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URBAN FORM AND FUNCTION
A MULTI-CRITERIA DECISION ANALYSIS APPROACH

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Introduction

Cities play an immensurable role in our society

Cities are complex systems, places of increasing population concentration, wealth generation and offer social and economic opportunities but also spend large quantities of energy and produce large amounts of pollution

The way cities are planned and built directly impacts the quality of life of billions of people

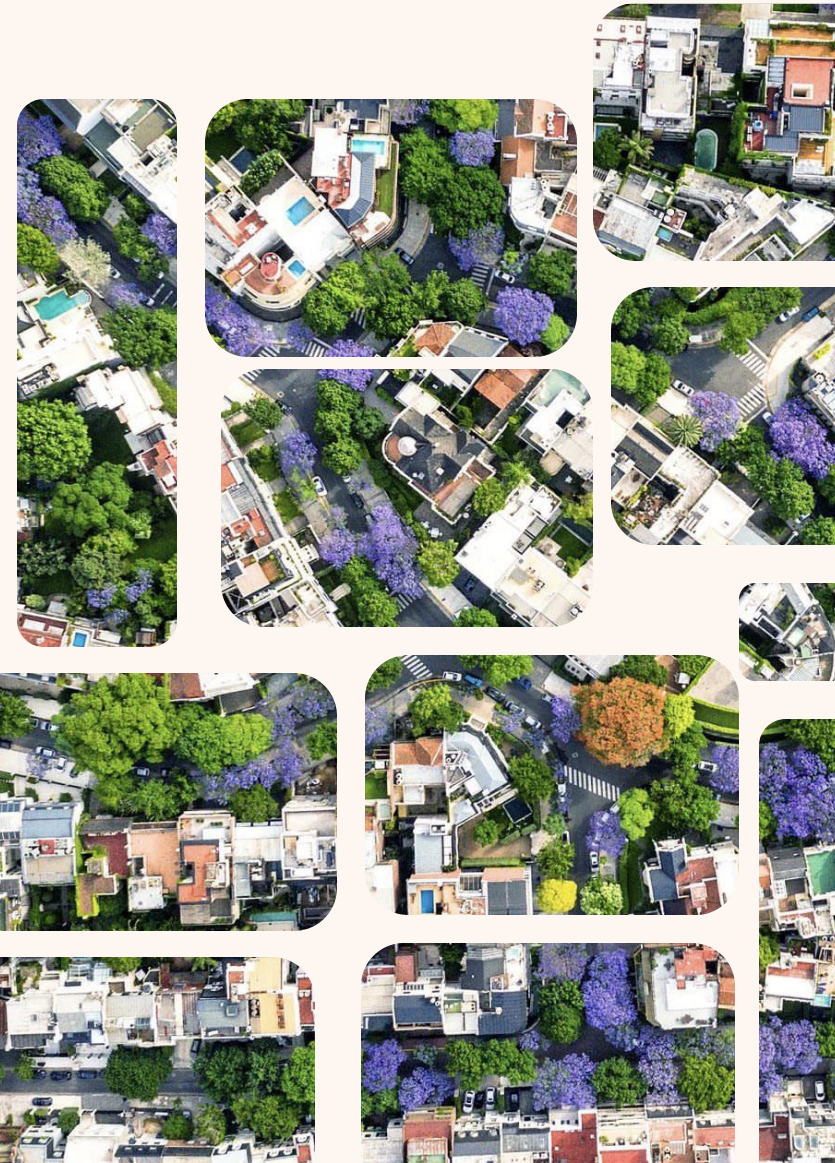
Introduction

The form and function define a city

The role of city planners:
Create solutions to not only solve the problems of today, but also the problems of tomorrow…

… towards a more sustainable, resilient, and equitable urban environment

Urban planning does not seek to attain the optimum solution '**irgendwie**, **irgendwo**, **irgendwann**' (somehow, somewhere, sometime)



Introduction

Urban planning problems are:

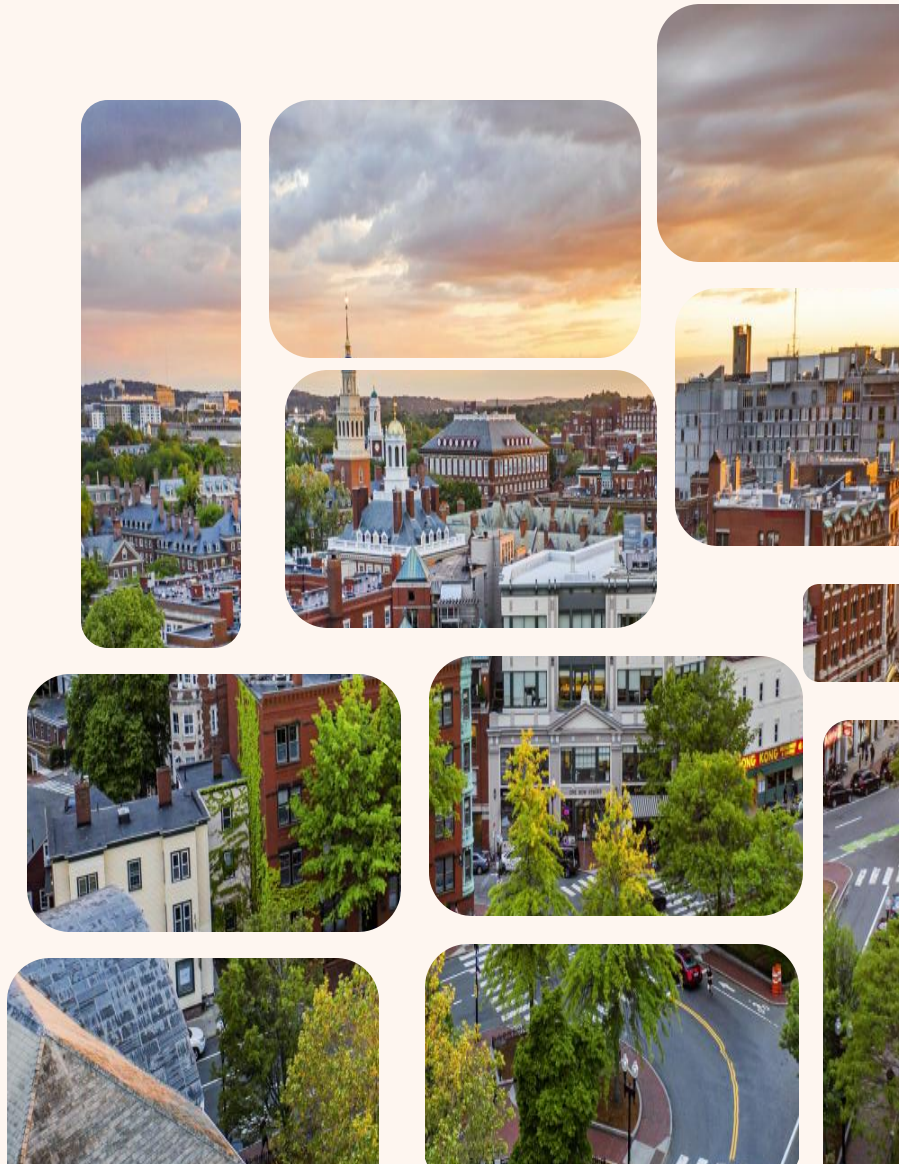
Complex, as the obstacles inhibiting efforts to achieve solutions are diverse; problem-solving occurs under uncertainty in changing environments

Ill-defined, as preferences structure, relevant criteria for effectiveness, solution paths, existing reality and goals may be unclear in usually multidisciplinary problems

Important but non-immediate, as unnecessary to find an instant solution being preferable to follow a systematic approach in the analysis

Literature Gap

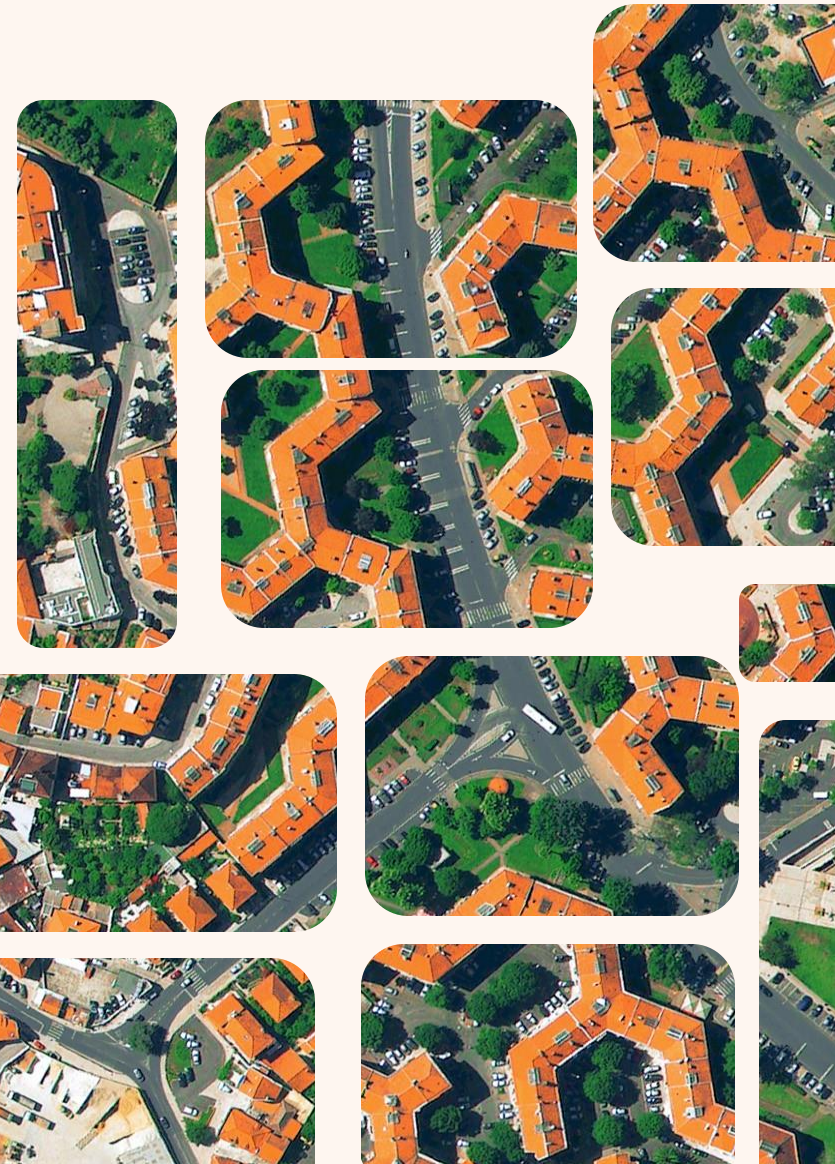
- Urban studies have long been an important research topic
- Modelling cities and studying their spatial layout has mostly been done by focusing on a single urban layout or benchmarking indicator
- Comparative studies between different city concepts were performed almost exclusively in a qualitative way



