



SotM BR 2025
STATE OF THE MAP BRASIL



OpenStreetMap

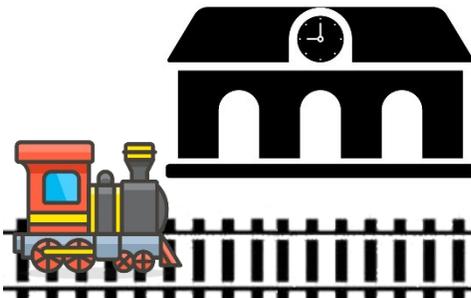


OpenStreetMap para análises de Mobilidade e Acessibilidade: aplicações com OSMnx (Python) e r5r (R)

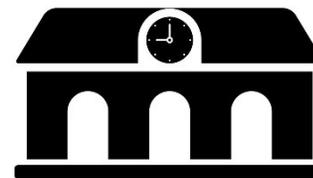
Jorge Ubirajara Pedreira Junior, DSc.
Professor Adjunto - Escola Politécnica da
UFBA

Agenda

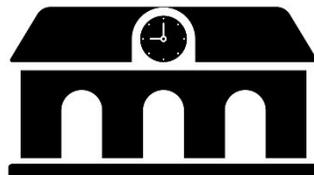
(1) Contexto



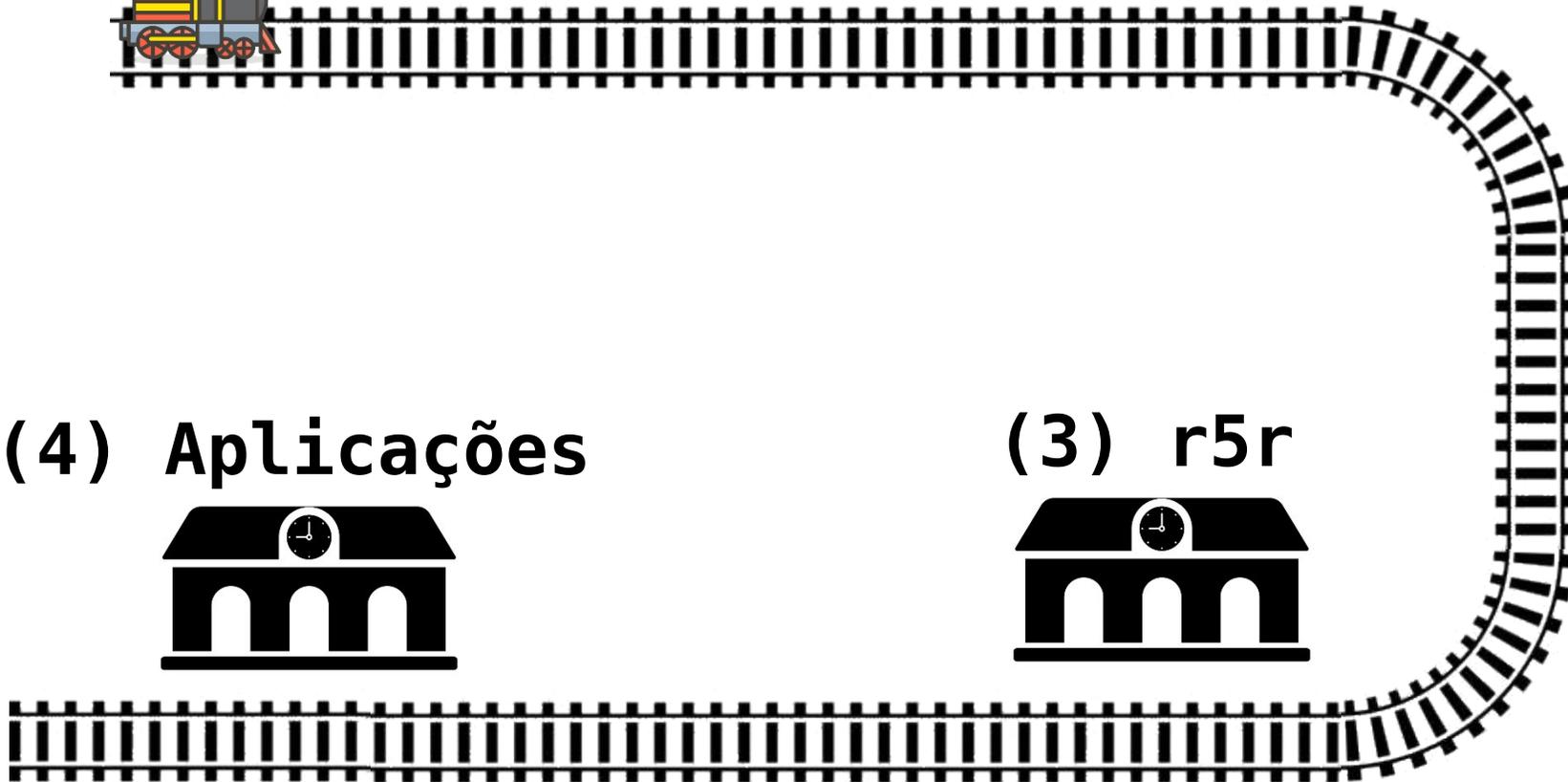
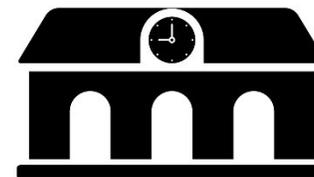
(2) OSMnx



(4) Aplicações



(3) r5r



(1) Contexto



(1) Contexto



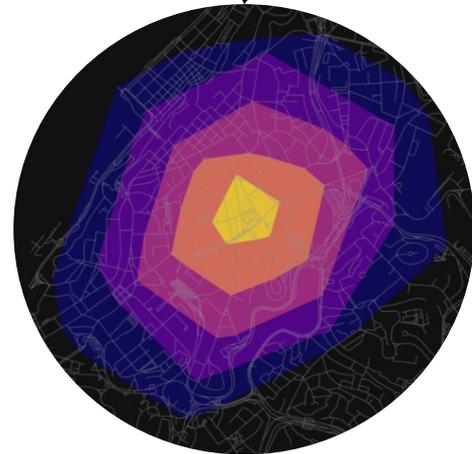
Otimização em
redes



(1) Contexto



Otimização em
redes

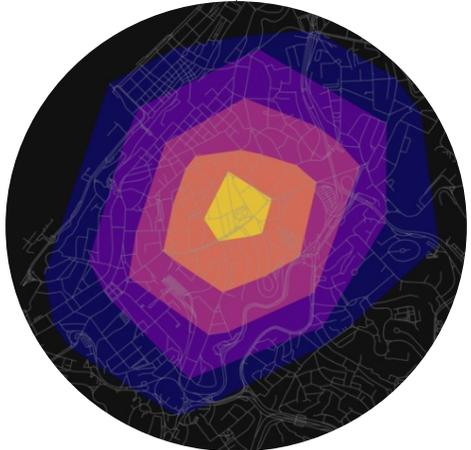


Mobilidad
e

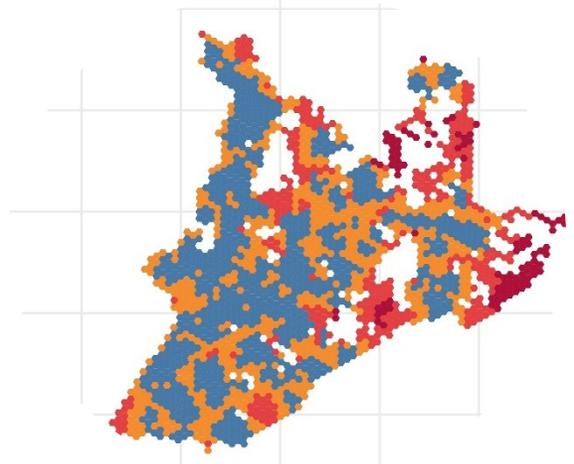
(1) Contexto



Otimização em
redes



Mobilidad
e

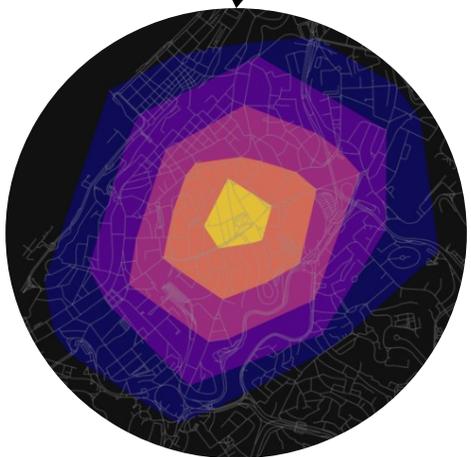


Acessibilidad
e

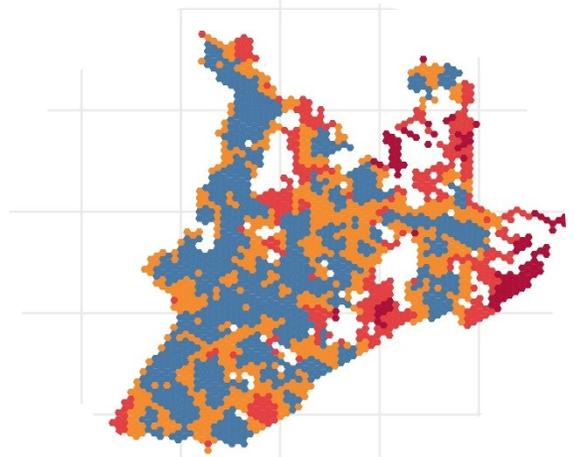
(1) Contexto



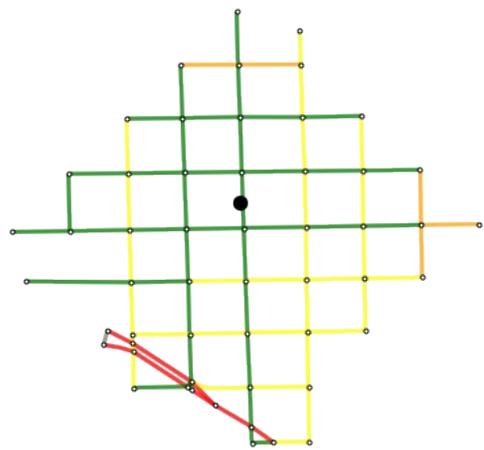
Otimização em redes



Mobilidade e



Acessibilidade e



Conectividade / Centralidade



(1) Contexto

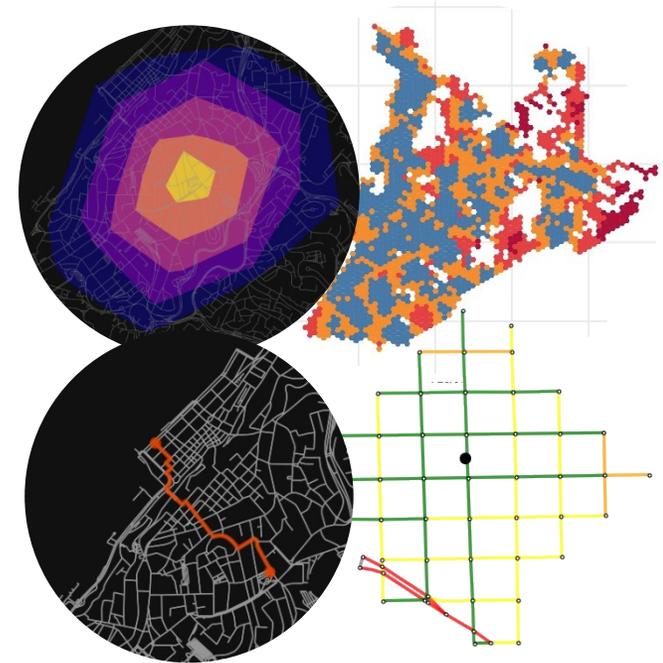


Desafio:



nodes
ways
relations

?

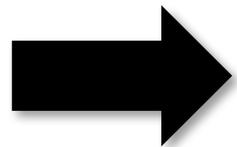


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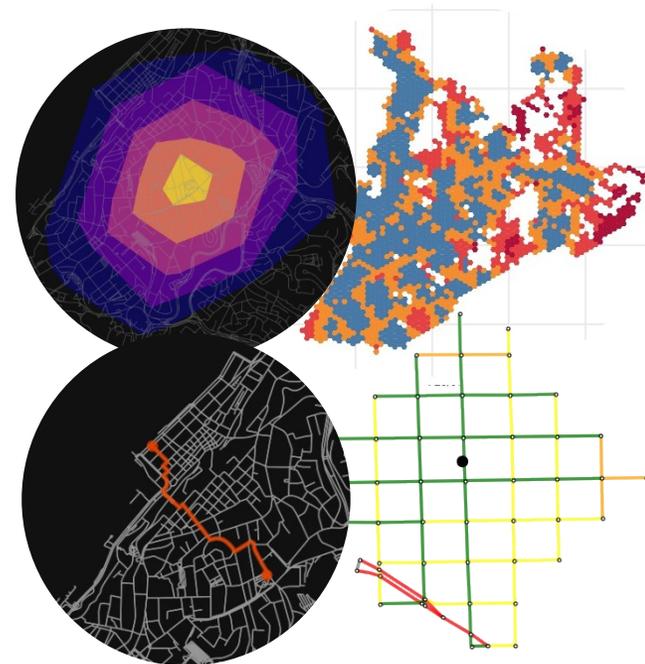
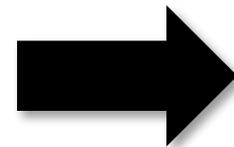
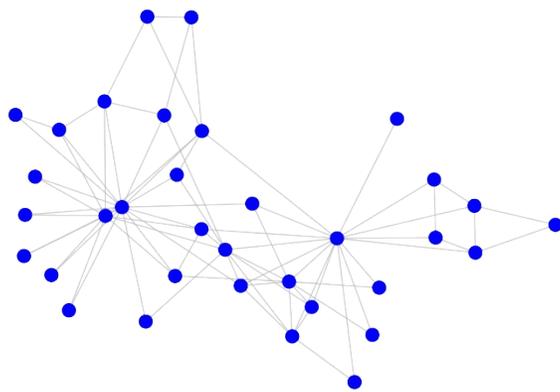
→
Desafio:



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$G(N, A)$

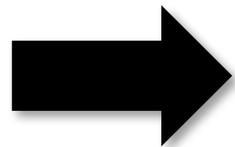


(1) Contexto

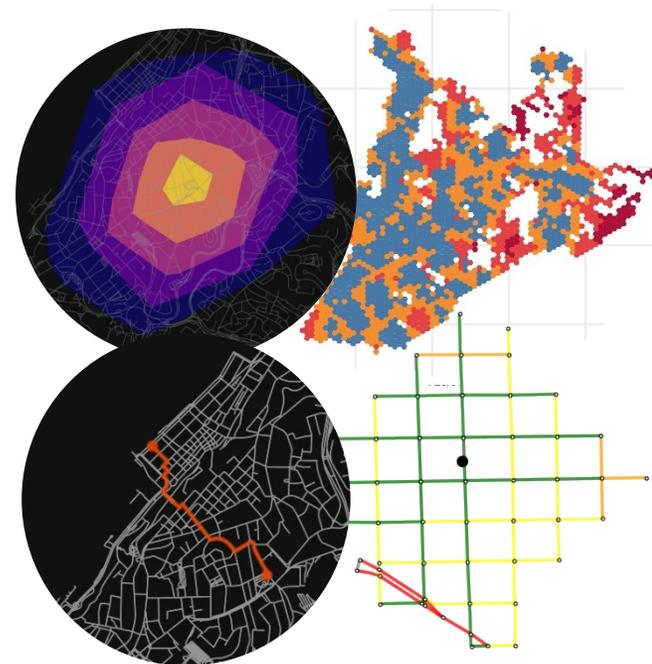
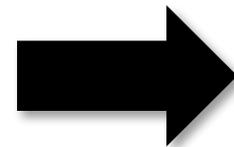
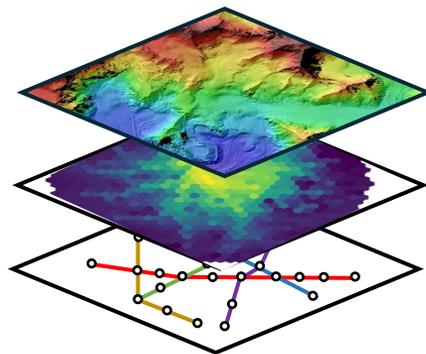
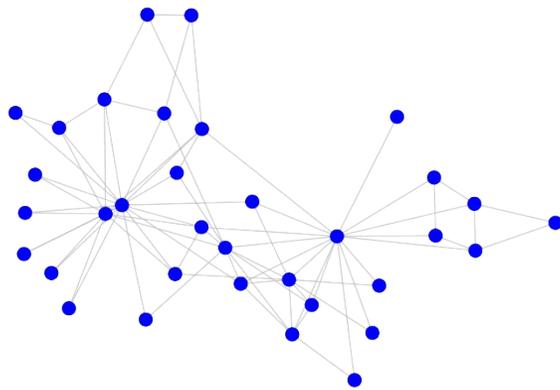
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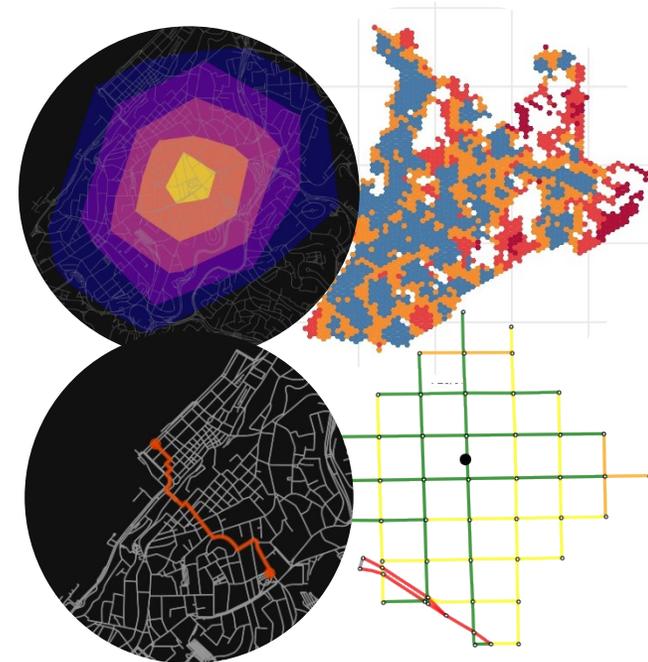
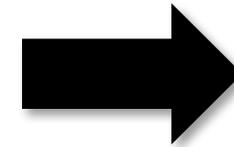
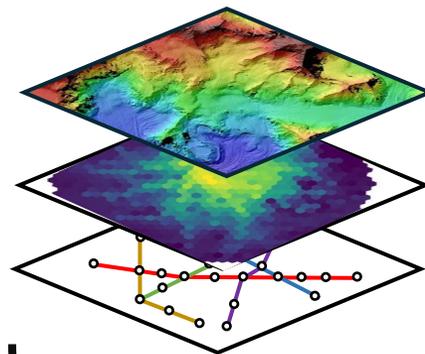
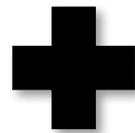
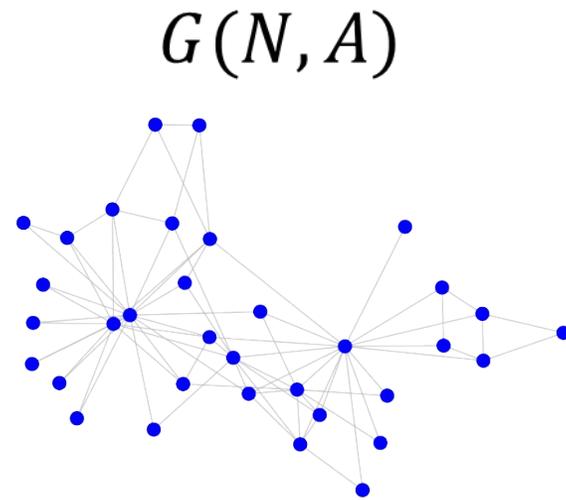
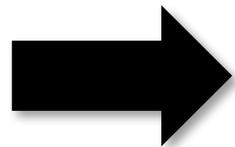


