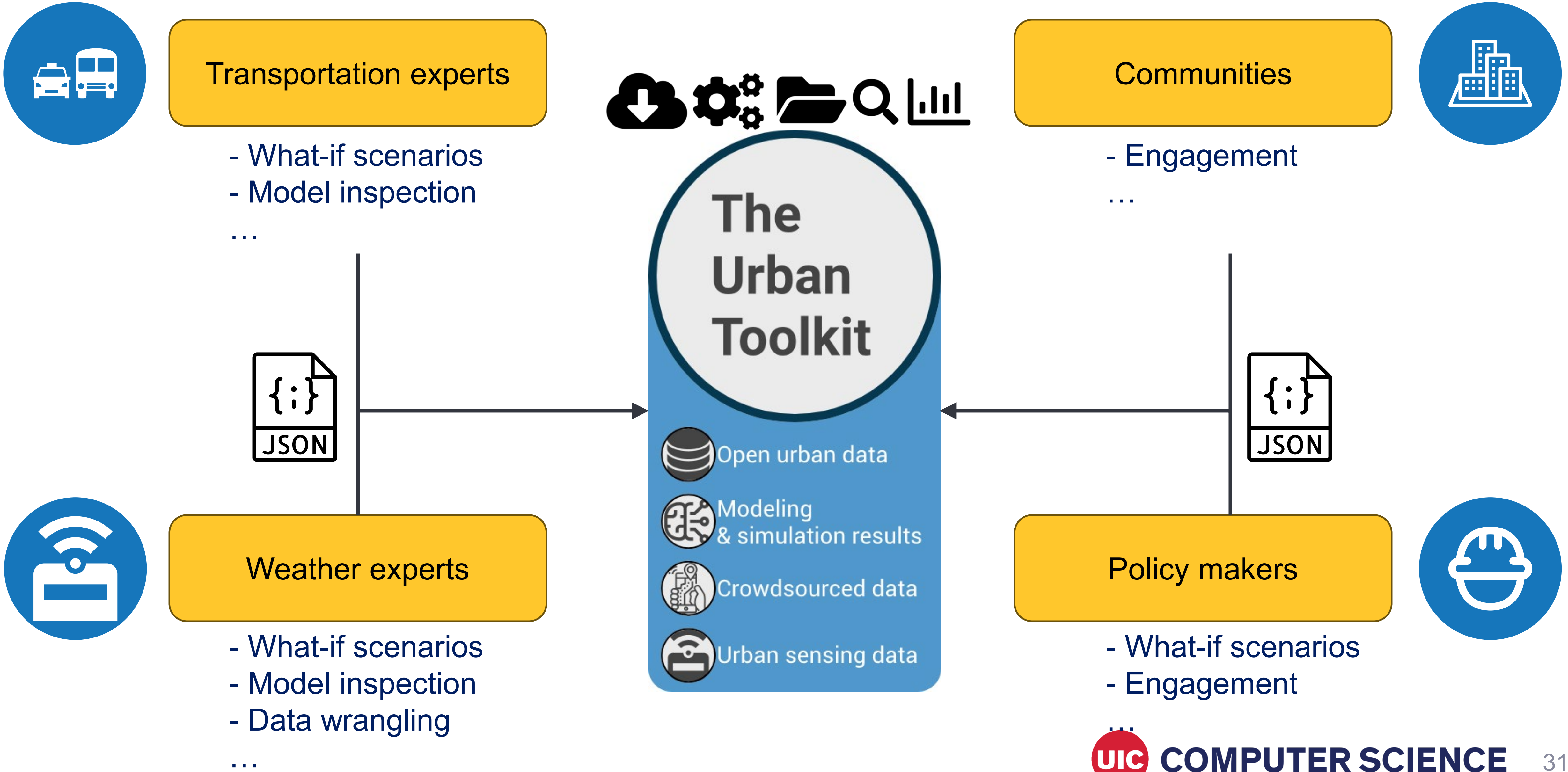
"… researchers could easily share their visualizations instead of cumbersome GIS files" (Urban planner)

