EXPERIMENTAL MODELLING FOR ALLOCATING MATERIAL RECOVERY FACILITIES IN THE METROPOLIS

Integrated research between Circular Economy and Urban Spatial Structure

P5 report by Weizhen Luo

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Delft, Netherlands

Delft University of Technology - Faculty of Architecture
Master of Architecture, Urbanism and Building Sciences – Track: Urbanism

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INTRODUCTION

01.1 MOTIVATION:

CRITICAL THINKING OF THE MASSIVE MIGRATION DURING THE SPRING FESTIVAL IN CHINA

A phenomenon in China motivated this graduation research. During the spring festival, there is a massive migration from the eastern coastal cities into the western part of China. Labour workers, white-collar workers, and students are the dominant groups in that movement.

The rationale behind the curtain is the imbalanced development between the eastern developed urban region and the western rural area. The long-distance and huge-quantity migration in short period is an accurate microcosm of the urbanisation in China during last three decades. Approximately, 150 million migrants have left home chasing better economic opportunities(Fan, 2007), and this movement changed the face of China (bring China to the second sizeable financial entity in the world) but also posed imminent social threats and other unsolved problems. In the early 1990s, the Chinese government has coordinated the economic development in the western regions as a strategic approach to alleviate the inequality between the coastal east areas and the inland of the western territory(Lin, 1999). Therefore, a rapid urbanisation process is a significant activity in west China during last 20 years.

Chengdu, the capital city of Sichuan province, is a vital centre regarding the economy, transportation and communication in western China, is experiencing the significant success of the development and urbanisation and aiming for further expansion as well. It is a convincible assumption that urbanising the west part of China will deter the migration flow from rural to urban areas. But from the perspective of urban planners and student from the 'urban metabolism' research group, how to avoid the problems experienced by many developed countries(Chen & Gao, 2011) and balance economic development and environmental protection is a more urgent and worthy topic.

Two trends are aiming to lead the world into a smarter and efficient way of development, namely, Circular Economy and Polycentric Urban Structure. Respectively, those two trends obtain the merit of raising resources utilisation rate, protecting and improving the environment and providing better spatial structure to address the rapid urban expansion.

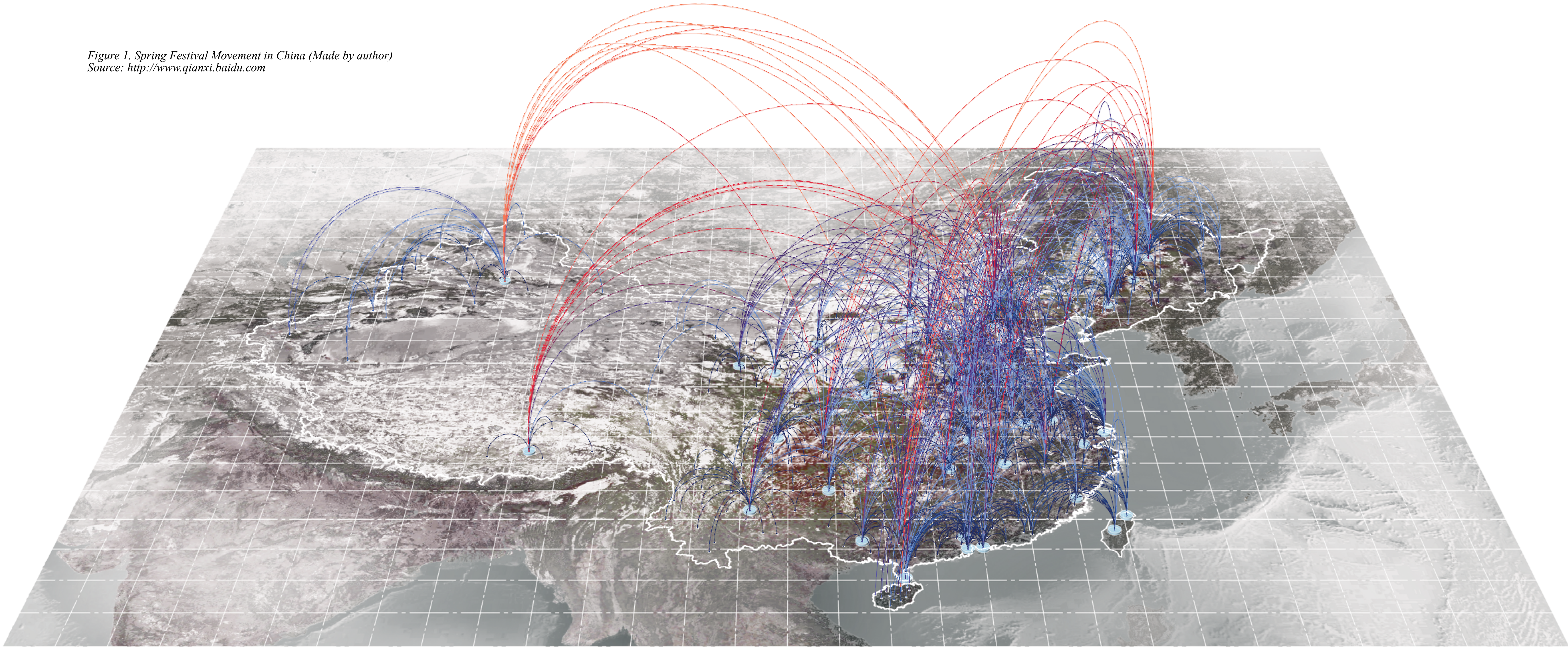
As a promising alternative economic model, CE has carried on numerous attention and expectation internationally.CE is fast becoming the critical instrument in the process of the economic transaction in China. From 2008, China claimed using CE as the underlying principles of economic transaction and future growth by enacting 'The Circular Economy Promotion Law'. In parallel, another primary strategy, which is the Coordinated Development, has been presented in the 11th Five-year Plan to address the unbalanced development nationally, and Chengdu is the first experimental city for this new strategy. According to the description of Coordinated Development, the underlying principles have substantial similarities with polycentric urban structure. For instance, different metropolitan area or villages should find their characters and complement each other to achieve more efficient use of land, resources, and energy. However, how to implementing the principle of the Circular Economy into the Polycentric Urban Structure is still obscure. Also, the performance of integrating those two trends needs to be evaluated and compared with the situation where the economic transaction happens in the monocentric urban structure.