(1) Contexto

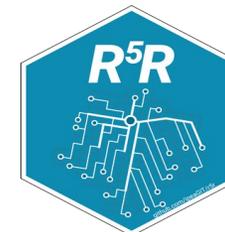
→
Desafio:



nodes
ways
relations



OSMnx

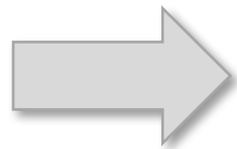


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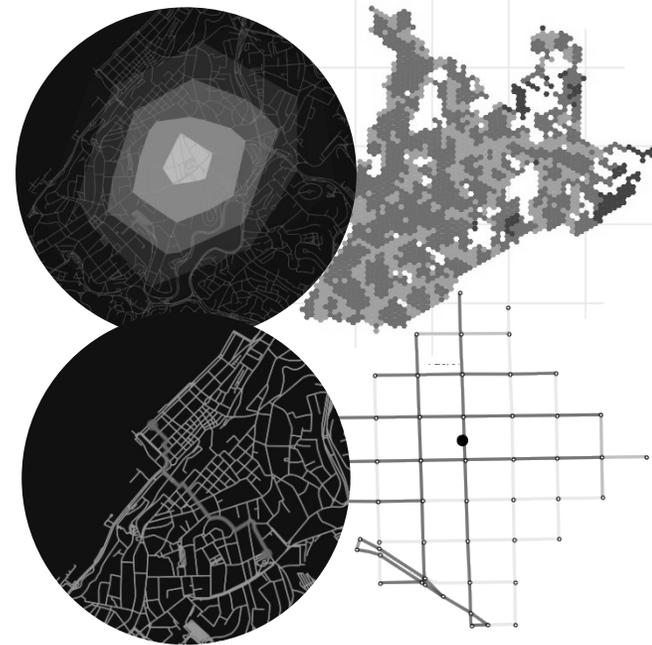
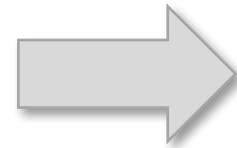
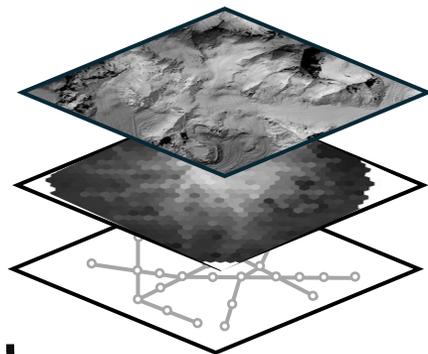
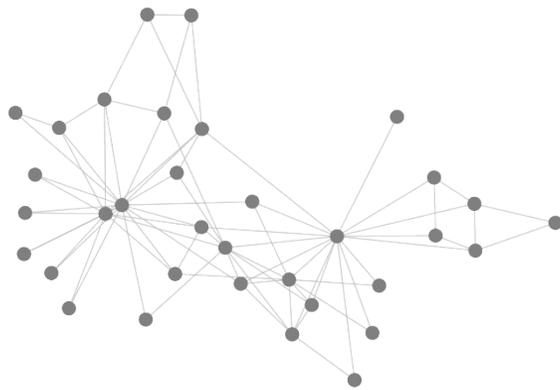
→
Desafio:



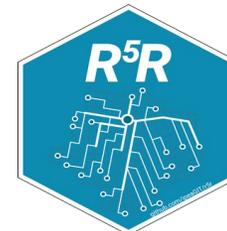
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$G(N, A)$

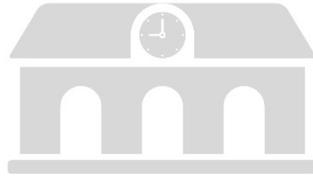


OSMnx

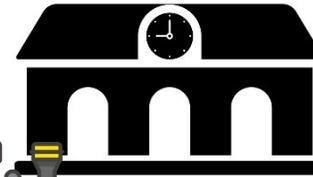


Agenda

(1) Contexto



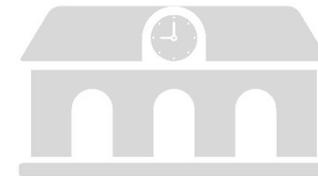
(2) OSMnx



(4) Aplicações



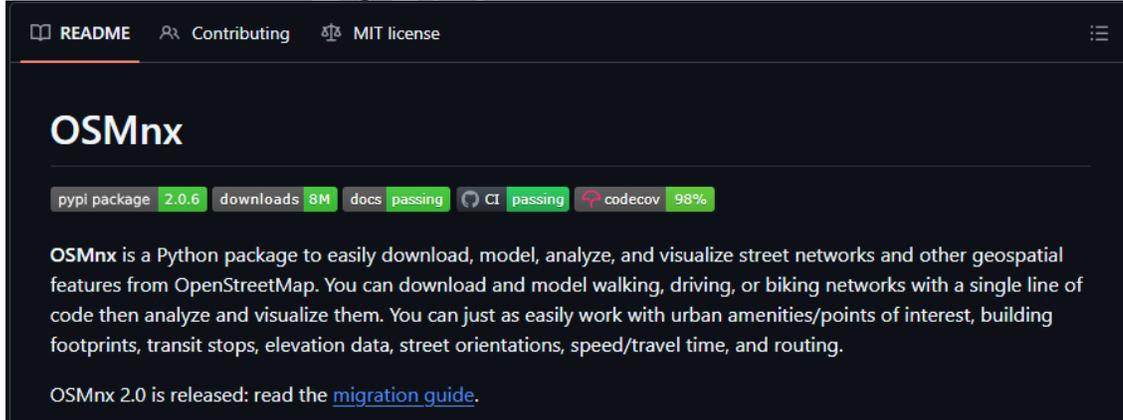
(3) r5r



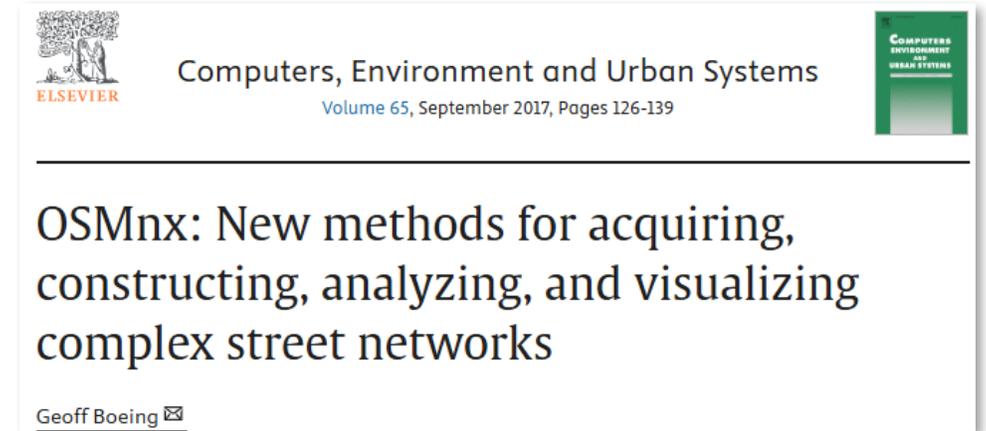


Histórico:

- Versão beta em 2016/Paper em 2017:



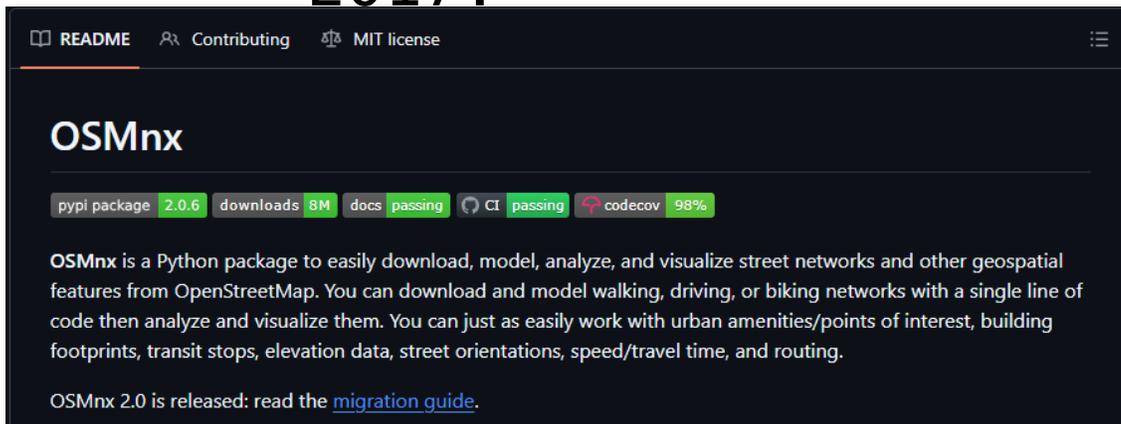
github.com/gboeing/osmnx





Histórico:

- Versão beta em 2016/Paper em 2017:



github.com/gboeing/osmnx

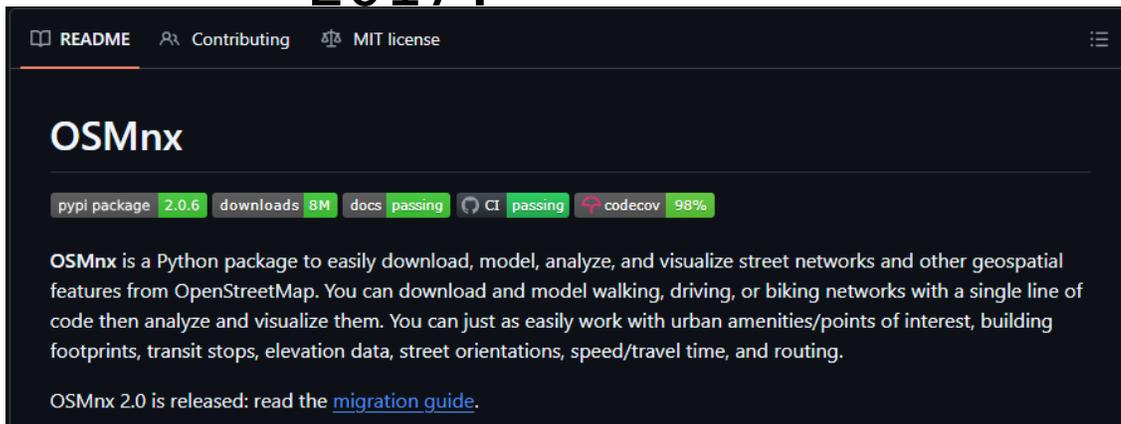


- **Pioneirismo:** 1º a permitir *download* e modelagem da topologia/geometria da rede viária para qualquer cidade.



Histórico:

- Versão beta em 2016/Paper em 2017:



github.com/gboeing/osmnx



- **Pioneirismo:** 1º a permitir *download* e modelagem da topologia/geometria da rede viária para qualquer cidade.
- Desde então, muitas funcionalidades e melhorias de performance incorporadas → API amigável e estável.

(2) OSMnx

→ 0 que acontece nos bastidores:

- Simplificação topológica:



(2) OSMnx

→ 0 que acontece nos bastidores:

- Simplificação topológica:



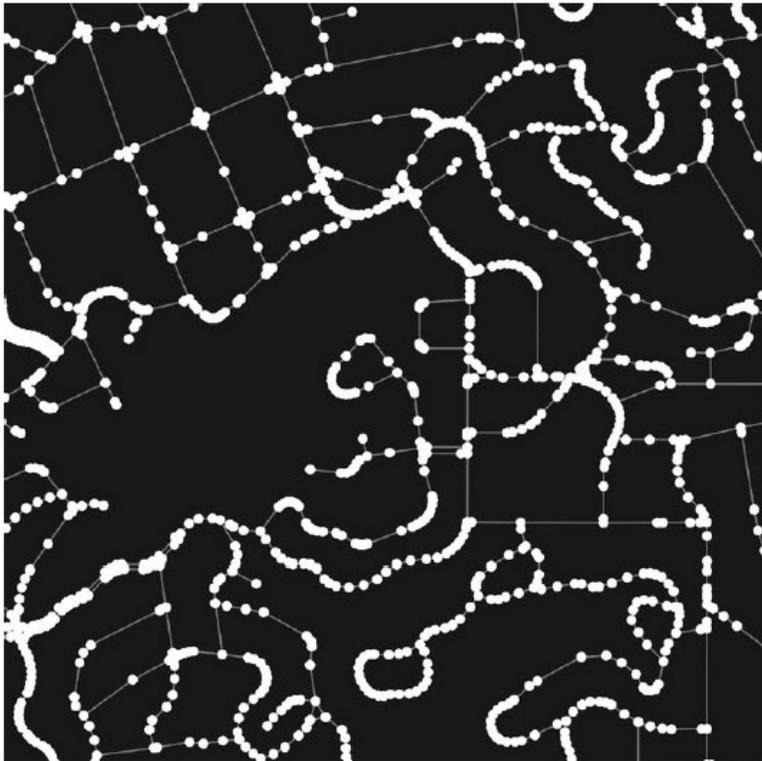
→ Relevância:

- Contagem de interseções

(2) OSMnx

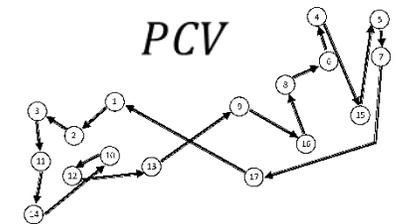
→ 0 que acontece nos bastidores:

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→ Relevância:

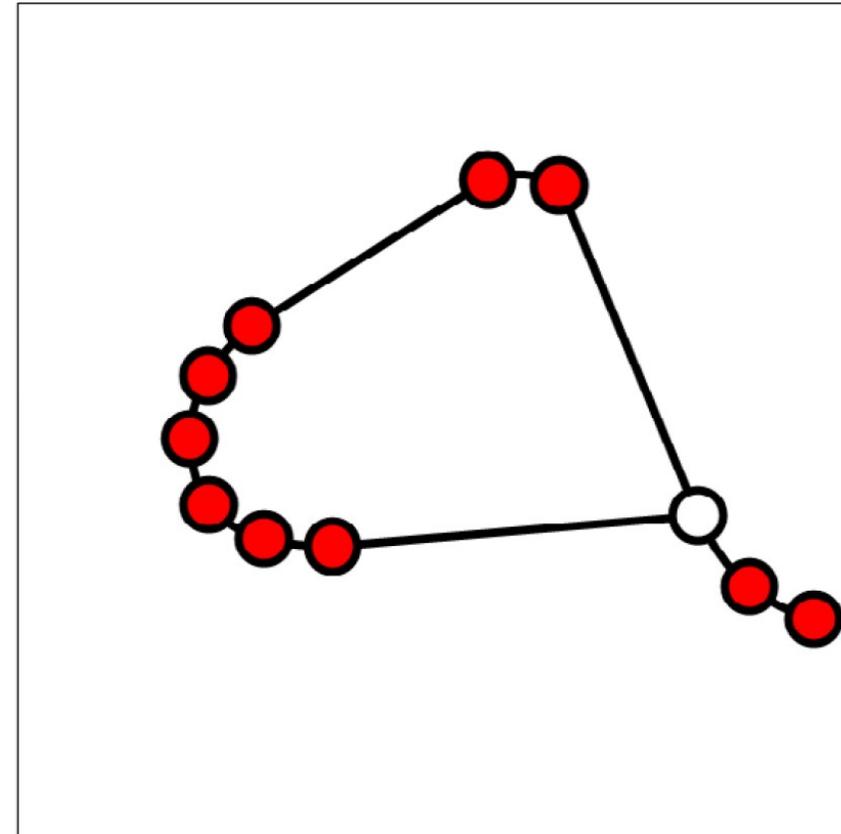
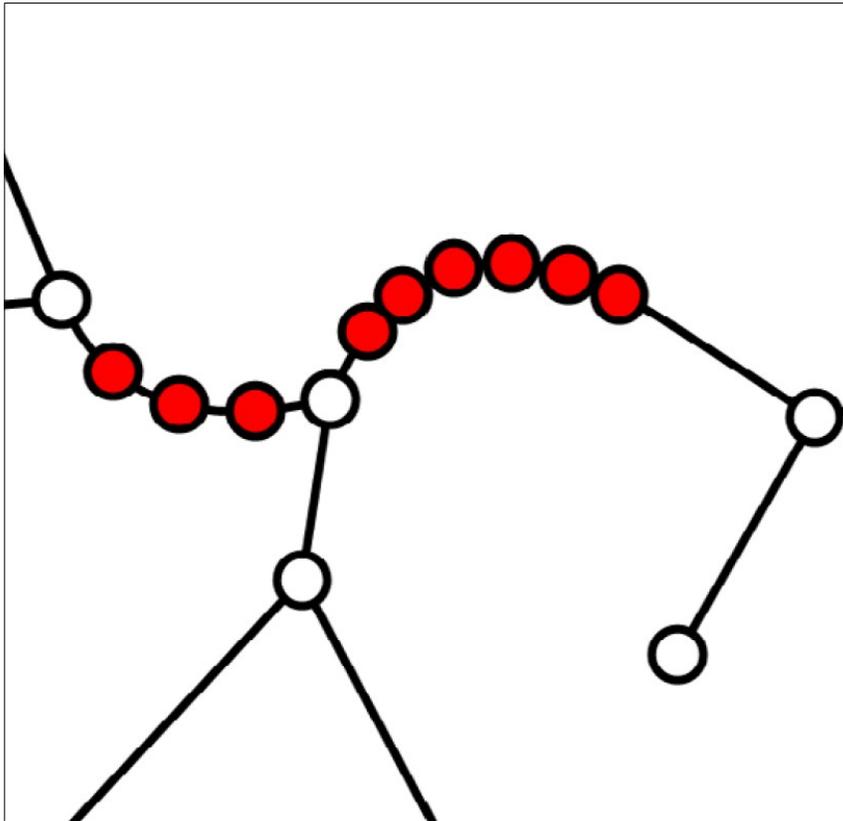
- Contagem de interseções
- Complexidade computacional:



$$O(n^2 2^n)$$

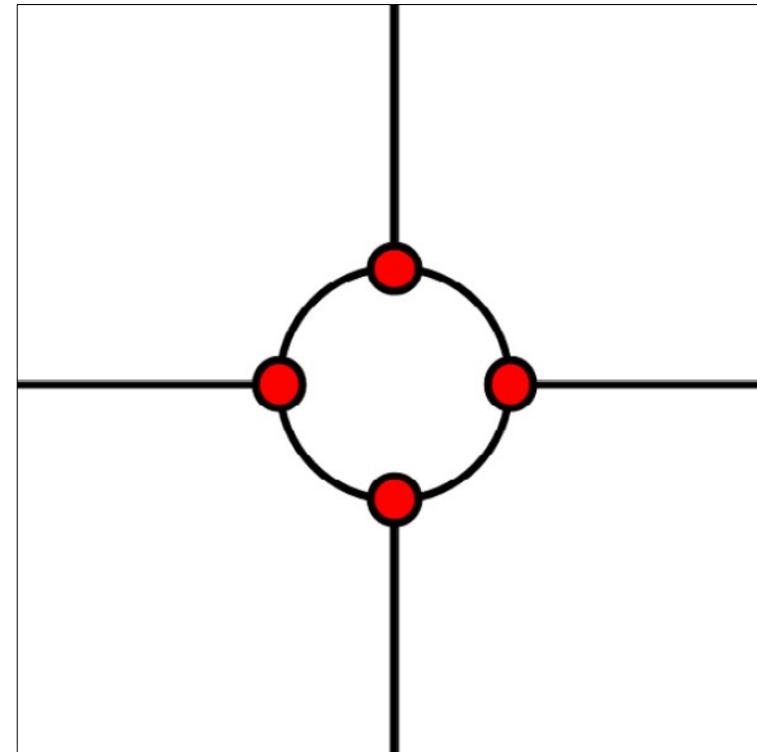
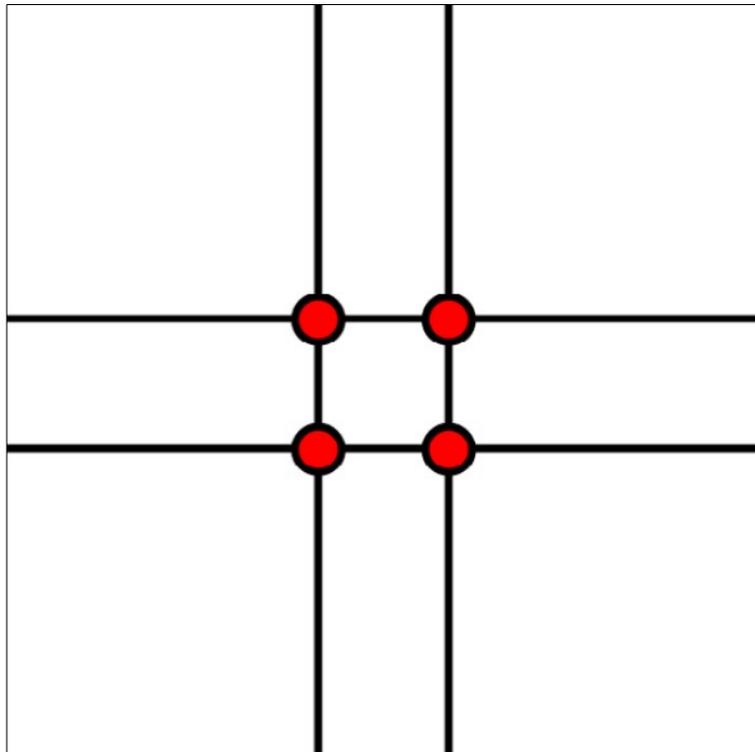
→ 0 que acontece nos bastidores:

(A) Simplificação de Arestas:



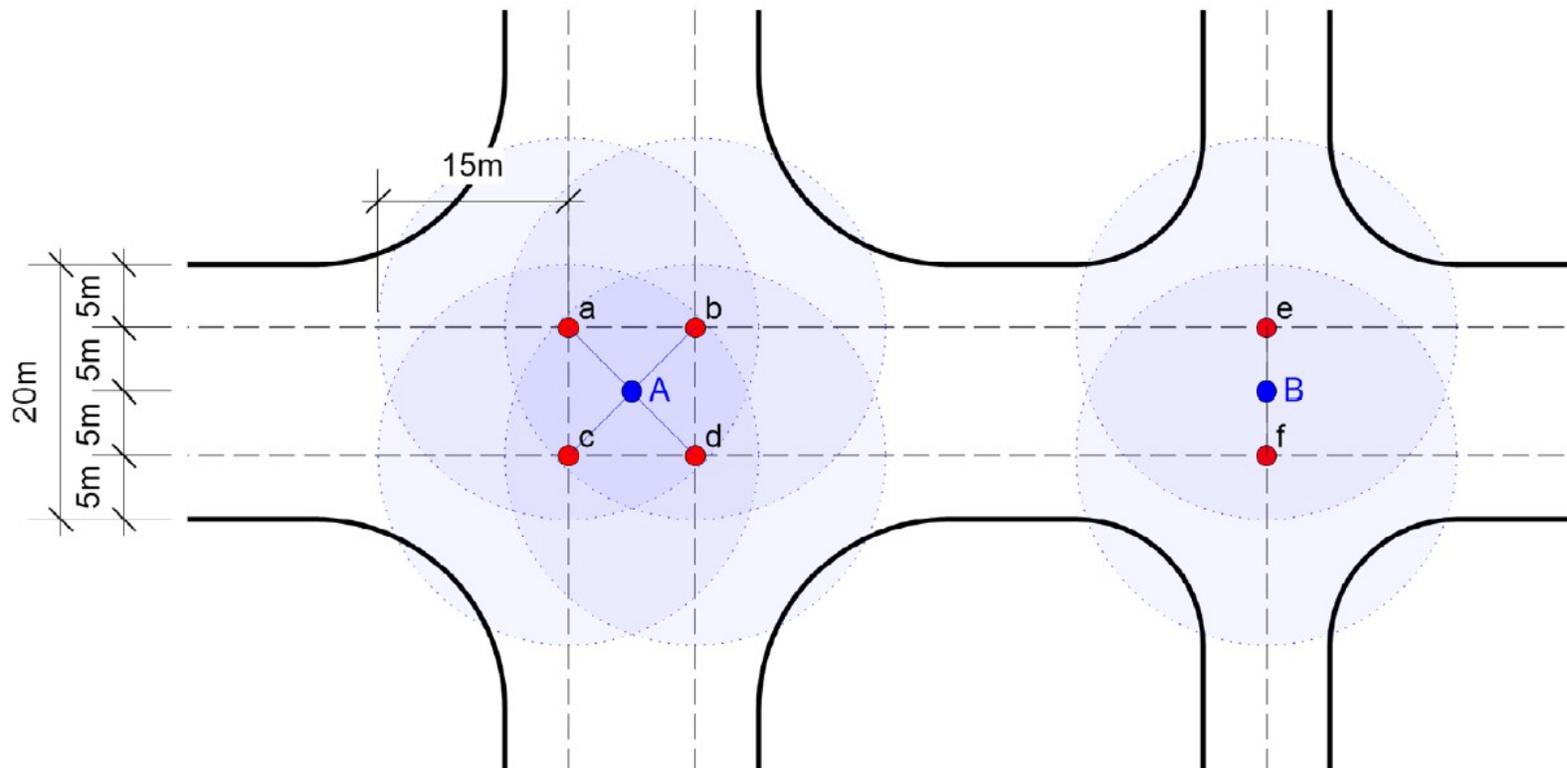
→ 0 que acontece nos bastidores:

(B) Consolidação de nós:



→ 0 que acontece nos bastidores:

(B) Consolidação de nós:



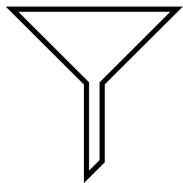
→ Validação (Boeing, 2025):

- 8910 cidades modeladas:

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- 8910 cidades modeladas:

160 mi ● 320 mi —



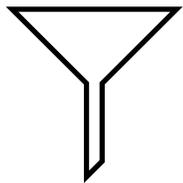
(A)
Simplificação de
Arestas

37 mi ● 53 mi —

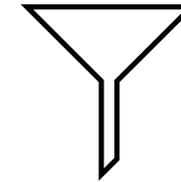
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160 mi ● 320 mi —



(A)
Simplificação de
Arestas



(B)
Consolidação de
Nós

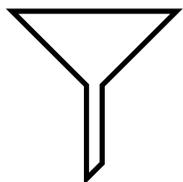
37 mi ● 53 mi —

Redução adicional de
14% nas interseções

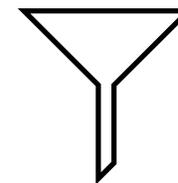
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160 mi ● 320 mi —



(A)
Simplificação de
Arestas



(B)
Consolidação de
Nós

37 mi ● 53 mi —

Redução adicional de
14% nas interseções

- Validação face-a-face (32 cidades):

(A) Simplificação de Arestas	(B) Consolidação de Nós
100% Acc	98% TPR; 87% TNR

(2) OSMnx

OSMnx



Dependências:



(2) OSMnx

OSMnx



Dependências:



→ Geração de redes com uma linha de

```
C[8] import networkx as nx
import osmnx as ox

G = ox.graph.graph_from_place("Salvador, Brazil", network_type="drive")
fig, ax = ox.plot.plot_graph(G)
```

A network graph visualization of Salvador, Brazil, showing a dense web of white nodes and edges on a black background. The graph represents the road network of the city, with nodes at intersections and edges representing road segments. The visualization is a high-contrast, black-and-white image.

