EXPERIMENTAL MODELLING FOR ALLOCATING MATERIAL RECOVERY FACILITIES IN THE METROPOLIS

Integrated research between Circular Economy and Urban Spatial Structure

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Delft, Netherlands

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Master of Architecture, Urbanism and Building Sciences – Track: Urbanism

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01. INTRODUCTION

02 PREPARATION FOR EXPERIMENTAL MODEL

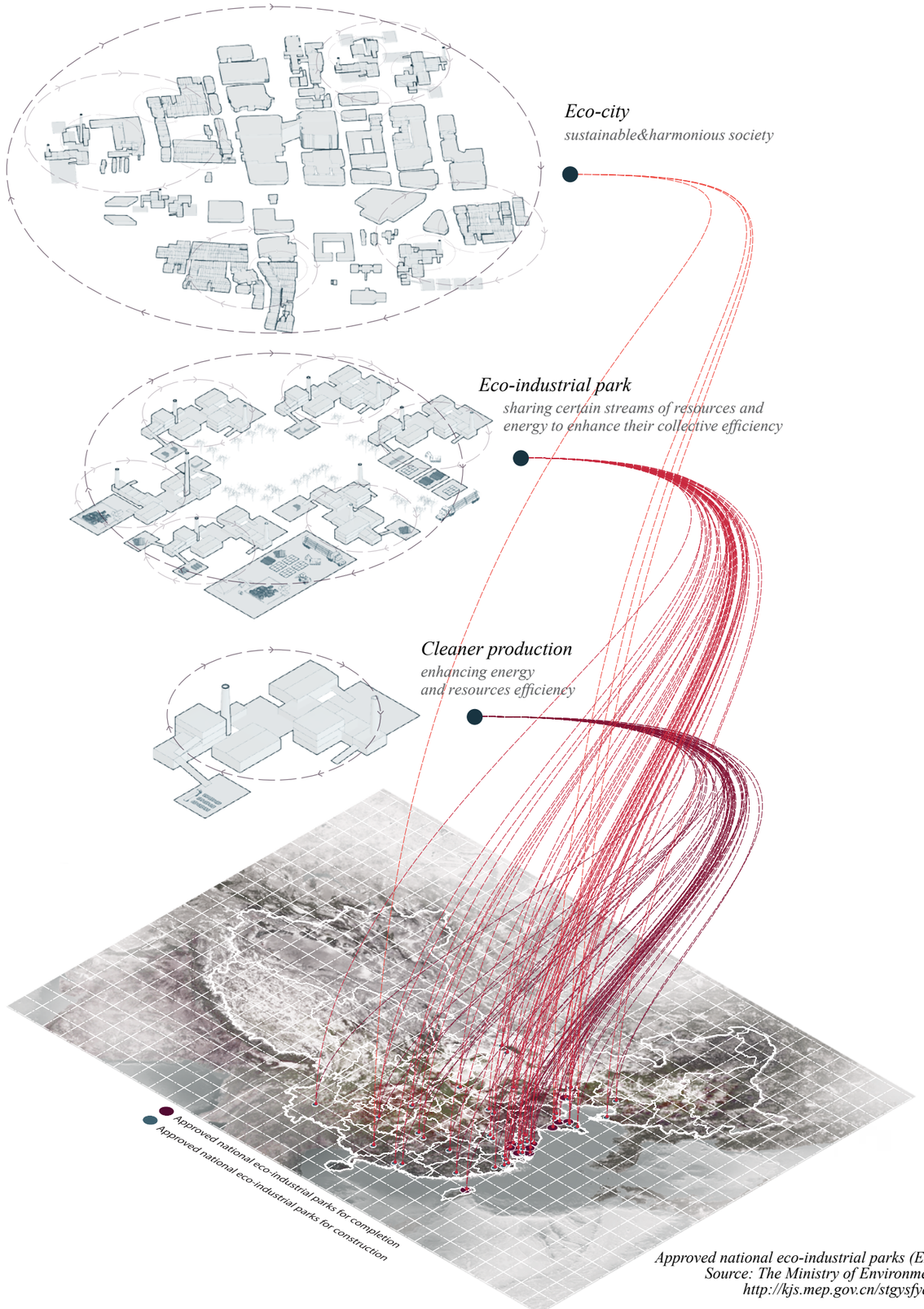
03 ABSTRACT MODEL

04 RESULT AND ANALYSIS

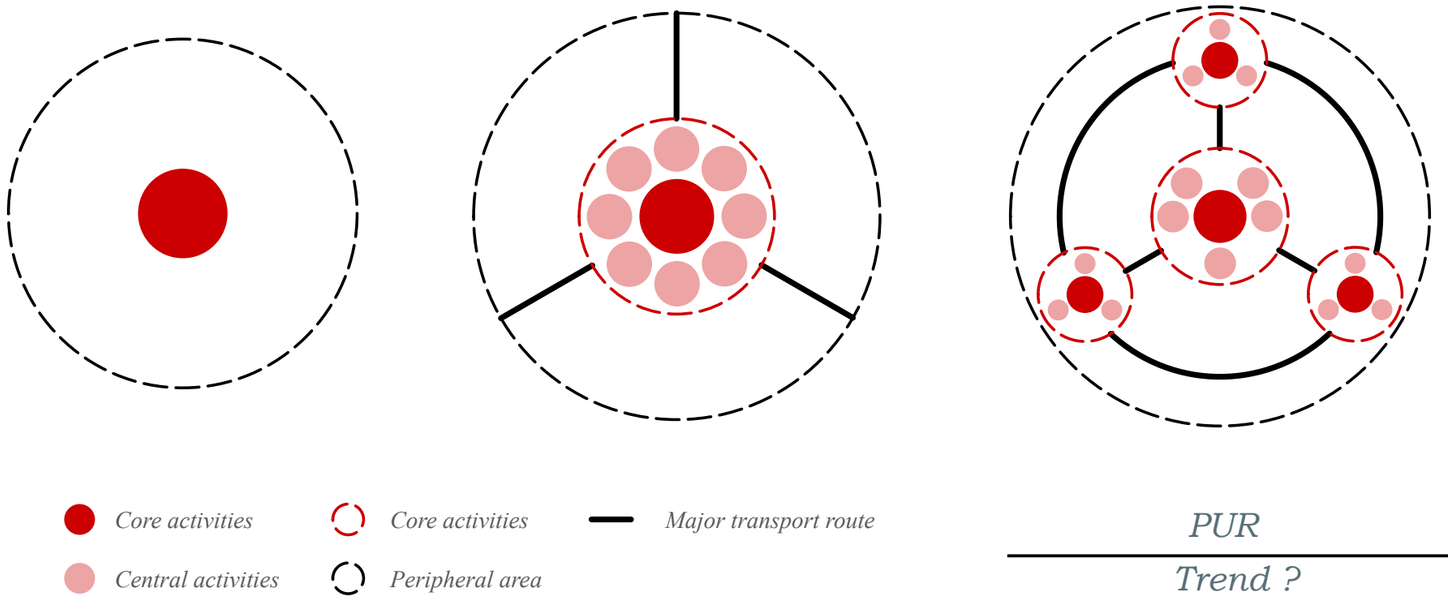
01. INTRODUCTION

01.1 PROBLEM FIELD

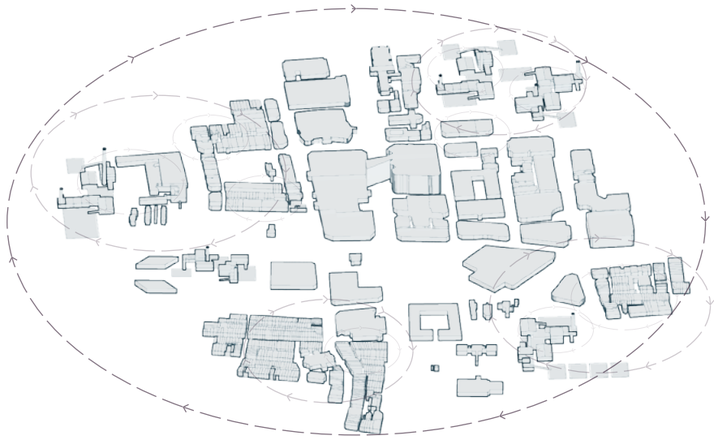
BATTLE OF MITIGATING THE NEGATIVE EFFECT OF URBANISATION



Approved national eco-industrial parks (EIPs). (Made by author)
Source: The Ministry of Environment Protection of China
http://kjs.mep.gov.cn/stgysfyq/m/200807/t20080718


Core activities
Central activities
Core activities
Peripheral area
Major transport route
PUR
Trend ?

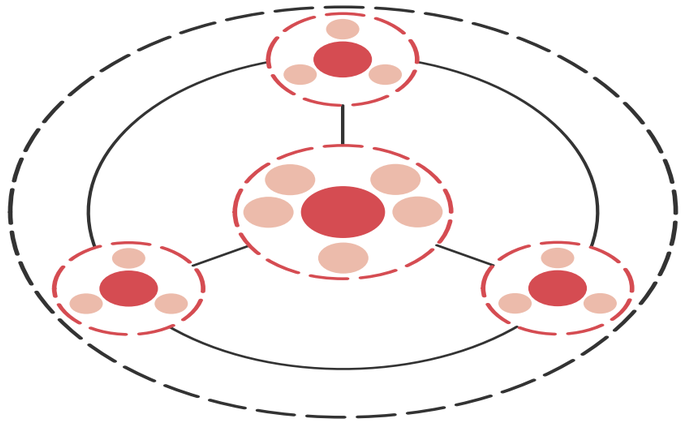
Circular Economy



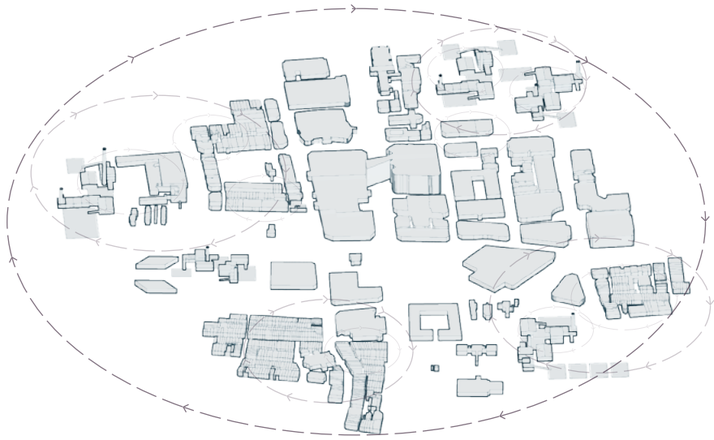
Urban Metabolism

01.1 PROBLEM FIELD

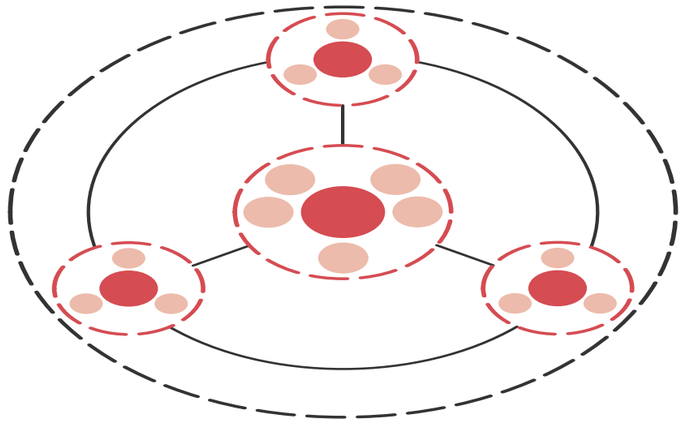
Polycentric Urban Structure



Provides Physical Platform



KNOWLEDGE GAP + EMPIRICAL EVIDENCE



01.2 PROBLEM STATEMENT:

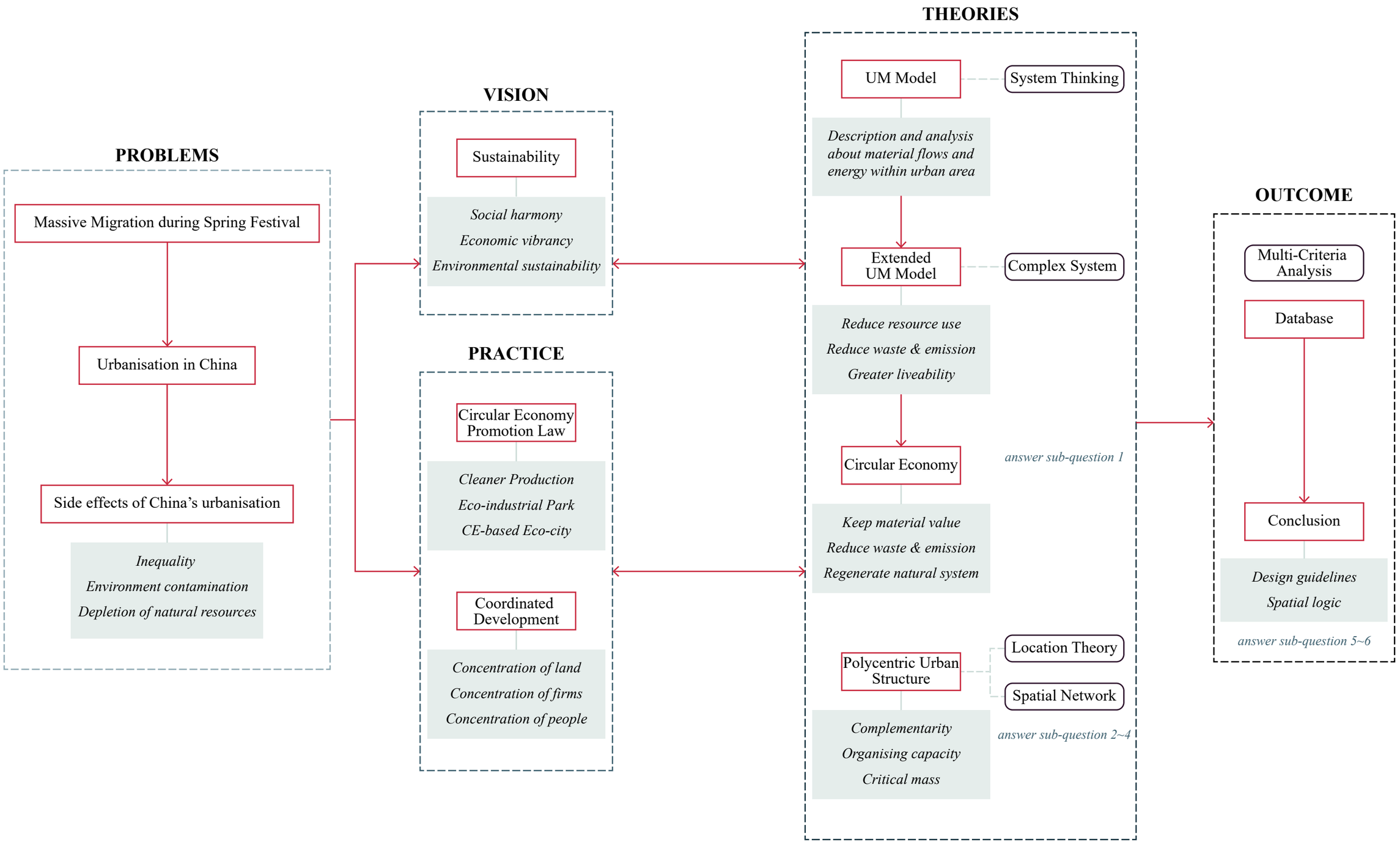
INTEGRATED RESEARCH BETWEEN
CIRCULAR ECONOMY AND URBAN SPATIAL STRUCTURE

The main aim of this project is to investigate an approach to integrate the study of CE with urban spatial structure, then form a tool to assist the procedure of decision making by analysing empirical data.

01.3 RESEARCH QUESTION:

Which spatial structure has more potential to facilitate urban symbiosis? What is the most compatible approach for allocating associated facilities in the metropolitan area?

01.4 THEORETICAL FRAMEWORK


PROBLEMS
Massive Migration during Spring Festival
Urbanisation in China
Side effects of China's urbanisation
Inequality
Environment contamination
Depletion of natural resources
VISION
Sustainability
Social harmony
Economic vibrancy
Environmental sustainability
PRACTICE
Circular Economy Promotion Law
Cleaner Production
Eco-industrial Park
CE-based Eco-city
Coordinated Development
Concentration of land
Concentration of firms
Concentration of people
THEORIES
UM Model
System Thinking
Description and analysis about material flows and energy within urban area
Extended UM Model
Complex System
Reduce resource use
Reduce waste & emission
Greater liveability
Circular Economy
answer sub-question 1
Keep material value
Reduce waste & emission
Regenerate natural system
Polycentric Urban Structure
Location Theory
Spatial Network
Complementarity
Organising capacity
Critical mass
answer sub-question 2~4
OUTCOME
Multi-Criteria Analysis
Database
Conclusion
Design guidelines
Spatial logic
answer sub-question 5~6

01.5 RESEARCH APPROACH

Generative multi-performance design system

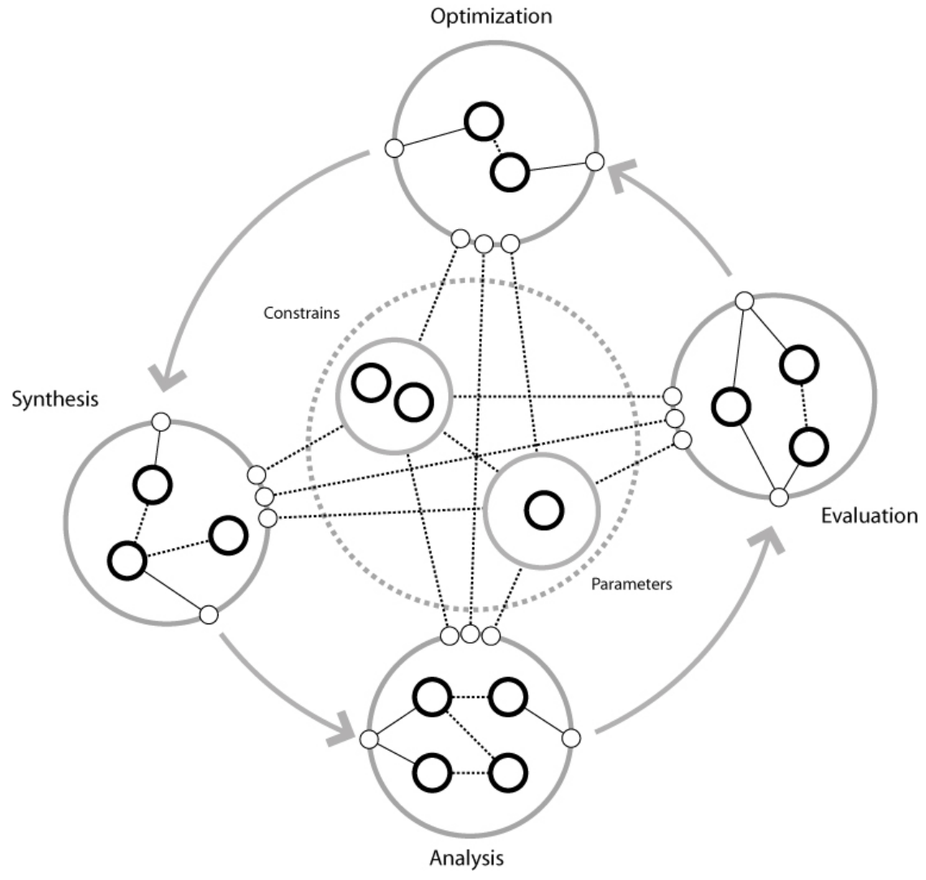
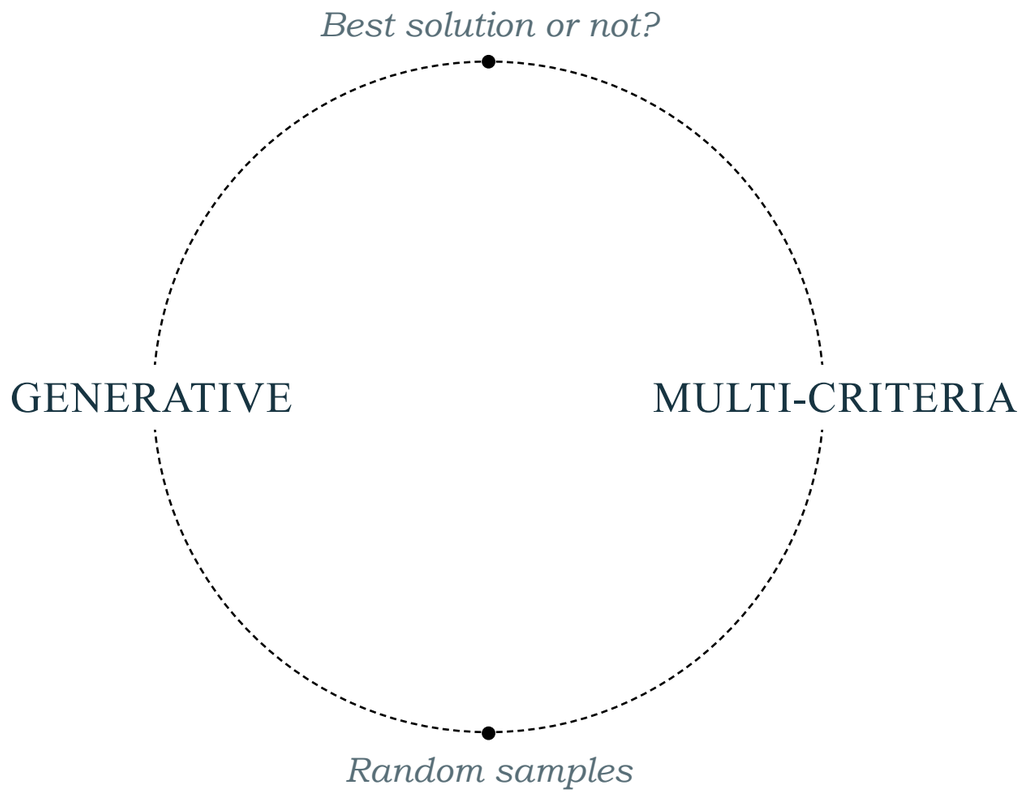
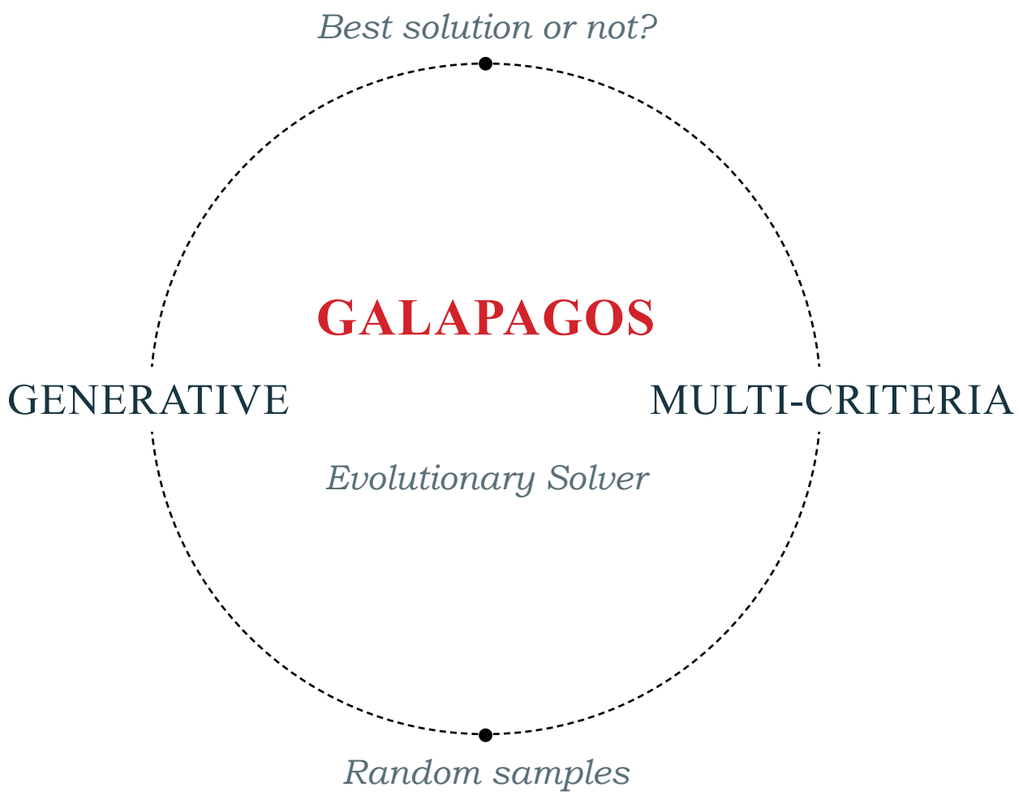
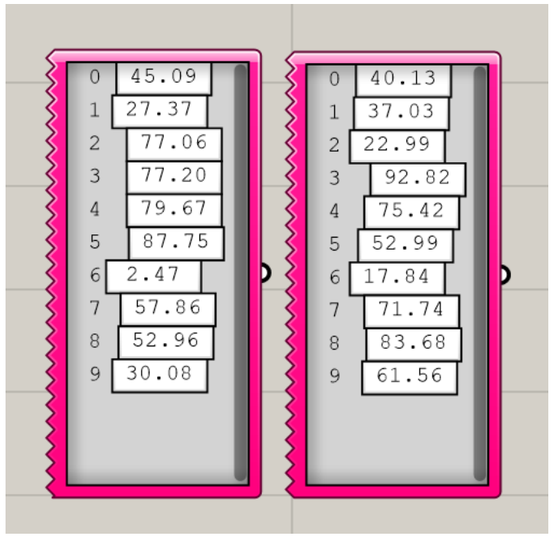


Diagram of generative multi-performance design system
Source: Alfaris, A., & Merello, R. (2008). The generative multi-performance design system.