Goal and Objectives

Key goal: provide additional knowledge and tools to quantitatively analyze, compare, and benchmark different cities layouts

- **Urban regeneration projects**
- **City expansions**
- **New cities**



Three main objectives:

1. Development of quantitative indicators
2. Benchmark real and ideal cities (individual indicators)
3. Multicriteria Comparative Analysis

Creation and Development of Quantitative Indicators

1 Creation and development of quantitative indicators

- Accessibility

Accessibility is a wide-ranging concept, directly related to urban layout, transport planning, land use, socioeconomic factors and environmental goals

Interpretation: average distance from origins to destinations, weighted by destination attractiveness and by choice factor

$$A_i = \frac{1}{\sum_j w_j} \sum_{jk} \frac{w_j L_{kj} d_{ij}^k}{\sum_k L_{kj}},$$

where

i: 1, ..., I number of origins;
j: 1, ..., J number of facility types (includes jobs);
k: 1, ..., K number of closest facilities (when it applies), and in this thesis, K = 3;
A_i: accessibility score of origin i;
d_{ij}^k: network distance from origin i to the k-th closest facility of type j (or job zone centroid).
w_j: weight of facility type j (destination attractiveness);
L_{kj}: freedom of choice factor for the k-th closest facility of type j; $L_{kj} > L_{k+1,j}$.

Destination type	Weight	Choice type	Extended trip?
Post offices	1	Closest	Yes
Sports facilities	1	*k*-closest	Yes
Cultural organizations	1	*k*-closest	No
Higher education institutions	1	*k*-closest	No
Elderly care centers	1	*k*-closest	No
Churches	1	*k*-closest	No
High schools	2	*k*-closest	No
Shopping centers	2	*k*-closest	Yes
Entertainment sites	2	*k*-closest	No
Primary healthcare services	2	Closest	No
Pharmacies	2	Closest	Yes
Restaurants	2	*k*-closest	No
Parks and green areas	2	Closest	No
Kindergartens	3	Closest	Yes
Primary schools	3	Closest	Yes
Middle schools	3	Closest	No
Grocery stores	3	*k*-closest	Yes
Supermarkets	3	*k*-closest	Yes
Bakeries and pastry shops	3	*k*-closest	Yes
Jobs	22	Job zone analysis	No

Creation and Development of Quantitative Indicators

1 **Creation and development of quantitative indicators**

- Accessibility
- Active modal share

Active transport, such as walking or cycling, promotes affordable, equitable, inclusive means of transport

Determined by transforming trip distances onto active trip probabilities using log-logistic distributions

$$M_i = \frac{1}{\sum_j w_j} \sum_{jk} \frac{w_j L_{kj} p_{Aij}^k}{\sum_k L_{kj}},$$

where

i: 1, ..., I number of origins;
j: 1, ..., J number of facility types (includes jobs);
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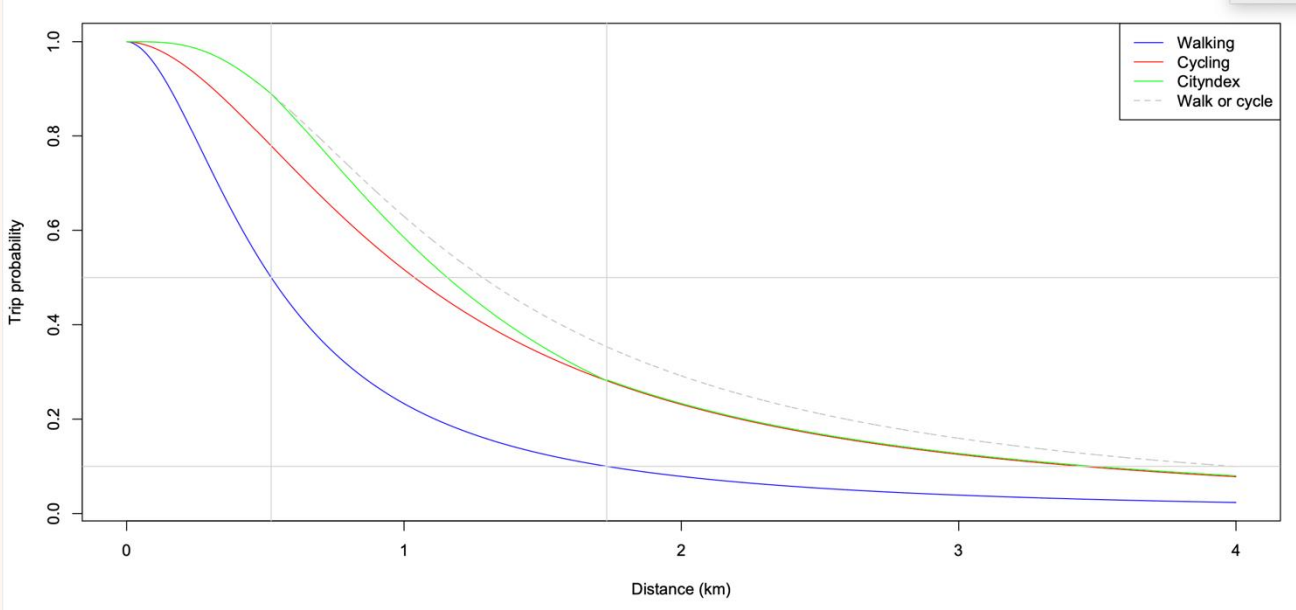
Active modal share probability based on trip distance