Metaphorically, CE represents the mechanism that how different resources are flowing around a city while the Polycentric Urban Structure provides the platform for the urban metabolism. Both of those two innovative notions could be traced back to classical theories. Circular Economy is a mature product from the study of Urban Metabolism Model, which is a tool of description and analysis of the material and energy flows around a city. PUR is the new competitive participant in the Spatial Structure field of research. In this study field, urbanists are aiming to find the underlying spatial logic which is an invisible hand to influence the urban fabric and settlement patterns.

There were several vital updates of UM and Spatial Structure theory, for instance, an extended UM model has been developed to assess the importance of liveability, and a quantitative revolution has taken place to transform the 'soft' descriptive study of cities into a 'hard' analytical science(Burton, 1963).

However, much uncertainty still exists about the relation between UM with Spatial Structure. Especially, far too little attention has been paid to the integrating CE with PUR, which is the most crucial motivation for this graduation project.

Figure 1. Spring Festival Movement in China (Made by author)
Source: http://www.qianxi.baidu.com



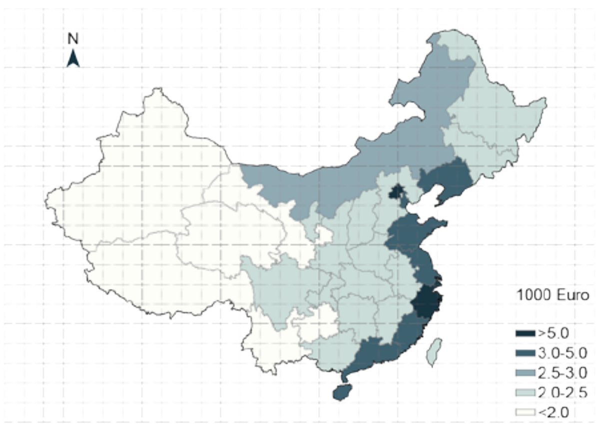


Figure 2. Disposable income per capita 2014 (Made by author)
Source: China statistical yearbook for regional economy 2014

This figure shows the income disparities nationally in China. The huge income gap between rural and developed urban area is the primary driving force for labour migration from western rural area to the eastern coastal cities.

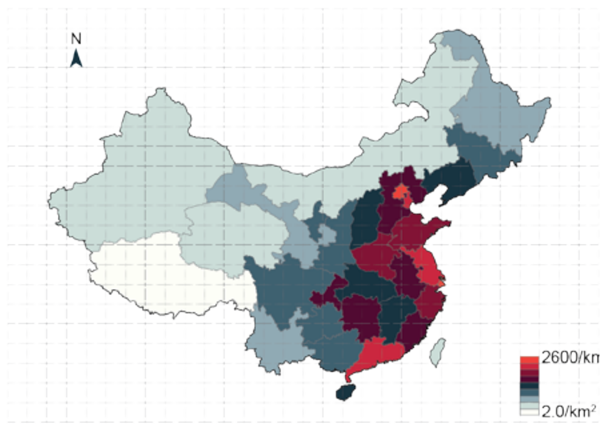


Figure 3. Population density 2015 (Made by author)
Source: http://www.stats.gov.cn sources: NBS (2015)

This figure shows the fact that the eastern part of China has higher population density, which is the result of labour migration during last three decades due to the rapid urbanisation.

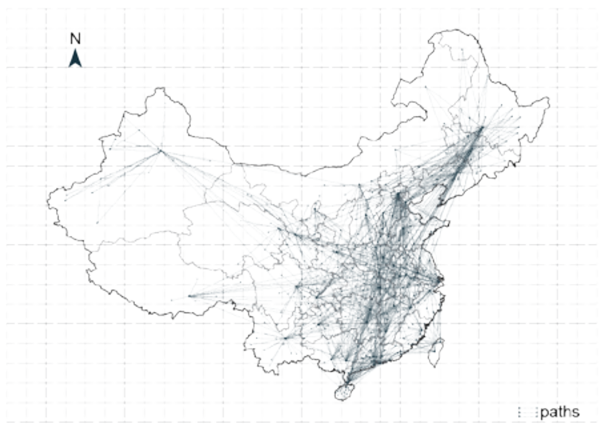


Figure 4. Migration pattern 2017 (Made by author)
Source: http://www.qianxi.baidu.com

This map shows the migration pattern during the spring festival, based on the data collected by Baidu. Most of the travels occurred in the east part of China where provide more job opportunities and better urban environment.