→ Geração de redes com uma linha de

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fig, ax = ox.plot.plot_graph(G)
```



→ Outras entradas de localização possíveis:

- Bounding box
- LAT-LON + distância
- Endereço + distância
- Polígono
- Arquivo XML formatado em .osm

→ Outras tipos de rede:

- Todas
- A pé
- Bicicleta
- Ruas e caminhos não privados do OSM
- Motorizado de serviço

→ Funcionalidades do **paco**

Module	Functionality
bearing	Calculate graph edge compass bearings and orientation entropy.
convert	Convert a graph to/from different data structures.
distance	Calculate spatial distances and find nearest graph node/edge(s) to point(s).
elevation	Attach node elevations from raster files or a Google Maps compatible elevation API, and calculate edge grades.
features	Download OSM geospatial features' geometries and attributes, such as points of interest, building footprints, transit stops, etc.
geocoder	Geocode place names or addresses or retrieve OSM elements by place name or ID, via the Nominatim API.
graph	Download and create graphs from OSM data, using filters to query the Overpass API for built-in network types or a custom filter.

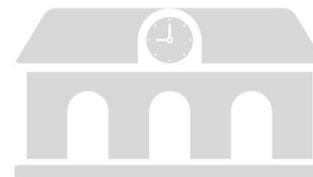
Module	Functionality
io	Save/load graphs to/from GraphML, GeoPackage, or OSM XML files.
plot	Visualize street networks, routes, orientations, and geospatial features.
projection	Project a spatial graph to a different coordinate reference system.
routing	Calculate graph edge speeds, travel times, and weighted shortest paths between nodes.
settings	Configure global package settings.
simplification	Simplify and consolidate spatial graph nodes and edges.
stats	Calculate geometric and topological network measures.
truncate	Truncate a spatial graph by distance, bounding box, or polygon.
utils	General utility functions.
utils_geo	Miscellaneous geospatial utility functions.

Agenda

(1) Contexto



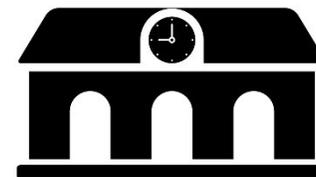
(2) OSMnx



(4) Aplicações



(3) r5r



(3) r5r



Histórico:

- R⁵: Rapid Realistic Routing on Real-world and Reimagined networks

conveyal/r5



Developed to power Conveyal's web-based interface for scenario planning and land-use/transport accessibility analysis, R5 is our routing engine for multimodal...

21

Contributors

213

Issues

338

Stars

82

Forks



<https://github.com/conveyal/r5>

(3) r5r



Histórico:

- R⁵: Rapid Realistic Routing on Real-world and Reimagined networks

conveyal/r5



Developed to power Conveyal's web-based interface for scenario planning and land-use/transport accessibility analysis, R5 is our routing engine for multimodal...

 21 Contributors  213 Issues  338 Stars  82 Forks



<https://github.com/conveyal/r5>

- r5r: implementação em R do R⁵

(3) r5r



Histórico:

- Versão beta no CRAN em 2020/Paper em 2021.

README License

r5r: Rapid Realistic Routing with R5 in R

CRAN 2.3.0 downloads 929K R-CMD-check passing codecov 92% lifecycle stable
DOI 10.32866/001c.21262