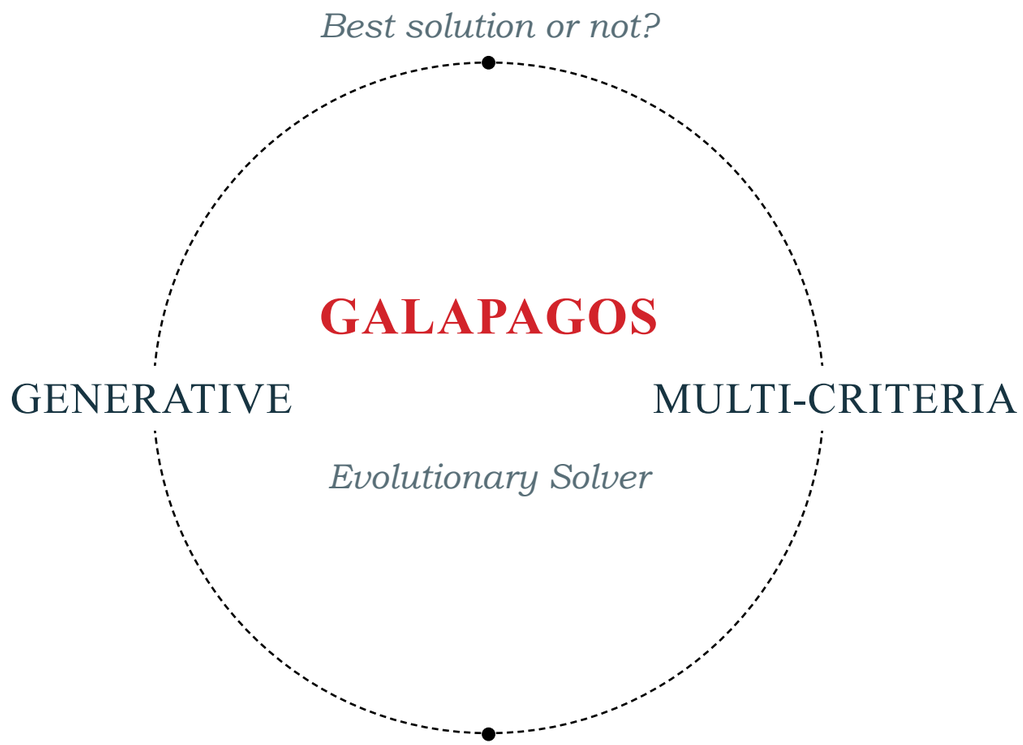

Best solution or not?
GENERATIVE
MULTI-CRITERIA
Random samples

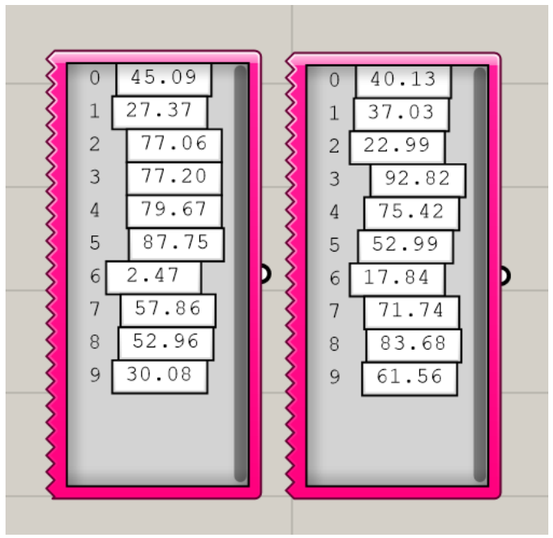

Best solution or not?
GALAPAGOS
GENERATIVE
MULTI-CRITERIA
Evolutionary Solver
Random samples



Gene Pools

which can control the attributes of geometries, such as 'area', 'height', 'color', 'coordinate' and so forth.





Gene Pools

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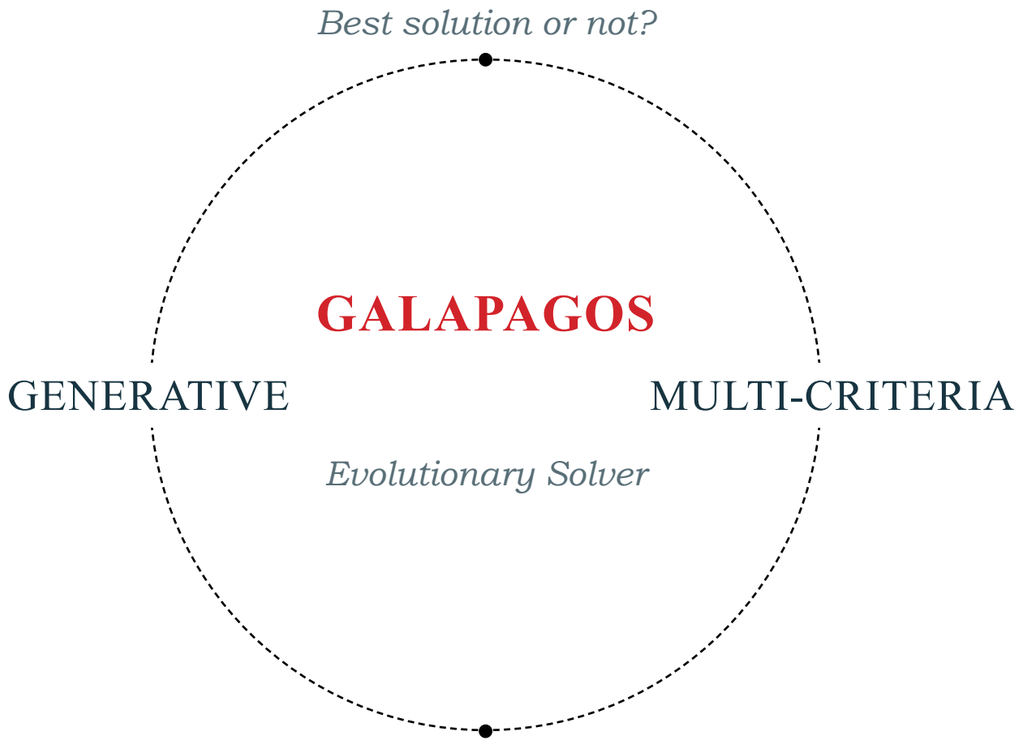
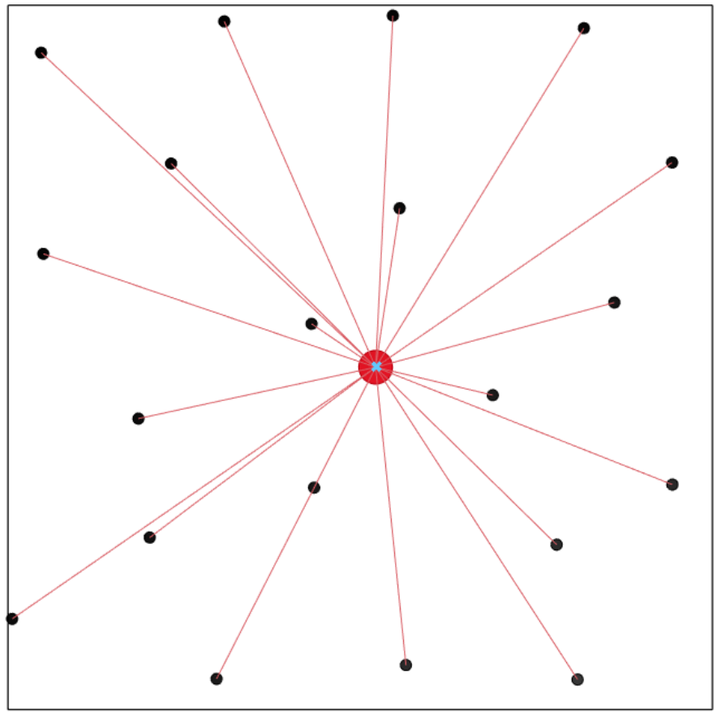
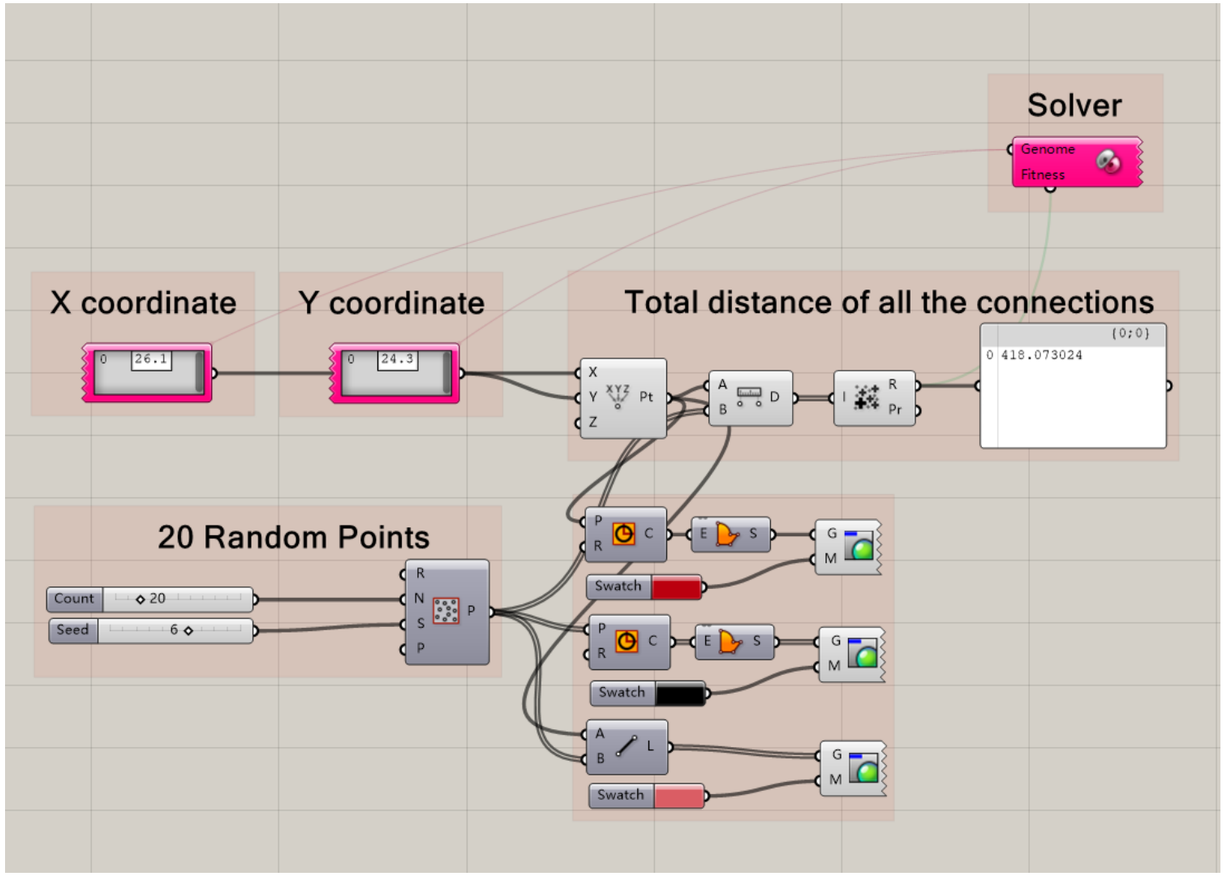
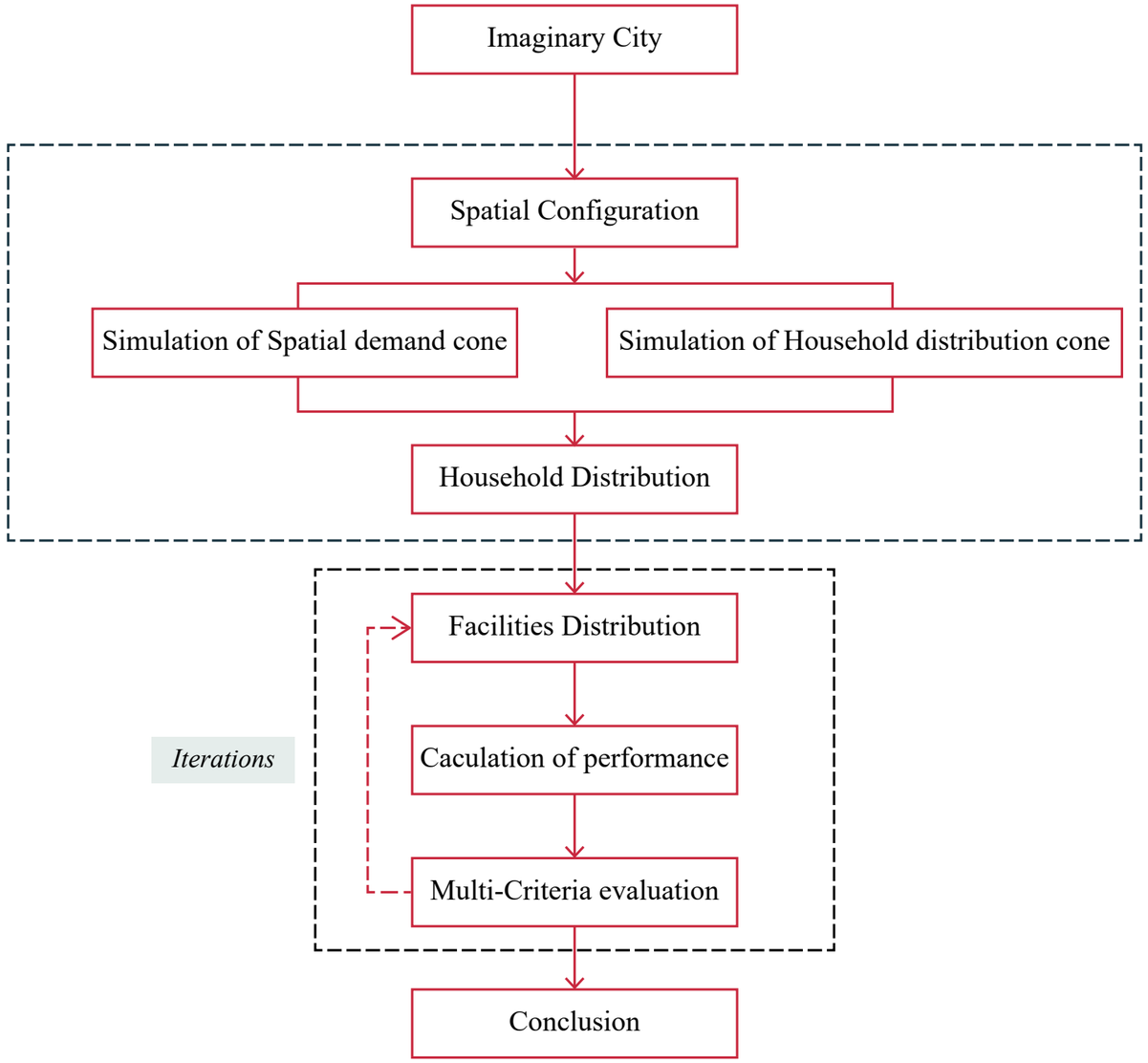


Fitness & Solver

Interface with Galapagos evolutionary solver. Fitness represents the goal that this solver is aiming to achieve



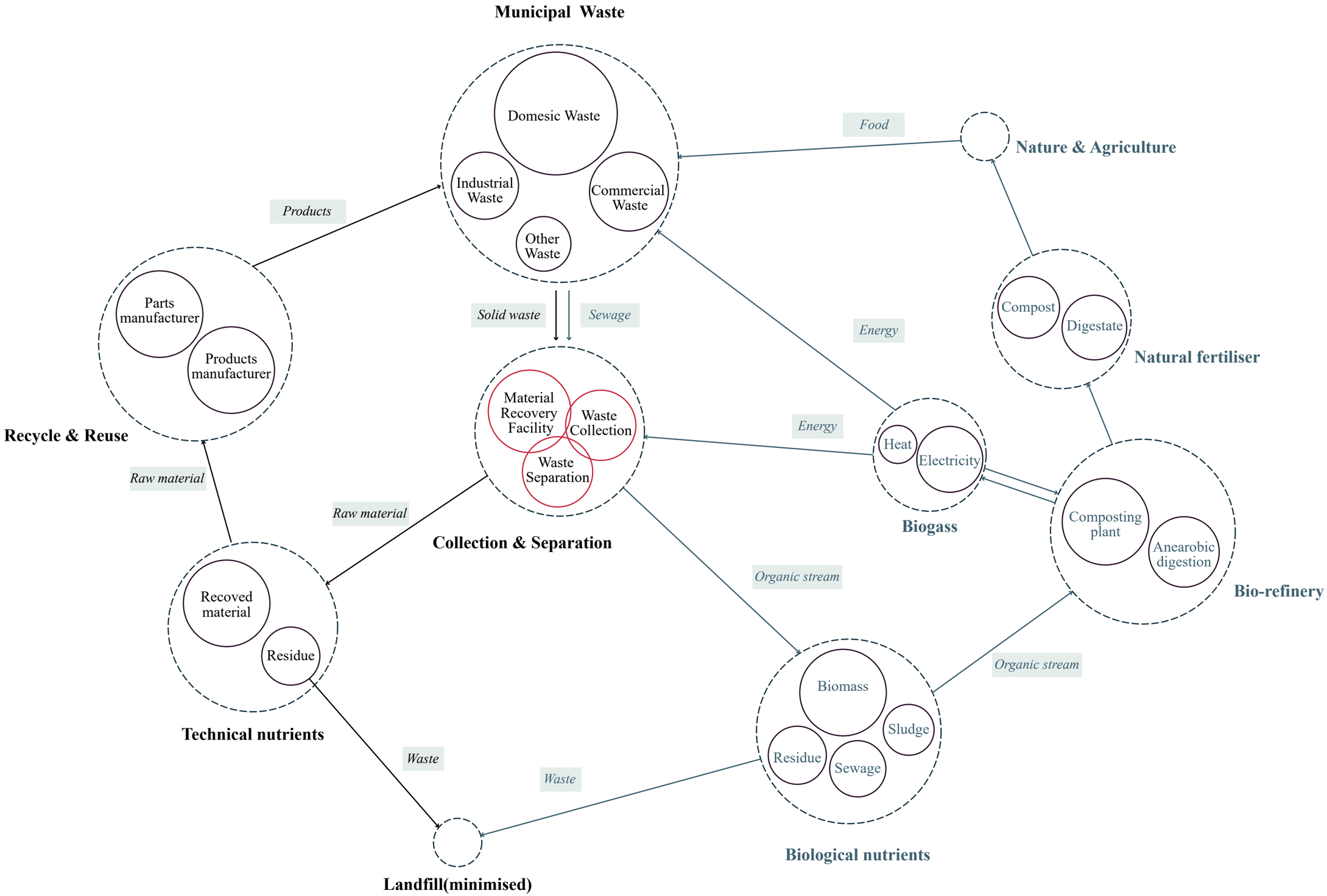

Solver
Genome
Fitness
X coordinate
Y coordinate
Total distance of all the connections
0 26.1
0 24.3
X
Y
Z
Pt
A
B
D
R
Pr
{0;0}
0 418.073024
20 Random Points
Count
20
Seed
6
R
N
S
P
P
R
C
E
S
G
M
Swatch
A
B
L

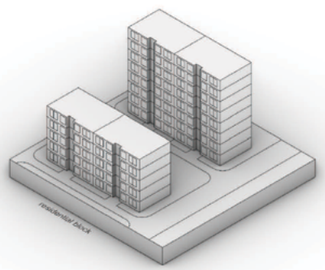


Methodology of the graduation project (Made by author)

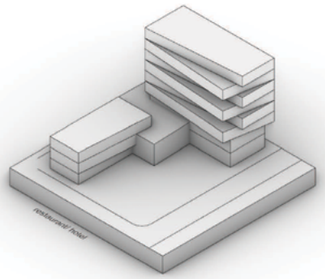
02 PREPARATION FOR EXPERIMENTAL MODEL

02.1 VITAL FLOW IN URBAN SYMBIOSIS

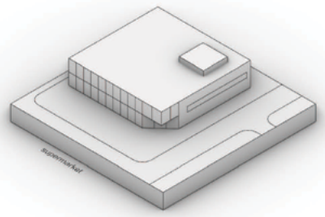

Municipal Waste
Domesic Waste
Industrial Waste
Commercial Waste
Other Waste
Food
Nature & Agriculture
Products
Parts manufacturer
Products manufacturer
Recycle & Reuse
Solid waste
Sewage
Energy
Compost
Digestate
Natural fertiliser
Material Recovery Facility
Waste Collection
Waste Separation
Energy
Heat
Electricity
Biogass
Raw material
Raw material
Collection & Separation
Composting plant
Anearobic digestion
Bio-refinery
Organic stream
Recoved material
Residue
Technical nutrients
Biomass
Sludge
Residue
Sewage
Organic stream
Waste
Waste
Biological nutrients
Landfill(minimised)