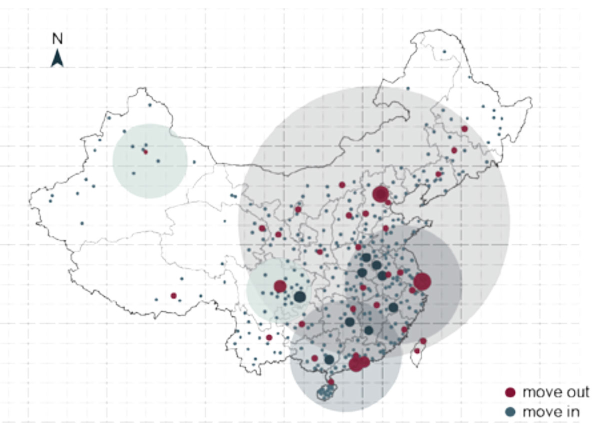
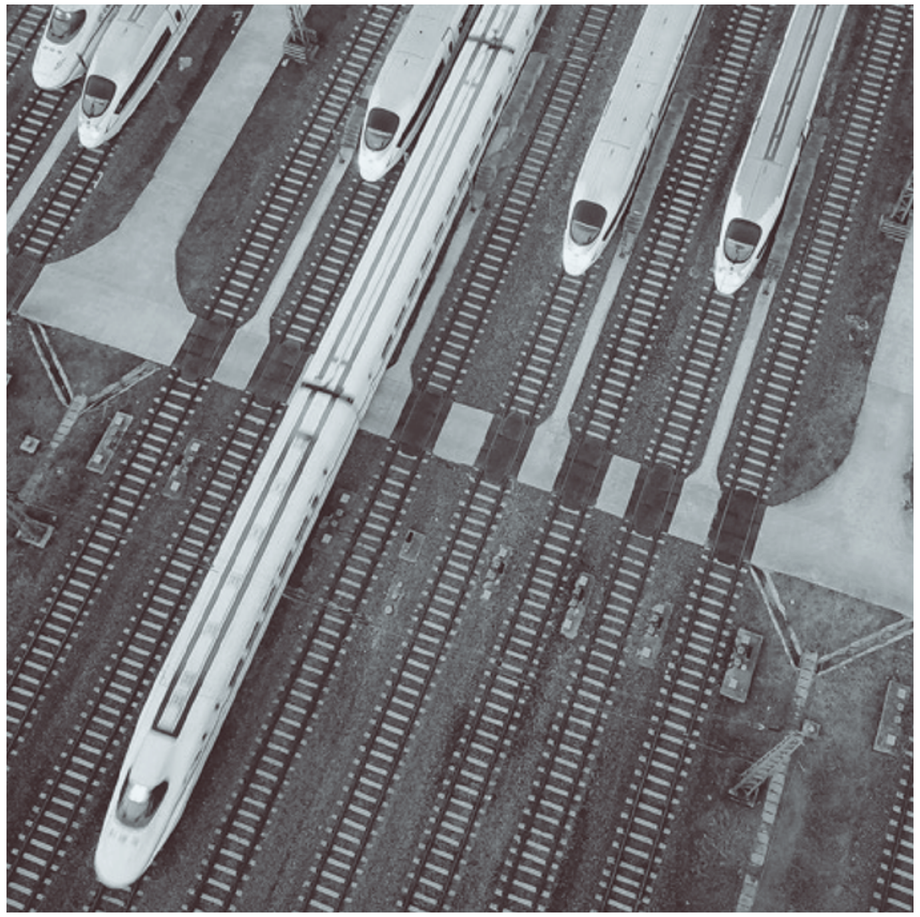


Figure 5. Popular destinations during 'Spring' (Made by author)
Source: http://www.qianxi.baidu.com

The red dots represent the most prominent cities where people are moving out during the holiday, which shows the fact that those cities are the most developed areas for living and working. Blue dots represent the destinations of the trips.



01.2 GENARAL BACKGROUND:

CHINA IS ON THE MOVE

'On the move' is a precise phrase to describe the current situation of China regarding the social change, economic reform, and ecological transformation. There is a remarkable economic achievement during last 30 years. However, the drawbacks are incredibly conspicuous, for instance, the environment pollution and regional disparities

Economic reform: from a command economy to a market economy

From the year of 1978, China has begun to transform its economy from command economy to market economy. The primary beneficiary of this reform is the coastal region due to the proximity to global economic entities. The early phases of China's economic opening were to attract foreign investors by setting up four special economic zones (SEZs). The largest SEZs is Shenzhen, which was aiming to attract spillover investment from Hong Kong, which was still the British colony. With friendly tax policy and land price, many industry factories have emerged along the coastal areas. From then on, the east part of China attracts tons of labour force and resources as well. That is the start point of urban growth and economic development of China and the escalation of regional inequality with outflows of resources from more impoverished places, along with local conflicts and protectionism (Wei & Ye, 2014).

Environmental change: from village/farmland to urban areas

Recently, the 'smoggy city' has become a notorious name of Beijing the capital city of China. To some degree, this is the indicator of the environmental quality. For most of the urbanised areas, the pollutions are always the urgency that draws significant attention. Besides, the farmland loss is an inevitable problem because the considerable conversion of farmland to urban uses is essential to achieve regional development(Schneider, Seto, & Webster, 2005).

China has experienced rapid urbanisation with its economic boom during last three decades: from 17.9% of the population who are living in the urban area in 1978 to more than 50% in 2011(Yearbook, 2012). As a profound process, urbanisation posted inevitable impacts on socioeconomics, human life and the environment(Zhao et al., 2015). Therefore, how and where does urbanisation develop is an urgent challenge for the transition toward sustainability(Bettencourt, Lobo, Helbing, Kühnert, & West, 2007). In other words, decoupling the economic development with resources abuse and environmental contamination is the crucial problem needed to be tackled. Next section will introduce several attempts from China.

To conclude, urbanisation created enormous social, economic and environmental changes. While enjoying the benefits of rapid development, China is facing severe threats from various fields. This situation urged the urban planners and policymakers to find a new path for urbanisation, which provides an opportunity for sustainability with the potential to use resources more efficiently, to create more sustainable land use and to protect the biodiversity of natural ecosystems.