r5r is an R package for rapid realistic routing on multimodal transport networks (walk, bike, public transport and car). It provides a simple and friendly interface to R⁵, the [Rapid Realistic Routing on Real-world and Reimagined networks](#), the routing engine developed independently by [Conveyal](#).

r5r is a simple way to run R⁵ locally, allowing R users to generate detailed routing analysis or calculate travel time matrices and accessibility using seamless parallel computing. See a detailed demonstration of r5r in the [intro Vignette](#). More details about r5r can be found on the [package webpage](#) or on this [paper](#). Over time, r5r might be expanded to incorporate other functionality from R⁵.

This repository contains the R code (r-package folder) and the Java code (java-api folder) that provides the interface to R⁵.

github.com/ipeaGIT/r5r

Findings

Pereira, Rafael H. M., Marcus Saraiva, Daniel Herszenhut, Carlos Kaue Vieira Braga, and Matthew Wigginton Conway. 2021. "R5r: Rapid Realistic Routing on Multimodal Transport Networks with R⁵ in R." *Findings*, March.
<https://doi.org/10.32866/001c.21262>

TRANSPORT FINDINGS

r5r: Rapid Realistic Routing on Multimodal Transport Networks with R⁵ in R

Rafael H. M. Pereira¹, Marcus Saraiva¹, Daniel Herszenhut¹, Carlos Kaue Vieira Braga¹, Matthew Wigginton Conway²

¹ Ipea - Institute for Applied Economic Research, ² School of Geographical Sciences and Urban Planning, Arizona State University

Keywords: travel impedance, accessibility, travel time, transport networks, routing, software

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(3) r5r



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- Versão beta no CRAN em 2020/Paper em 2021.

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TRANSPORT FINDINGS

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Keywords: travel impedance, accessibility, travel time, transport networks, routing, software

<https://doi.org/10.32866/001c.21262>

- Funcionalidades iniciais:

setup_r5()

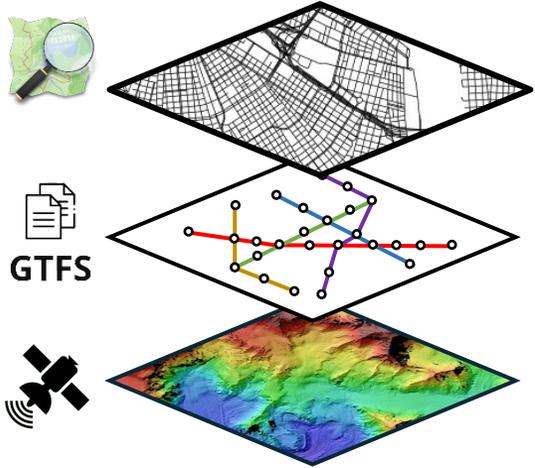
travel_time_matrix()

detailed_itineraries()

(3) r5r



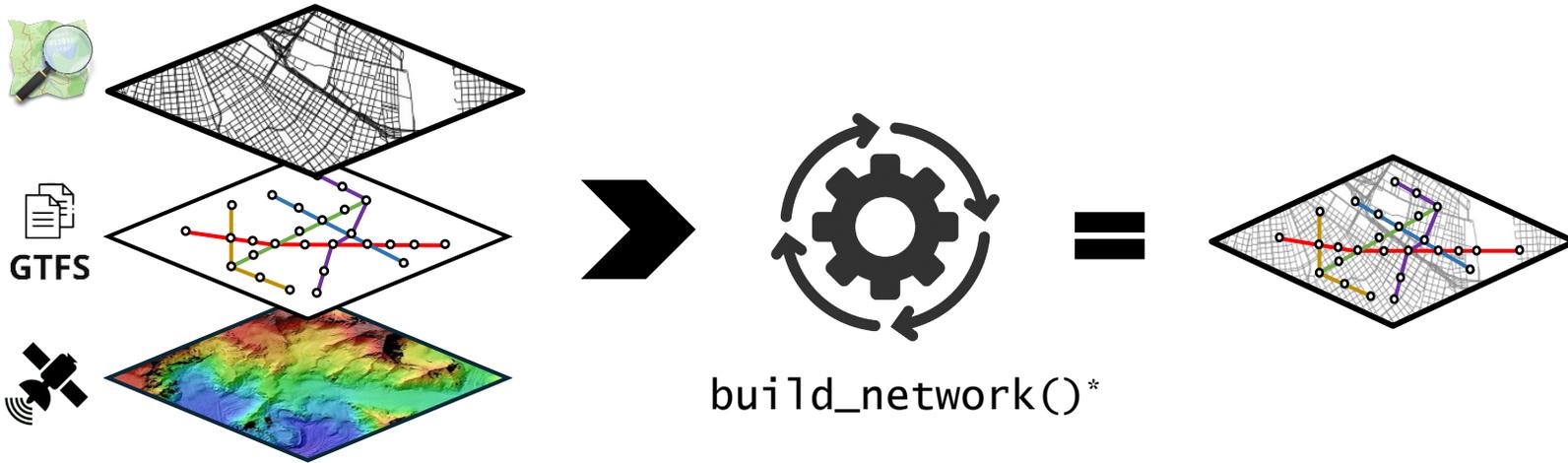
→
Lógica:



(3) r5r



→
Lógica:



* Substituiu `setup_r5r()` em v. 2.3.0 (ago/2025)

(3) r5r

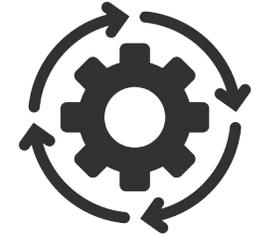
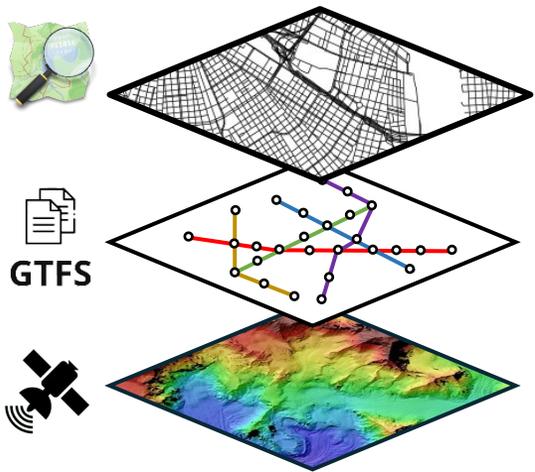
→
Lógica:



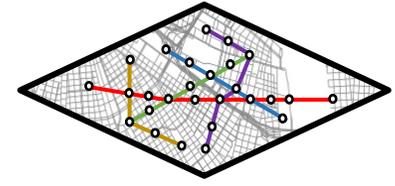
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$$\begin{bmatrix} t_{11} & \dots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{m1} & \dots & t_{mn} \end{bmatrix}$$

`travel_time_matrix()`



=

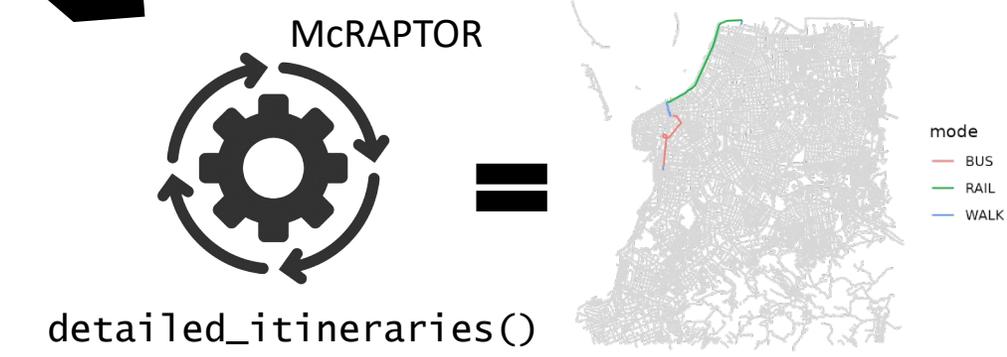
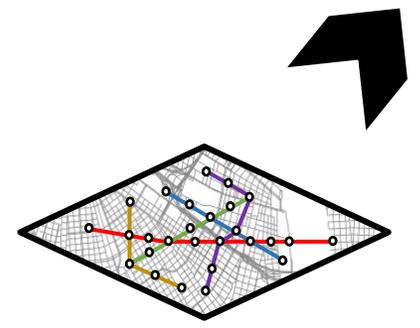
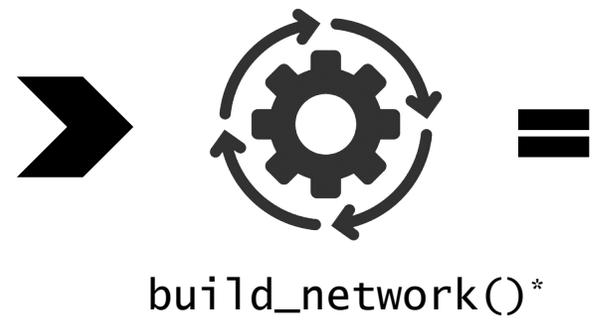
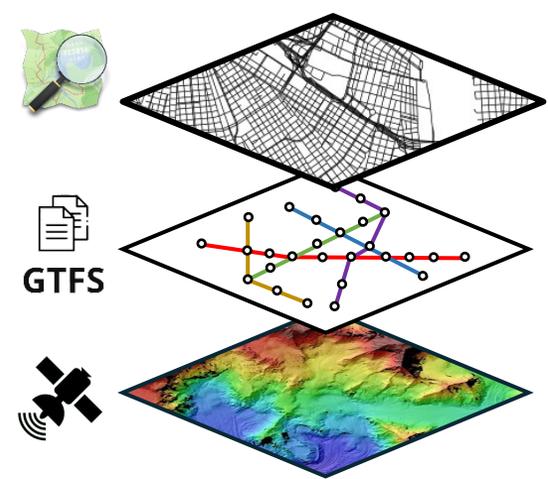
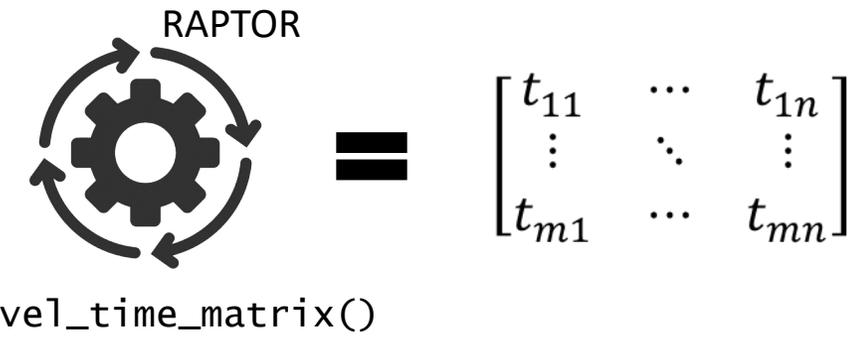


`build_network()*`

* Substituiu `setup_r5r()` em v. 2.3.0 (ago/2025)

(3) r5r

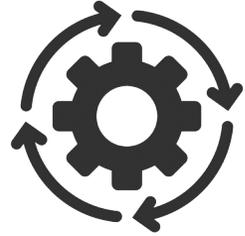
→ Lógica:



* Substituiu setup_r5r() em v. 2.3.0 (ago/2025)

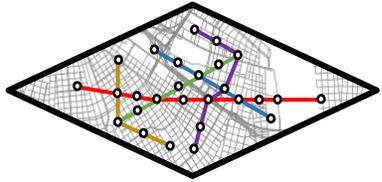
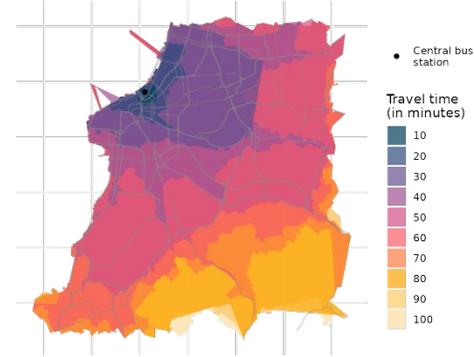
(3) r5r