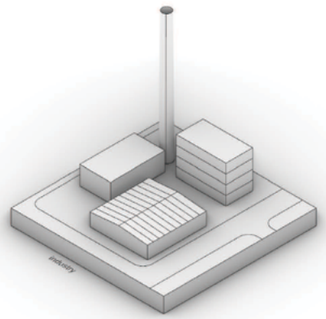
residential block



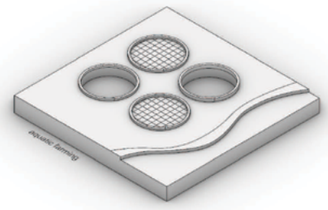
restaurant / hotel



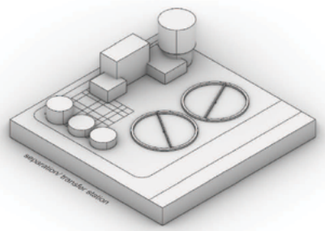
supermarket



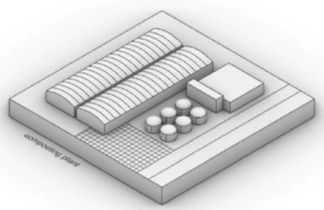
industrial plants



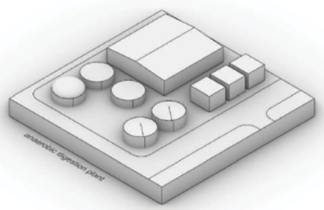
aquatic farming



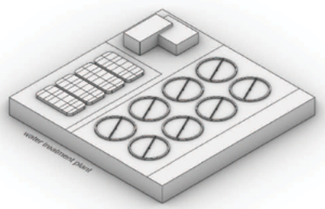
separation/ transfer station



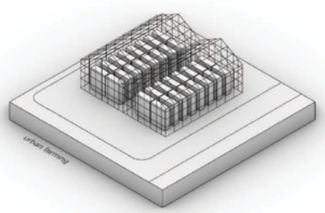
composting plant



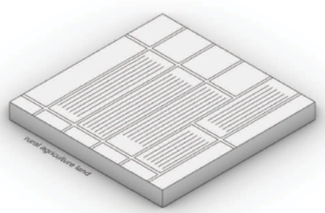
anearobic digestion plant



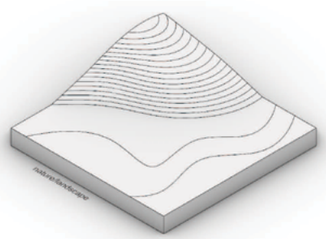
water treatment plant



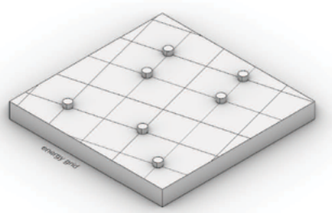
urban farming



rural area agriculture

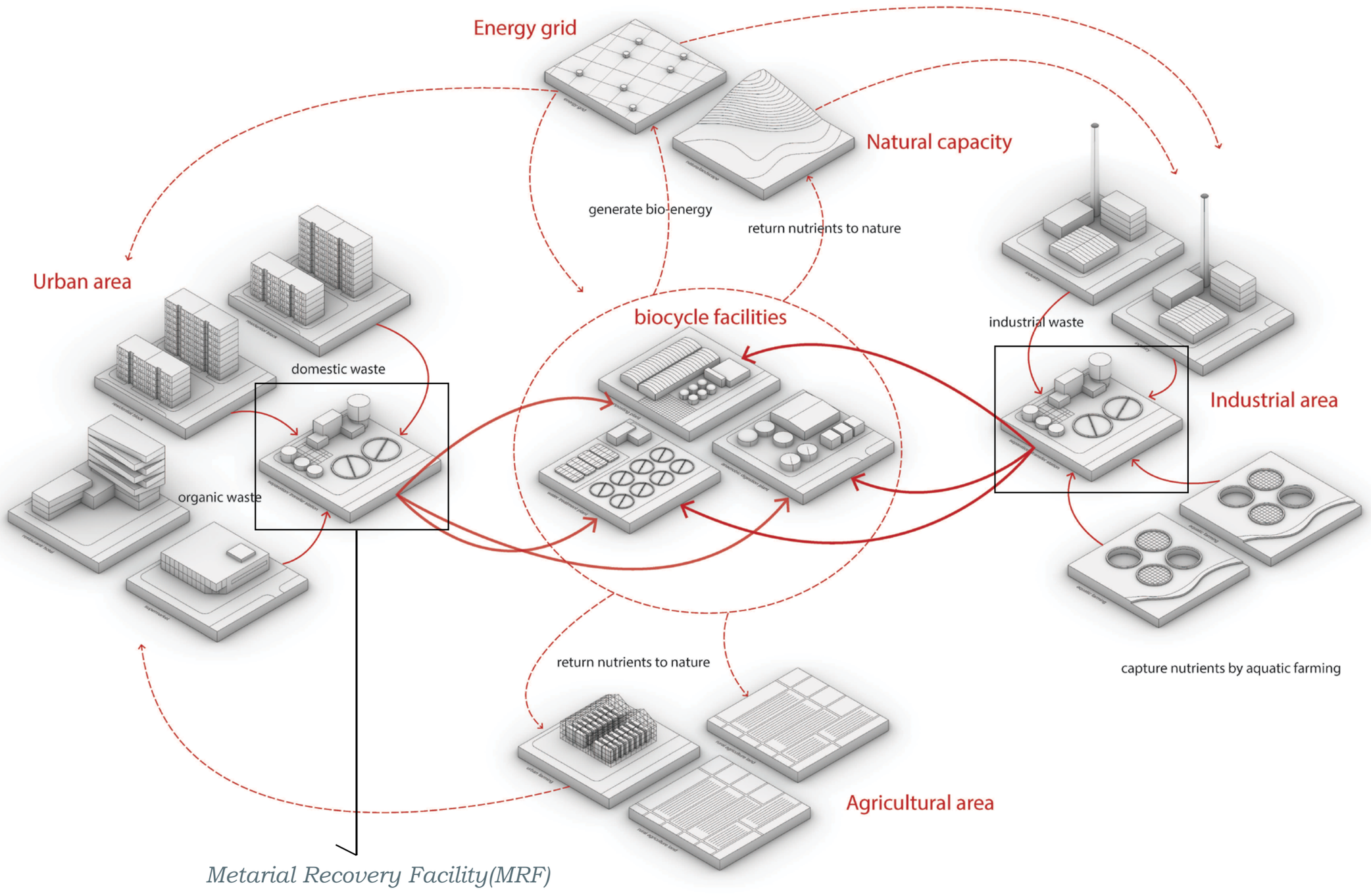


nature / landscape

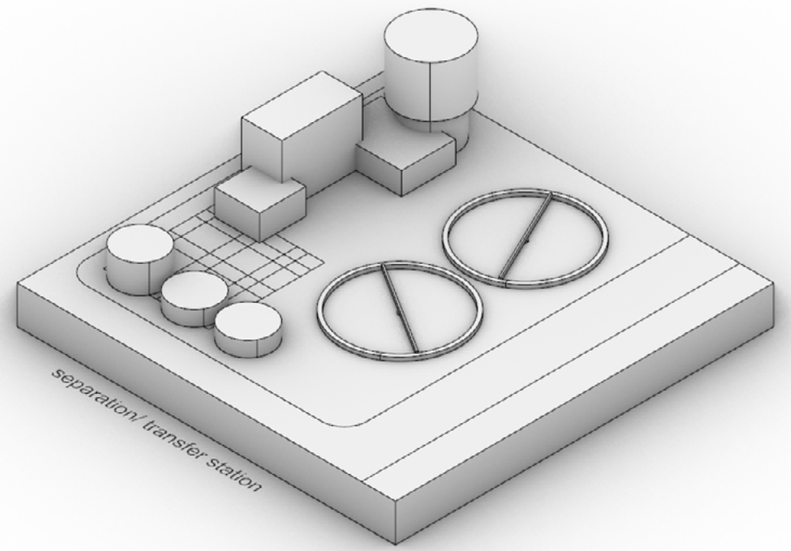


energy grid

Lists of major sectors in urban symbiosis (Made by author based on literature review)



Spatial relationships between major sectors (Made by author based on literature review)

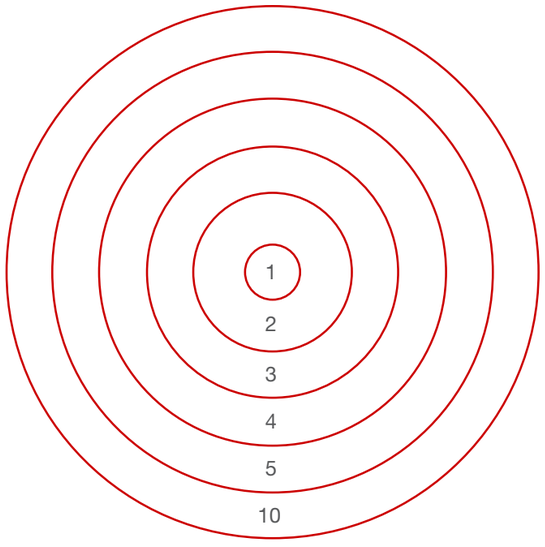


Metarial Recovery Facility(MRF)

02.2 THEORIES OF SPATIAL STRUCTURE

Concentric-ring theory

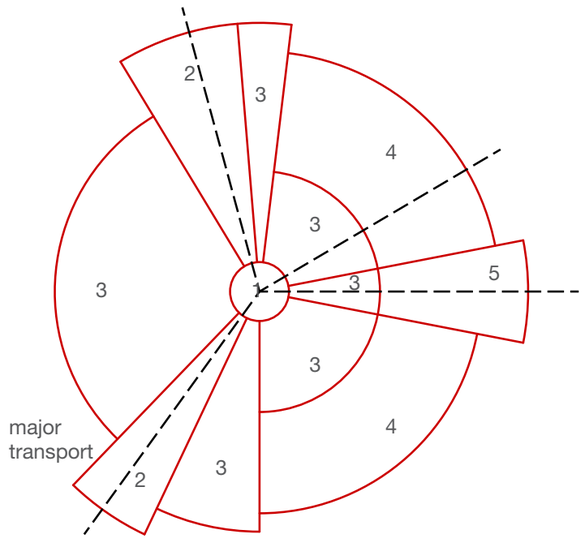
by Burgess (1927)



1. central business district (CBD)
2. wholesale light manufacturing
3. low-cost housing
4. medium-cost housing
5. high-cost housing
10. commuter zone

Sector theory

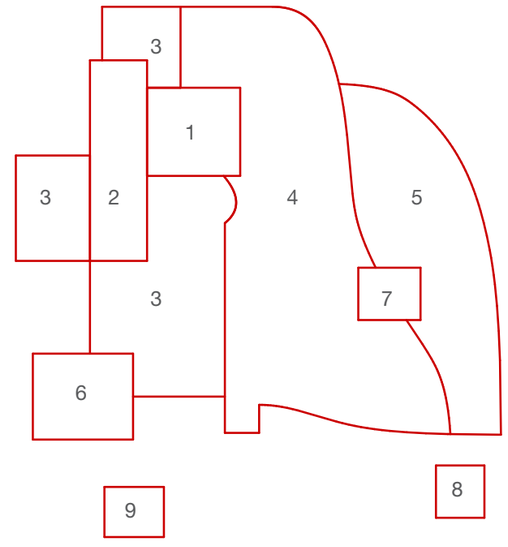
by Hoyt (1939)



1. central business district (CBD)
2. wholesale light manufacturing
3. low-cost housing
4. medium-cost housing
5. high-cost housing

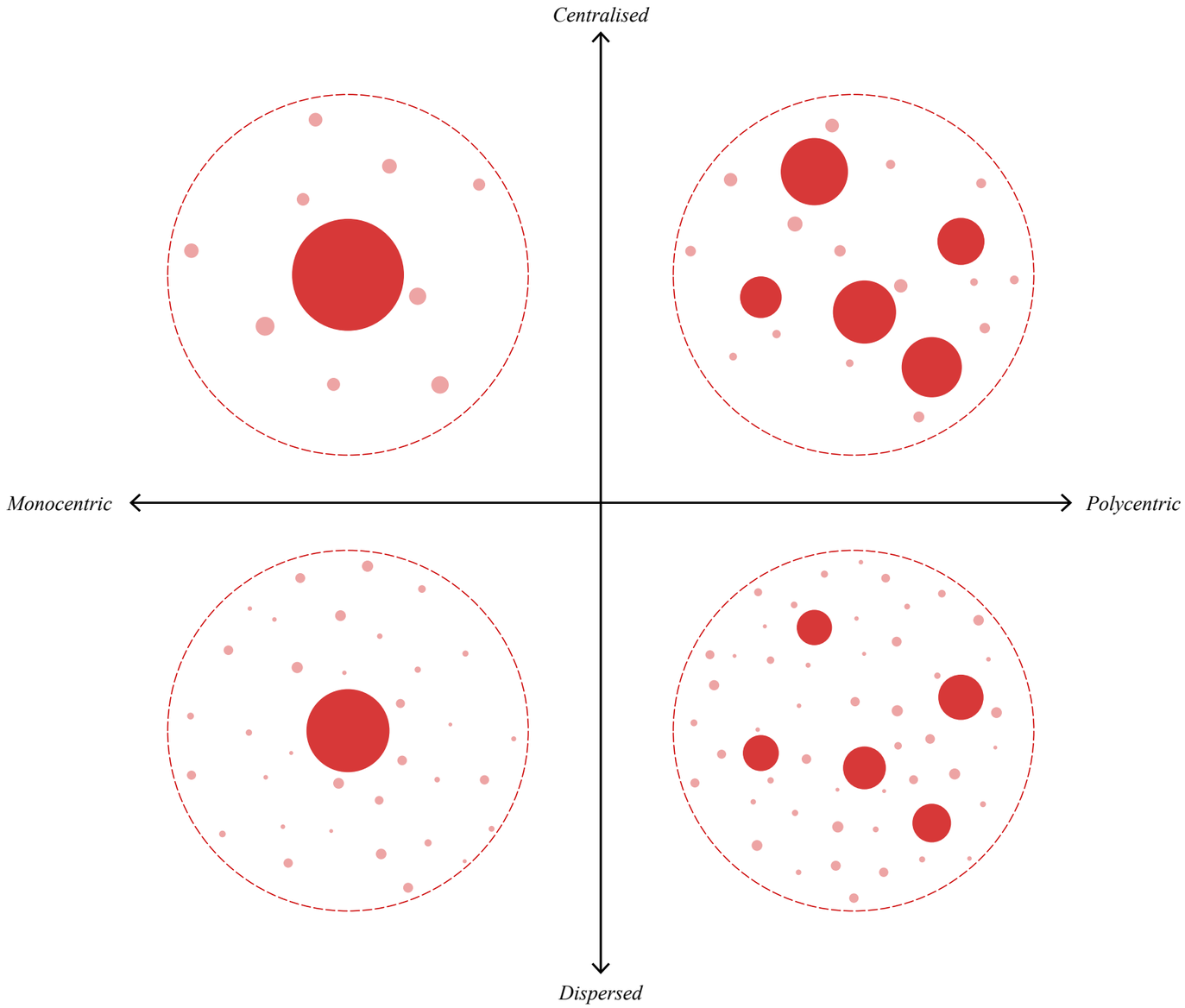
Multiple-nuclei theory

by Ullman and Harris (1945)

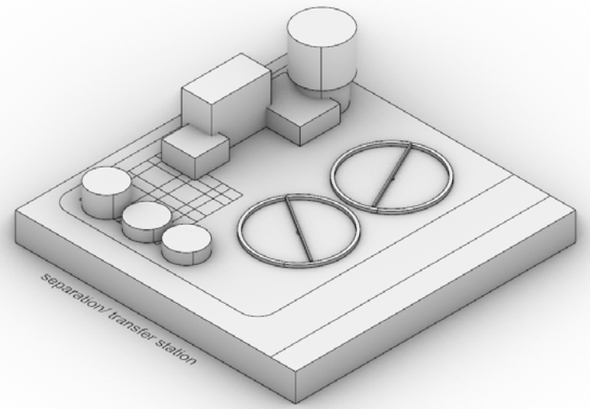


1. central business district (CBD)
2. wholesale light manufacturing
3. low-cost housing
4. medium-cost housing
5. high-cost housing
6. heavy manufacturing
7. outlying business district
8. residential suburb
9. industrial suburb

Dimensions of regional urban form

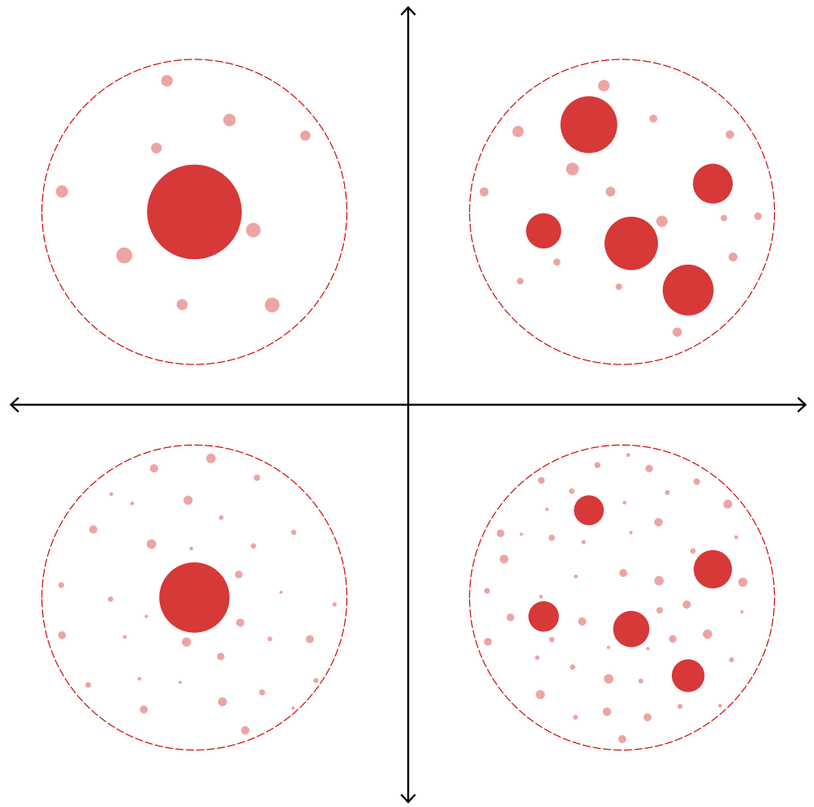


Source: Meijers, E., & Burger, M. (2010). Spatial Structure and Productivity in US Metropolitan Areas. Environment And Planning A, 42(6), 1383-1402.



MRF

+

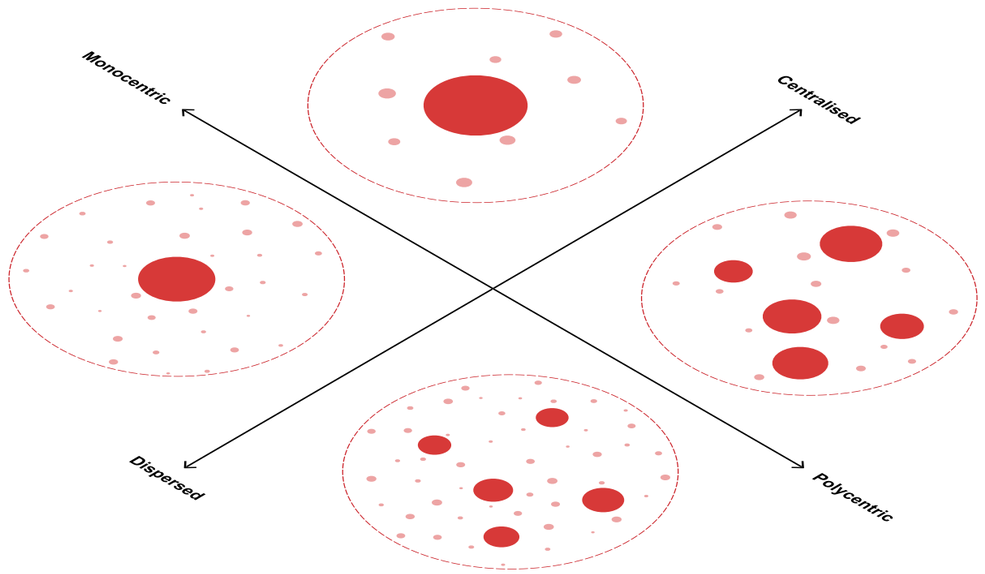


SPATIAL MODEL

03 ABSTRACT MODEL

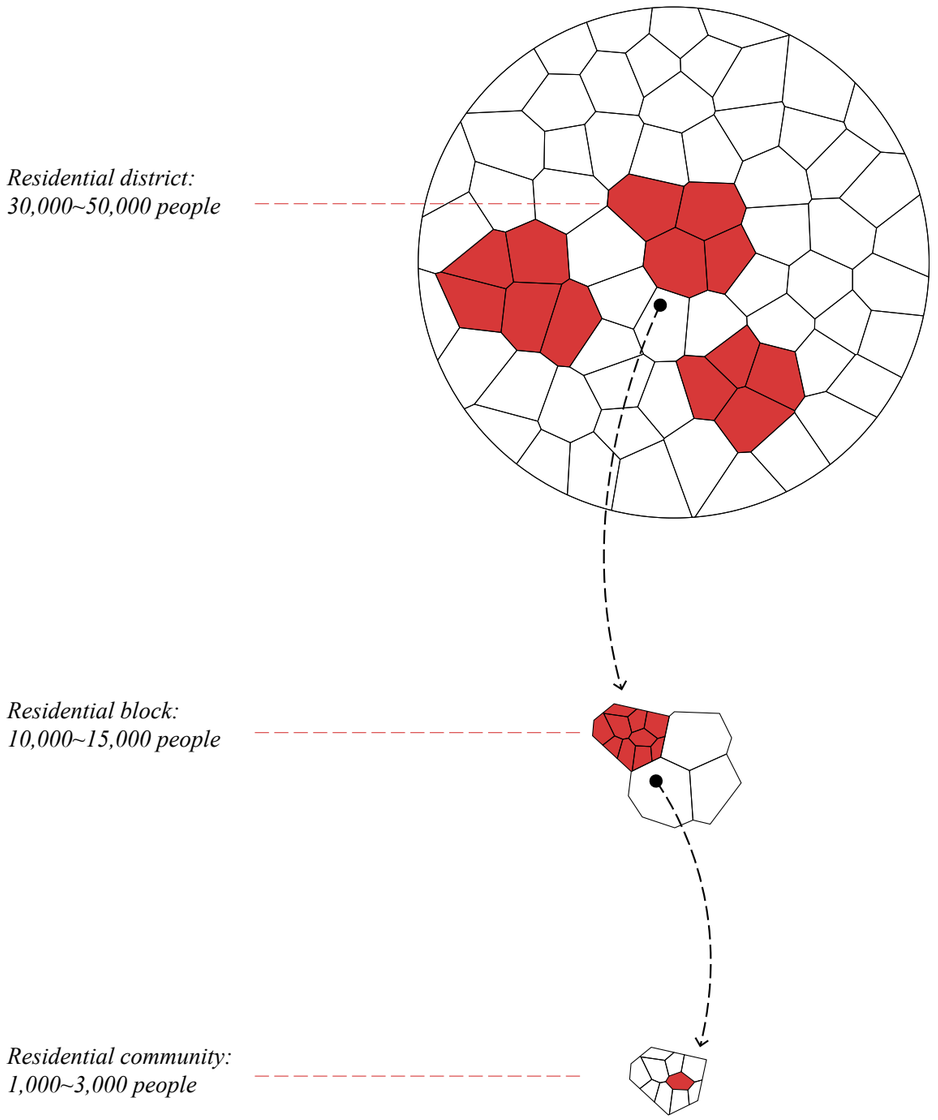
03.1 PREREQUISITE OF MODEL

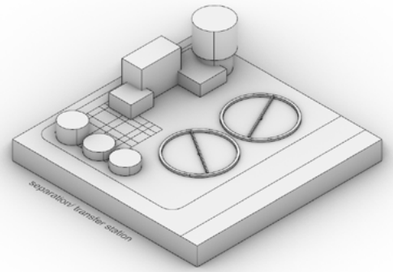
Metropolis with 10 Million people



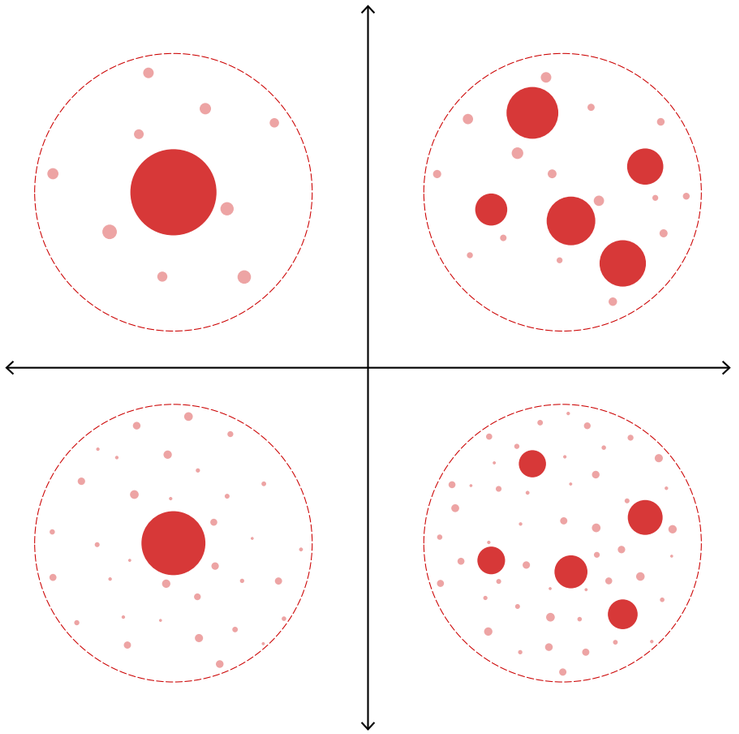
Population: 10 milion
*Area: 100km*100km*
MSW: 1.2 kg/person/day
Total MSW:12000 tonnes/day