Next section will first briefly summarise the side effects caused by the current approach of urbanisation, which also related to the term of modernisation and industrialisation. Then the reasons and existing solutions proposed by scholars and governments will be explained for better understanding of the rapid development in China. This part is the foundational knowledge that will lead to the problem statement for this project.

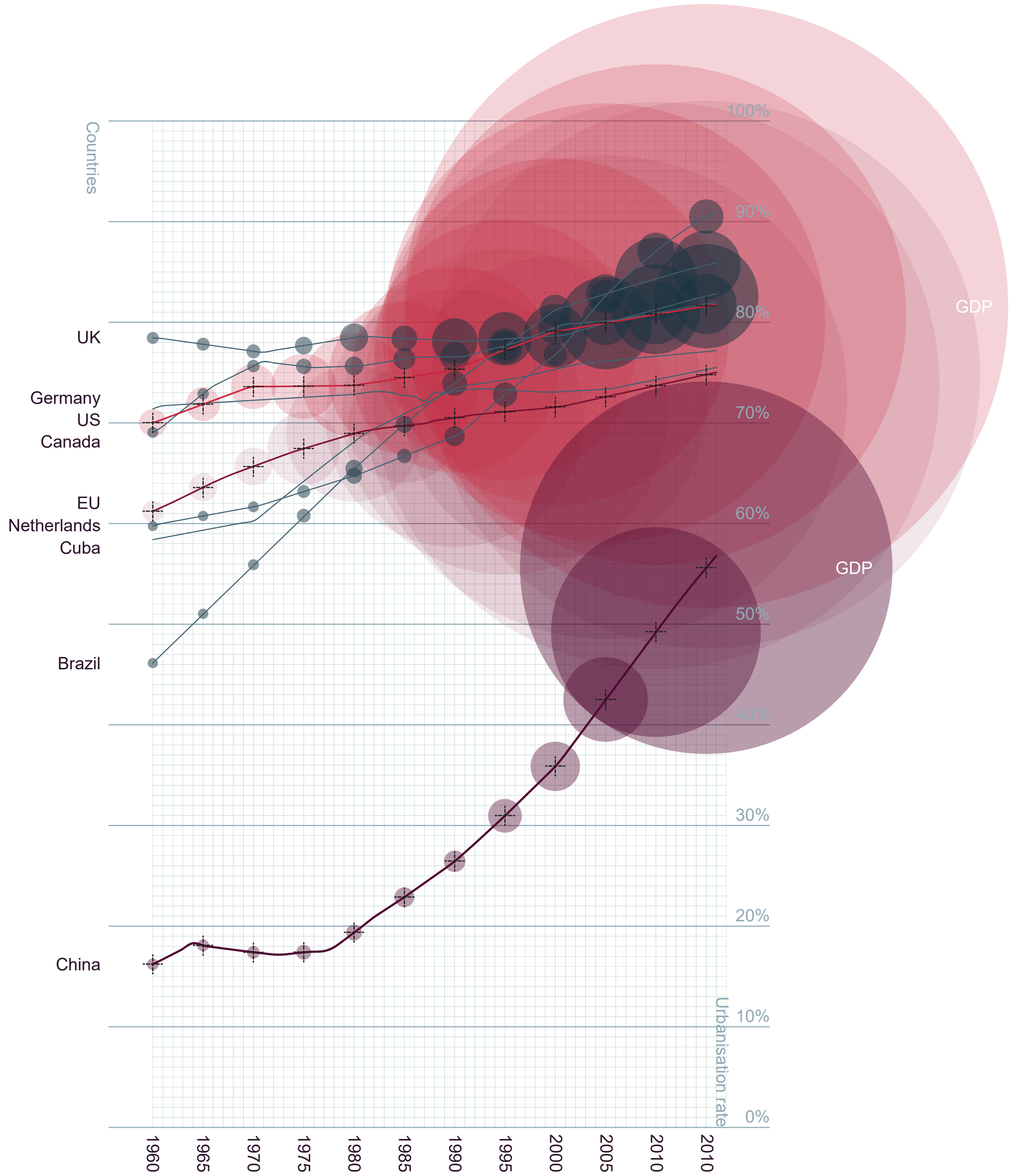


Figure 6. Urbanisation rate and GPD from 1960~2016 (Made by author)
Source: World Bank national accounts data, and OECD National Accounts data files. https://data.worldbank.org/

This diagram shows China has experienced rapid urbanisation with its economic boom during last three decades: from 17.9% of the population who are living in the urban area in 1978 to more than 50% in 2011(Yearbook, 2012). However, the urbanisation rate in China is still low compared to other developed countries such as the UK, USA and Netherlands. Besides, some developing countries like Brazil and Cuba have a higher rate than China.

Figure 7. The 30 largest interprovincial migration flows, 1990 census (Made by author)
Source: http://www.stats.gov.cn sources: SSB (1992); adapted from Fan (2005b)