→ Outras funcionalidades:



isochrones()

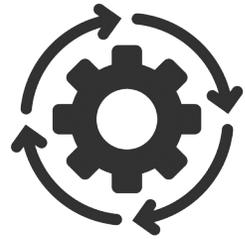
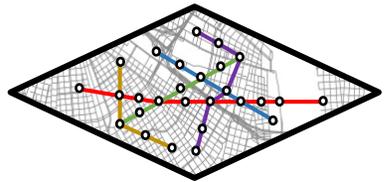
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(3) r5r

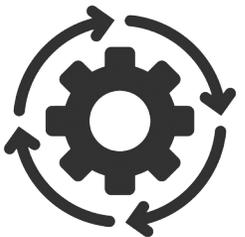
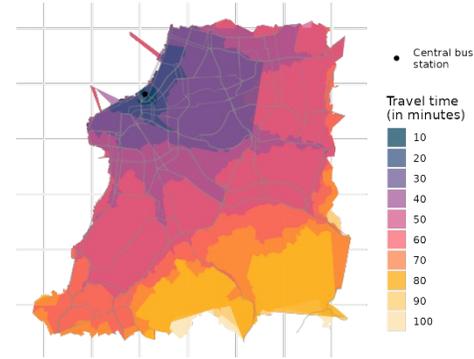


→ Outras funcionalidades:



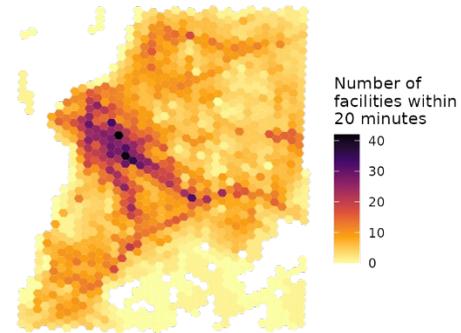
isochrones()

=



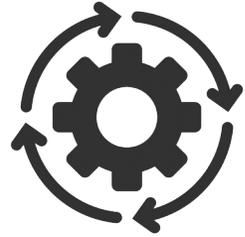
accessibility()

=



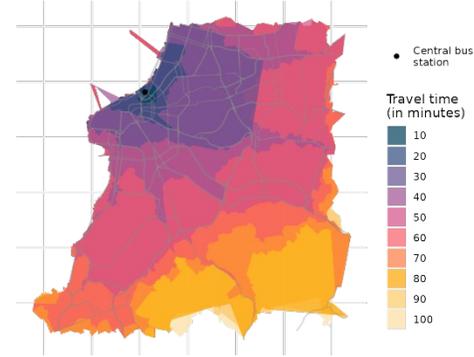
(3) r5r

→ Outras funcionalidades:



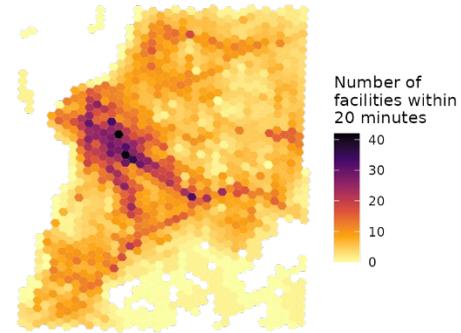
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isochrones()



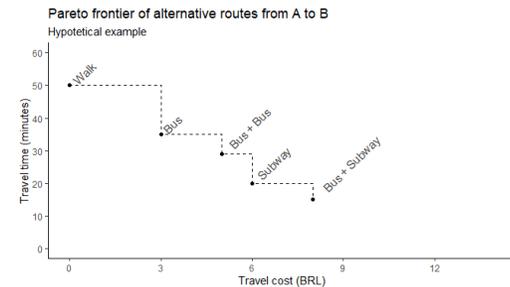
=

accessibility()



=

pareto_frontier()

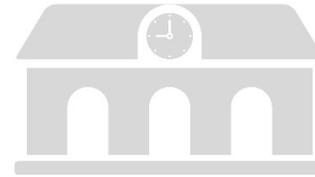


Agenda

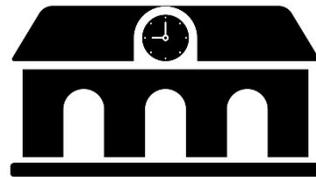
(1) Contexto



(2) OSMnx



(4) Aplicações

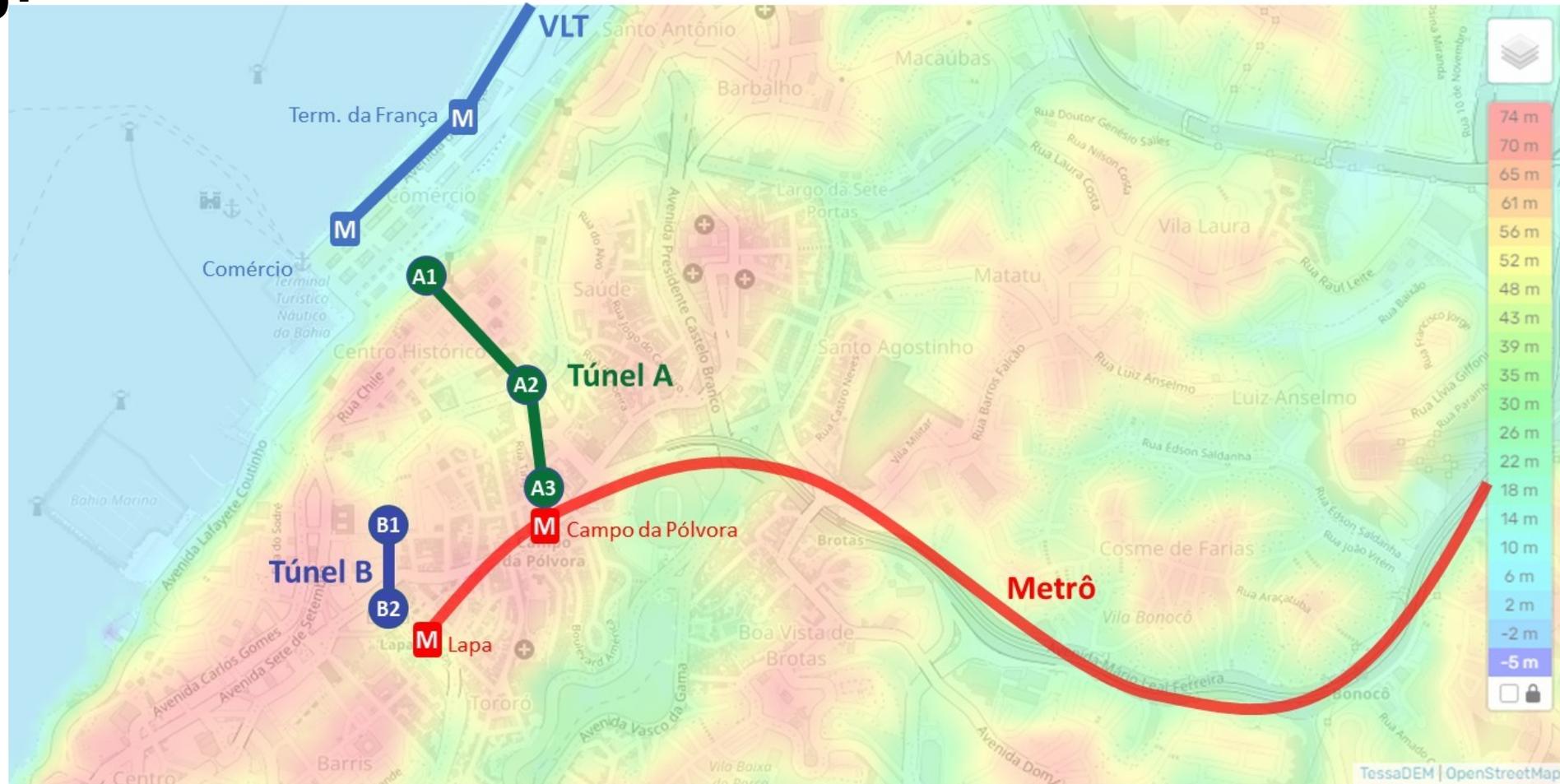


(3) r5r



(4) Aplicações

→ Impacto do Túnel de Pedestres no CH de Salvador:



(4) Aplicações

→ Impacto do Túnel de Pedestres no CH de Salvador:



OSMnx

(4) Aplicações

→ Impacto do Túnel de Pedestres no CH de Salvador:

- $v = f(s)$:

Tobler's hiking function is an [exponential function](#) determining the [hiking speed](#), taking into account the [slope angle](#).^{[1][2][3]} It was formulated by [Waldo Tobler](#). This function was estimated from empirical data of [Eduard Imhof](#).^[4]

Formula [\[edit \]](#)

Walking velocity:

$$W = 6e^{-3.5 \left| \frac{dh}{dx} + 0.05 \right|}$$

$$\frac{dh}{dx} = S = \tan \theta$$

where

W = walking velocity [km/h]^[2]

dh = elevation difference,

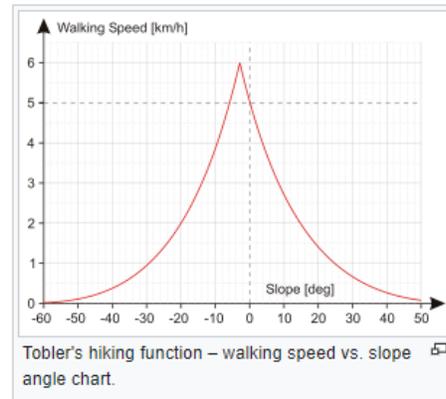
dx = distance,

S = slope,

θ = angle of slope (inclination).

The velocity on the flat terrain is 5 km / h, the maximum speed of 6 km / h is achieved roughly at -2.86° .^[5]

On flat terrain this formula works out to 5 km/h. For off-path travel, this value should be multiplied by 3/5, for horseback by 5/4.^[1]



(4) Aplicações

→ Impacto do Túnel de Pedestres no CH de Salvador:

- $v = f(s)$:

- $E = f(s, v)$:

Tobler's hiking function is an [exponential function](#) determining the [hiking speed](#), taking into account the [slope angle](#).^{[1][2][3]} It was formulated by [Waldo Tobler](#). This function was estimated from empirical data of [Eduard Imhof](#).^[4]

Formula [\[edit\]](#)

Walking velocity:

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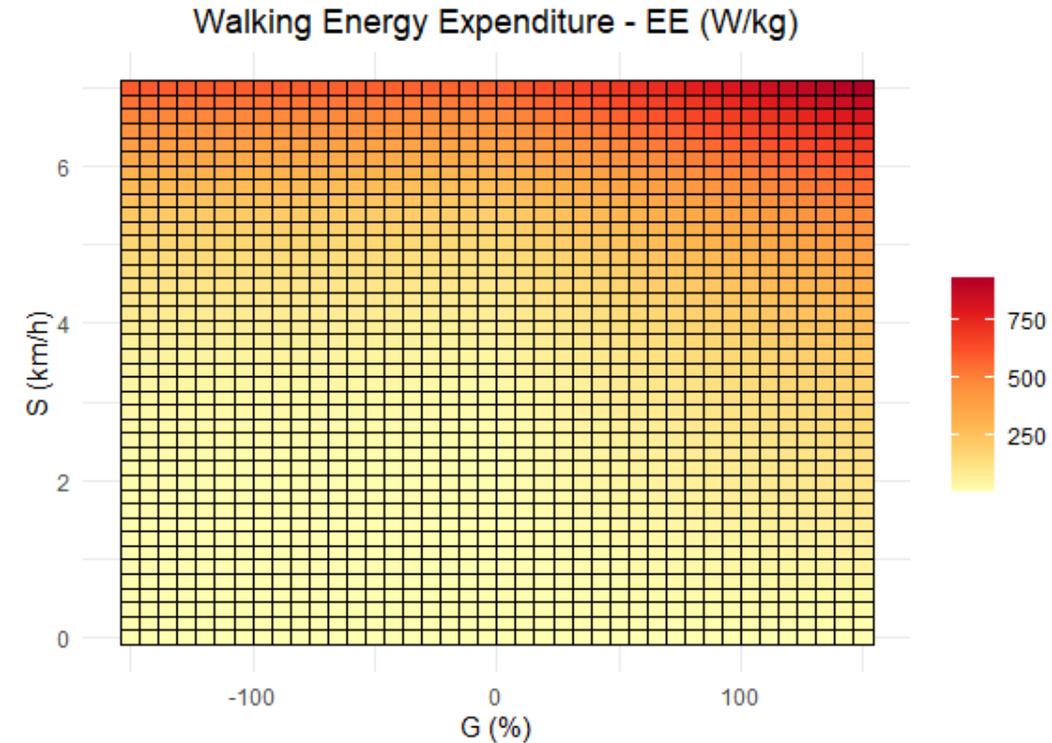
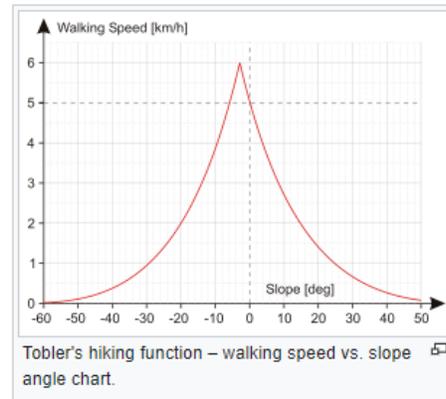
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On flat terrain this formula works out to 5 km/h. For off-path travel, this value should be multiplied by 3/5, for horseback by 5/4.^[1]



$$EE = 1,44 + 1,94S^{0,43} + 0,24S^4 + 0,35SG(1 - 1,05^{1-1,1^{G+32}})$$

(4) Aplicações

→ Impacto do Túnel de Pedestres no CH de Salvador:

- Minimizando **TEMPO** de rota:

(A) SEM TÚNEL



(B) COM TÚNEL



Campo da Pólv. → Comércio:

25,5 min

1382 m

59.181 J/kg

Comércio → Campo da Pólv.:

26 min

1382 m

53.167 J/kg

19 min

1376 m

52.829 J/kg

21,4 min