Three types of Chinese residential area

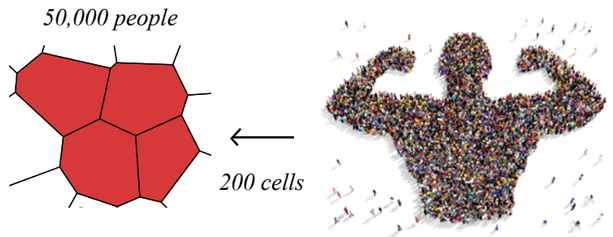




MRF



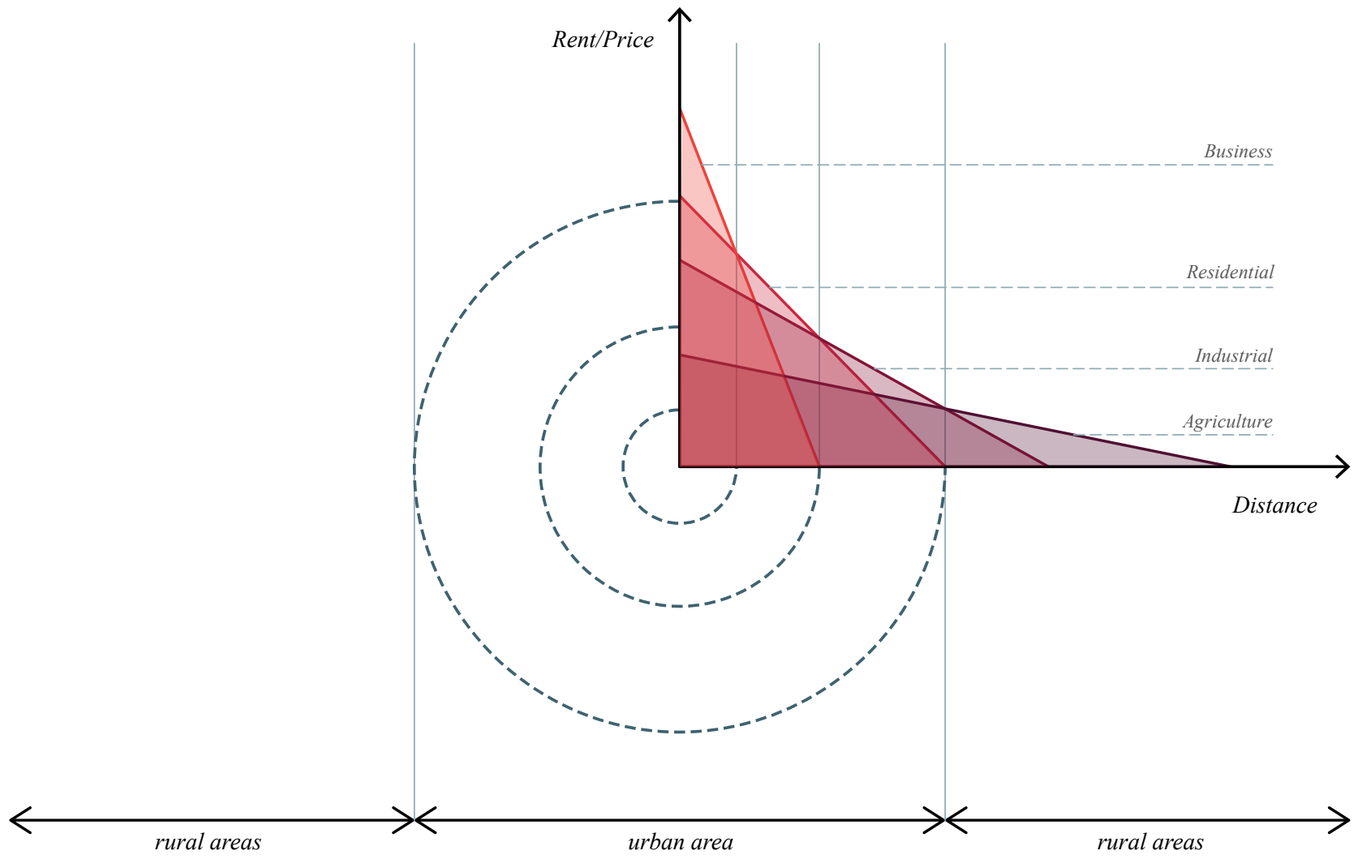
SPATIAL MODEL



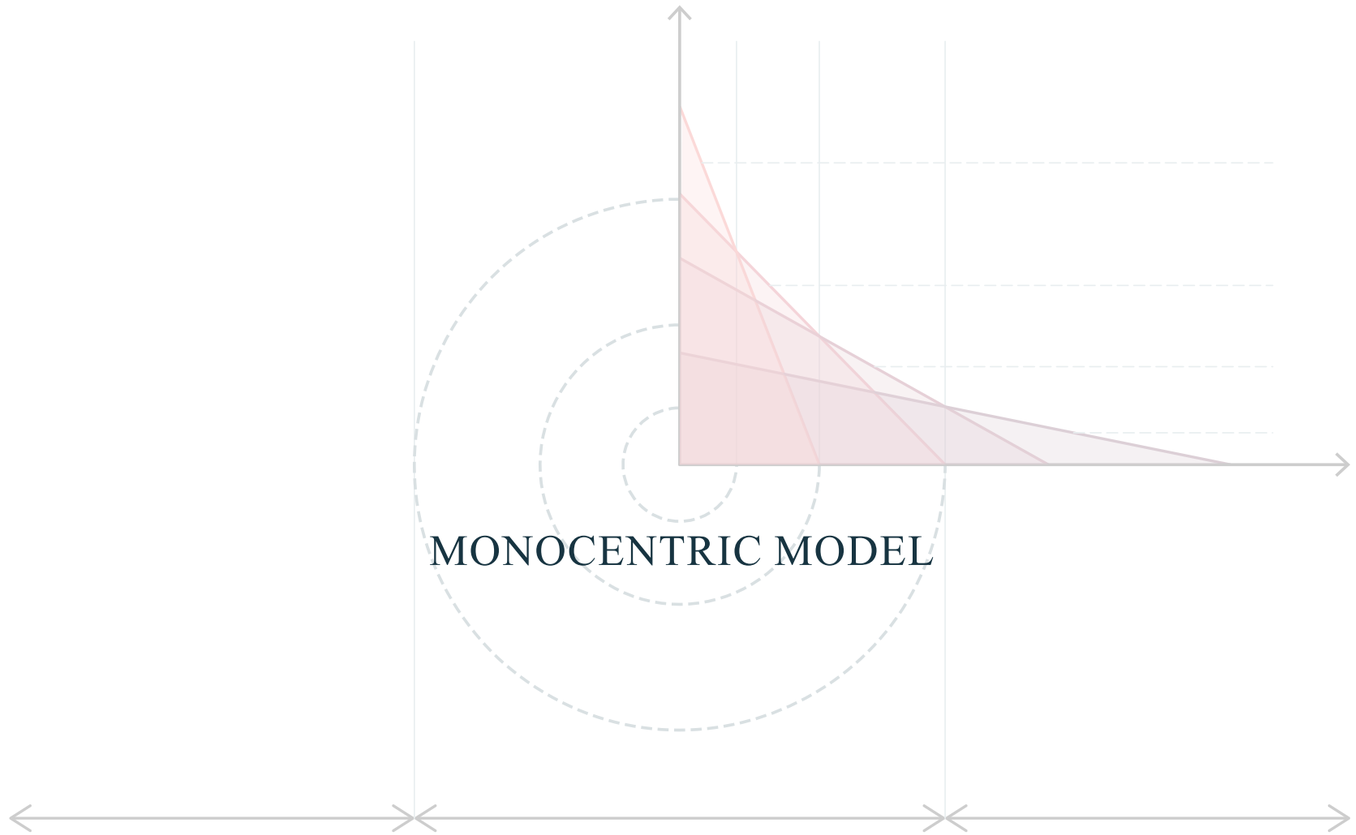
RESIDENTIAL CELL

03.2 SPATIAL DEMAND CONE SIMULATION

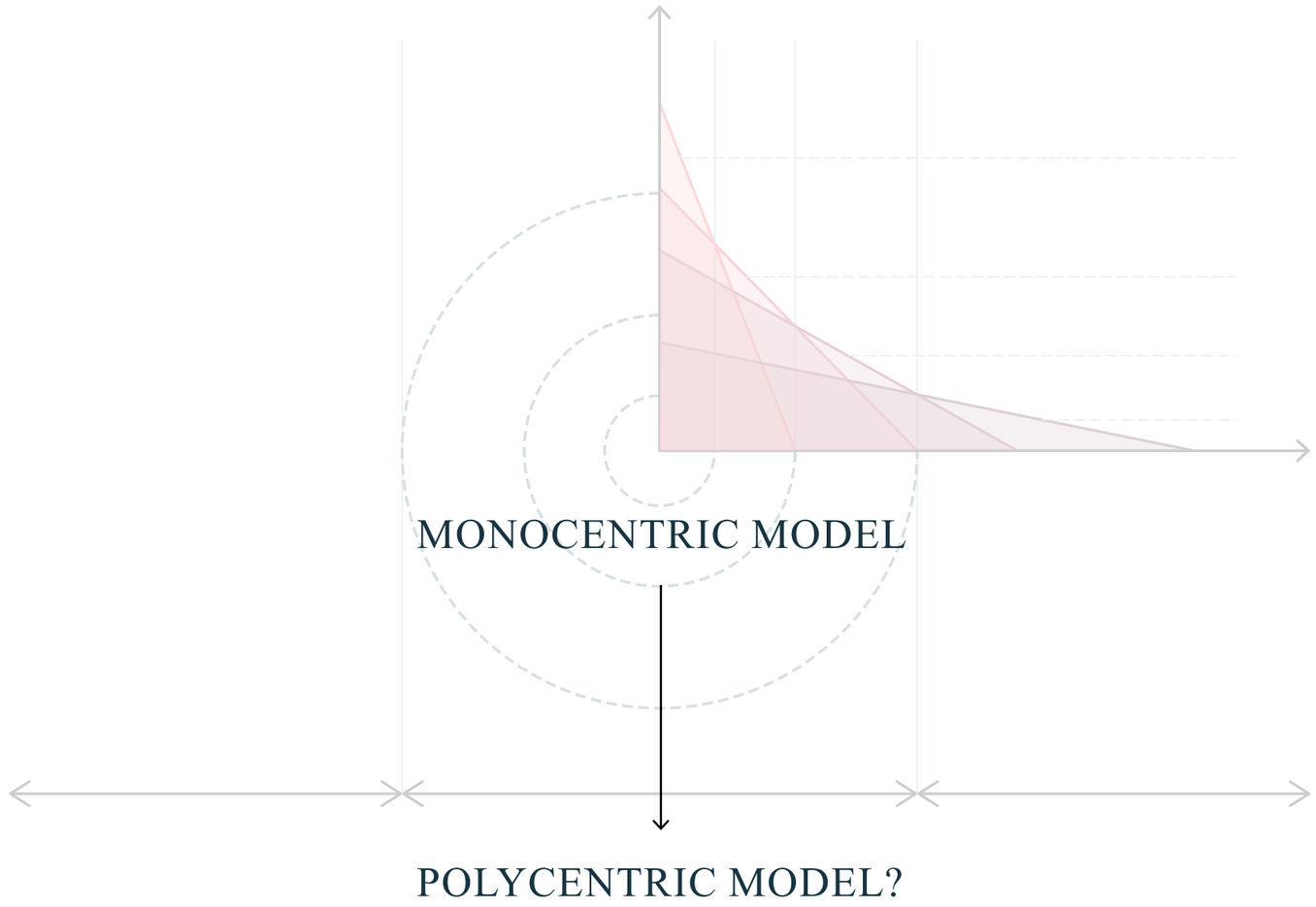
Density and Land Price: Spatial demand curves



Source: spatial demand curves(Made by author based on the location theory by Alonso (1964))

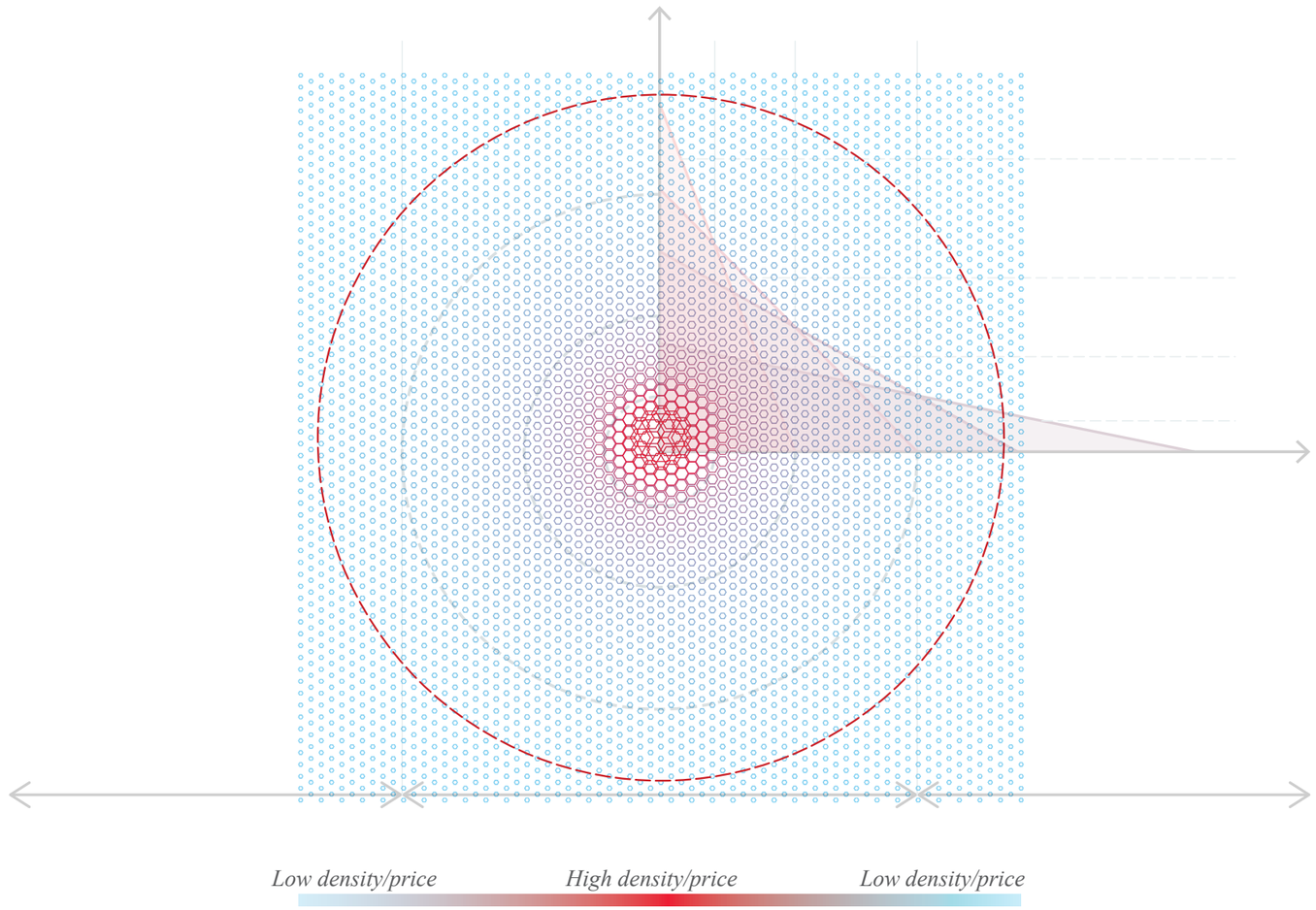


MONOCENTRIC MODEL


MONOCENTRIC MODEL
POLYCENTRIC MODEL?

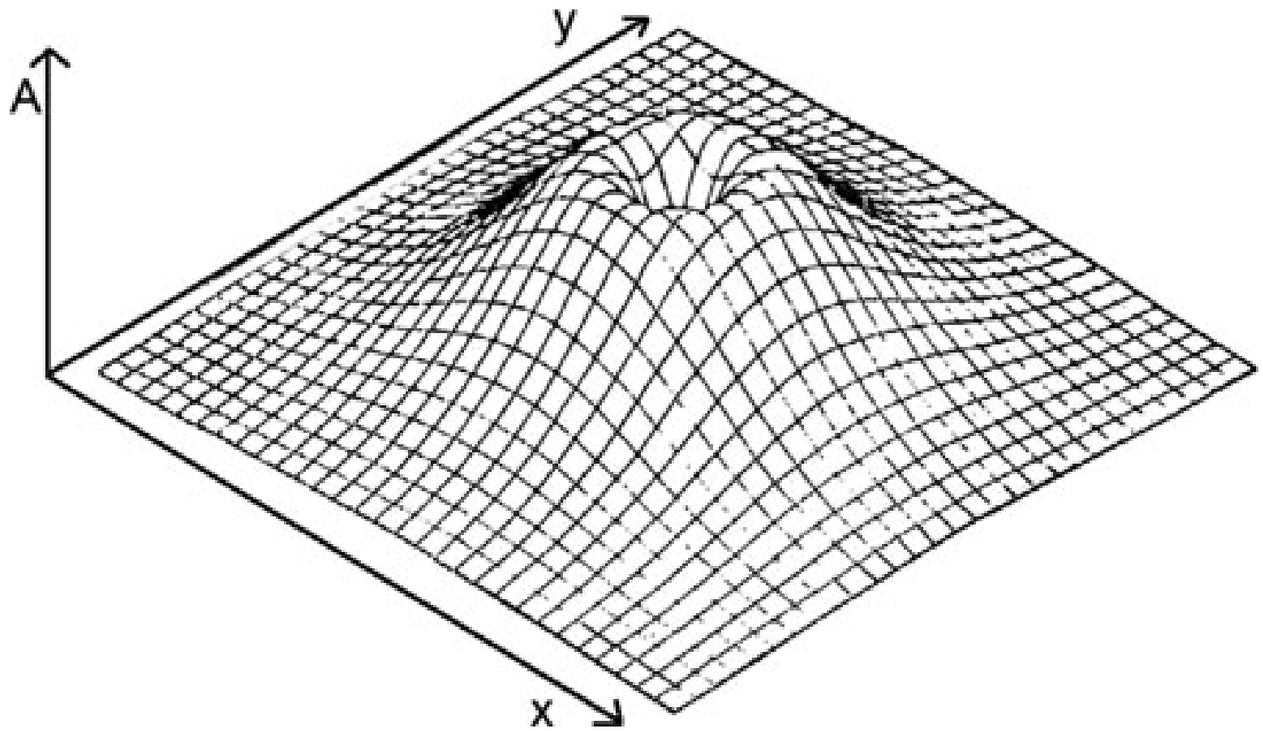
Electric field simulation

A built-in function in Grasshopper



ANSWER

Theoritical basis : Gravity Cities



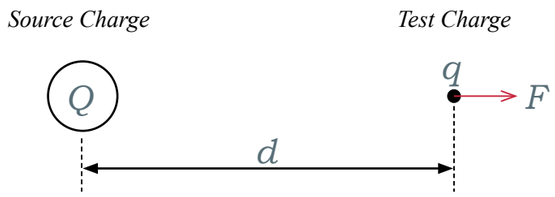
Source: Angel and Hyman (1972)

There are exist two places, which are numbered by i and j. According to first law of geography (Tobler, 1973), the two places are attracted to each other. The interaction between the two places can be measured with the gravity model

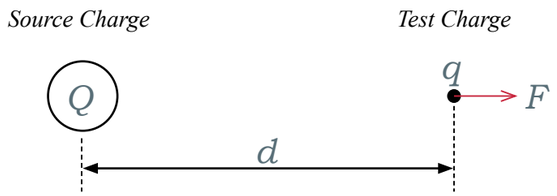
$$I_{ij} = G\frac{P_i P_j}{r_{ij}^b},$$

where Iij denotes the gravity between places i and j, which can be represented with the quantity of the flow from one place to the other, Pi and Pj are the "mass", which can be reflected by the population size of places i and j, rij is the distance between i and j, G refers to a proportionality coefficient, and b, to the distance exponent.

Electric field definition



Electric field definition



$$Electric\ Field\ Strength = \frac{Force}{Charge}$$

$$E = \frac{F}{q}$$

$$F = \frac{kqQ}{d^2} \dashrightarrow I_{ij} = G\frac{P_i P_j}{r_{ij}^b},$$

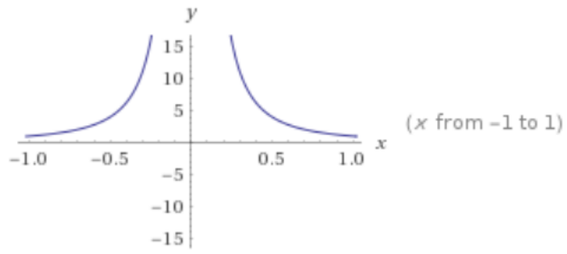
where d=separation distance between charges (meters)