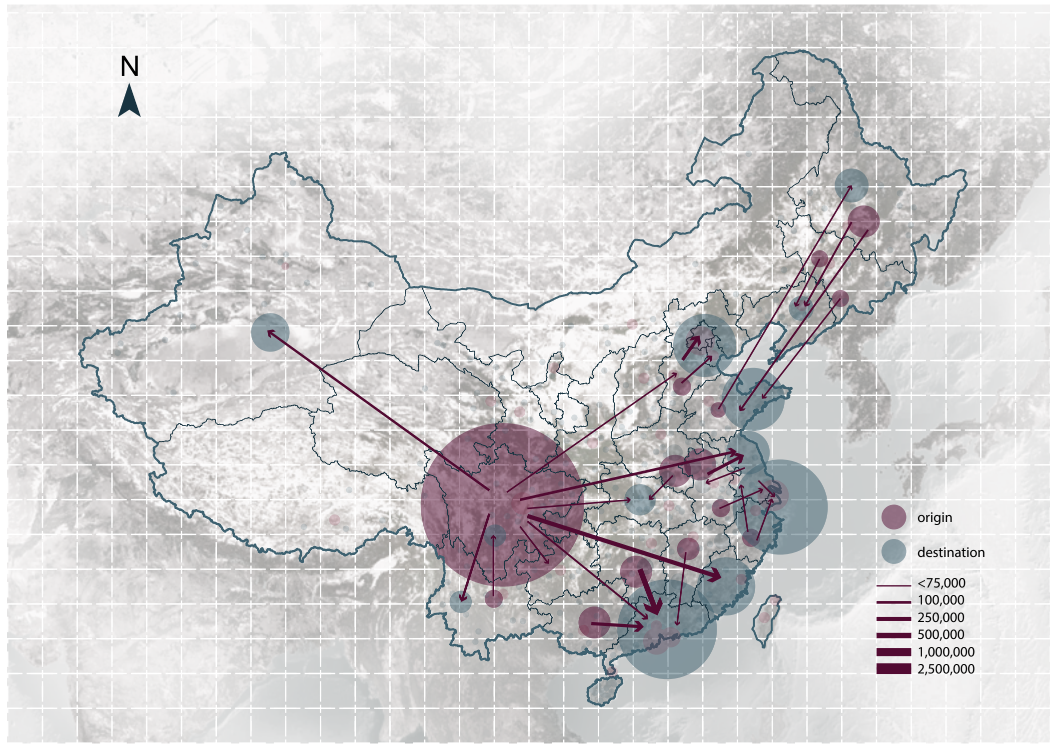
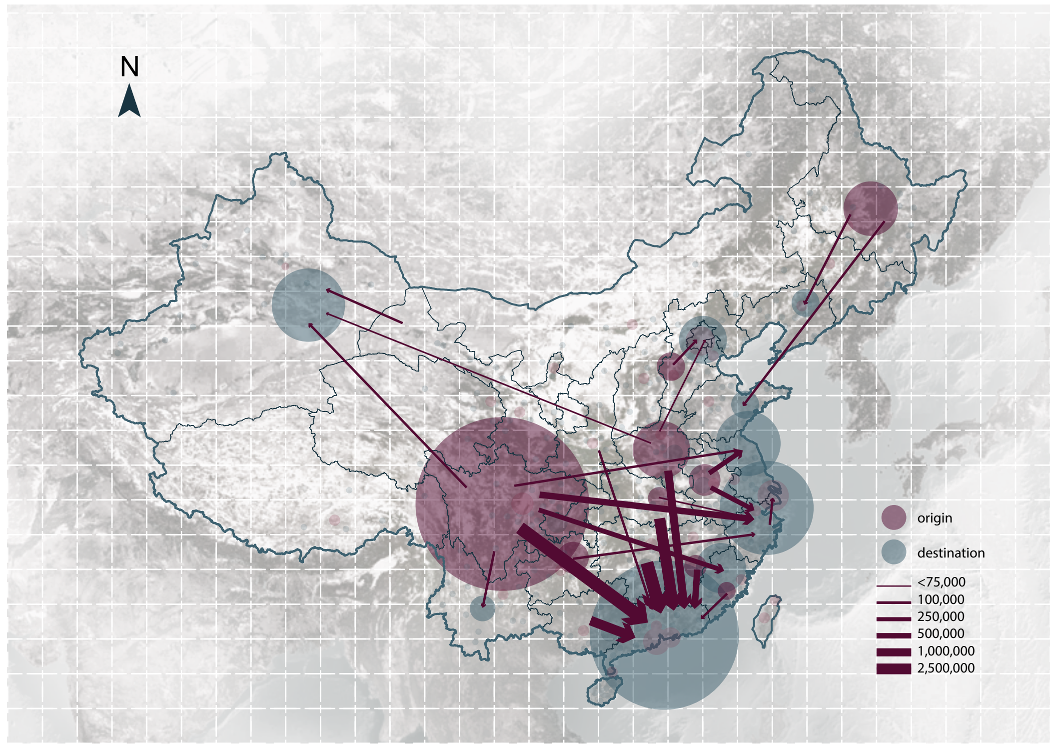


Figure 8. The 30 largest interprovincial migration flows, 2010 census (Made by author)
Source: http://www.stats.gov.cn sources: NBS (2010)



Different from figure 1, which demonstrates an ephemeral phenomenon, these two maps show the long-term migration during last 30 years based on the population census from NBS. The population shift from rural to urban areas is the active process of urbanisation. Seeking for better job opportunities and living environment is the primarily driven force behind this massive migration flow. Figure 7,8 show the fact that most of the interprovincial migration flows occurred from the inland area towards the eastern coastal region. This movement entailed the unbalanced development nationally. Although the central government issued several policies to help the development of the west, there are more people are willing to move into the developed cities such as Shenzhen and Shanghai.

01.3 PROBLEM FIELD:

BATTLE OF MITIGATING THE NEGATIVE EFFECT OF URBANISATION

The environment contamination, regional disparity, misallocation of resources and shrinkage of quality space are the derivatives of the rapid urbanisation process. Since China experienced quick success based on the combination of market interests and governmental powers, the side effects of urbanisation in China is more self-evident.