"3D makes it more attractive to users and a great tool for communication" (Urban planner)

"It would require training to educate people on the grammar, with examples to showcase its use" (Urban planner)

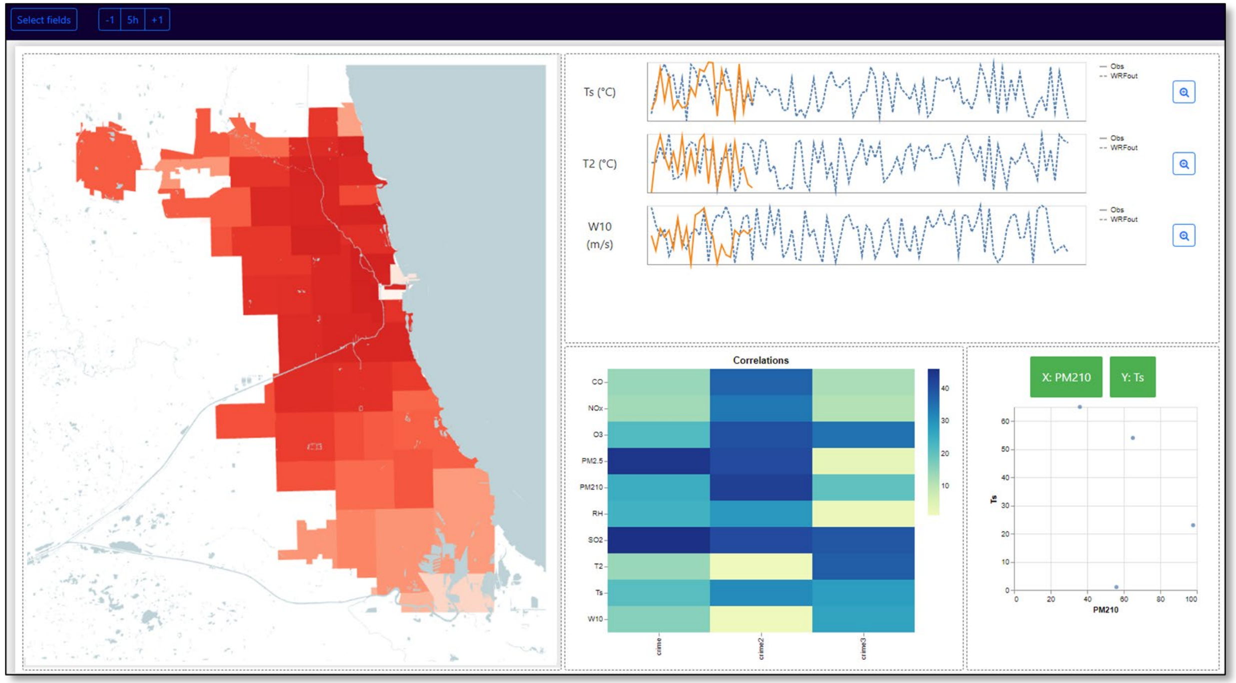
Future opportunities

- Incorporate other functionalities that have been highlighted in previous urban visual analytics works:
  - Computational topology
  - Wavelet
  - Techniques for model inspection


Transportation experts
- What-if scenarios
- Model inspection
…
Communities
- Engagement
…
The Urban Toolkit
Open urban data
Modeling & simulation results
Crowdsourced data
Urban sensing data
JSON
JSON
Weather experts
- What-if scenarios
- Model inspection
- Data wrangling
…
Policy makers
- What-if scenarios
- Engagement
…

Ongoing works extending UTK

Urban accessibility



Environmental justice

UrbanTK

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Nivan Ferreira, Universidade Federal de Pernambuco
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Code & tutorials:
urbantk.org