$$E = \frac{F}{q} = \frac{kQ}{d^2}$$

⇢ *Influence power of urban centre*

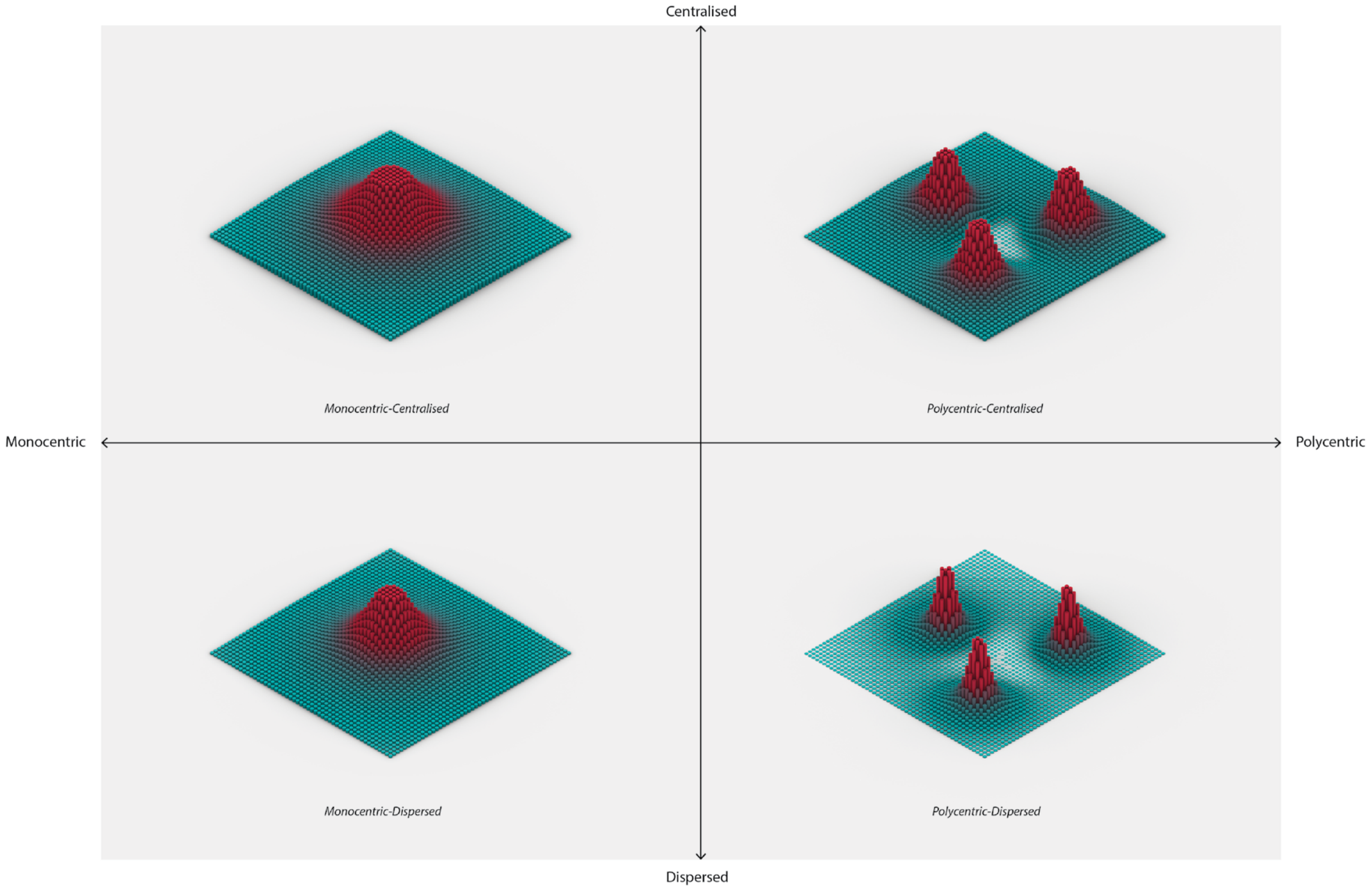
⇢ *Distance to urban centre*

An inverse square law

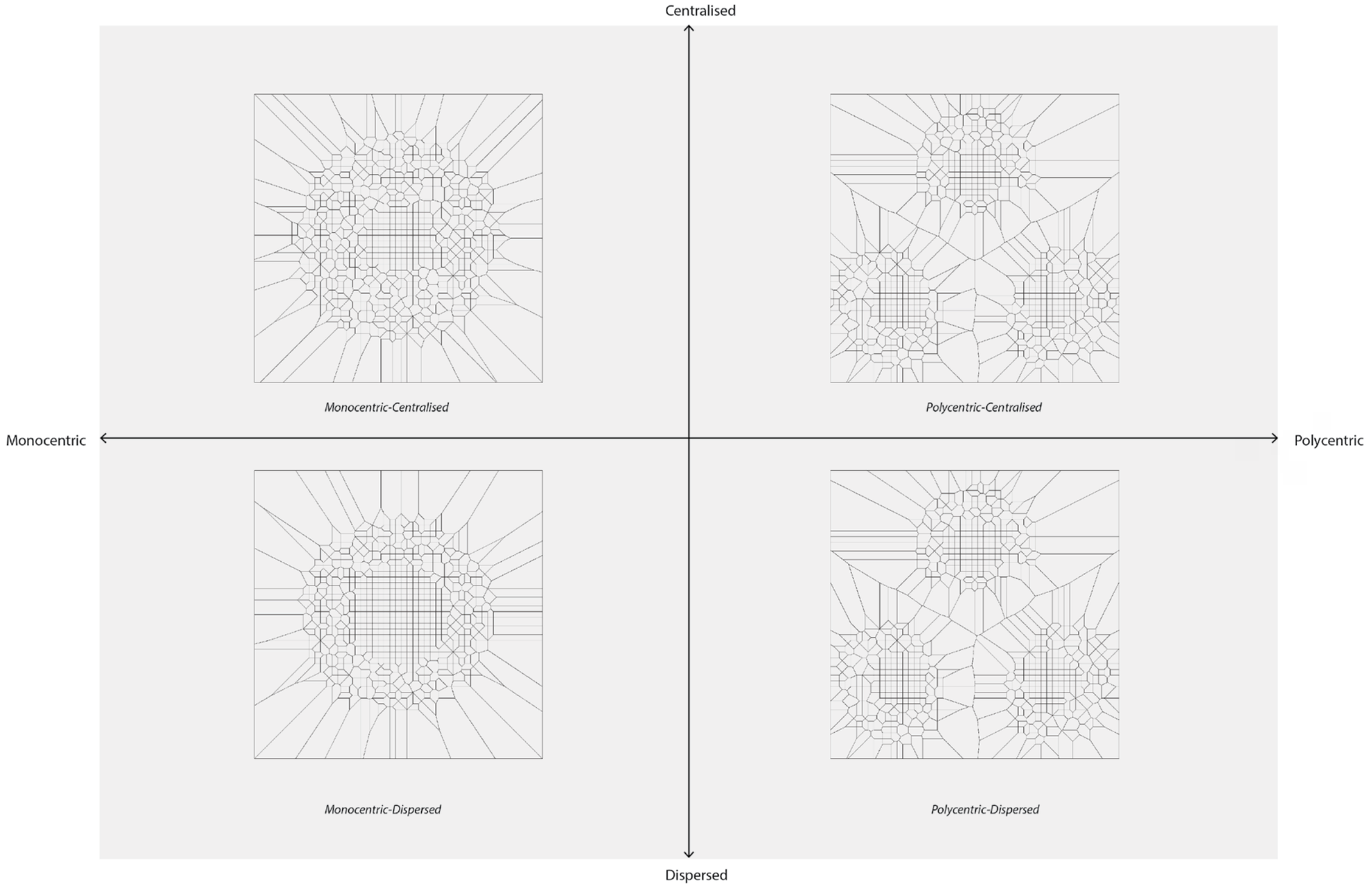


Source: http://www.wolframalpha.com/input/?i=y%3D1%2Fx%5E2

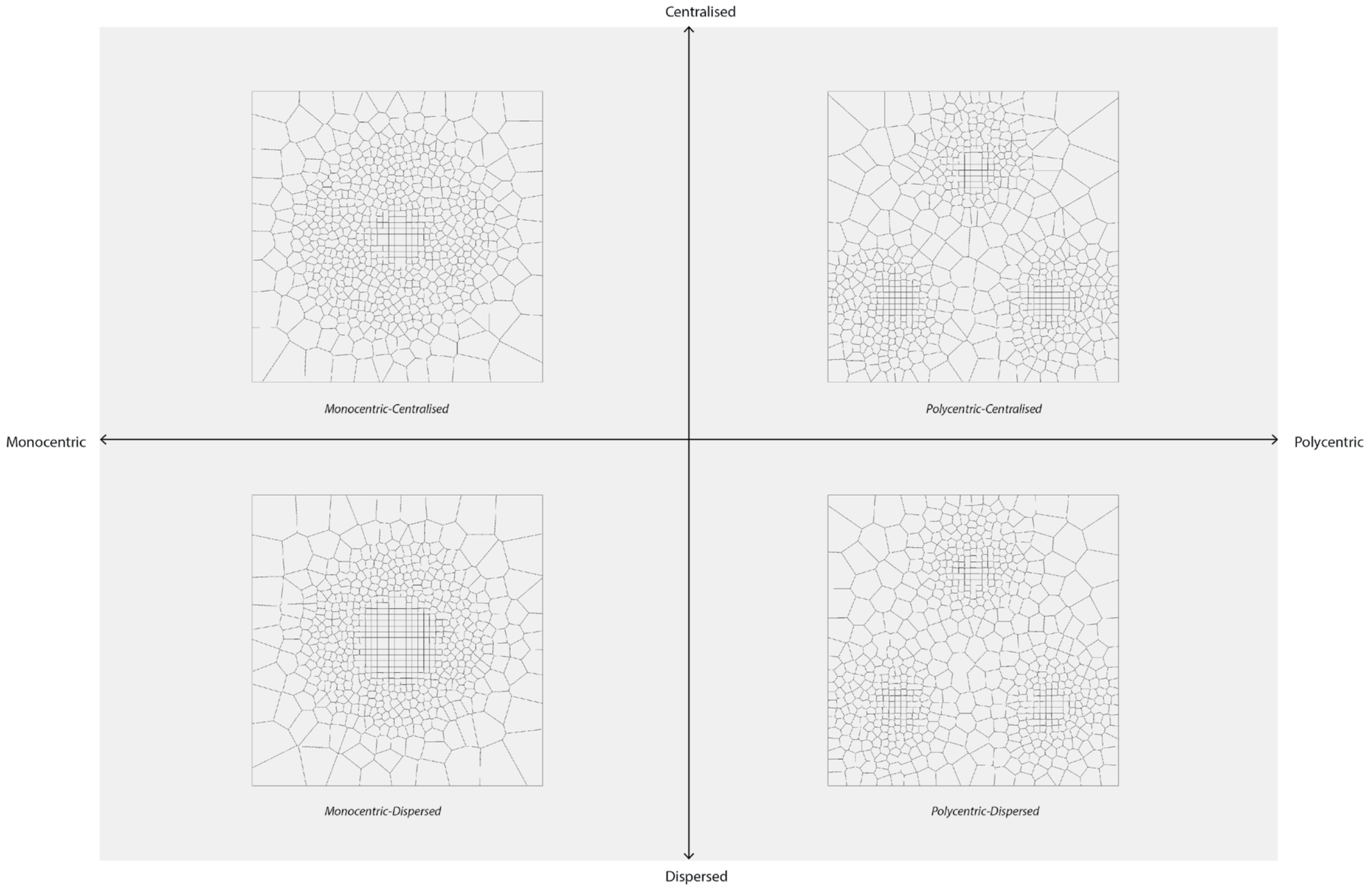
Results of electric field simulation



Urban fabric based on the previous simulation

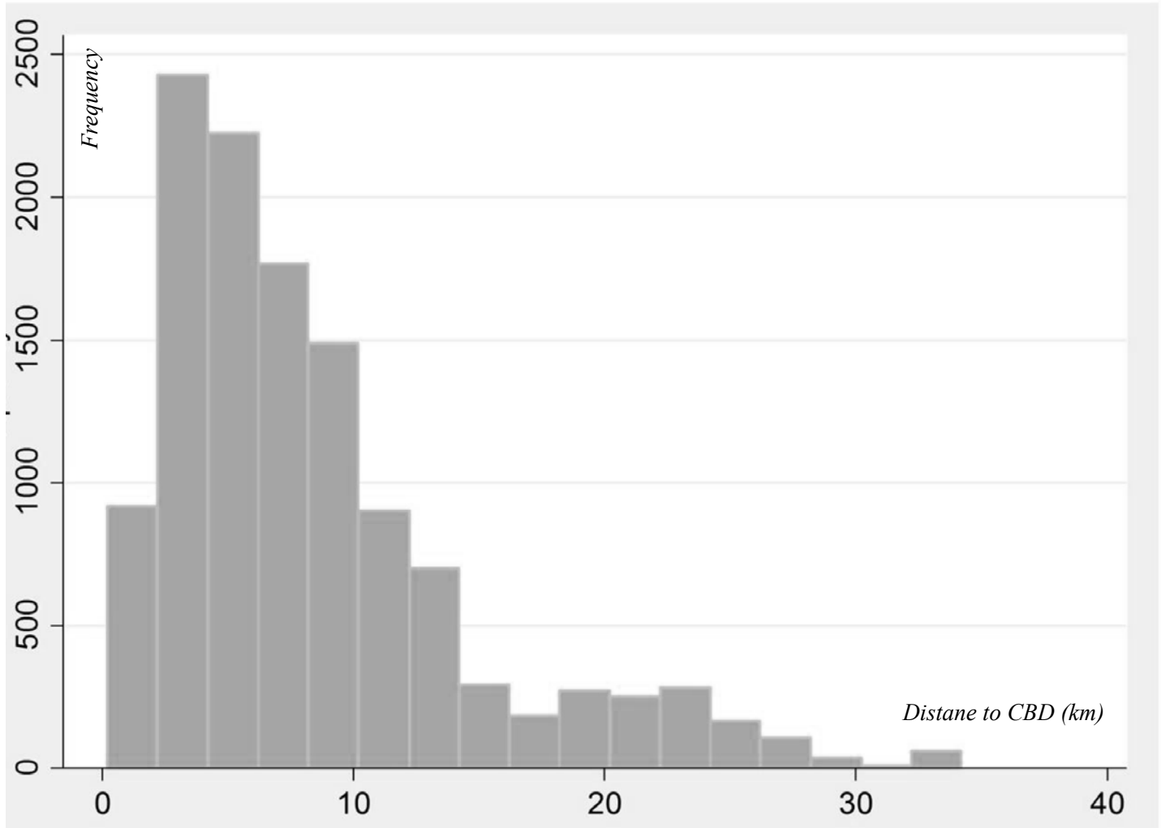


Urban fabric after Vornonoi relaxation



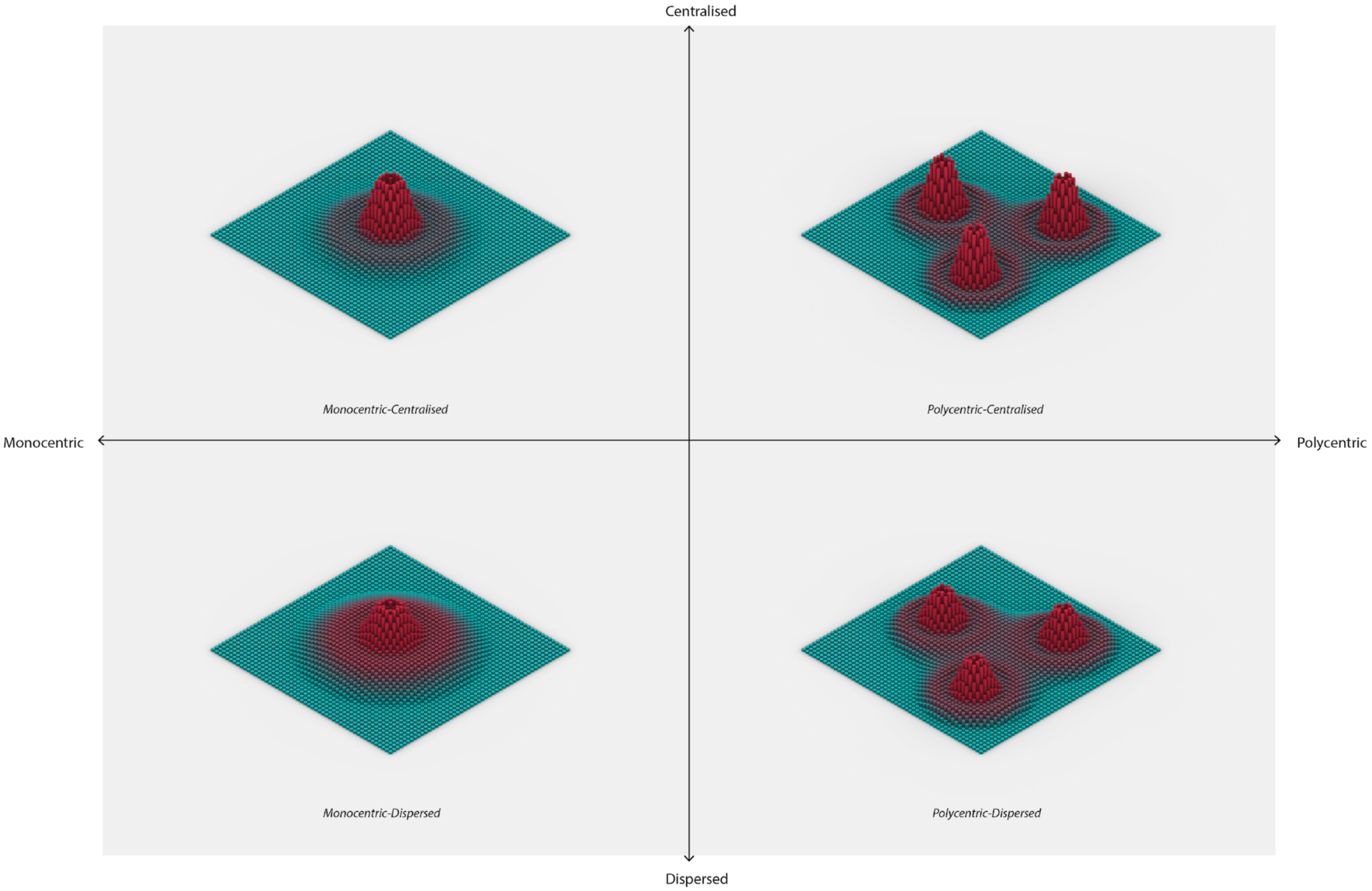
03.3 HOUSEHOLDS DISTRIBUTION CONE SIMULATION

Histogram of household's distance (km) to the CBD



Source: Cuberes, D., & Roberts, J. (2015). Household location and income: a spatial analysis for British cities. The Sheffield Economic Research Paper Series (SERPS), 201502(022).

Results of households distribution simulation



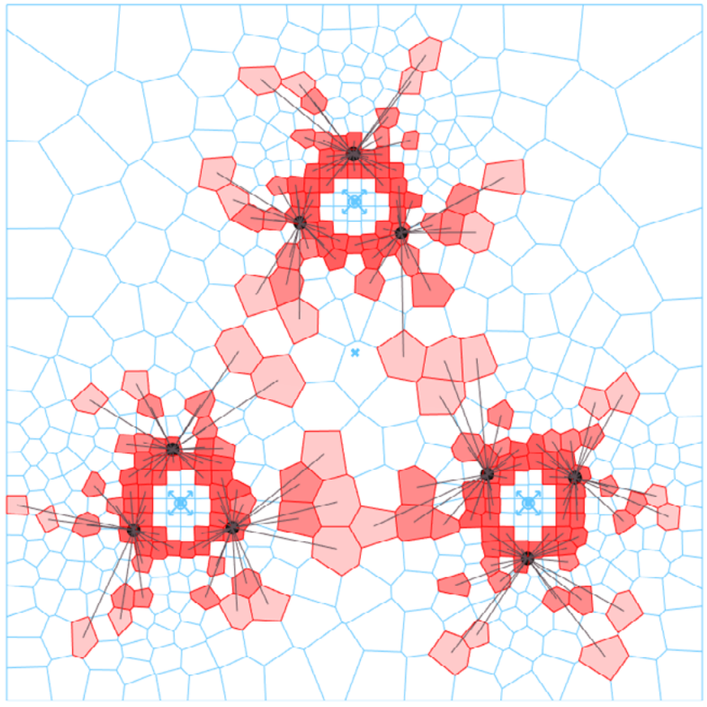
Results of distributing 200 residential cells

03.4 DISTRIBUTION OF MATERIAL RECOVERY FACILITIES

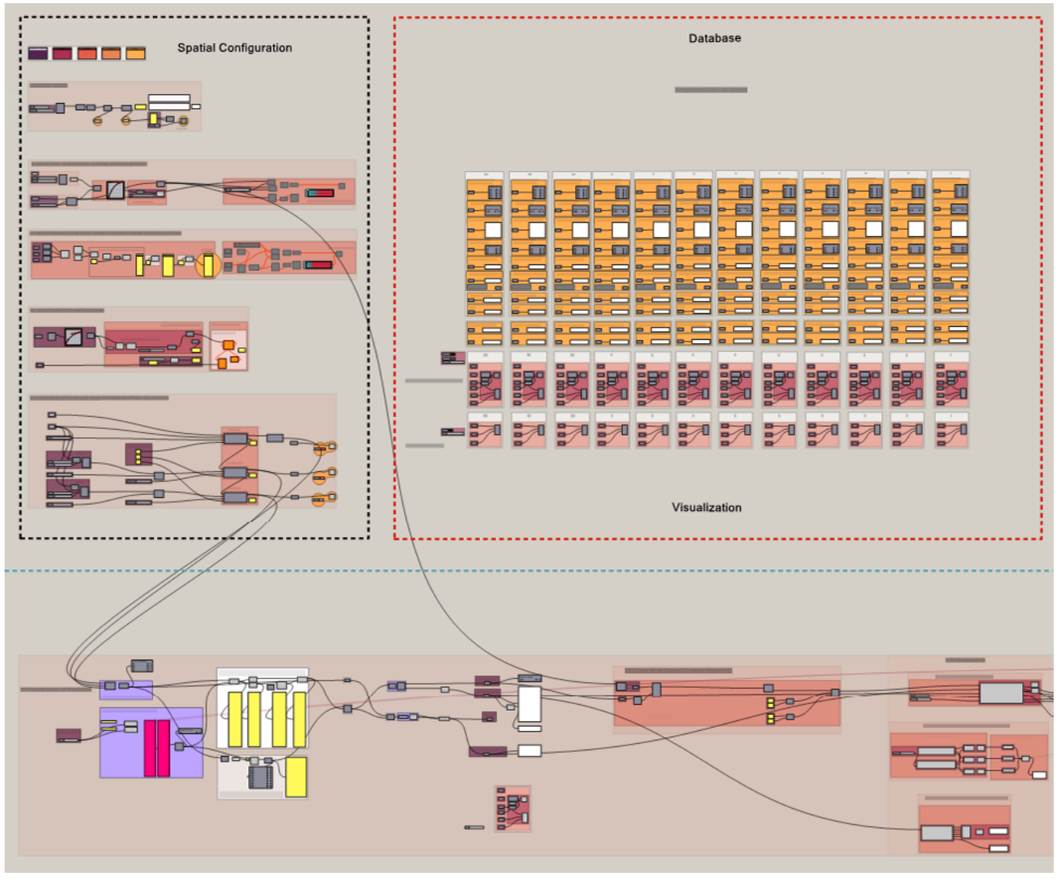
Capacity of MRF (TPD, means Tons/Day)

200TPD 400TPD 660TPD 1000TPD 1500TPD 3000TPD 12000TPD

Visualisation



Script

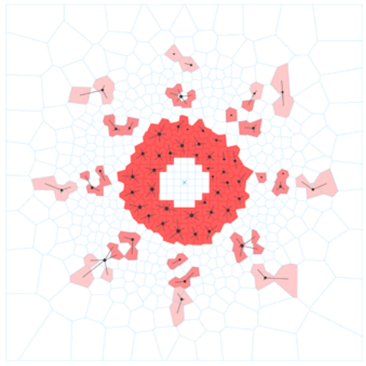


First try: Fitness is minimised total distance for all the connections (ignored the influence of land price)

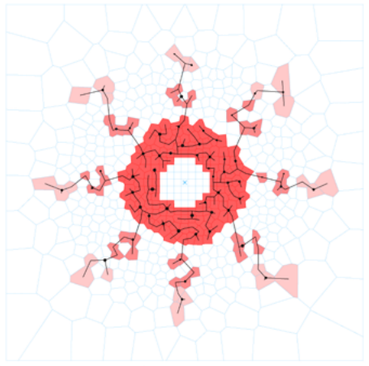
03.5 RESULT FOR FIRST DISTRIBUTION

Distributing MRF in Monocentric-centrialised model

1. Average capacity:200TPD (60 facilities)

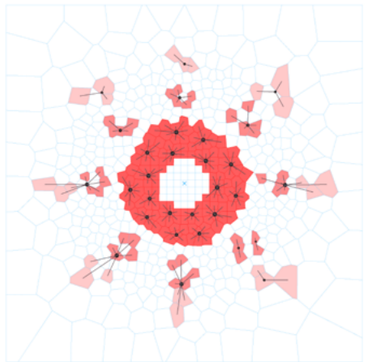


linkeages between facilities and serverd cells

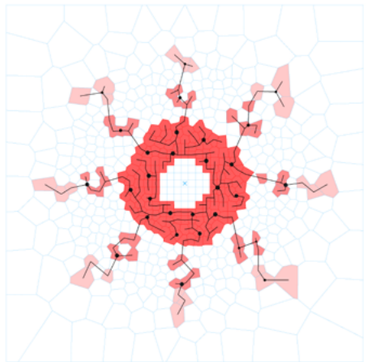


'minimal spanning' among entire cells and plants

2. Average capacity:400TPD (30 facilities)

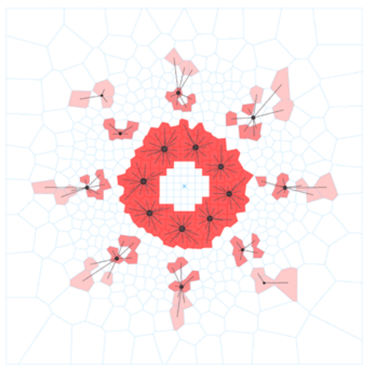


linkeages between facilities and serverd cells

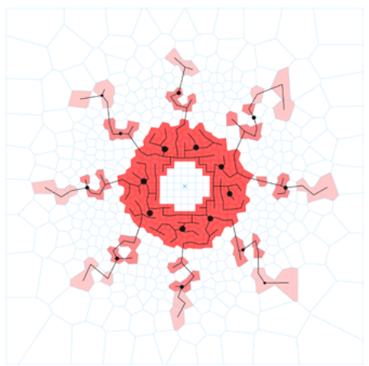


'minimal spanning' among entire cells and plants

3. Average capacity:660TPD (18 facilities)

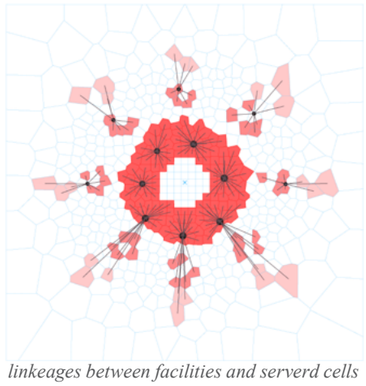


linkeages between facilities and serverd cells

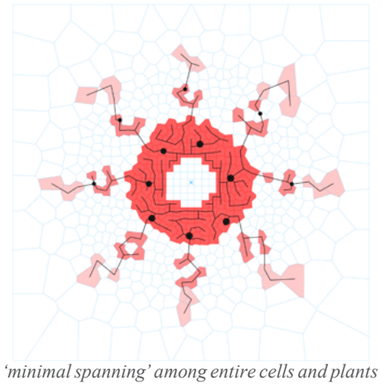


'minimal spanning' among entire cells and plants

4. Average capacity:1000TPD (12 facilities)

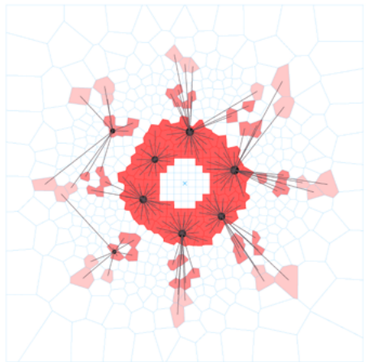


linkeages between facilities and serverd cells

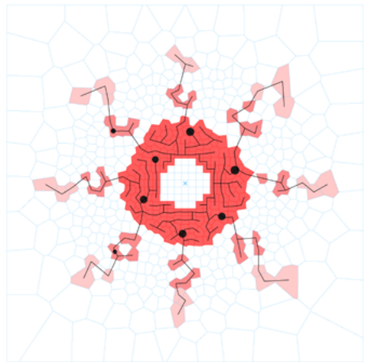


'minimal spanning' among entire cells and plants

5. Average capacity:1500TPD (8 facilities)

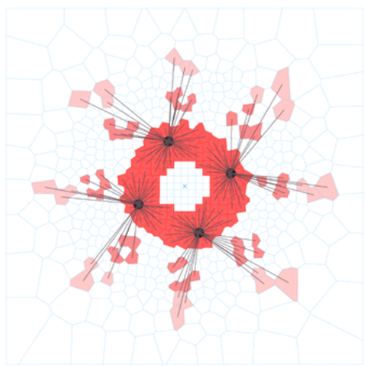


linkeages between facilities and serverd cells

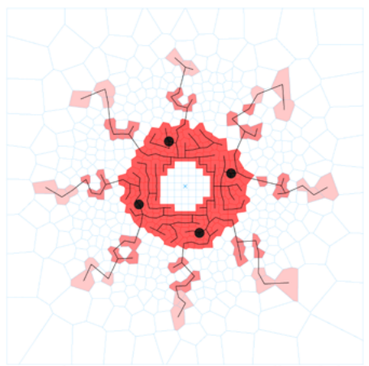


'minimal spanning' among entire cells and plants

6. Average capacity:3000TPD (4 facilities)



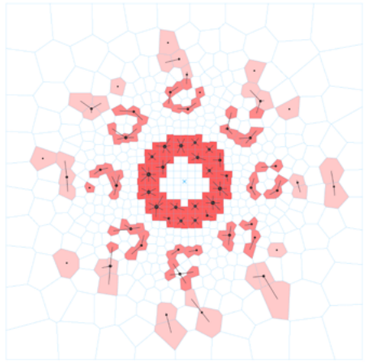
linkeages between facilities and serverd cells



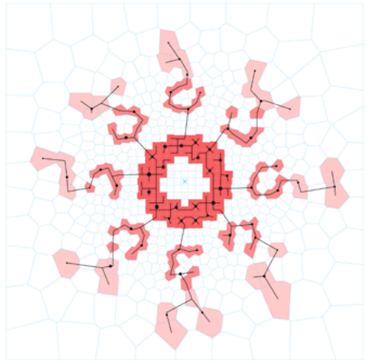
'minimal spanning' among entire cells and plants