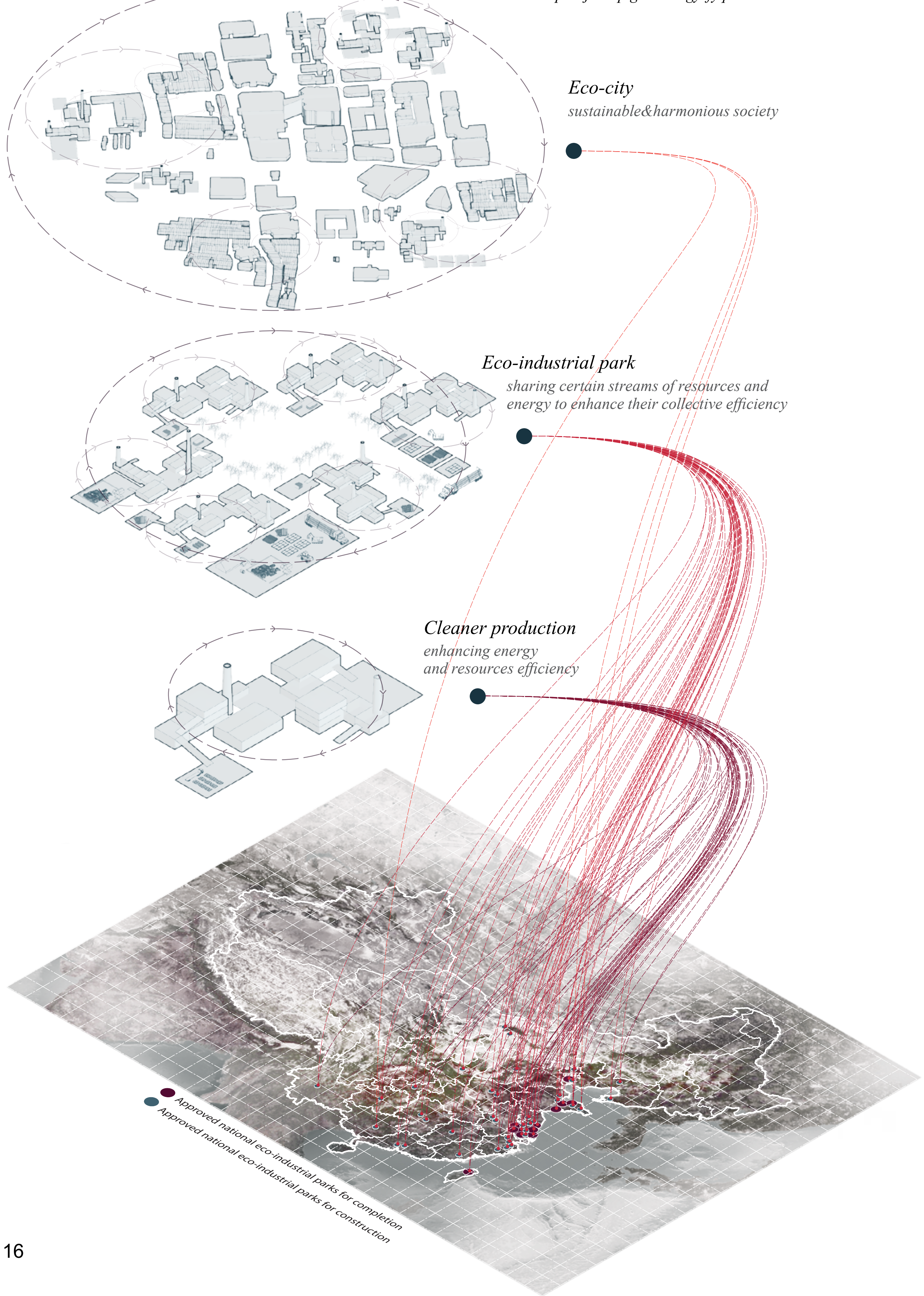
Given the fact that China is still a developing country especially most of the western area is extremely poor, the process of urbanisation will not stop in the coming 50 years. The Chinese government is aiming to create healthy and vital growing urban areas with higher equality and less resource-intensive growth. From statistical analysis, the share of urban residences is expected to swell to near two-thirds by 2030 in China(Bank, 1905). How to mediate the side effects of urbanisation is urgent to the urban planners and policymakers. The rationale of the side effects of urbanisation is that from the beginning of economic reform in 1978, China's single-minded focus on economic growth generated inevitable problems, especially imbalance across geographies, sectors, and classes. Another reason is the linear economy model, which is the foundation of the currently industrialised world.

The linear economy model has embedded in the world for more than 200 years. The mechanism of this model is quite simple, which is 'take, make, use and throw away.' Therefore, significant corporates extracted natural resources and transformed them into products, and then consumers use the products until the products no longer fulfil their needs. Every time, when consumers need new products or services, the corporates would harness the precious nature again. The natural resources include all the material, energy and labour force for construction, manufacture and other industries. Also, the land itself is one of the most crucial resources. As the result of linear-economy based urbanisation, the resources and land became scarce continually while the amounts of all the wastes, outdated products, and the urban area remain increase. That is because the linear model ignores the high economic, environmental and social costs related to the extraction, transformation, and disposal of resources, and is therefore unsustainable in the long term (Herrschel & Newman, 2003).

How to decouple economic growth from environmental impacts and rebalance urban and rural areas are the primary concern for the Chinese government. Therefore, several policies and strategies came out as the critical approaches for addressing this problem. Among them, Circular Economy and the Coordinated Development are the most fundamental principles underlying various initiatives and laws.

At next section, a brief review of those two approaches will be introduced.

Figure 9. 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



Review of Policies(CE, CD) in China:

1.The Objectives of Chinese government

Achieving the sustainable development is the ultimate goal for the policy maker and scholars in China. At the 11th Five-Year Plan for Economic and Social Development, the government presented two concepts for addressing the problems caused by rapid urbanisation. One was the Coordinated Development, and it still is a prime policy to optimise economic transformation and address the disparities between rural and urban areas. Another one is CE, which is a vital part of the solution for China's battle to solve the environmental problems while maintaining economic growth.