1453 m

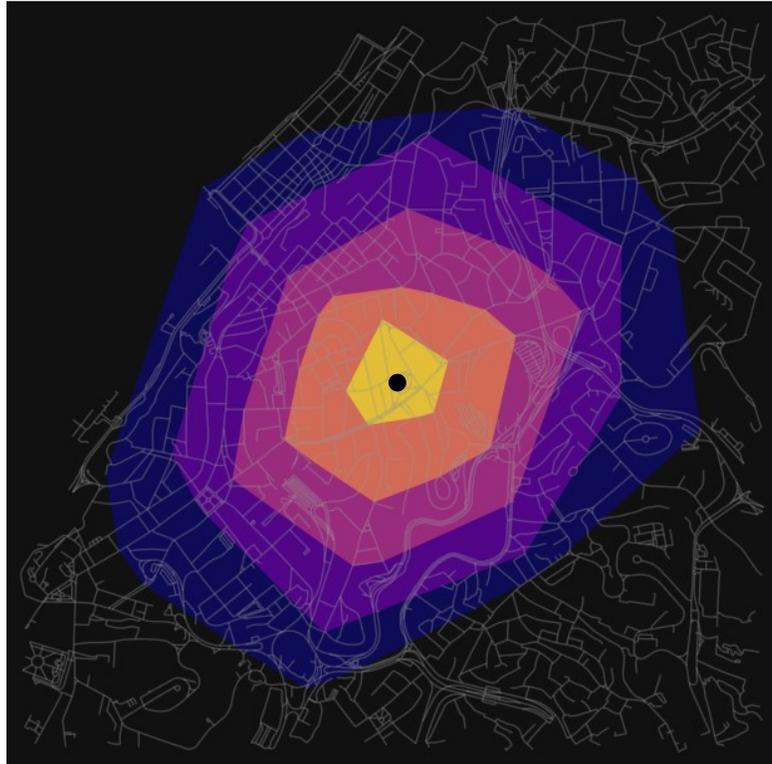
39.051 J/kg

(4) Aplicações

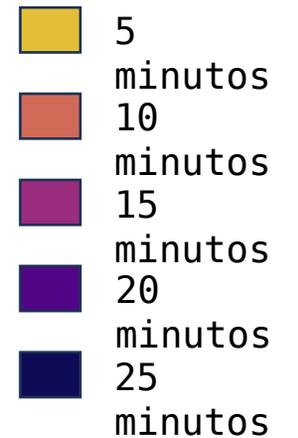
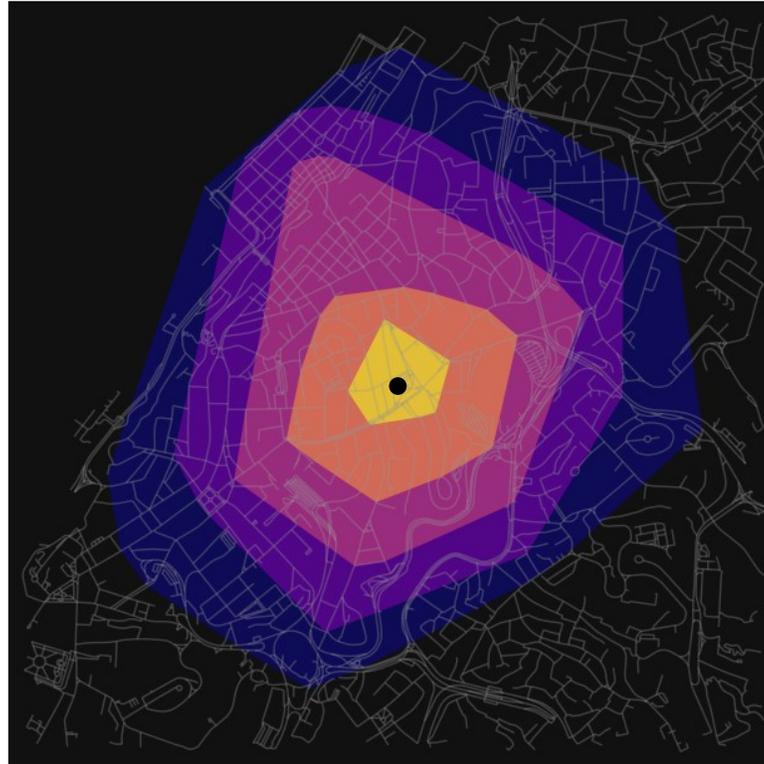
→ Impacto do Túnel de Pedestres no CH de Salvador:

- Minimizando **TEMPO** de rota:

Sem Túnel



Com Túnel



(4) Aplicações

→ Impacto do Túnel de Pedestres no CH de Salvador:

- Minimizando **DISPÊNDIO ENERGÉTICO** de rota:

(A) SEM TÚNEL



(B) COM TÚNEL



Campo da Pólv. → Comércio:

29,4 min	1523 m	56.487 J/kg
----------	--------	-------------

Comércio → Campo da Pólv.:

26 min	1382 m	53.167 J/kg
--------	--------	-------------

24,1 min

1453 m

34.937 J/kg

28,9 min

1453 m

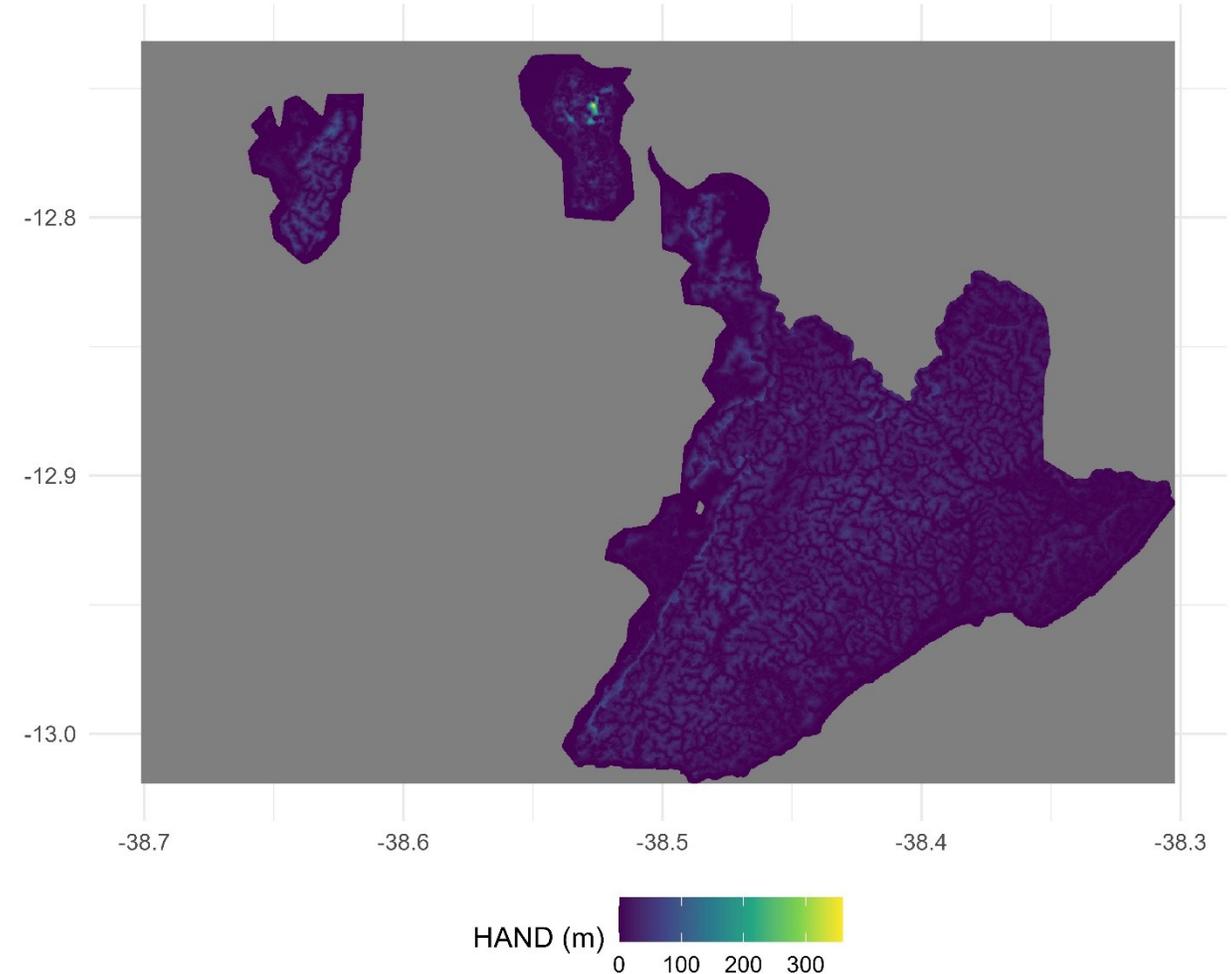
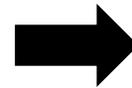
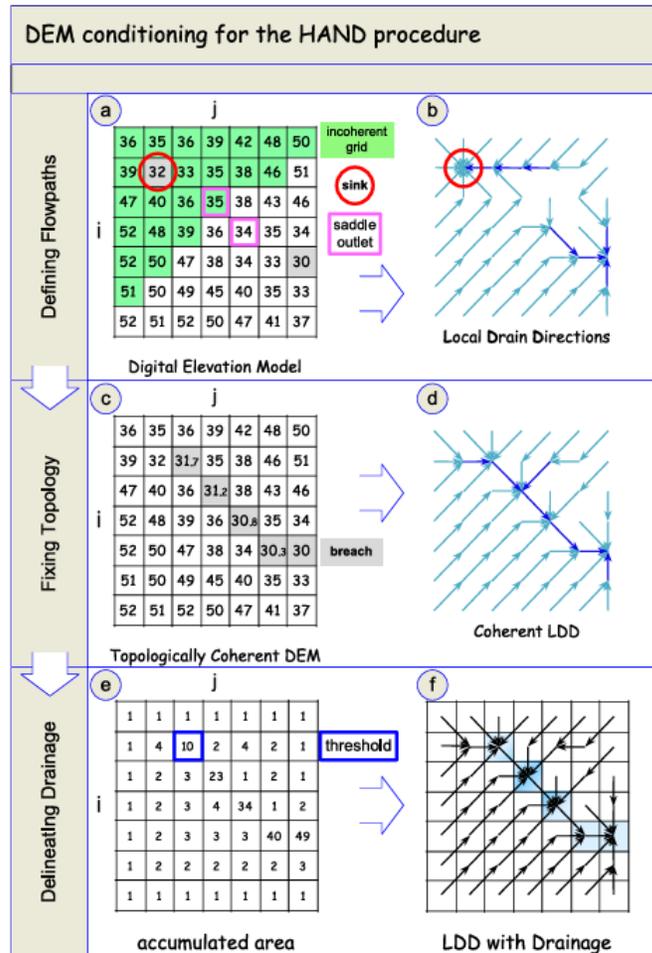
30.575 J/kg

(4) Aplicações

→ **Risco de inundações e conectividade da rede:**

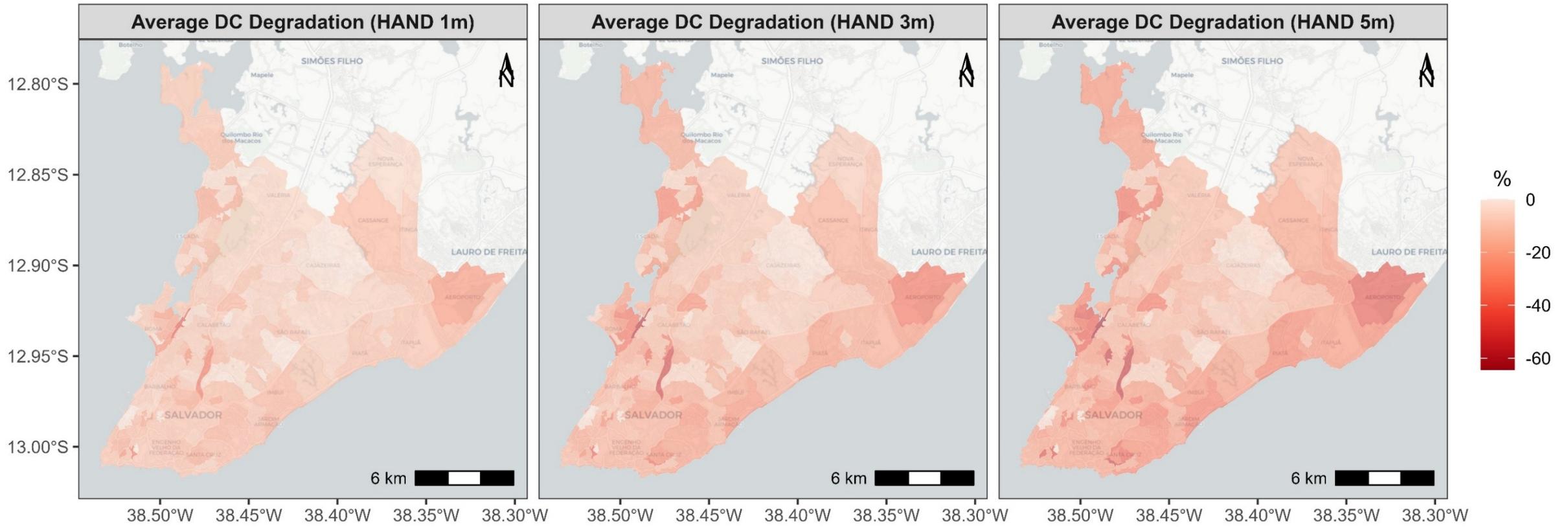
(4) Aplicações

→ Suscetibilidade a inundações e conectividade da rede:



(4) Aplicações

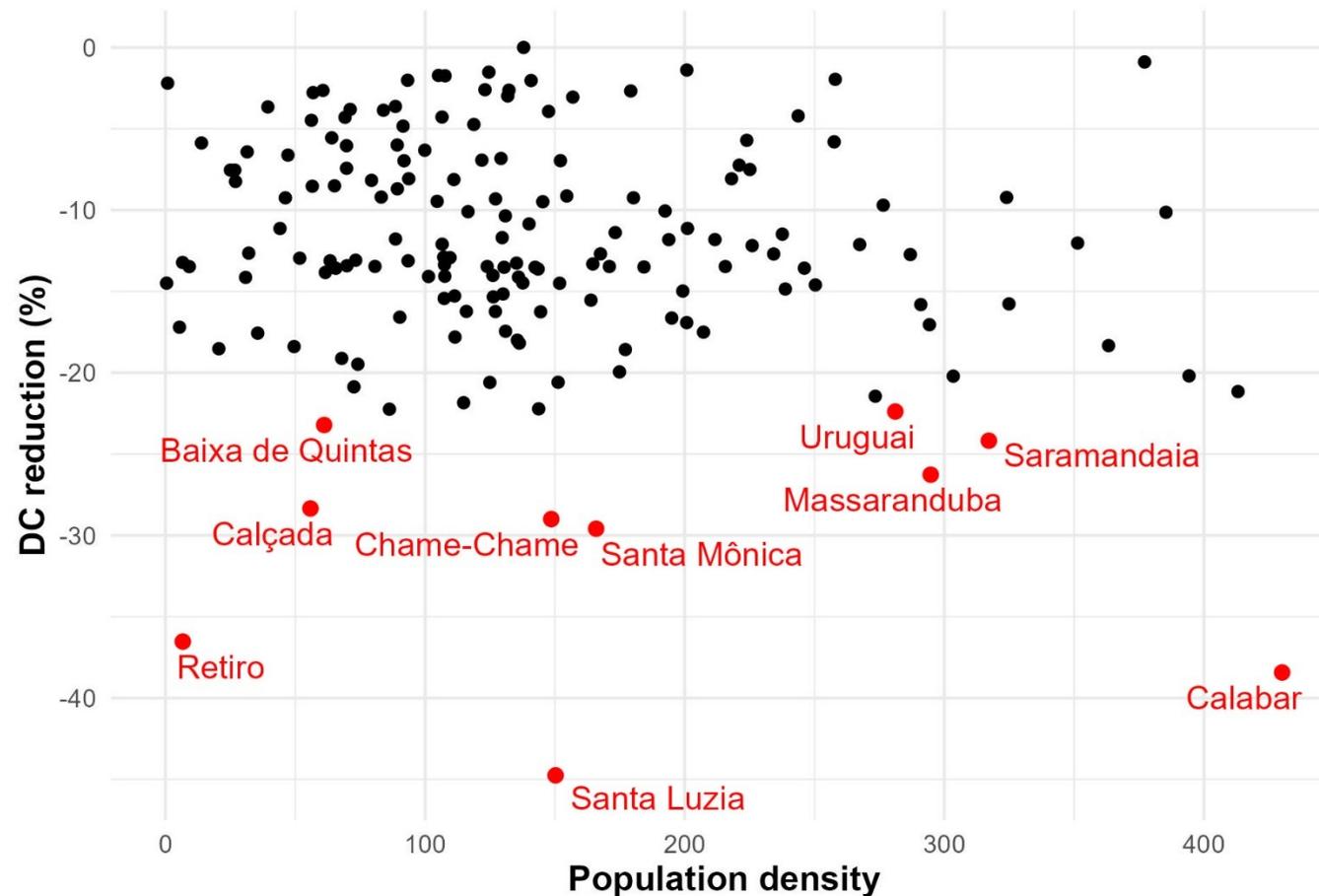
→ Suscetibilidade a inundações e conectividade da rede:



OSMnx

(4) Aplicações

→ Suscetibilidade a inundações e conectividade da rede:



(4) Aplicações

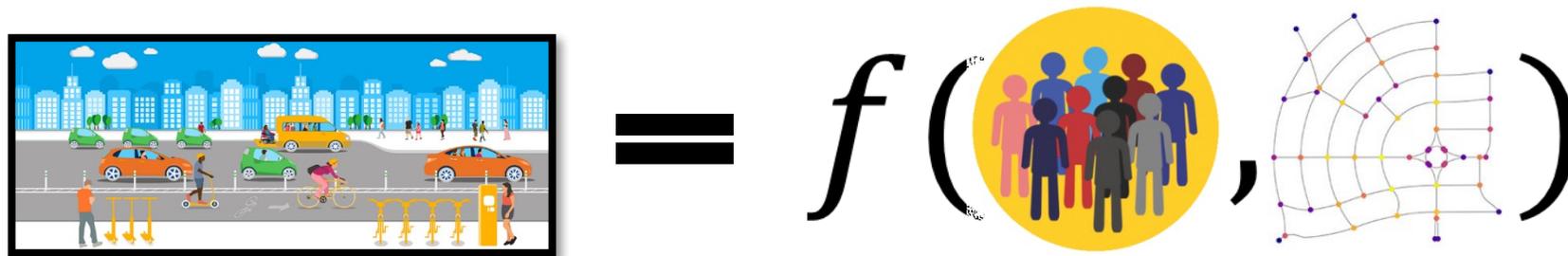
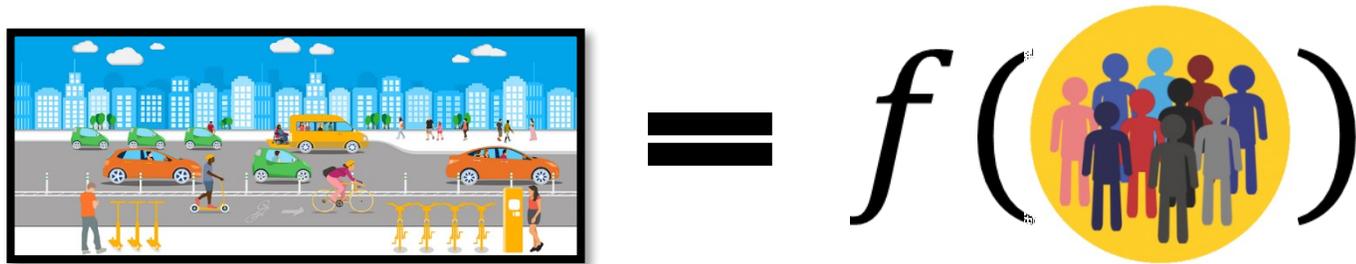
→ Indicadores de rede p/ Predição de Padrões de Viagem:



$$= f(\text{Group of People})$$

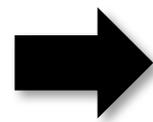
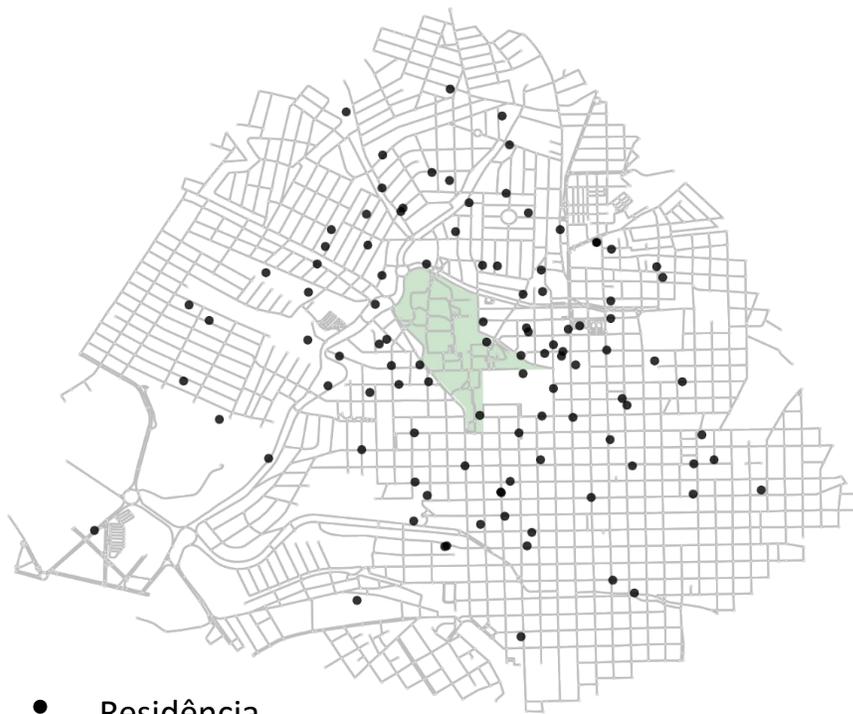
(4) Aplicações

→ Indicadores de rede p/ Predição de Padrões de Viagem:

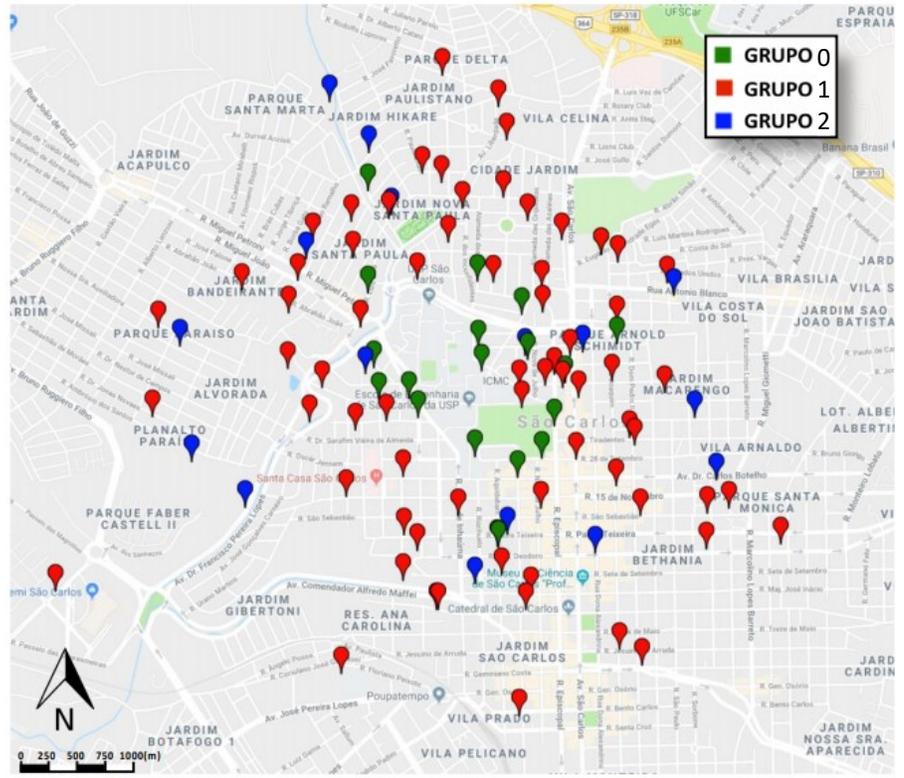


(4) Aplicações

→ Indicadores de rede p/ Predição de Padrões de Viagem:

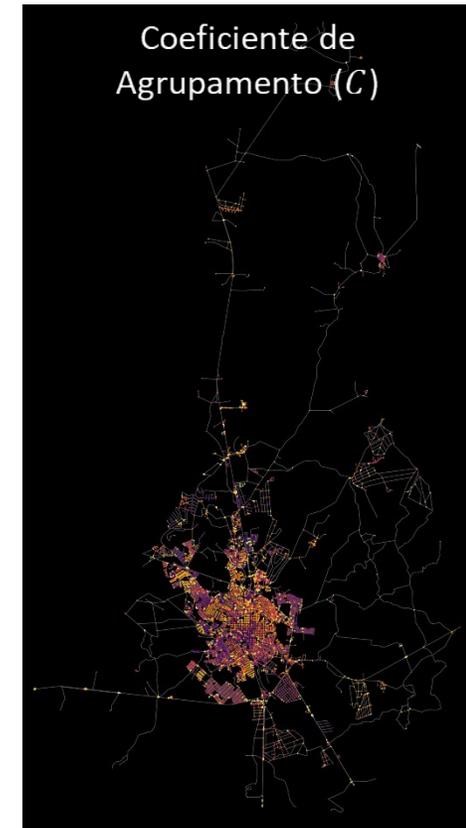
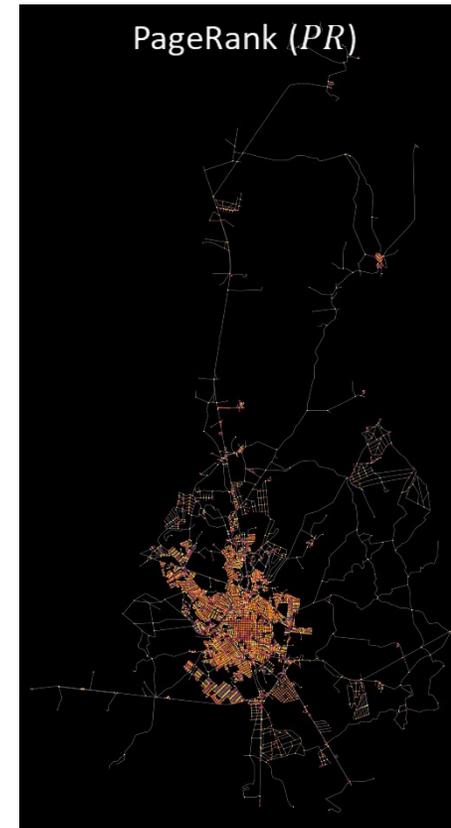
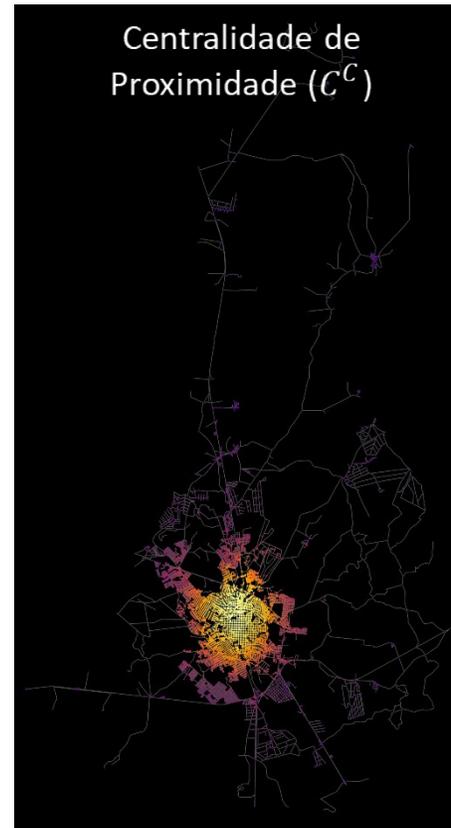
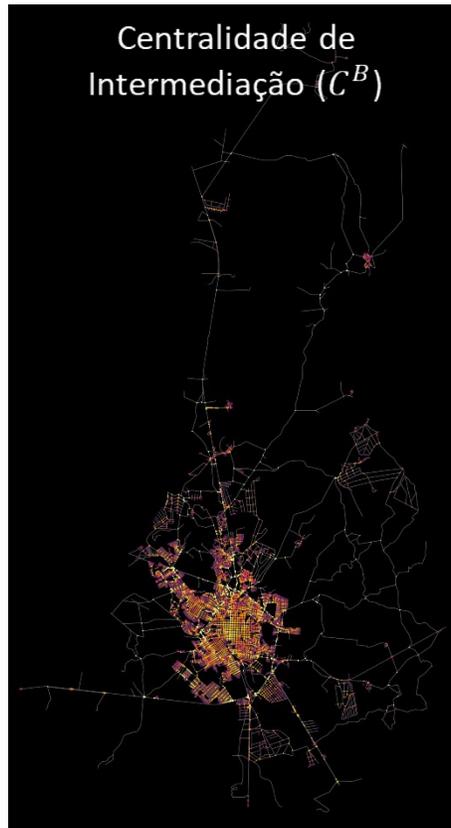


K-
Médias



(4) Aplicações

→ Indicadores de rede p/ Predição de Padrões de Viagem:



OSMnx

(4) Aplicações

→ Indicadores de rede p/ Predição de Padrões de Viagem:

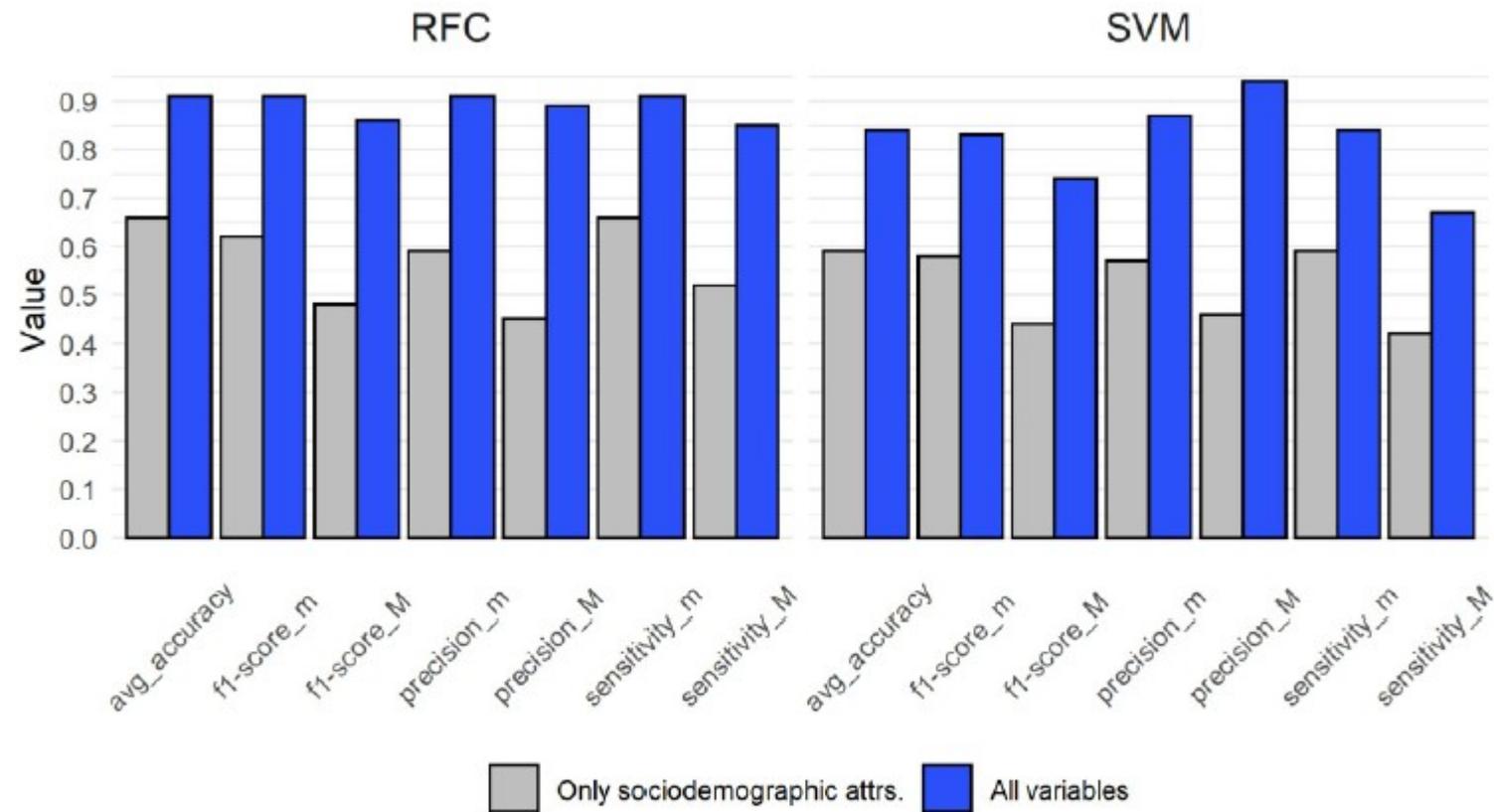


Fig. 12. Classification performance of RFC and SVM in both scenarios.

(4) Aplicações

→ Indicadores de rede p/ Predição de Padrões de Viagem:

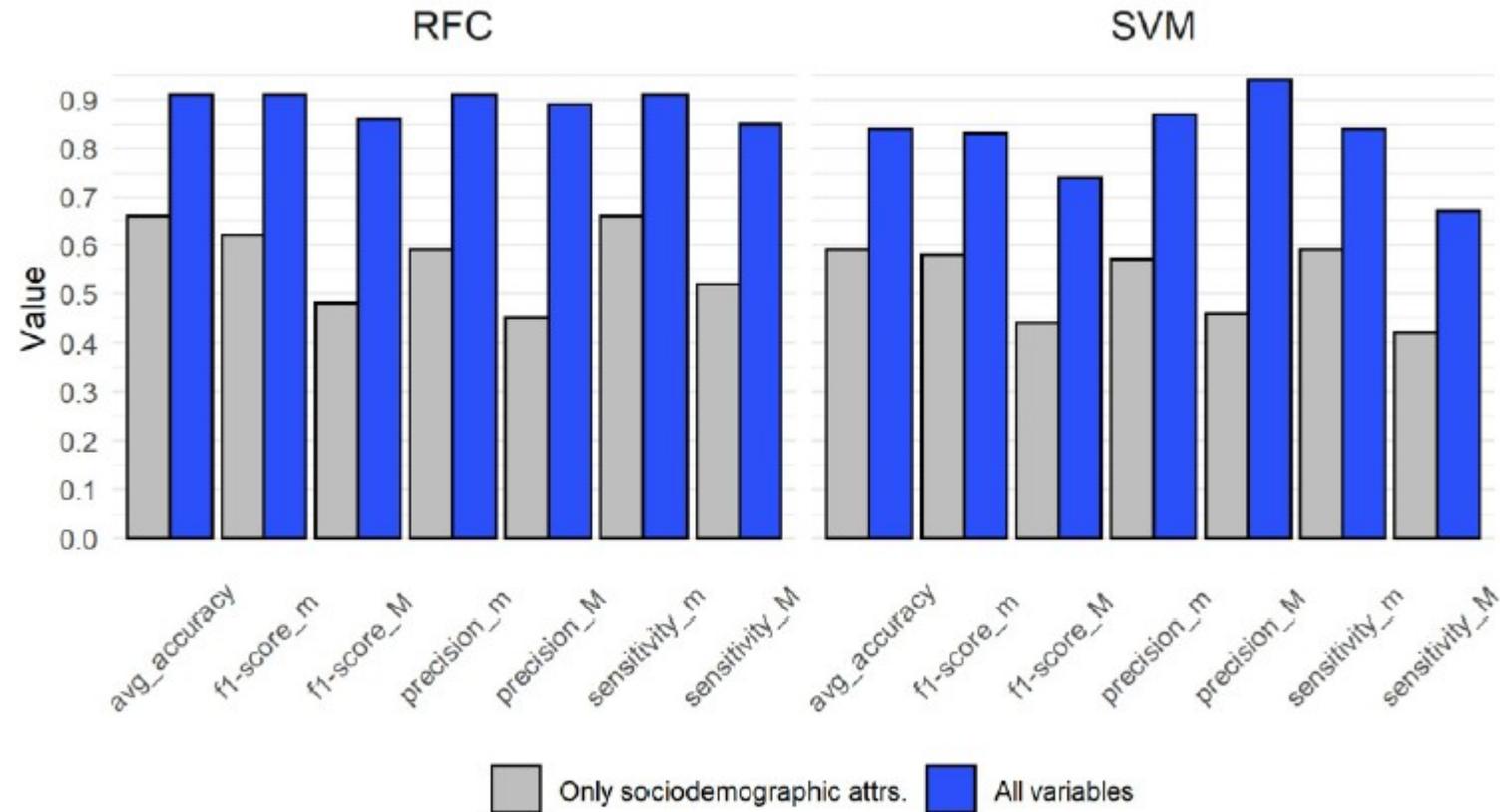


Fig. 12. Classification performance of RFC and SVM in both scenarios.

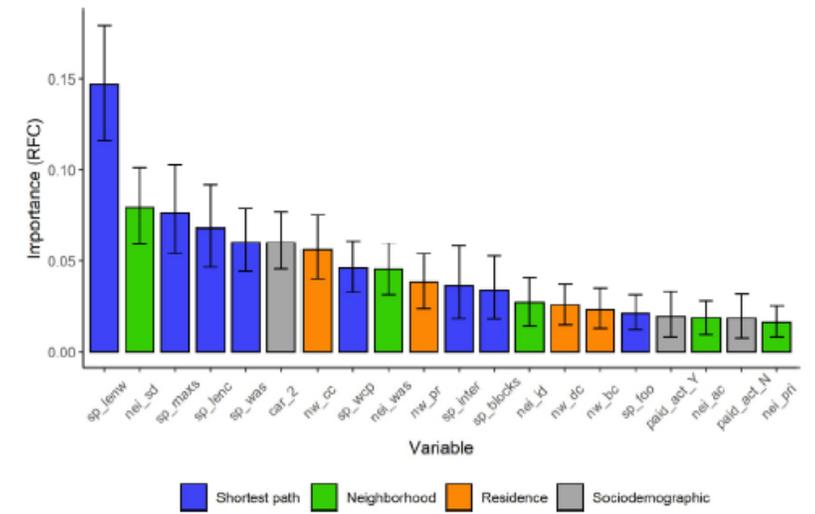


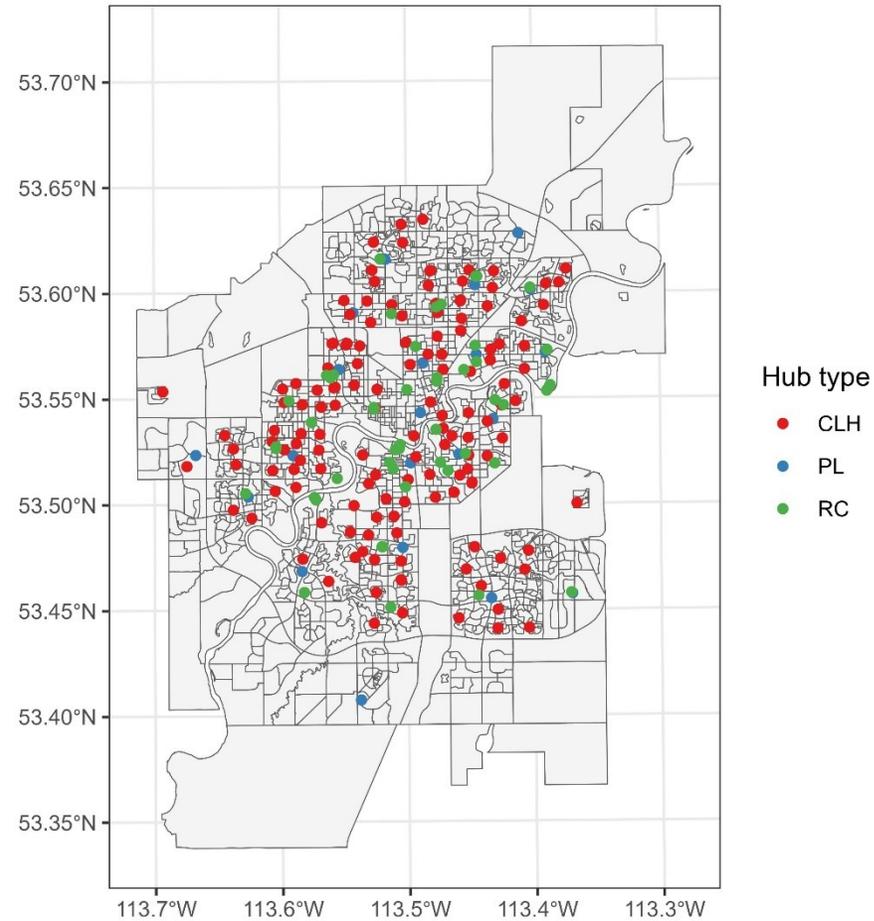
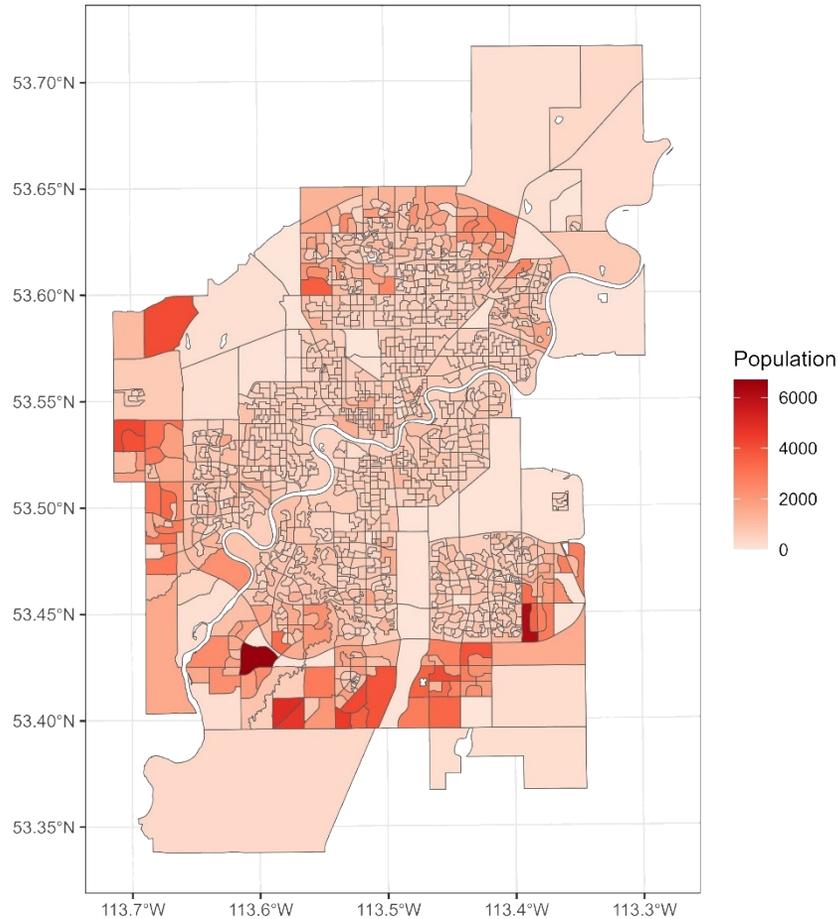
Fig. 13. Variable importance of the RFC (average and bootstrap 95% confidence interval). sp_lenw: length of the shortest path (walking); nei_sd: street density in the neighborhood; sp_maxs: max slope; sp_lenw: length of the shortest path (by car); sp_was: weighted-average slope; car_2: owns 2 cars (binary); nw_cc: closeness centrality of the residence node; sp_wcp: proportion between shortest path length walking and by car; nei_was: weighted-average slope in the neighborhood; nw_pr: PageRank of the residence node; sp_inter: number of intersections in the shortest path to campus; sp_blocks: average block size in the shortest path to campus; nei_id: intersection density in the neighborhood; nw_dc: degree centrality of the residence node; nw_bc: betweenness centrality of the residence node; sp_foo: proportion of footway streets in the shortest path to campus; paid_act_Y: has a paid job (binary); nei_ac: average circuitry of the neighborhood; paid_act_N: does not have a paid job (binary); nei_pri: proportion of primary streets in the neighborhood.