Distributing MRF in Monocentric-dispersed model

1. Average capacity:200TPD (60 facilities)

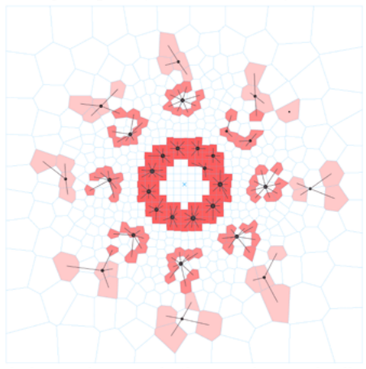


linkeages between facilities and serverd cells

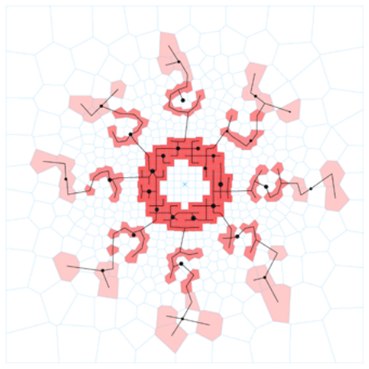


'minimal spanning' among entire cells and plants

2. Average capacity:400TPD (30 facilities)

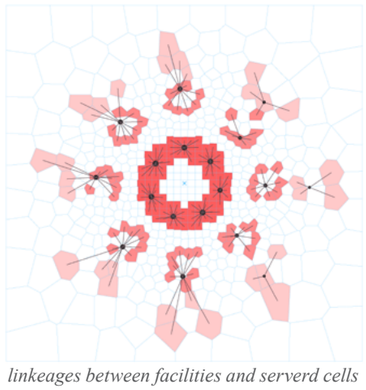


linkeages between facilities and serverd cells

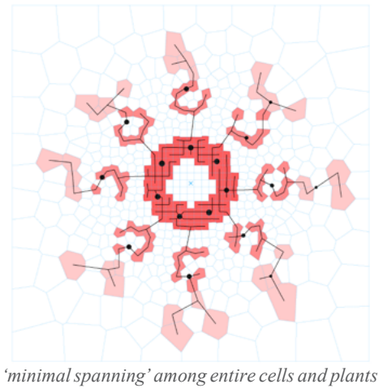


'minimal spanning' among entire cells and plants

3. Average capacity:660TPD (18 facilities)

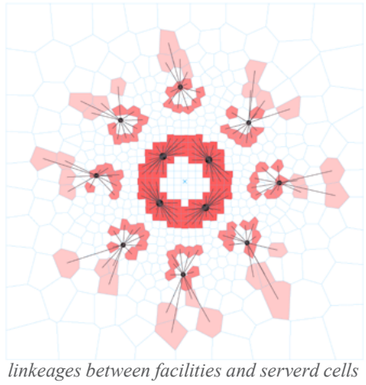


linkeages between facilities and serverd cells

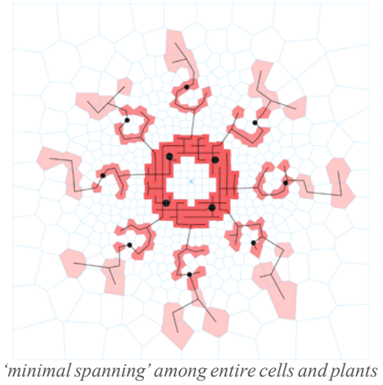


'minimal spanning' among entire cells and plants

4. Average capacity:1000TPD (12 facilities)

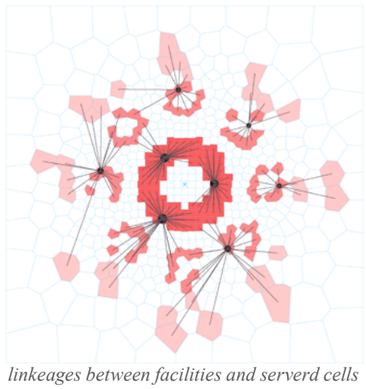


linkeages between facilities and serverd cells

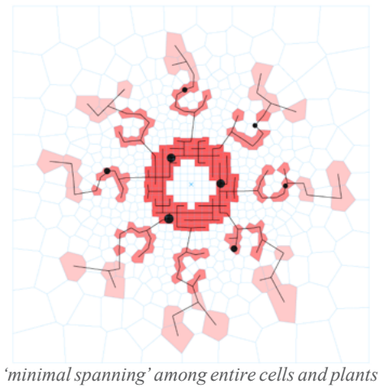


'minimal spanning' among entire cells and plants

5. Average capacity:1500TPD (8 facilities)

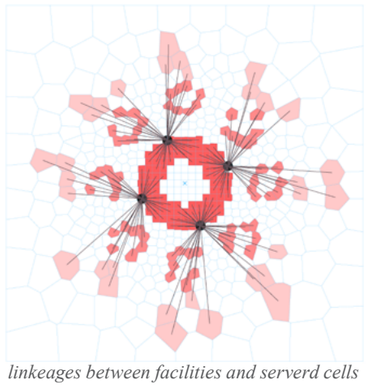


linkeages between facilities and serverd cells

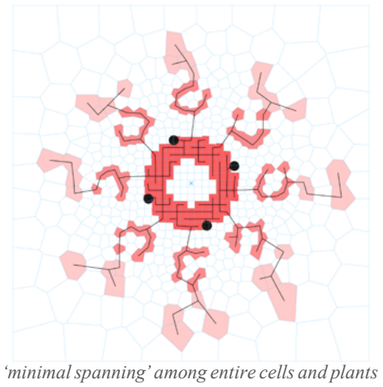


'minimal spanning' among entire cells and plants

6. Average capacity:3000TPD (4 facilities)



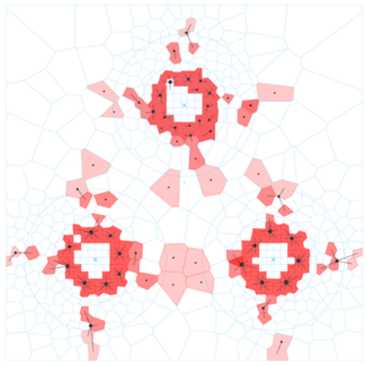
linkeages between facilities and serverd cells



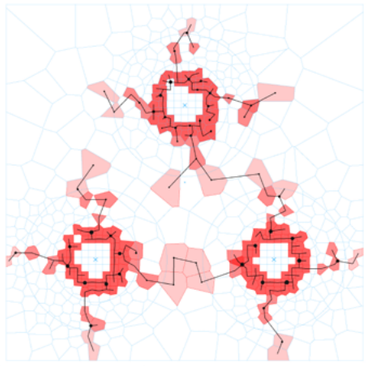
'minimal spanning' among entire cells and plants

Distributing MRF in Polycentric-centrialised model

1. Average capacity:200TPD (60 facilities)

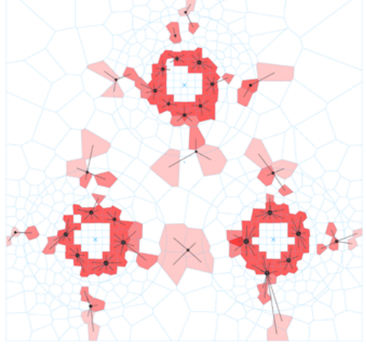


linkeages between facilities and serverd cells

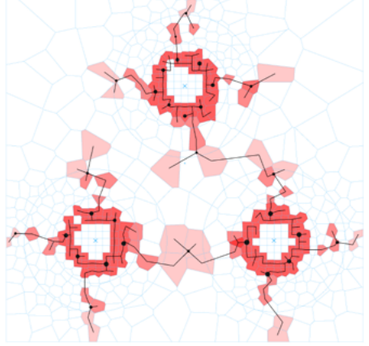


'minimal spanning' among entire cells and plants

2. Average capacity:400TPD (30 facilities)

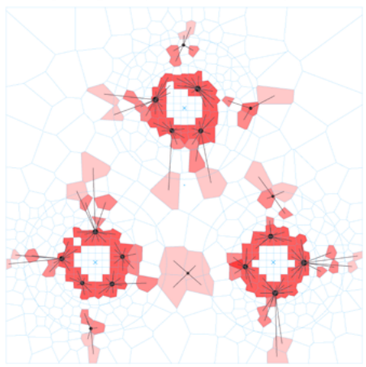


linkeages between facilities and serverd cells

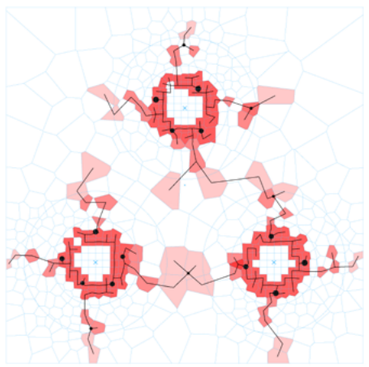


'minimal spanning' among entire cells and plants

3. Average capacity:660TPD (18 facilities)

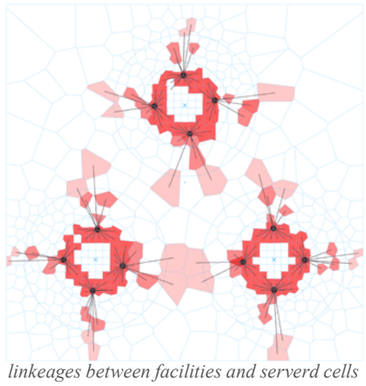


linkeages between facilities and serverd cells

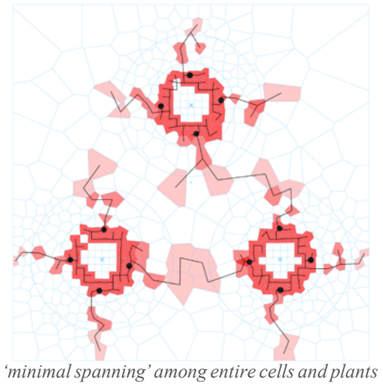


'minimal spanning' among entire cells and plants

4. Average capacity:1000TPD (12 facilities)

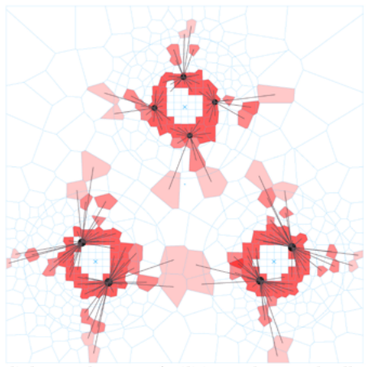


linkeages between facilities and serverd cells

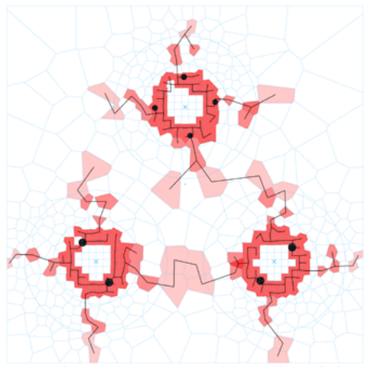


'minimal spanning' among entire cells and plants

5. Average capacity:1500TPD (8 facilities)

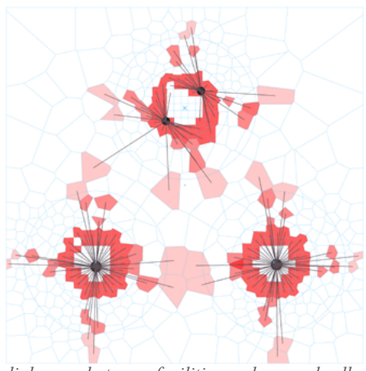


linkeages between facilities and serverd cells

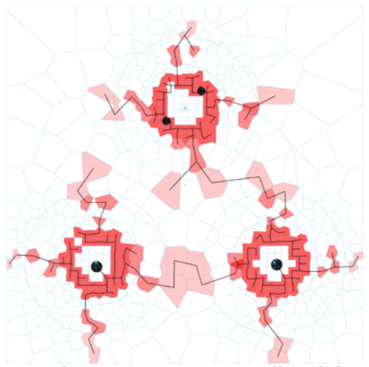


'minimal spanning' among entire cells and plants

6. Average capacity:3000TPD (4 facilities)



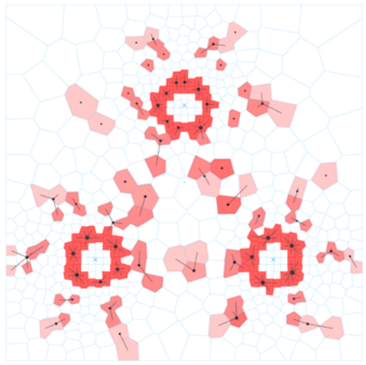
linkeages between facilities and serverd cells



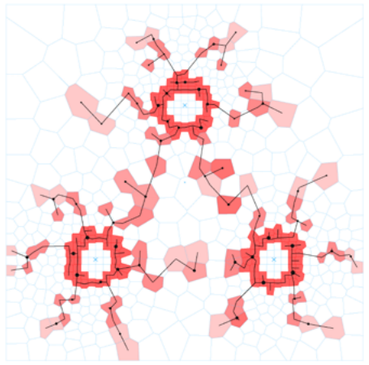
'minimal spanning' among entire cells and plants

Distributing MRF in Polycentric-dispersed model

1. Average capacity:200TPD (60 facilities)

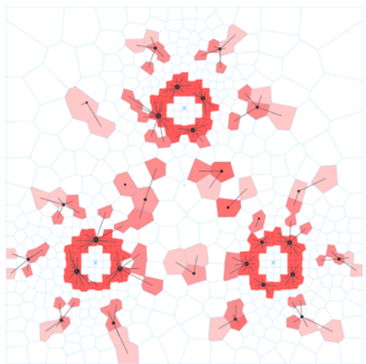


linkeages between facilities and serverd cells

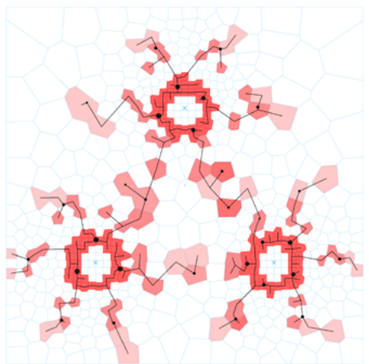


'minimal spanning' among entire cells and plants

2. Average capacity:400TPD (30 facilities)

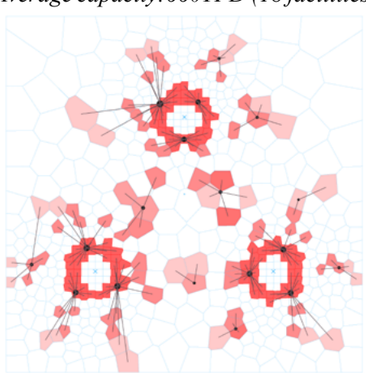


linkeages between facilities and serverd cells

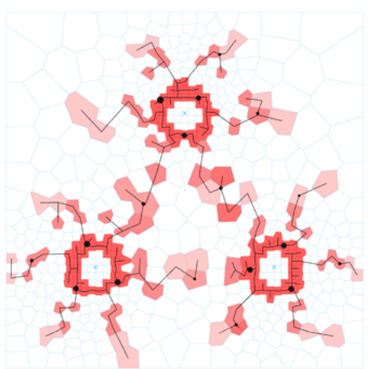


'minimal spanning' among entire cells and plants

3. Average capacity:660TPD (18 facilities)

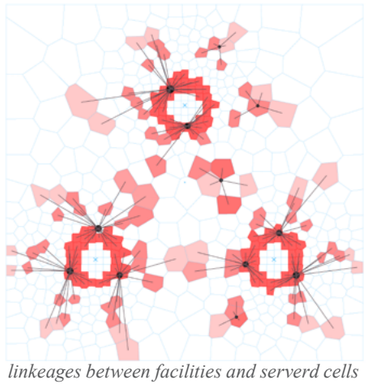


linkeages between facilities and serverd cells

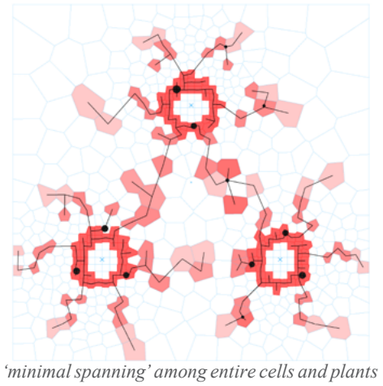


'minimal spanning' among entire cells and plants

4. Average capacity:1000TPD (12 facilities)

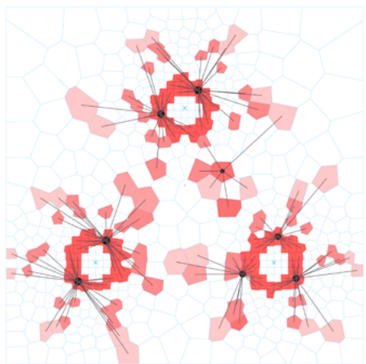


linkeages between facilities and serverd cells

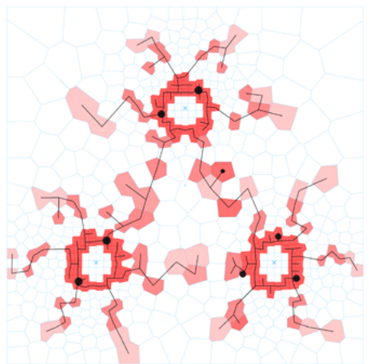


'minimal spanning' among entire cells and plants

5. Average capacity:1500TPD (8 facilities)

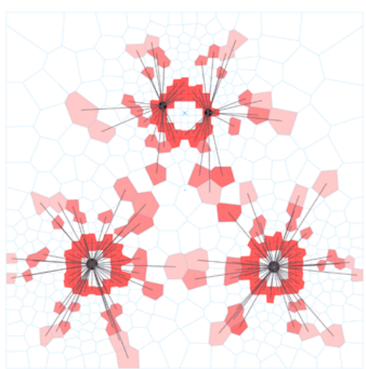


linkeages between facilities and serverd cells

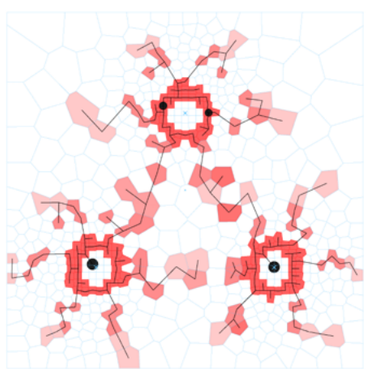


'minimal spanning' among entire cells and plants

6. Average capacity:3000TPD (4 facilities)



linkeages between facilities and serverd cells



'minimal spanning' among entire cells and plants

03.6 EVALUATION OF PERFORMANCE

Attributes

Total linkage distance

Mininmal spanning

indoor floor area

site area

Monetary Cost

Cost of construction

Cost of land lease

Cost of diesel

Cost of electricity

Cost of equipment

Ecological Cost

CO_2 emission

CH_4 emission

N_2O emission

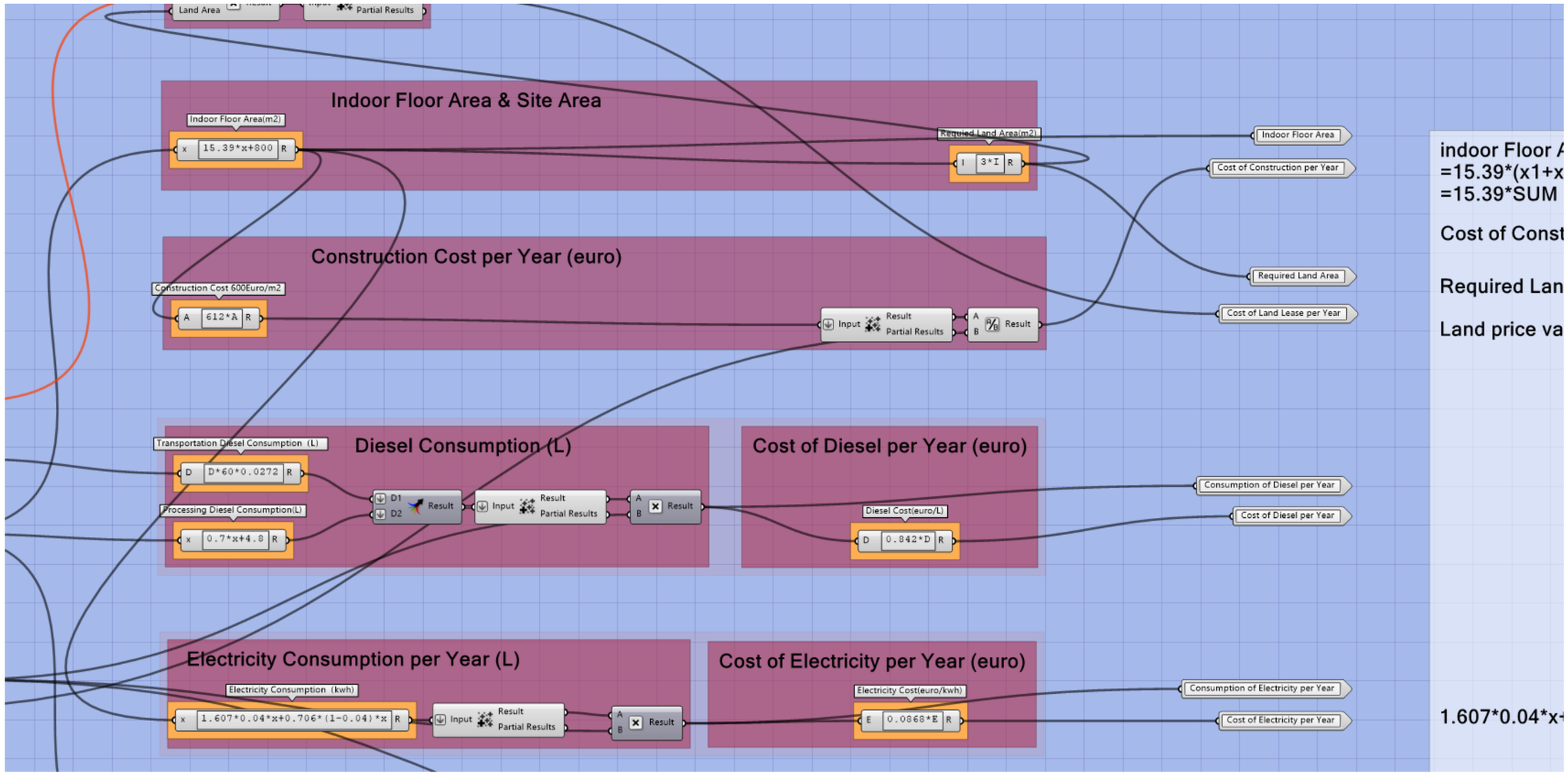
Global Warming Potential

Revenue

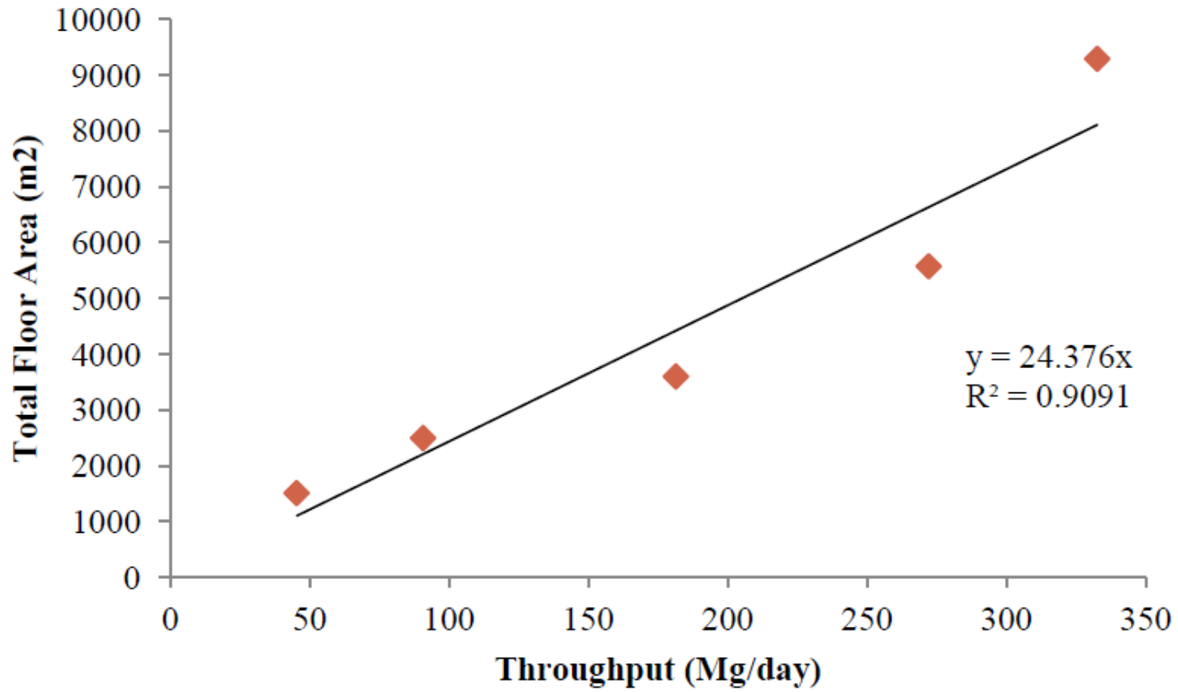
Material revenue

Recovered organic waste

Script for all the caculations



Example: indoor area caculation



Source: Combs, A. R. (2011). Life Cycle Analysis of Recycling Facilities in a Carbon Constrained World.

$$y = 15.39x + 800$$

Where y represents the needed total indoor floor area (m2), x is the total material processed per day, which is equal to the capacity(TPD) of the MRF.