1. Circular Economy in China

The concept of CE was introduced in China in the early 1990s and formally accepted in 2002 by the central government. Then as a significant national framework, the Circular Economy Promotion Law came into force in 2009 (Mathews & Tan, 2011). China got inspiration from the examples of implementation in Europe, the United States and Japan(Zhang & Wen, 2008), such as cleaner production, industrial ecology and ecological modernisation. There are some differences in the breadth of the CE concept. In European policies, they more focus on the materials, resources and waste, but put less attention to broader environmental pollution. In contrast, the scope of CE in Chinese policies is broader. Besides the management of materials, resources and waste, the Chinese perspective includes a prominent role for pollution concerns as well as the need to build a 'resource-saving and environmentally friendly society' and 'ecological civilisation'(Yong, 2007).

The initiatives of CE in China occur at multiple levels. The smallest scale is the 'cleaner production', which aims to enhance the energy and resources efficiency within companies. The middle scale is the 'eco-industrial parks' where a group of companies share certain streams of resources and energy to enhance their collective efficiency. The largest scale is the 'eco-city' where will focus on the sustainable production and consumption. Finally, the aim is to establish a harmonious society.

The eco-industrial development is the leading practice based on CE in China. Some eco-industrial initiatives have been designed and implemented for addressing the environmental problems. In 2005, the National Development and Reform Commission launched the first batch of national pilot demonstration projects, which included 13 industrial parks, 42 enterprises. After two years, the second batch of demonstration projects involved more cities and enterprises to participate in this industrial transition. Until 2010, the Ministry of Environment protection designated 50 EIPs across the country (fig.14 bottom). Those included 11 EIPs approved for completion and 39 approved for construction.

However, while the CE has deeply rooted in the industrial symbiosis in China, this concept only has a subtle influence on citizens' daily life. How to increase citizens' awareness of sustainability and change their behaviour based on CE's principles are the prime barrier to achieving 'eco-city'.

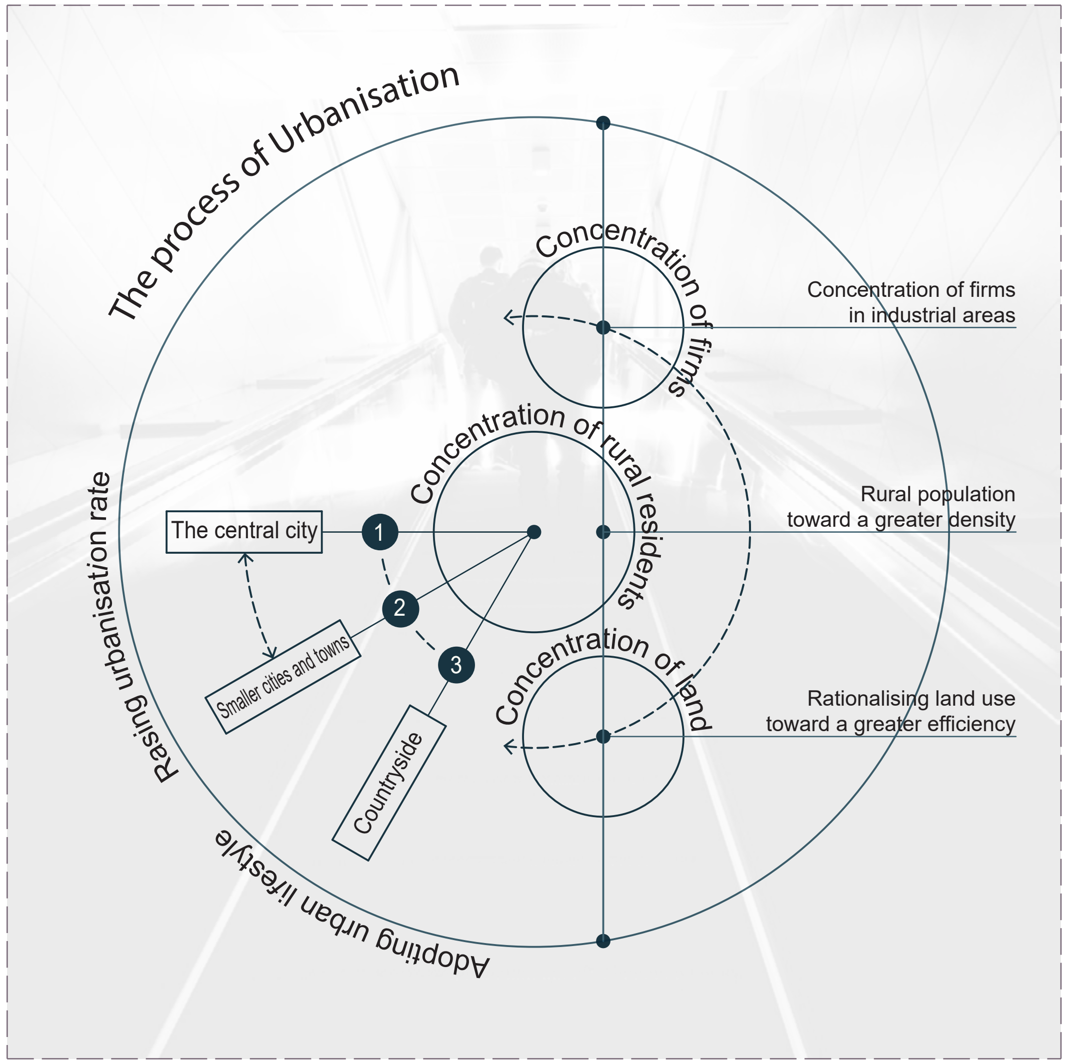


Figure 10. Working mechanism of urbanization under coordinated development (Made by author)

1. Lower entry barriers of the urban household registration. Eliminate discrimination against rural resident.
2. Enhance urban capacity and attractiveness, encourage farmers to become citizens.
3. Buildding new countryside to industrialize and urbanizae the rural area.