Creation and Development of Quantitative Indicators

1 **Creation and development of quantitative indicators**

- Accessibility
- Active modal share
- Transport energy consumption

Trips not made by active mode require motorized transport, which in turn consumes energy and typically produces GHG emissions

In Coimbra, motorized trips resort almost totally to fossil fuels, with a modal split of 70% for private cars and 30% for public transport

$$E_i = \frac{1}{\sum_j w_j} \sum_{jk} \frac{w_j L_{kj} \left(1 - p_{Aij}^k\right) \left(f_{car} F_{car} + f_{pub} F_{pub}\right) \left(d_{ijk}^{\rightarrow} + d_{ijk}^{\leftarrow}\right)}{\sum_k L_{kj}},$$

where
E_i: average fuel consumption of accessibility-related trips originating in i;
f_{car}: fraction of motorised trips made using the private car;
f_{pub}: fraction of motorised trips made using public transport;
F_{car}: private car average fuel economy (MJ/passenger.km);
F_{pub}: public transportation average fuel economy (MJ/passenger.km);
$d_{ijk}^{\rightarrow}, d_{ijk}^{\leftarrow}$: one-way distances from origin i, respectively, towards/away the k-th closest destination of type j.

Creation and Development of Quantitative Indicators

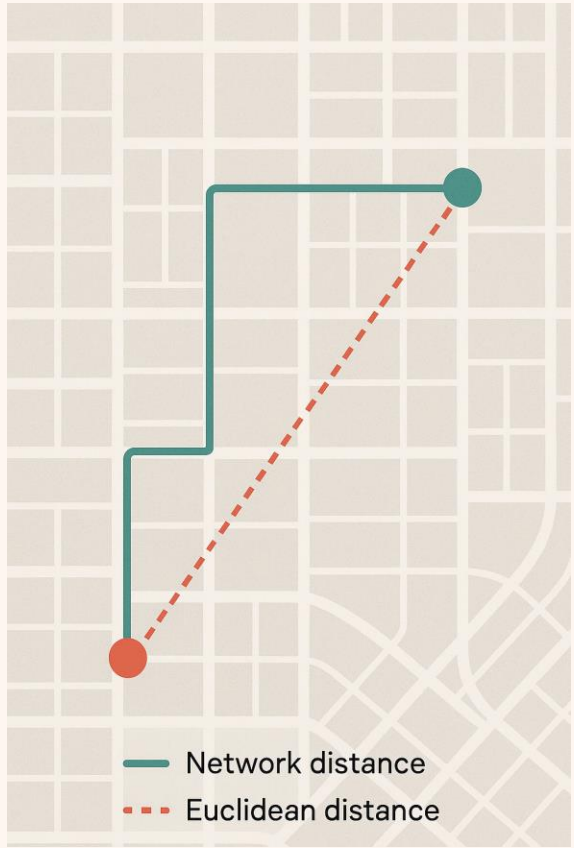
1 **Creation and development of quantitative indicators**

- Accessibility
- Active modal share
- Transport energy consumption
- Road network directness

Although for most transport related analysis network distances are preferred to Euclidean distances, the latter may be used as a reference for network performance

Route directness, is the ratio of the shortest distance between two points on a network, to the Euclidean distance between the same points

Directness is permeability, a measure of the extent to which urban form facilitates (or restricts) movement



Creation and Development of Quantitative Indicators

1 Creation and development of quantitative indicators

- Accessibility
- Active modal share
- Transport energy consumption
- Road network directness
- Pleasantness

Living in an urban environment provides citizens with a lot of benefits but the urban landscape might not coincide with what people consider as a pleasant physical environment

This indicator, quantitatively evaluates the human perception of the built environment

Based on a statistical model (CLMM) with geometric and land use elements as explanatory variables. Calibrated with over +1300 worldwide survey responses

Measured city square units on a Likert scale 1-5

Geometric and land use elements considered

Variable	Definition	Measurement Unit	Scale	Level
Green area	The publicly available green areas in the study unit	Percentage (%)	0–5 6–25 26–60 >61	None Small Medium High
Street width	Average street width, including cycle lanes, parking space and sidewalks	Meters (m)	0–8 9–18 >19	Narrow Wide Very wide
Number of floors	Average floor number of all buildings in the study unit	Integer	1–2 3–5 6–11 12–37 >38	House Short Medium Tall Skyscraper
Building distance	Average building side setbacks	Meters (m)	0 1–14 >15	Compact Spaced Sprawled
Green private area	Average private green area	Square meters (m^2)	0–10 >11	Not relevant Backyard