Hierarchy of all the results

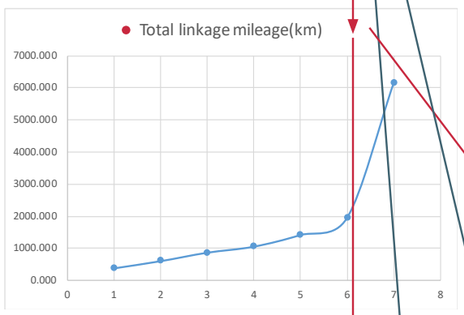
Attributes

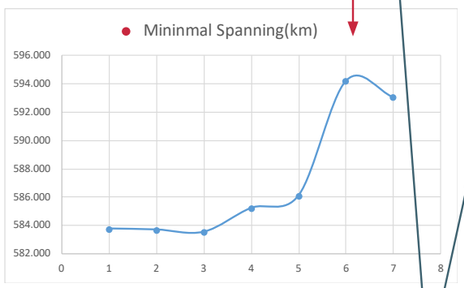
Number of facilities

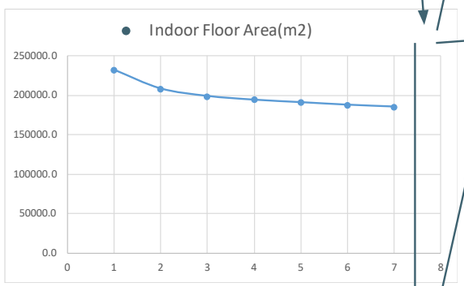
Location of facilities

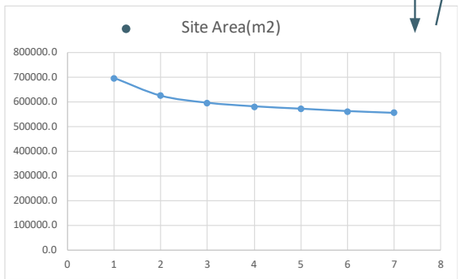
Monetary cost

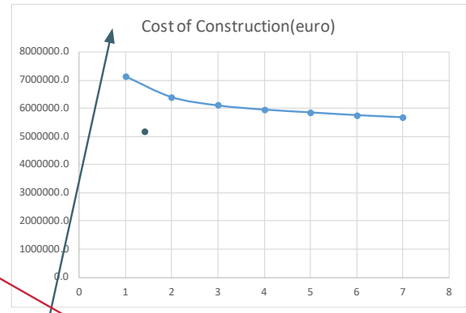
Ecological cost

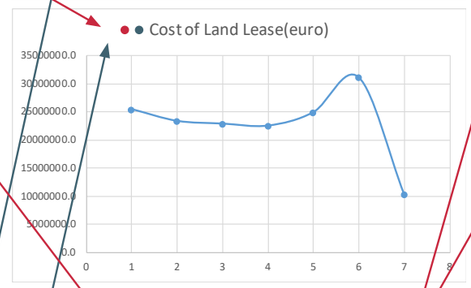


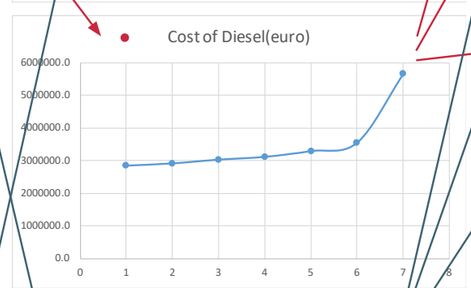


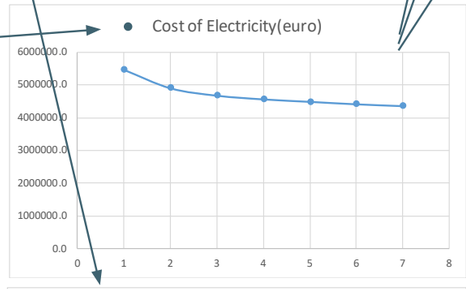


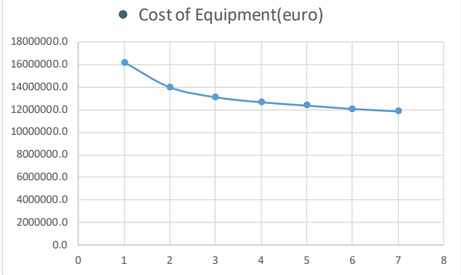


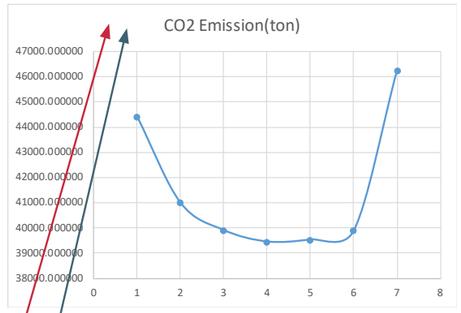


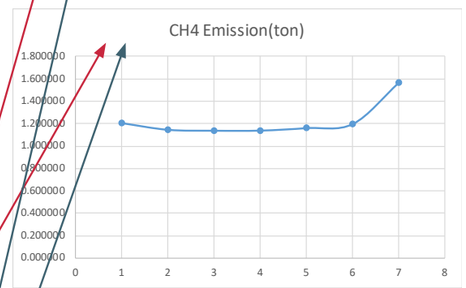


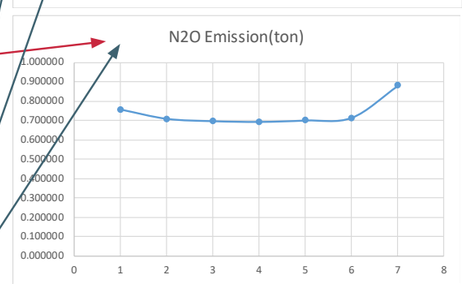


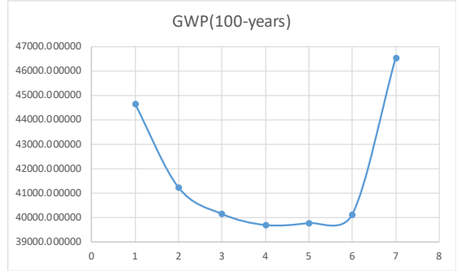


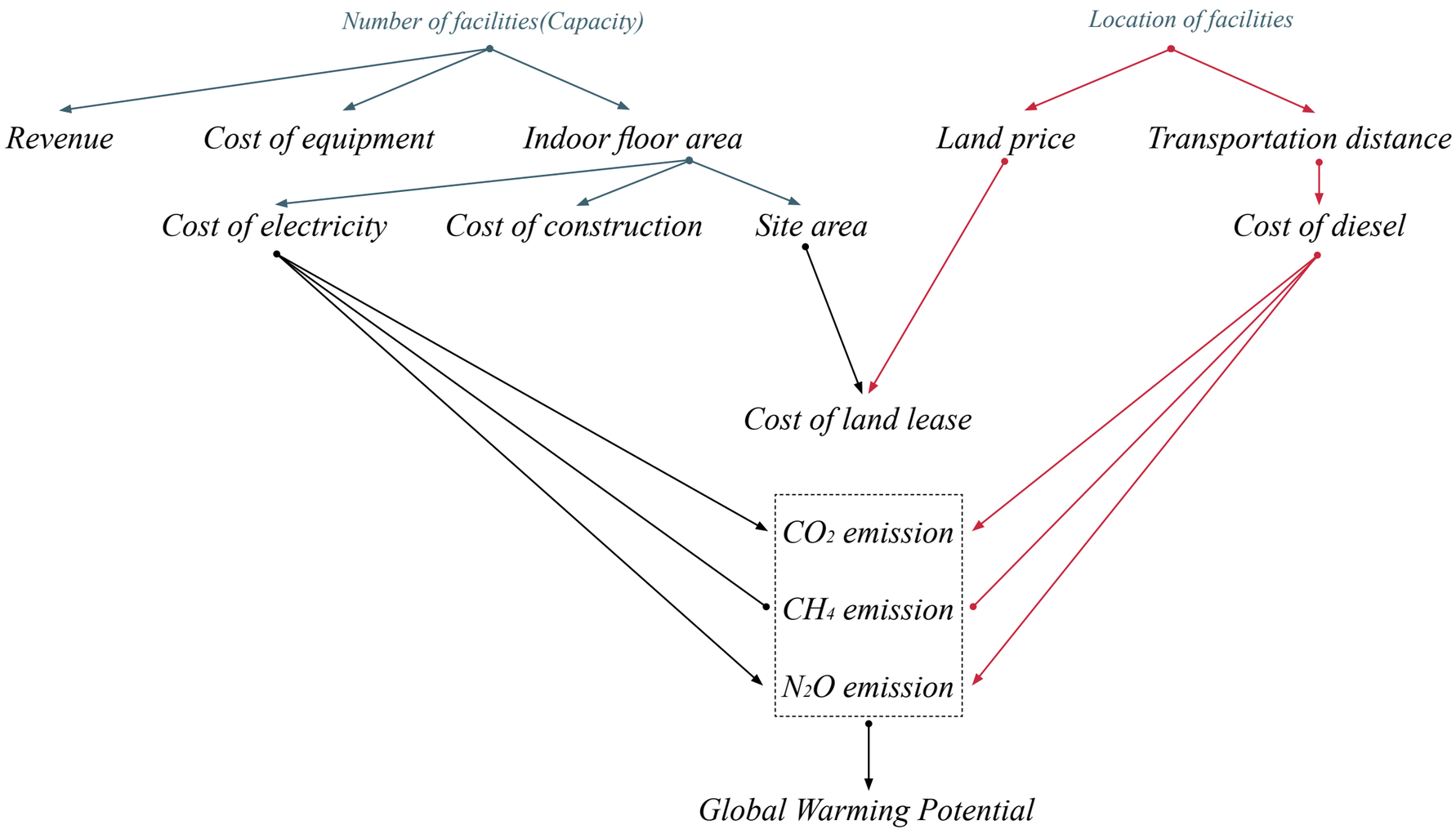








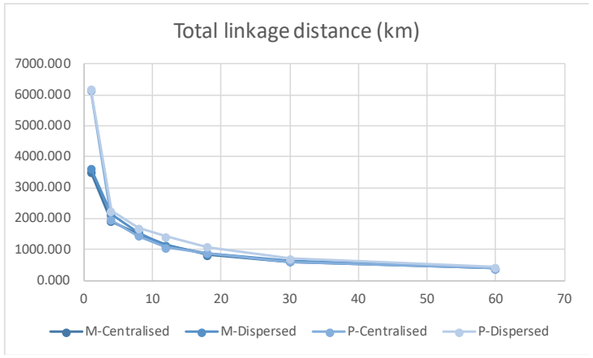



Number of facilities(Capacity)
Location of facilities
Revenue
Cost of equipment
Indoor floor area
Land price
Transportation distance
Cost of electricity
Cost of construction
Site area
Cost of diesel
Cost of land lease
CO_2 emission
CH_4 emission
N_2O emission
Global Warming Potential

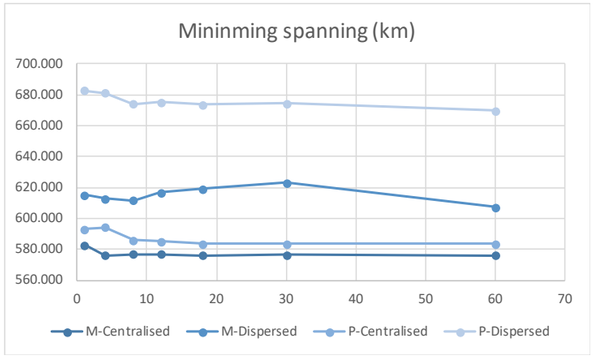
04 RESULT AND ANALYSIS

04.1 COMPARISON OF THE PERFORMANCE IN FOUR MODELS

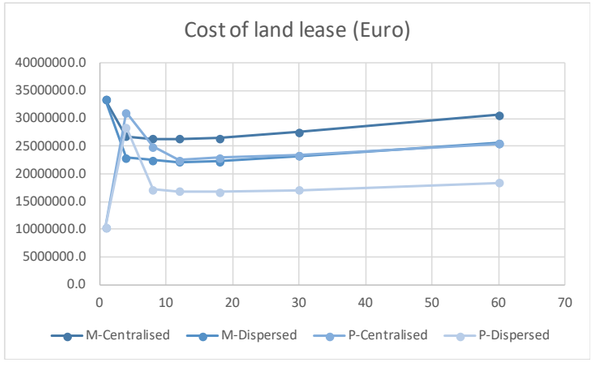
04.1 COMPARISON OF THE PERFORMANCE IN FOUR MODELS



This chart shows polycentric model has less total linkage distance, which can represents the transportation cost. With the increasing of the number of facilities, the total cost of transportation will reduce.

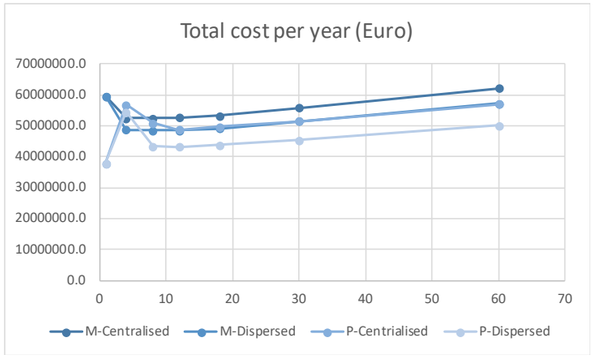


This chart shows the centralised model could use less infrastructure to cover all the cells and facilities. Within the centralised mode or dispersed model, polycentric dimension will require more distance to cover the whole territory.

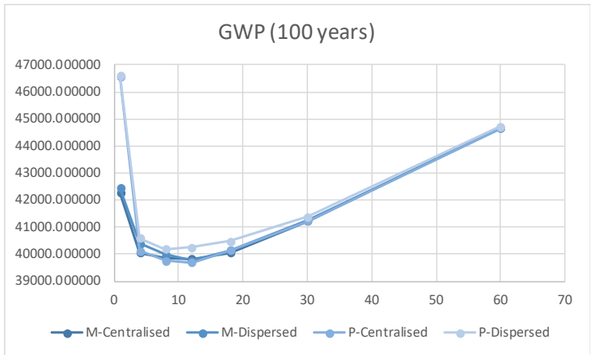


This chart indicates that the polycentric dispersed model need the smallest amount of money for land lease while monocentric centralised model is most expensive. With the increase of facilities number, the land cost will rise slightly.

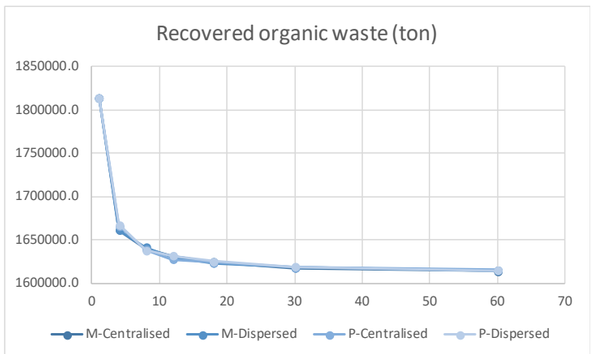
04.1 COMPARISON OF THE PERFORMANCE IN FOUR MODELS



Because the land cost and construction cost are the largest part of the total cost, with the percetage from 40% to 60%, the trend of total cost is similar to land cost. Again, monocentric model is the most costly form for allocating MRF.



This chart shows the Global Warming Potential, which can represent the ecological cost. Generally, the polycentric model generates more emissions due to the longer transport distance. When the number of facilities within the range from six to twelve, the all city will have lowest influence to the environment.



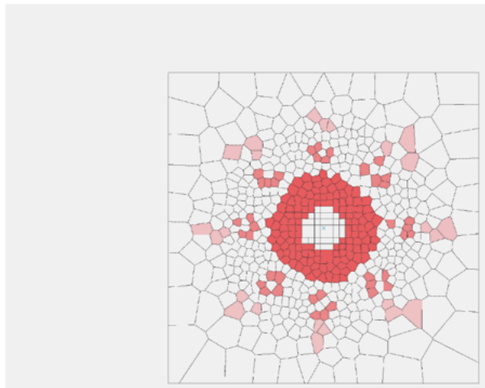
The ability of recovering the organic waste rarely influenced by the different spatial structures. By contrary, the collective efficiency heavily rely on the number of facilities. With the decrease of capacity, the efficiency of MRF will also decrease.

04.2 OPTIMISING THE DISTRIBUTION OF MRF

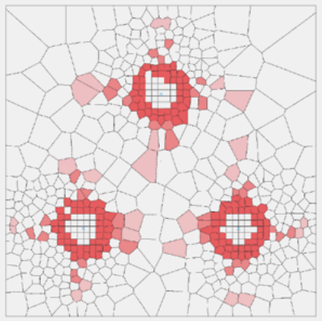
Number of MRF

1 2 3 4 5 6 7 8 9 10 11 12

Centralised



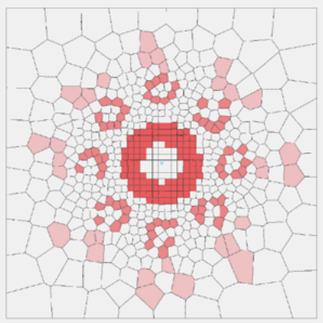
Monocentric-Centralised



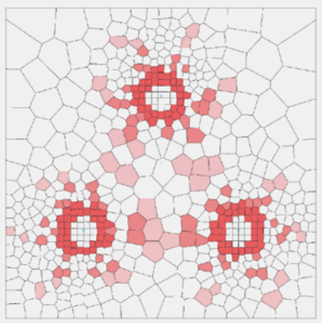
Polycentric-Centralised

Monocentric

Polycentric



Monocentric-Dispersed

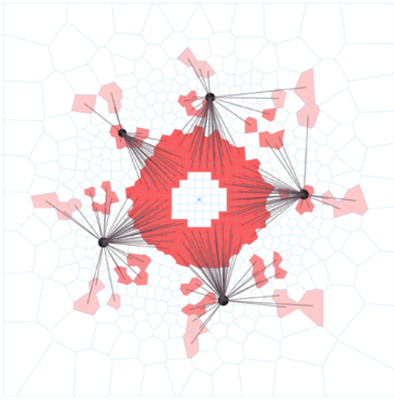


Polycentric-Dispersed

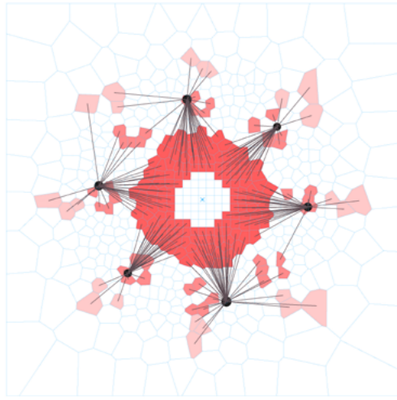
Dispersed

Distributing MRF in Monocentric-centrialised model

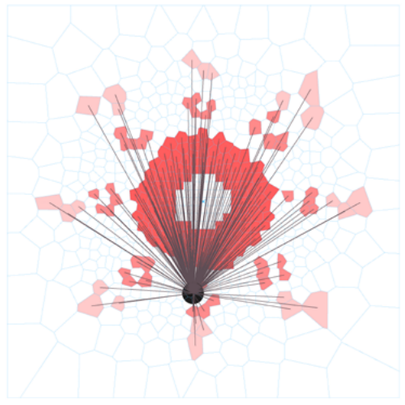
MONETARY COST 50%
ECOLOGICAL COST 50%



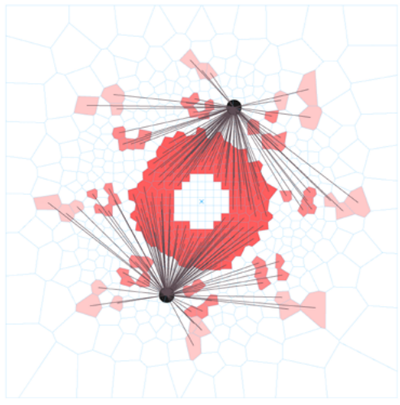
5 facilities



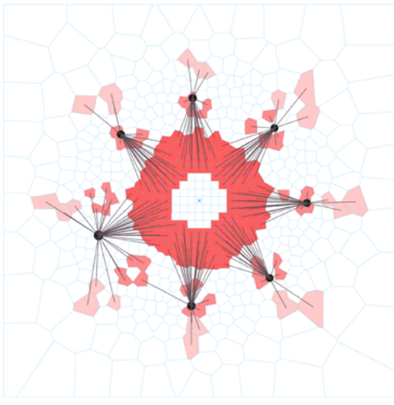
6 facilities



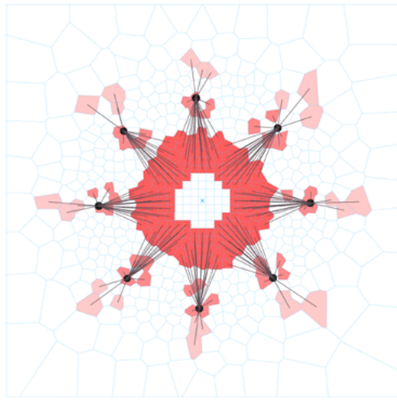
1 facility



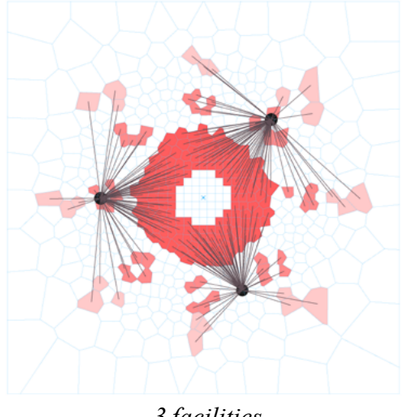
2 facilities



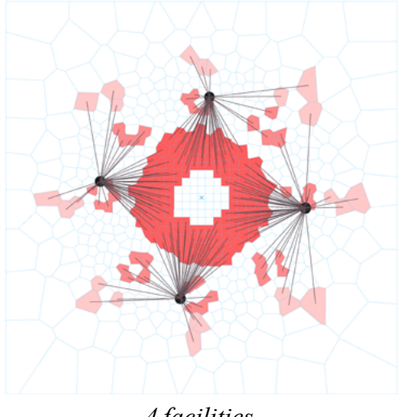
7 facilities



8 facilities

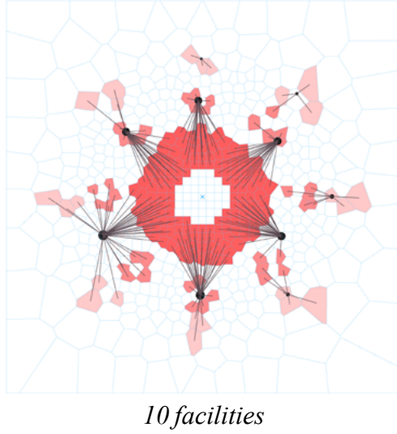


3 facilities



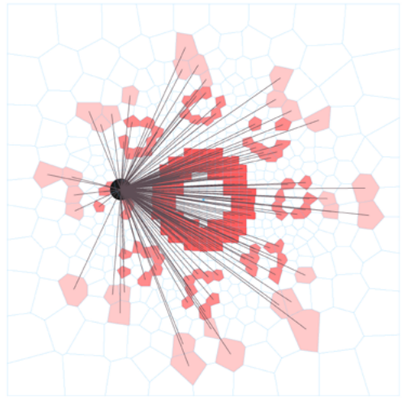
4 facilities

9 facilities

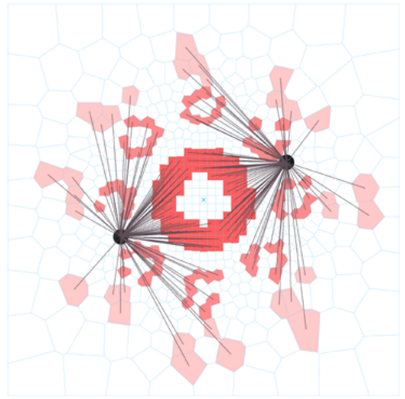


10 facilities

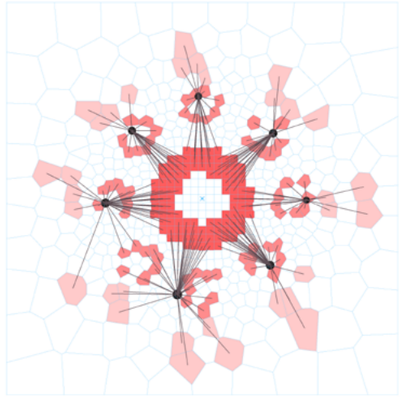
Distributing MRF in Monocentric-dispersed model