(4) Aplicações

→ Localização ótima de Resilience Hubs:

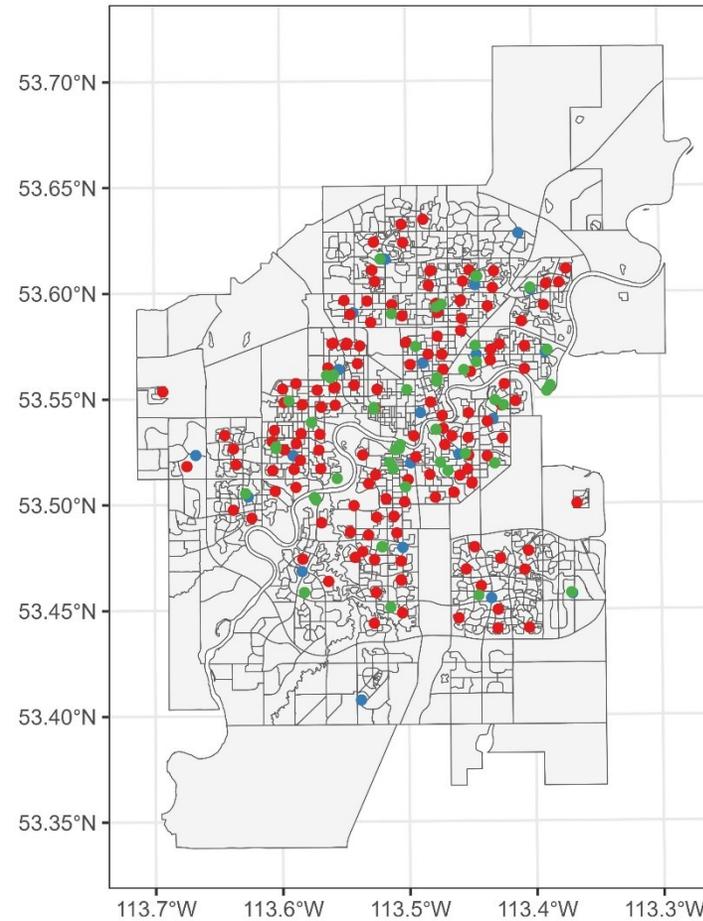
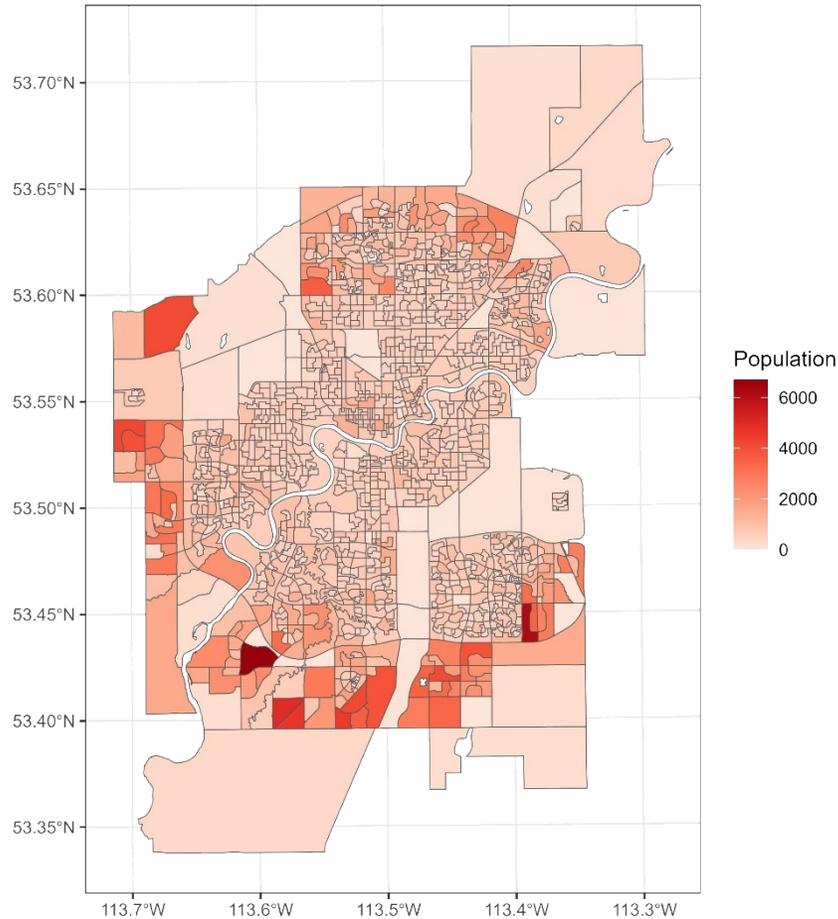
(4) Aplicações

→ Localização ótima de Resilience Hubs:



(4) Aplicações

→ Localização ótima de Resilience Hubs:

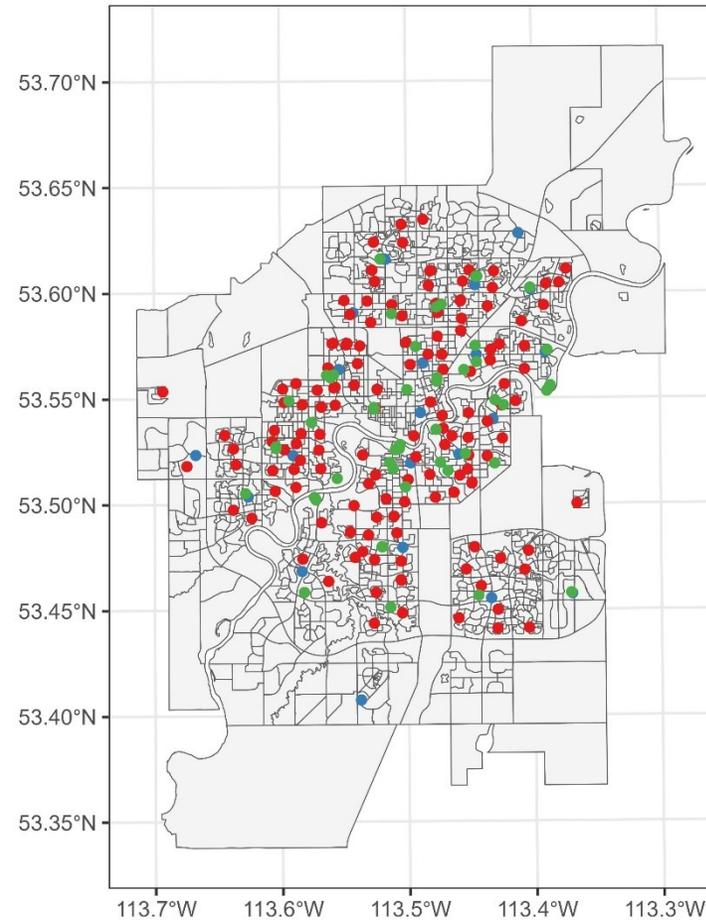
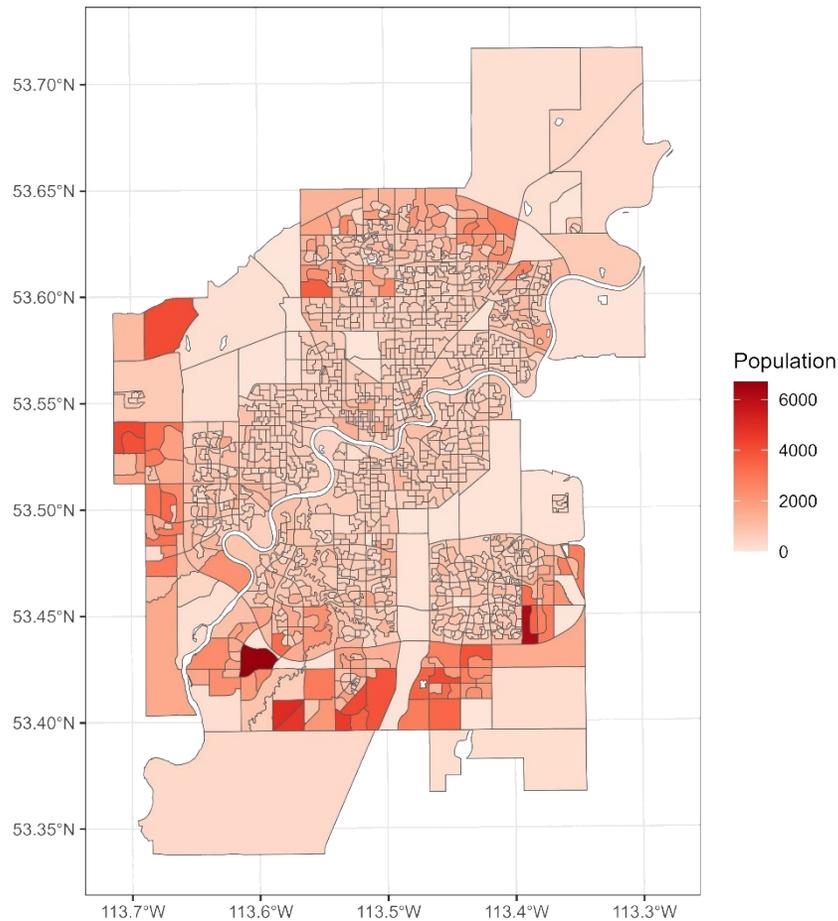


$$\begin{aligned} & \text{Max } \sum_i P_i x_i \\ & \text{s.t.} \\ & \sum_{j \in N_i} y_j \geq x_i \quad \forall i \\ & \sum_j y_j \leq p \\ & x_i \in \{0,1\} \quad \forall i \\ & y_j \in \{0,1\} \quad \forall j \end{aligned}$$

(4) Aplicações

→ Localização ótima de Resilience Hubs:

Hubs:



Hub type

- CLH
- PL
- RC

s.t.

$$\text{Max} \sum_i P_i x_i$$

$$\sum_{j \in N_i} y_j \geq x_i \quad \forall i$$

$$\sum_j y_j \leq p$$

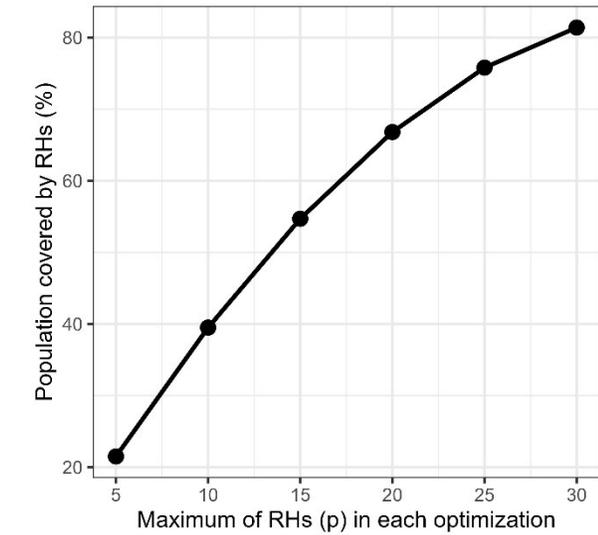
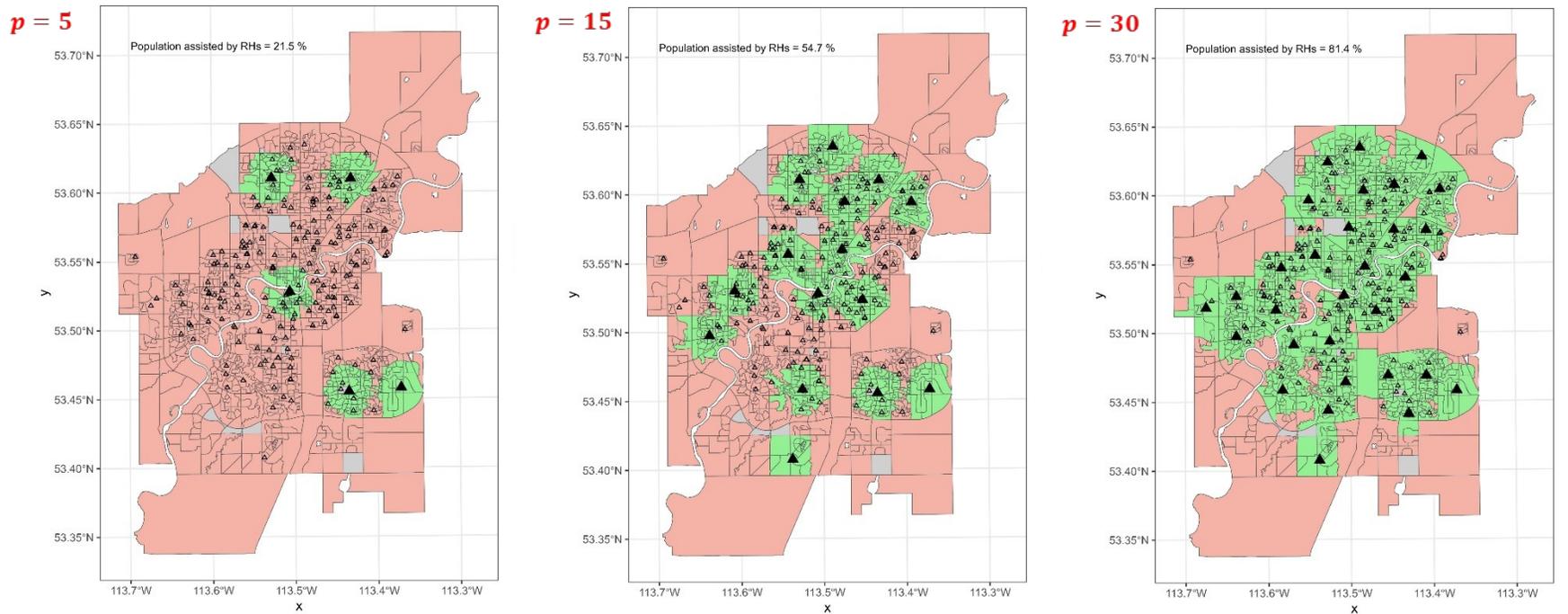
$$x_i \in \{0,1\} \quad \forall i$$

$$y_j \in \{0,1\} \quad \forall j$$



(4) Aplicações

→ Localização ótima de Resilience Hubs:



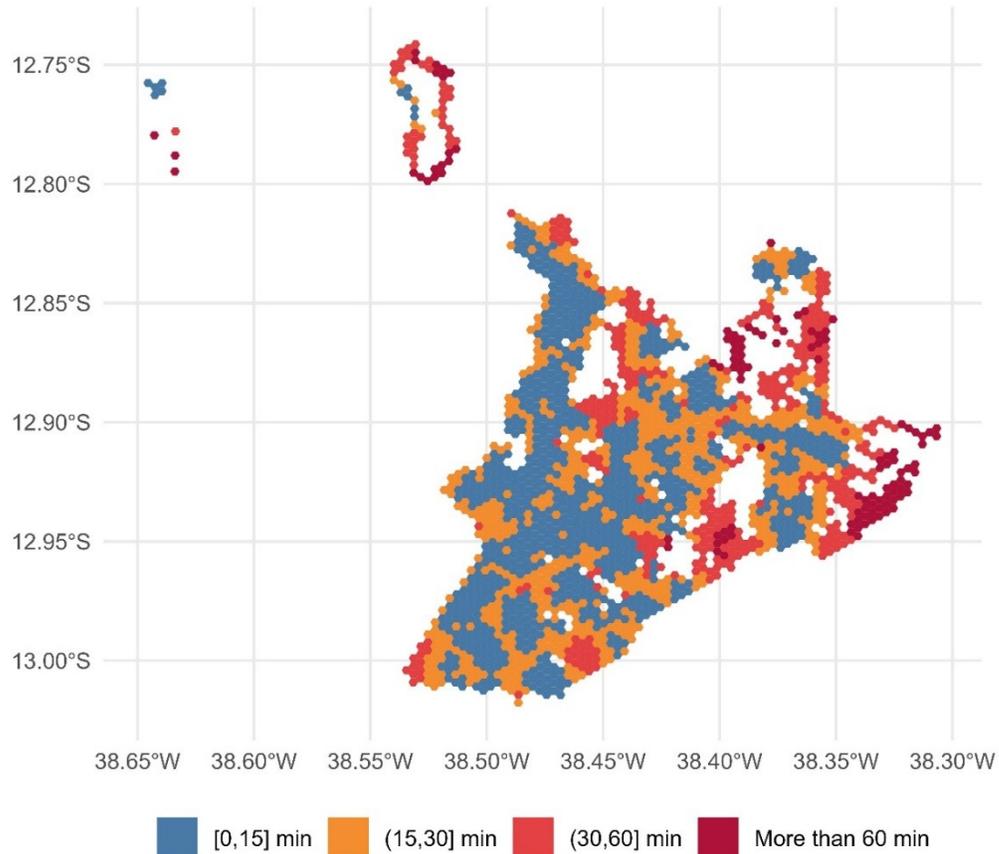
(4) Aplicações

→ **Cidades de X-Minutos na dimensão Saúde Primária:**

(4) Aplicações

→ Cidades de X-Minutos na dimensão Saúde Primária:

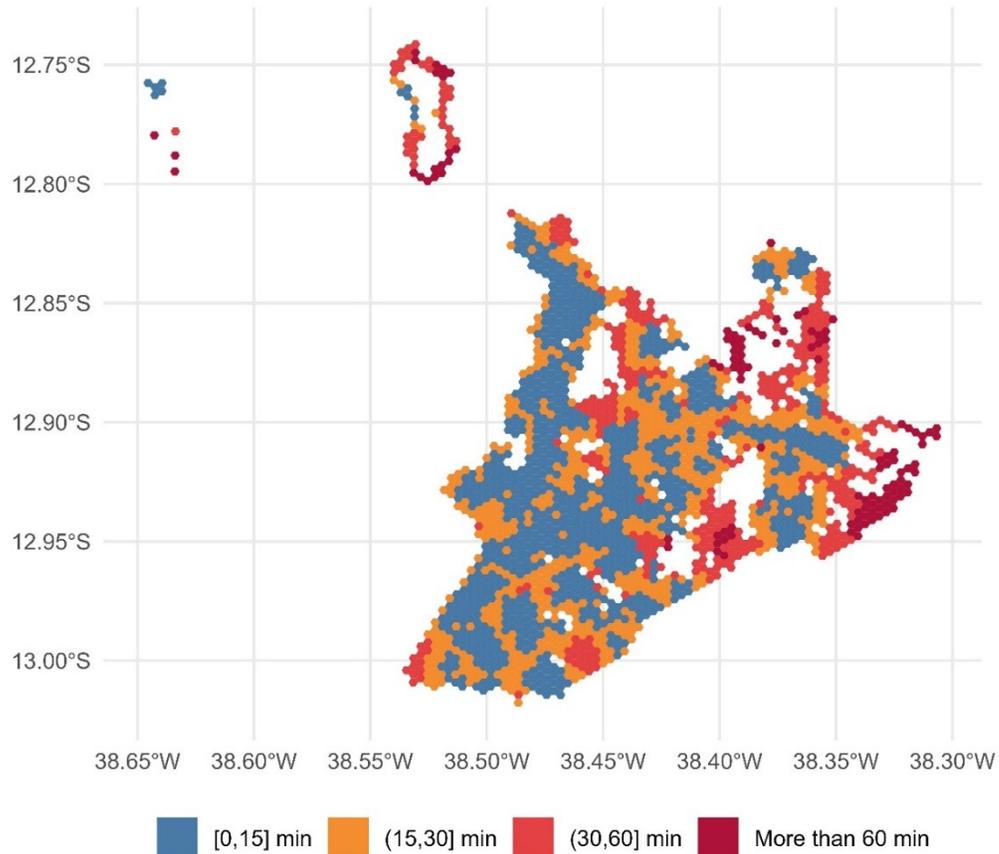
Walking travel time to the nearest primary health facility



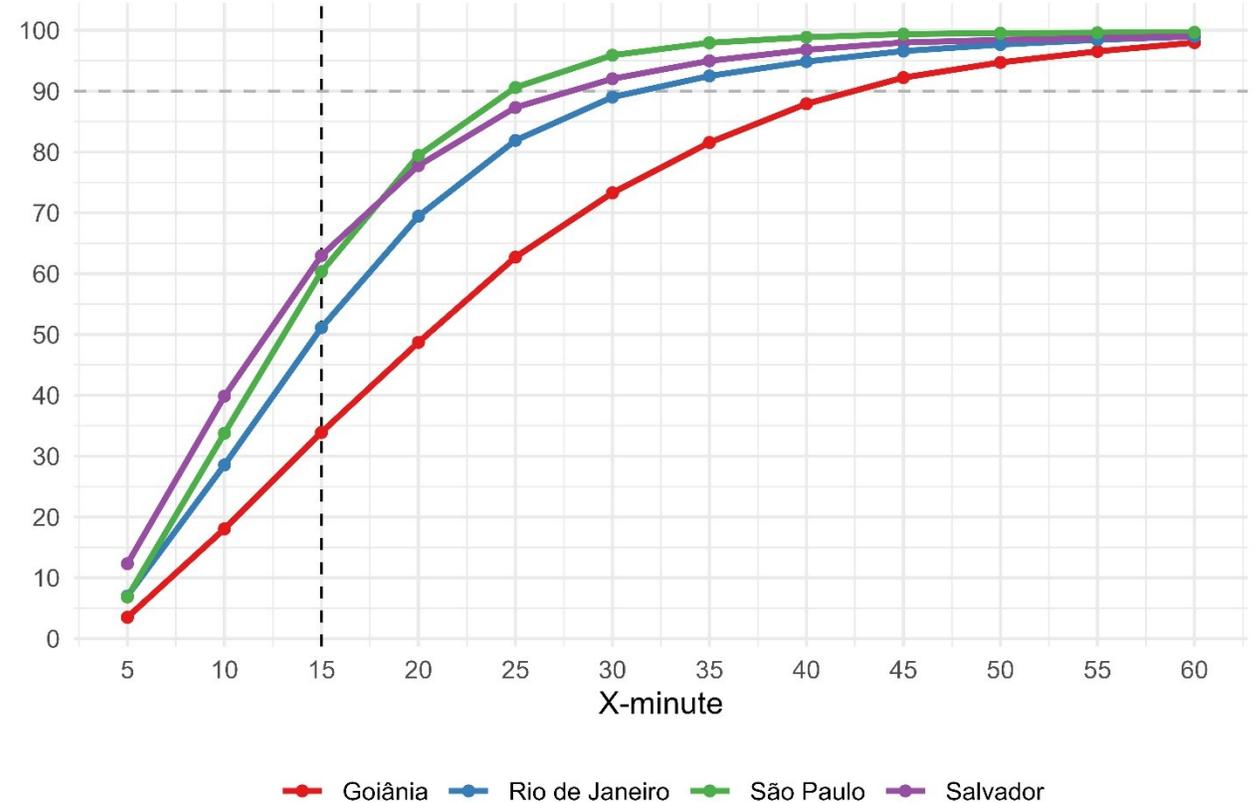
(4) Aplicações

→ Cidades de X-Minutos na dimensão Saúde Primária:

Walking travel time to the nearest primary health facility



% of population covered by the X-minute city (regarding primary health facilities)



(4) Aplicações

→ Influência do nível de estresse na acessib. a empregos

(4) Aplicações

→ Influência do nível de estresse na acessib. a empregos



LTS 1

comfortable for all
ages and abilities



LTS 2

comfortable for most
adults



LTS 3

comfortable for
confident bicyclists



LTS 4

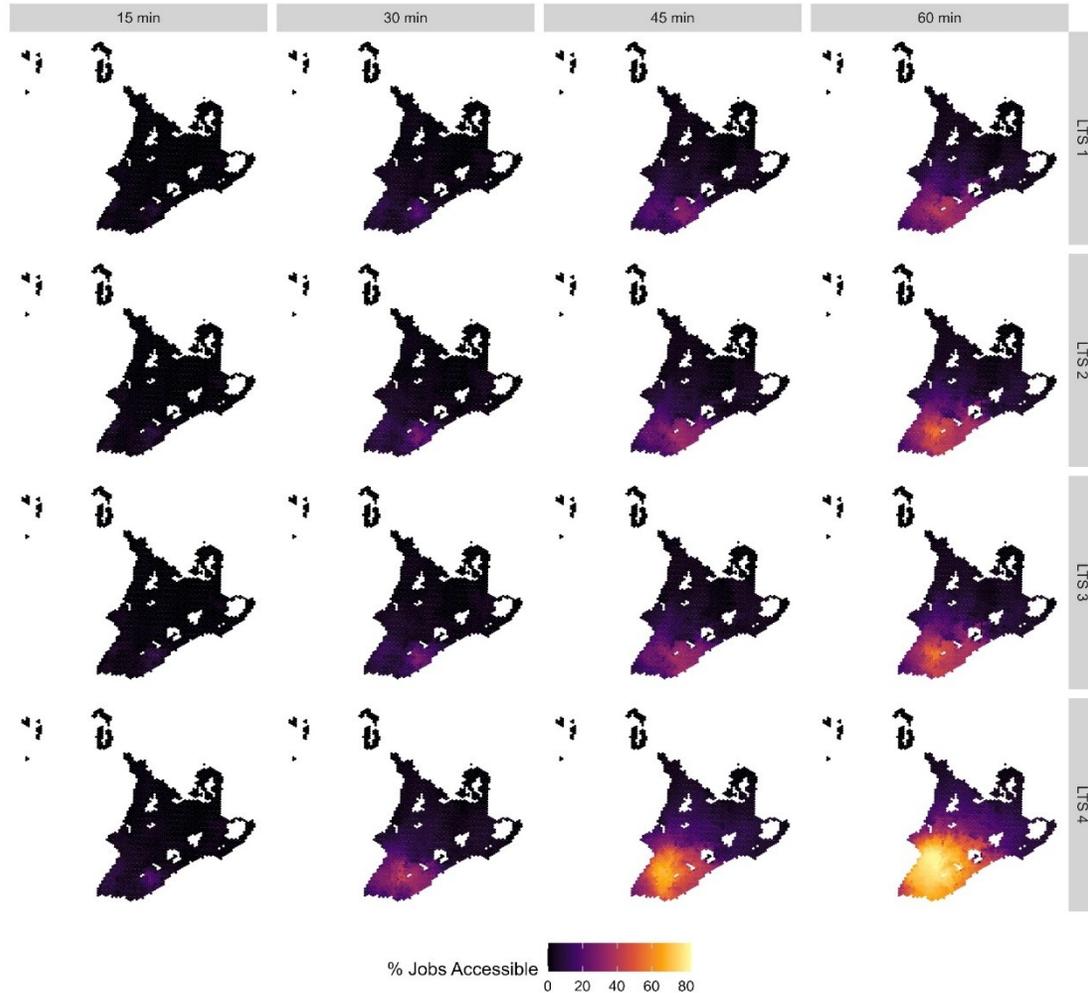
uncomfortable for
most

Mekuria, M.C., P.G. Furth, and H. Nixon. Low-Stress Bicycling and Network Connectivity. Research report 11-19, Mineta Transportation Institute, 2012.

(4) Aplicações

→ Influência do nível de estresse na acessib. a empregos

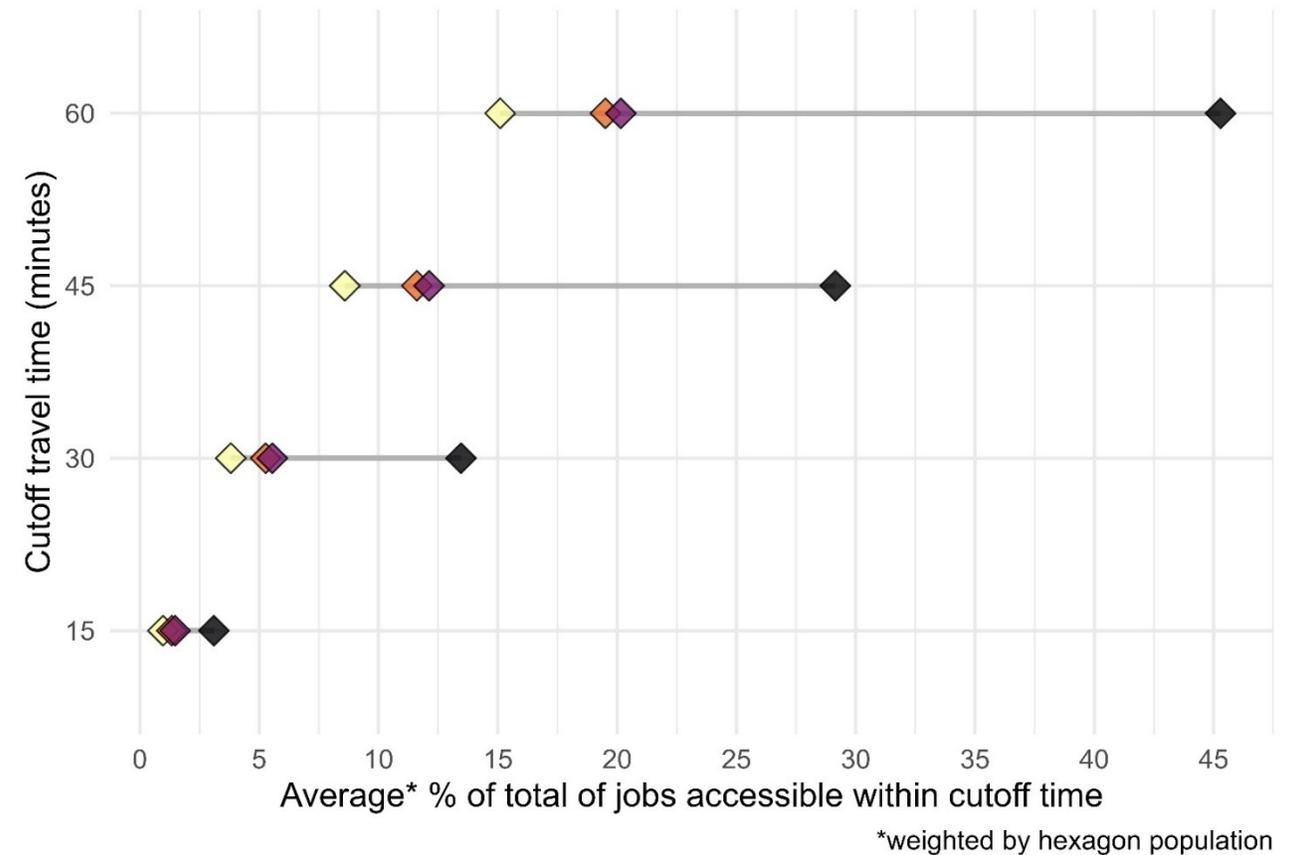
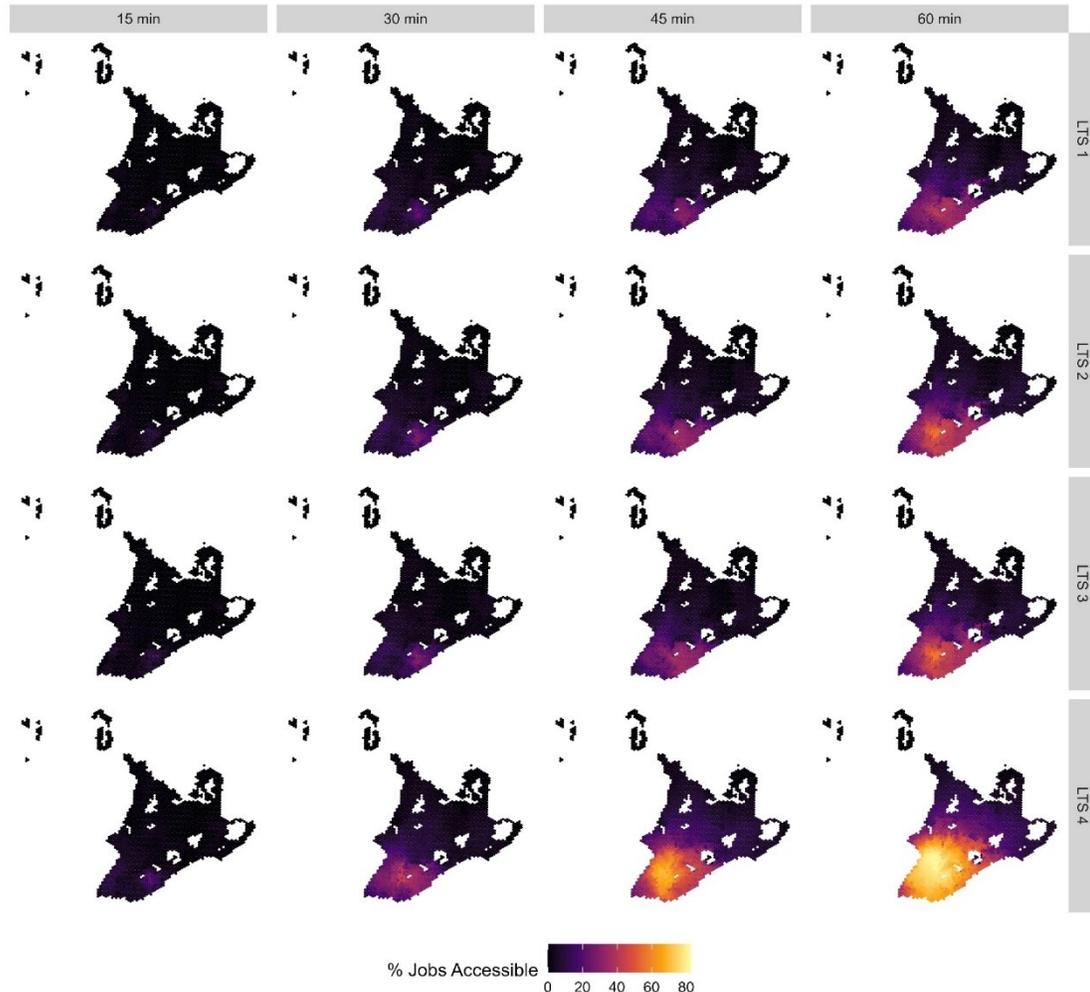
Cumulative Accessibility to Jobs by LTS and Travel Time Cutoff
Percent of total jobs accessible within cutoff time



(4) Aplicações

→ Influência do nível de estresse na acessib. a empregos

Cumulative Accessibility to Jobs by LTS and Travel Time Cutoff
Percent of total jobs accessible within cutoff time



Mensagem final



Mensagem final



OSMnx



Mensagem final



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