Creation and Development of Quantitative Indicators

1 **Creation and development of quantitative indicators**

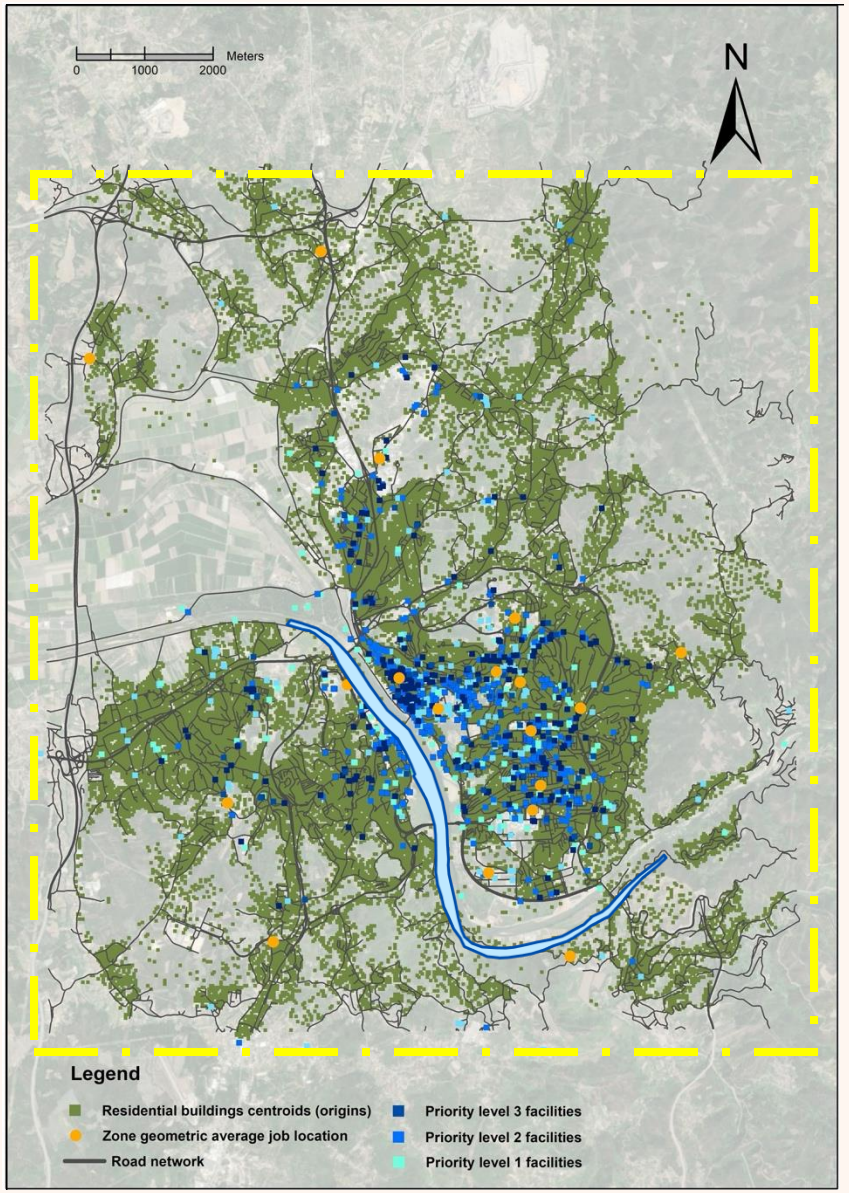
- Accessibility
- Active modal share
- Transport energy consumption
- Road network directness
- Pleasantness
- Mix land use

Mixed land use refers to the planning and development of an area that combines different functions within a single space or neighborhood

Mix land use leads to proximity life, urban vibrancy, environmental quality, and comfort – Vibrant, busy streets with people circulating all the time, creating a sense of belonging and of safety

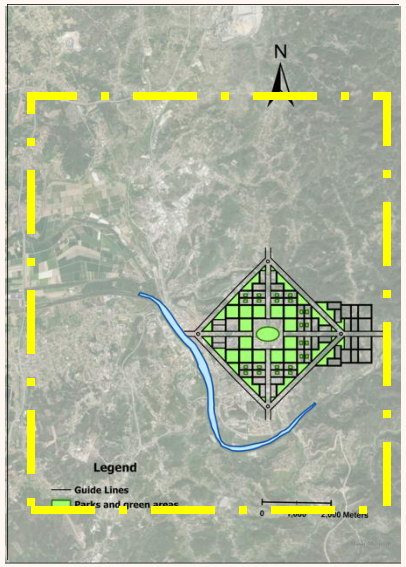
Measured based on the number of different functions present in a single square unit. 8 different types of land uses