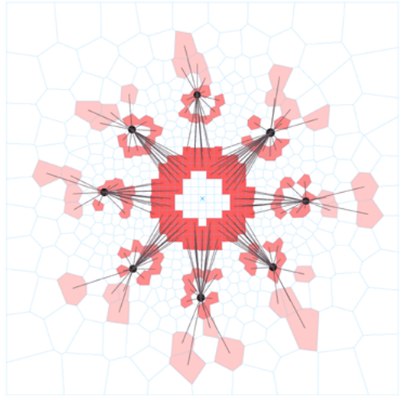
1 facility



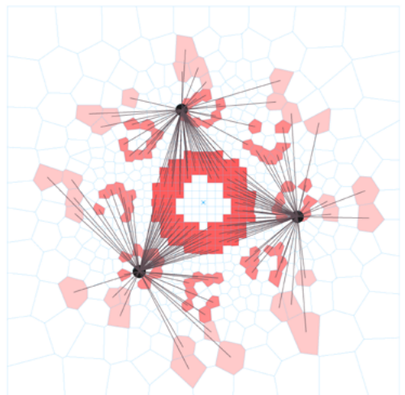
2 facilities



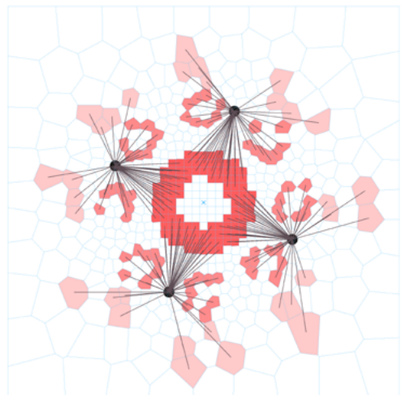
7 facilities



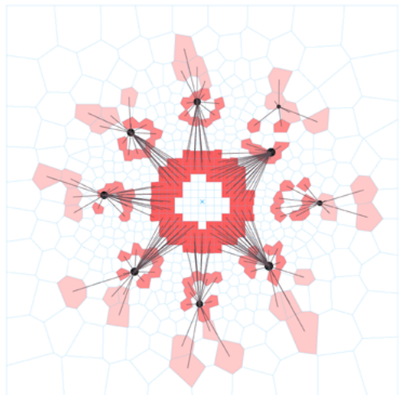
8 facilities



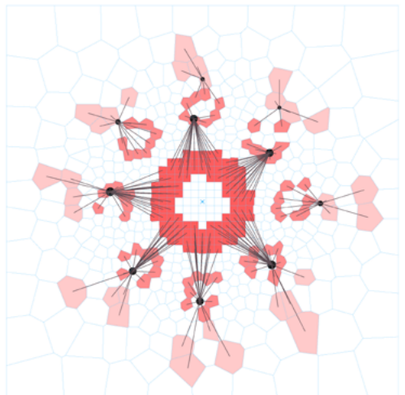
3 facilities



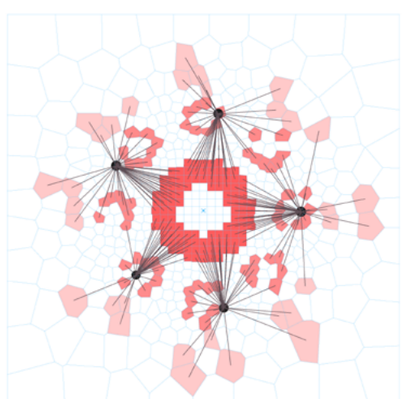
4 facilities



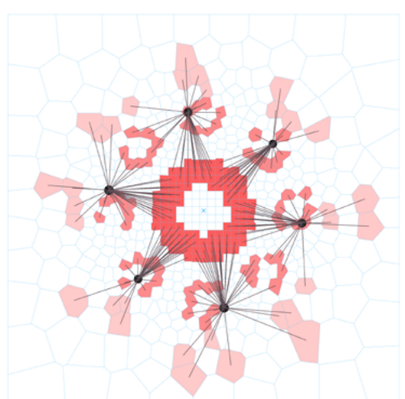
9 facilities



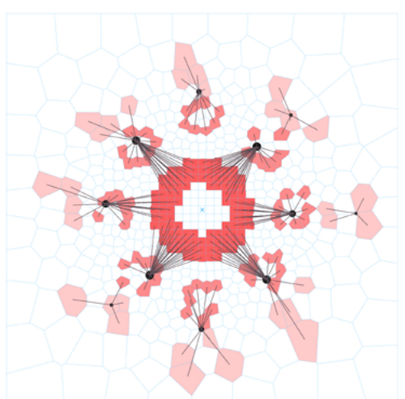
10 facilities



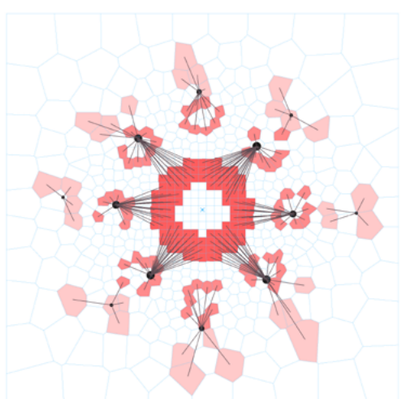
5 facilities



6 facilities



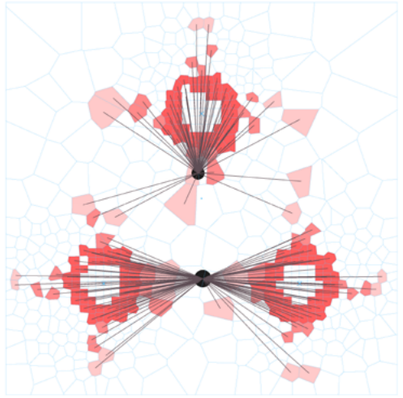
11 facilities



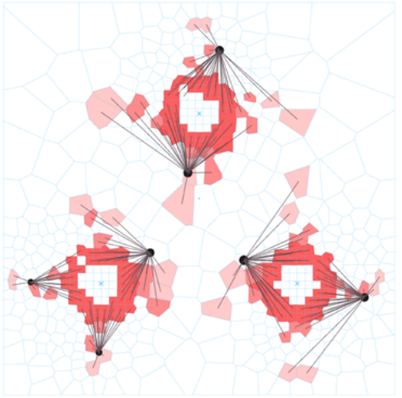
12 facilities

Distributing MRF in Polycentric-centrialised model

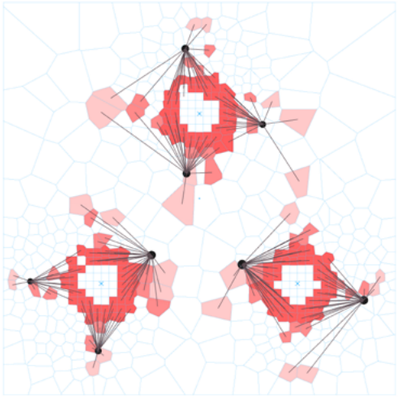
1 facility



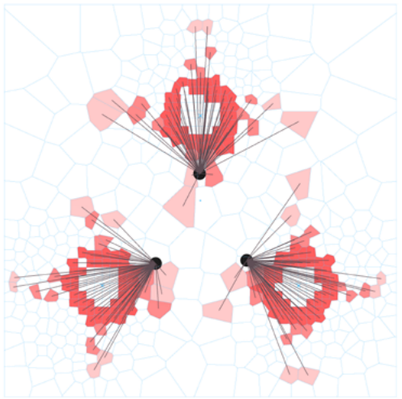
2 facilities



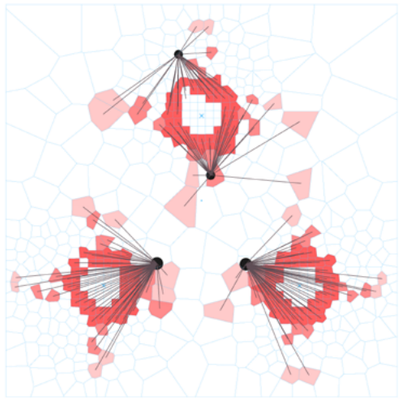
7 facilities



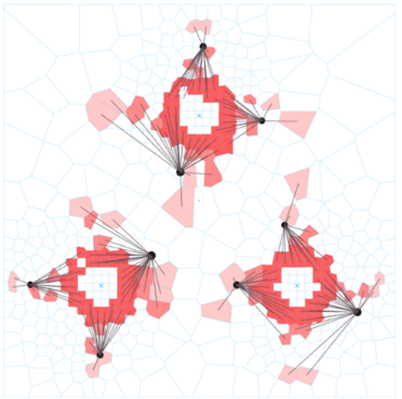
8 facilities



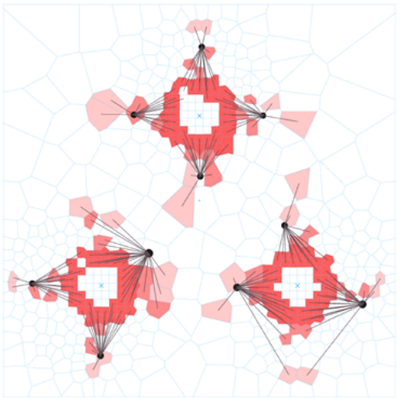
3 facilities



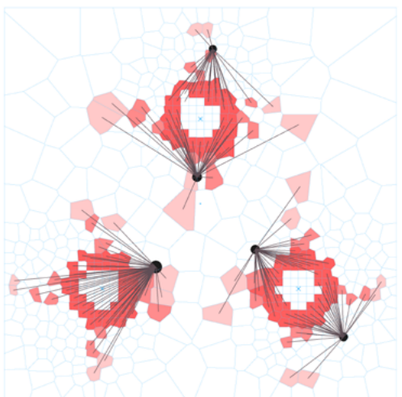
4 facilities



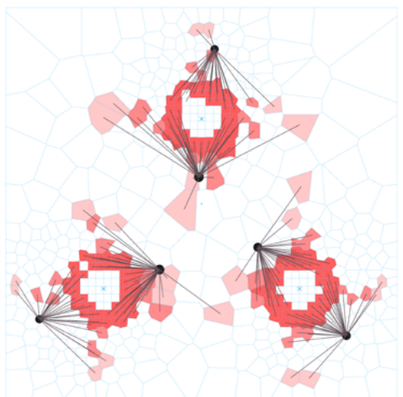
9 facilities



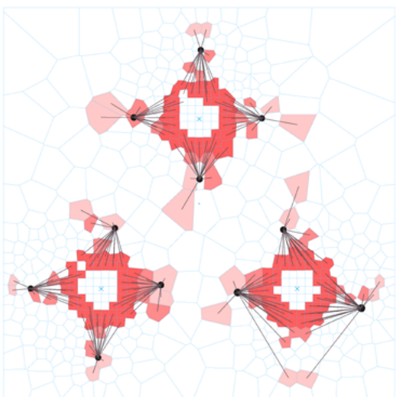
10 facilities



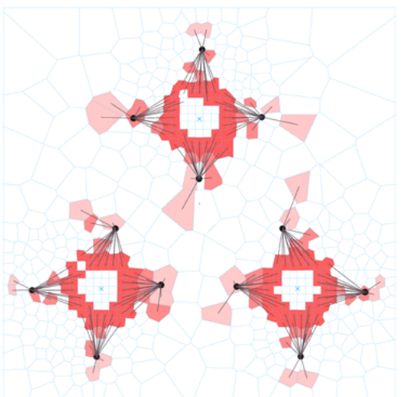
5 facilities



6 facilities

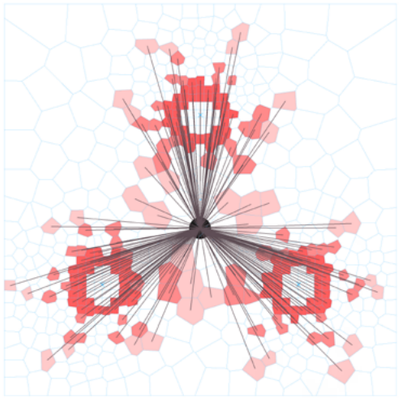


11 facilities

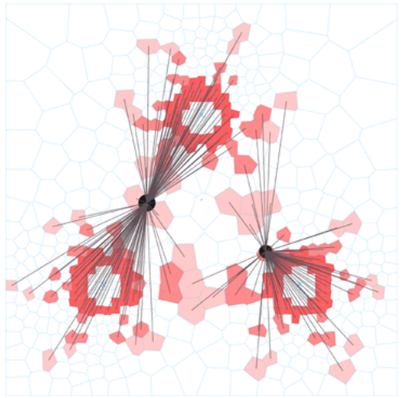


12 facilities

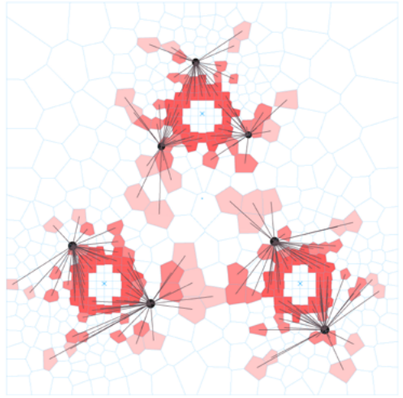
Distributing MRF in Polycentric-dispersed model



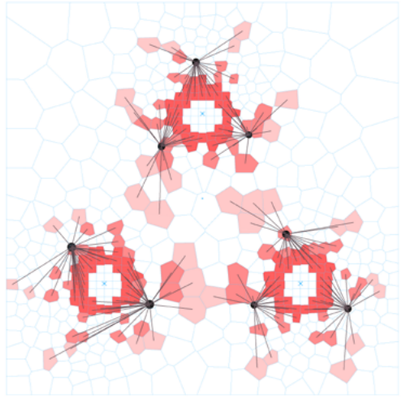
1 facility



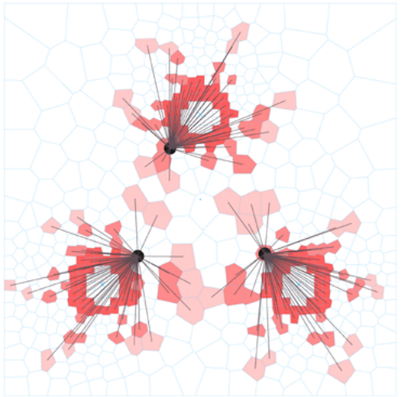
2 facilities



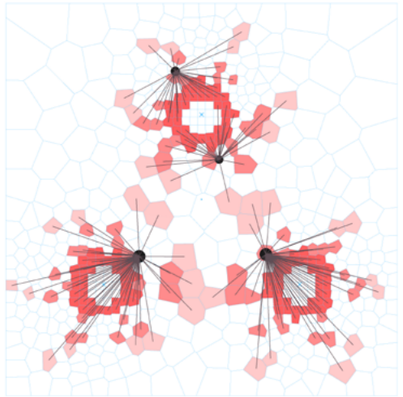
7 facilities



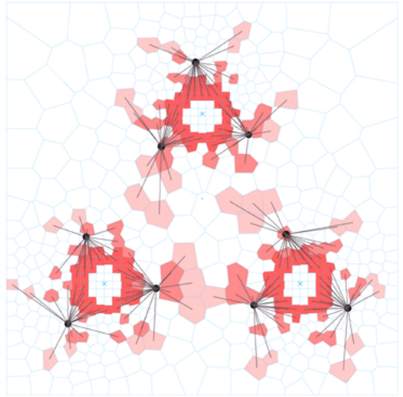
8 facilities



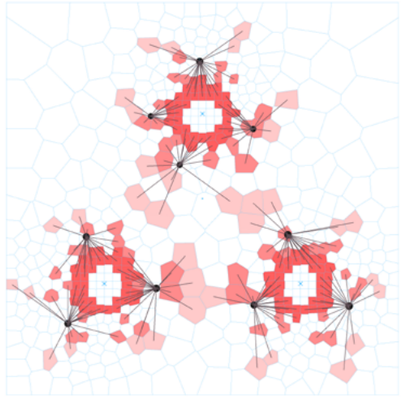
3 facilities



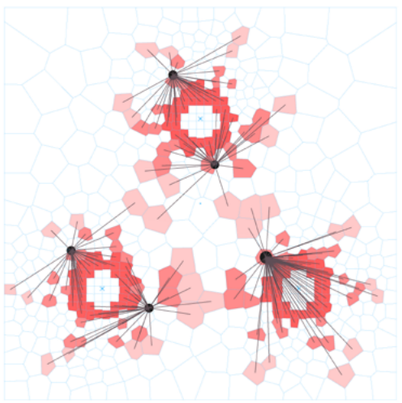
4 facilities



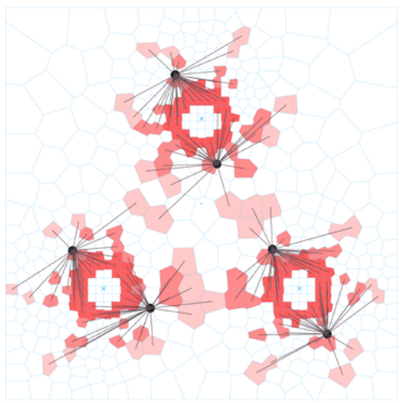
9 facilities



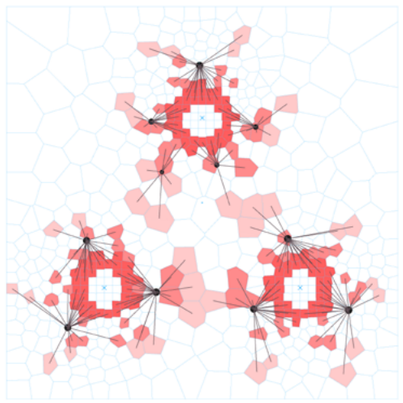
10 facilities



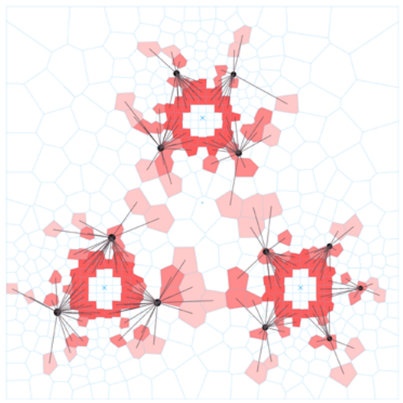
5 facilities



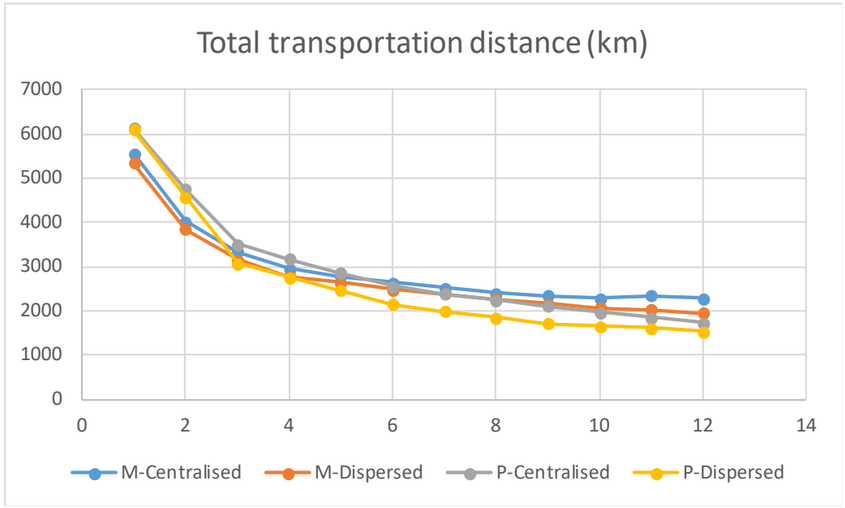
6 facilities

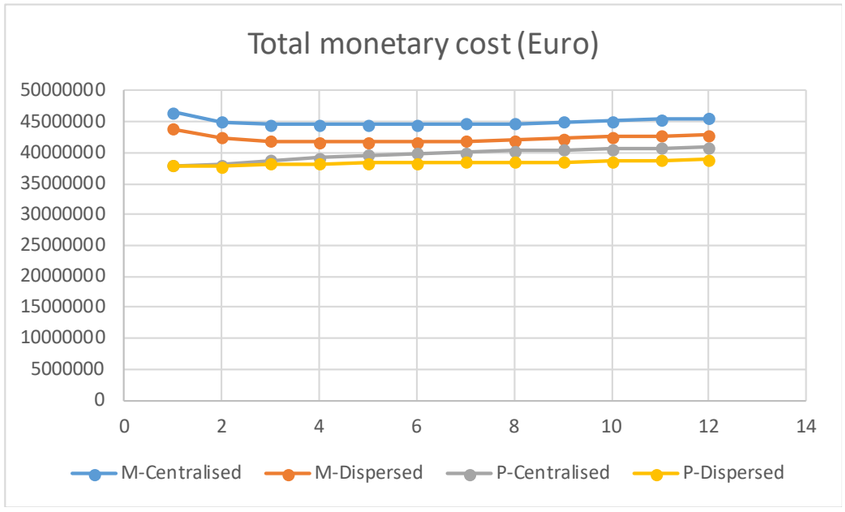


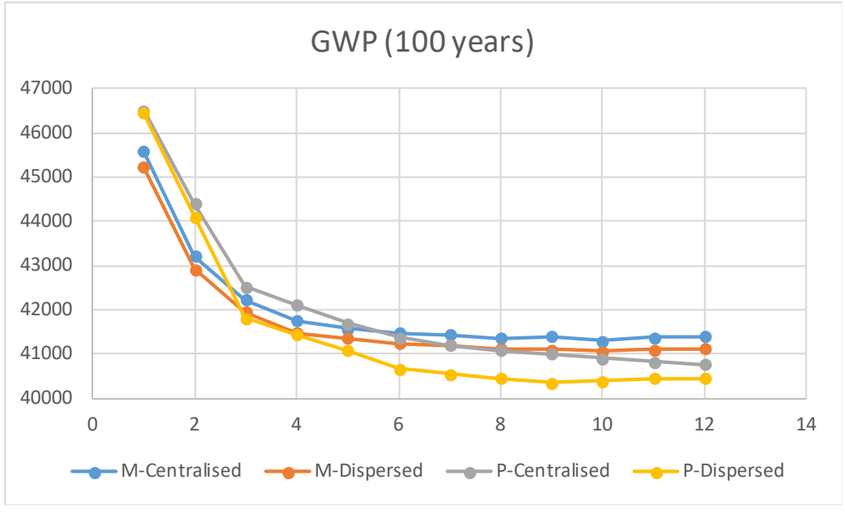
11 facilities



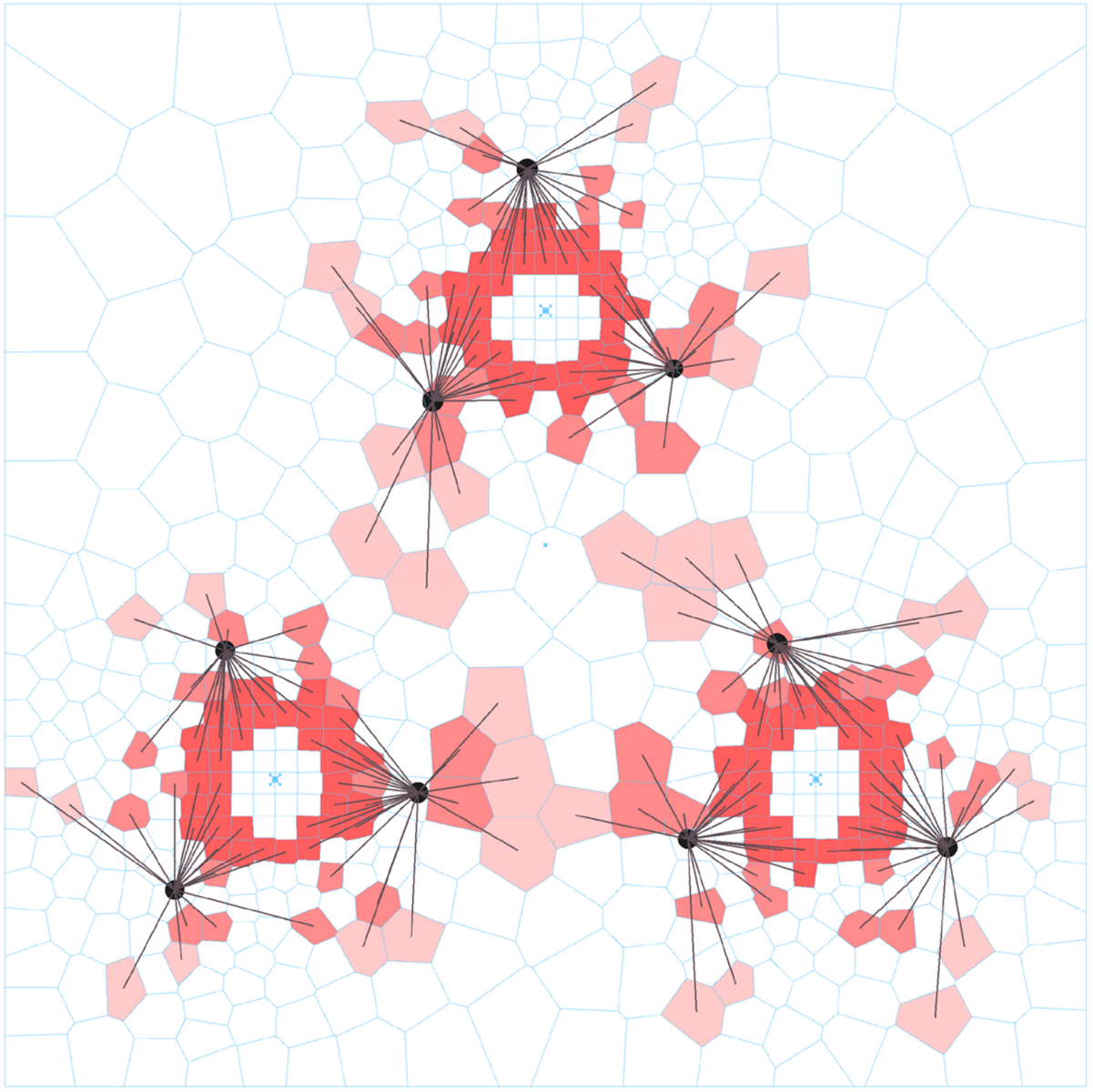
12 facilities


Total transportation distance (km)
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
M-Centralised
M-Dispersed
P-Centralised
P-Dispersed


Total monetary cost (Euro)
50000000
45000000
40000000
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
0
2
4
6
8
10
12
14
M-Centralised
M-Dispersed
P-Centralised
P-Dispersed


GWP (100 years)
47000
46000
45000
44000
43000
42000
41000
40000
0
2
4
6
8
10
12
14
M-Centralised
M-Dispersed
P-Centralised
P-Dispersed

Polycentric-dispersed model with 9 MRFs



1. Polycentric-dispersed spatial structure is more cost efficient.
2. Each urban subcentre needs around 3 facilities to cover the whole territory in a most eco-friendly and economical way.
3. Facilities should be located about 12~15km away from the subcentre.

THE END. THANKS