Real and Ideal City Models - Alternatives

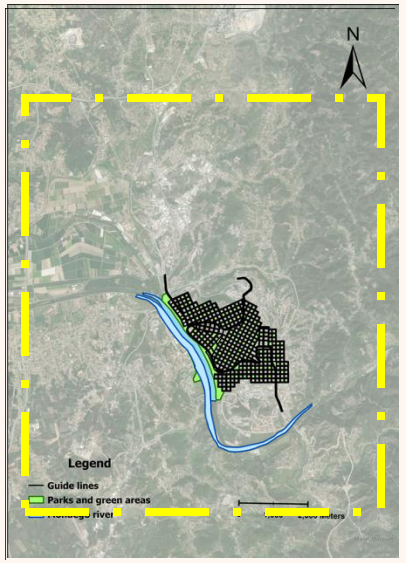


Coimbra

Infill Coimbra



Ville Radieuse



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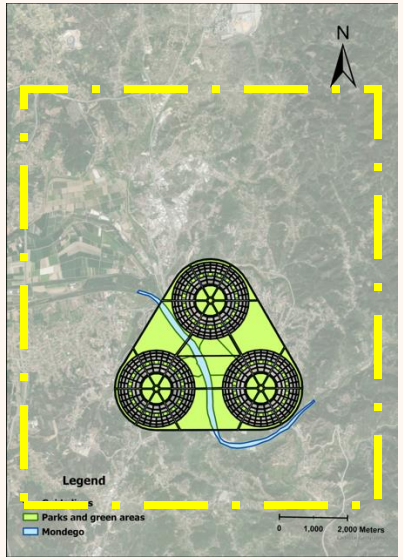
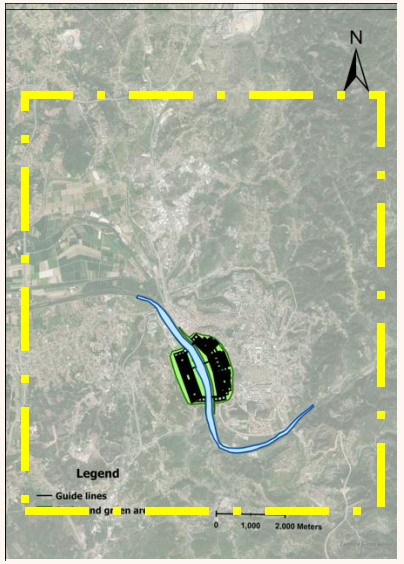
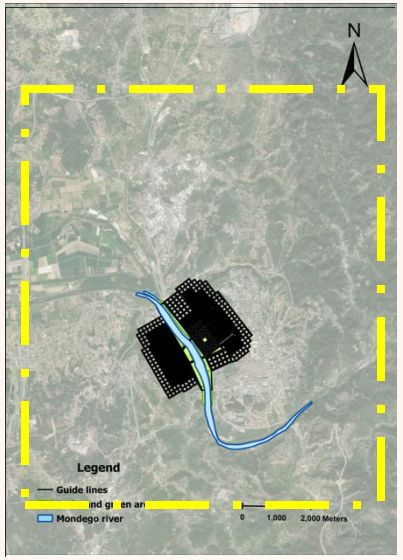


Garden City



Compact City Theory



Transect Planning

Creation and Development of Quantitative Indicators

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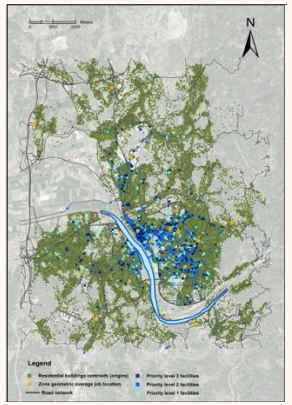
- Mix land use

2 Benchmark real and ideal cities

Coimbra



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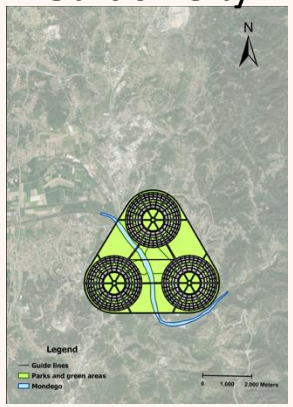
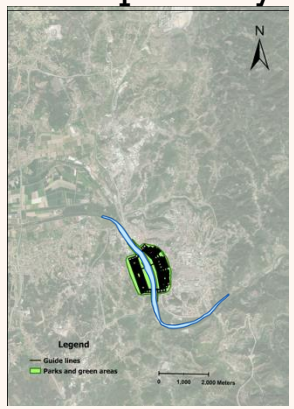
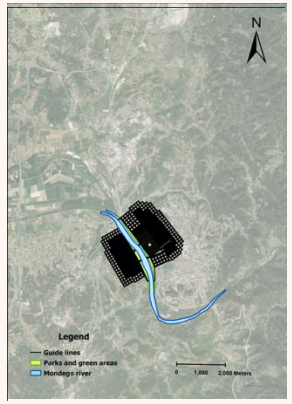


Compact City



Transect



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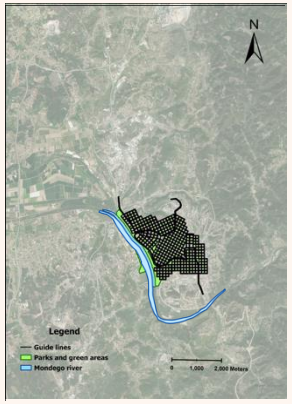
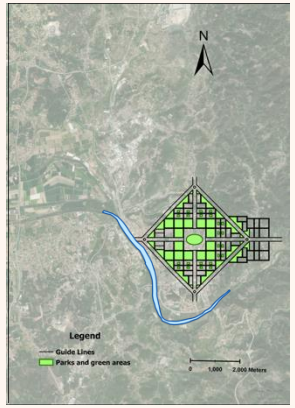


Ville Radieuse



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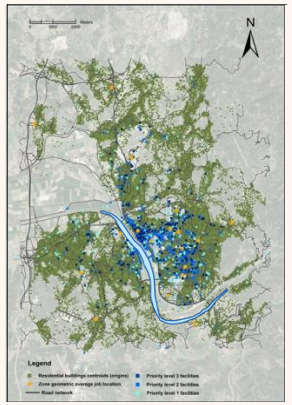

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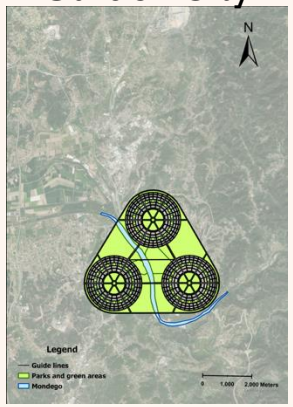

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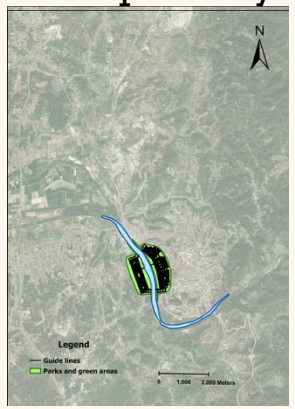

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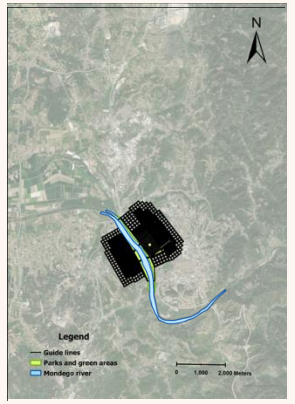

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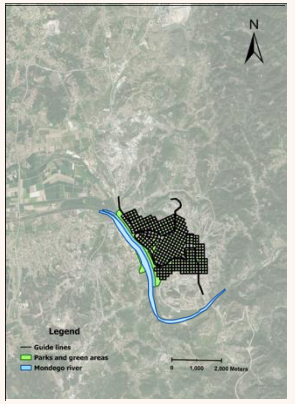

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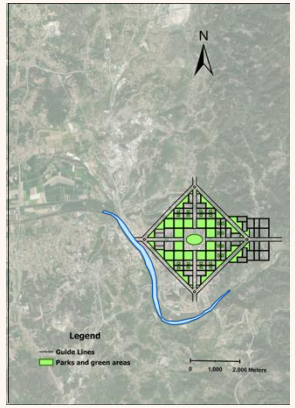

3 Development of a Multicriteria Comparative Analysis: Combined Spatial City Index (CSCI)

Multicriteria Analysis

Multicriteria matrix:

Table 2: Initial multicriteria matrix

Concepts / Criteria	Accessibility (m)	Active modal share (%)	Transport energy consumption (MJ/pass.-trip)	Road network directness (≥1)	Mix land use (1-8)	Pleasantness (1-5)
Transect Planning	649	85.1	1.06	1.29	6.4	2.9
Compact City Theory	572	87.8	0.85	1.26	7.3	2.3
TOD	623	85.8	0.87	1.22	6.0	2.5
Garden City	1487	62.3	5.34	1.26	3.9	3.6
Ville Radieuse	1230	66.6	3.68	1.28	4.3	2.9
Infill Coimbra	1602	59.1	5.75	1.58	3.7	2.4
Real Coimbra	2578	42.6	10.88	1.34	2.6	2.7
Preference direction	Min	Max	Min	Min	Max	Max

- Three of the criteria are **highly correlated**. If the three were considered, a bias would be created towards accessibility
- **Sensitive analysis:** combining the three into one; consider only one criteria of the three
- **Accessibility**, the most basic of the three, is taken into consideration

Multicriteria Analysis

MULTICRITERIA MATRIX:

Concepts / Criteria	Accessibility (m)	Road network directness (≥1)	Mix land use (1-8)	Pleasantness (1-5)
Transect Planning	649	1.29	6.4	2.9
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Real Coimbra	2578	1.34	2.6	2.7
Preference direction	Min	Min	Max	Max

Weight sets	w_{access}	w_{direct}	$w_{pleasnt}$	w_{mix}
Set 1	1/4	1/4	1/4	1/4
Set 2	2/5	1/5	1/5	1/5
Set 3	1/5	2/5	1/5	1/5
Set 4	1/5	1/5	2/5	1/5
Set 5	1/5	1/5	1/5	2/5
Set 6	1/3	1/3	1/6	1/6
Set 7	1/3	1/6	1/3	1/6
Set 8	1/3	1/6	1/6	1/3
Set 9	1/6	1/3	1/3	1/6
Set 10	1/6	1/3	1/6	1/3
Set 11	1/6	1/6	1/3	1/3
Set 12	2/7	2/7	2/7	1/7
Set 13	2/7	2/7	1/7	2/7
Set 14	2/7	1/7	2/7	2/7
Set 15	1/7	2/7	2/7	2/7

MCDM: TOPSIS

Rather than selecting a particular set of weights (or using AHP), it was more elucidating to explore the weight space: each criteria weight took the value 1 or 2 and all the possible combinations were evaluated

Multicriteria Analysis

MULTICRITERIA RESULTS:

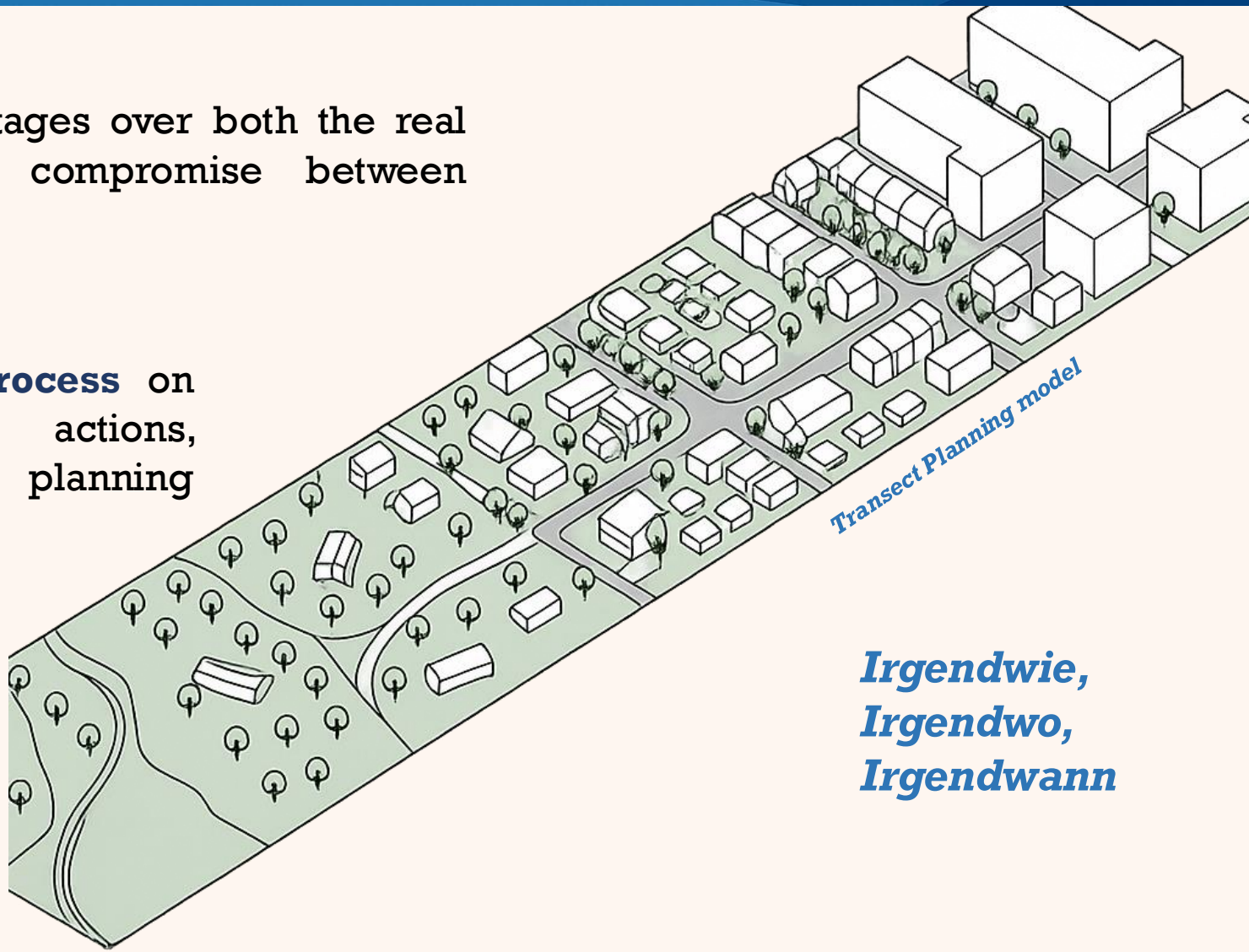
Concepts / Criteria	Accessibility (m)	Road network directness (≥1)	Mix land use (1-8)	Pleasantness (1-5)	TOPSIS Ranking Av.	
Transect Planning	649	1.29	6.4	2.9	1.40	Best
Compact City Theory	572	1.26	7.3	2.3	1.60	
TOD	623	1.22	6.0	2.5	3.00	
Garden City	1487	1.26	3.9	3.6	4.40	
Ville Radieuse	1230	1.28	4.3	2.9	4.60	
Infill Coimbra	1602	1.58	3.7	2.4	6.20	
Real Coimbra	2578	1.34	2.6	2.7	6.80	Worst
Preference direction	Min	Min	Max	Max		

- The more compact layouts come out on top of the quantitative analysis
- Pleasantness-oriented group tries to combine efficiency with greener and more pleasant urban environments
- The Infill proves to be an overall improved version of the real layout, but still considerably far from planned layouts
- The Coimbra comes last, proving it has clear problems of inefficiency due to urban sprawl

Conclusions

Compact layouts offer tangible advantages over both the real and other layouts which offer a compromise between accessibility and pleasantness

Results **help the decision-making process** on new policies, urban regeneration actions, infrastructure interventions, and planning strategies for city expansions

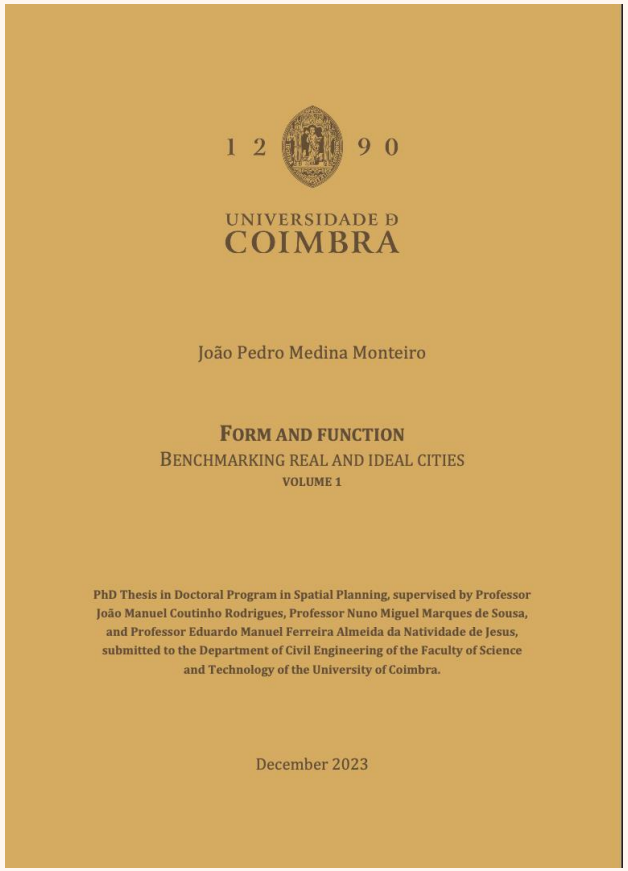


Irgendwie, Irgendwo, Irgendwann

Towards making better choices and achieve a more sustainable future for our cities

Research outputs

Journal	Scopus Quartiles	Publication date
Energies	Q1	January-2024
ICE - Municipal Engineer	Q2	May-2023
Sustainability	Q1	April-2022
International Journal of Geo-Information	Q1	February-2023
International Journal of Geo-Information	Q1	March-2023
Environment and Planning B: Urban Analytics and City Science	Q1	September-2022
Land	Q2	April-2023
Cities	Q1	April-2024



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