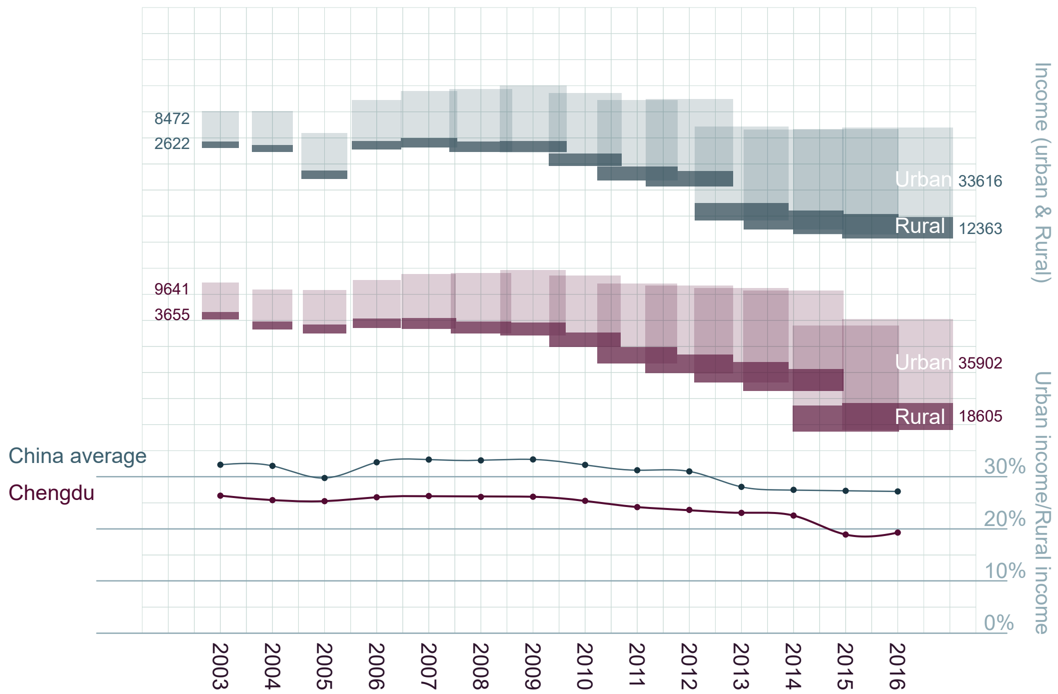


Figure 11. Urban–rural income disparity: Chengdu compared with national average (Made by author)
Source: National Bureau of Statistics of China http://data.stats.gov.cn/english/easyquery.htm?cn=A01

3.Coordinated Development in China

Coordinated development refers to cooperate with more than two parties or resources to achieve an objective under win-win situation(Lan & Zhong, 2016). This concept shares significant similarities with the theory of Polycentric Urban Structure. They both require and encourage different areas to find their advantages and complement each other, which can increase the efficiency of resource, energy and land use.

CD is especially important in China where provincial rivalries have contributed to industrial duplications and overcapacities. The challenge is to get provinces and cities to cooperate as well as to compete to stimulate economic development. It means different regions, especially adjacent areas, should be more complementary, not competitive. From spatial dimension, CD requires integrating the developmental planning of more vibrant and more deprived areas, such as rural regions of poverty on the outskirts of modern cities.

In 1980, the Chinese government proposed a strategy, which is 'small town (city)', aiming to boost the development of rural area. Due to the reason that at the starting phase of economic reform, most of China's town was in general to small and lacked enough power to support any investment for sustained local industrialisation. Therefore, the small town strategy failed to narrow the gap between rural and urban area. After 20 years, CD has been launched officially to solve this problem consecutively. Different from the previous strategy, based on the CD principles, the method of optimising the rural area's economic development is enhancing the efficient usage and equitable access to resources by increasing the connection and complementarity with richer areas instead of only focusing on building small towns. The main working mechanism of CD is three 'Concentration', namely land, firms and rural residents (fig.10).

Chengdu is the first experimental city of CD in China. After 15-years developing, the achievement is noticeable. Chengdu became the most developed city in the west of China while narrowing the gap of rural-urban income disparity (fig.11). Besides, this experimental city is approaching a more balanced development by introducing multi-urban centres and improving the quality of infrastructure. However, there is still plenty room for improvement due to several innovations, such as new economic model, state of the air technology and advanced urban planning structure. From the perspective of the synthesis in author's project, integrating CE with CD would generate a more comprehensive approach for achieving eco-city.

Also, China's CE policy includes an express concern for the integration of CE principles into land-use planning(McDowall et al., 2017) and the theory of CD also focus on the environmentally sensitive spatial combination of residential, agricultural and industrial activities.

Extensive research has shown detailed knowledge of Circular Economy and Polycentric Urban Structure. A large body of research just focuses on its own field. However, as a complex system, metropolitan area or even a small town requires the excellent operation of physical interactions based on a compatible spatial structure. Therefore, integrating research between Urban Metabolism with Spatial Structure is significant.

01.4 PROBLEM STATEMENT:

INTEGRATED RESEARCH BETWEEN CIRCULAR ECONOMY AND URBAN SPATIAL STRUCTURE

As the primary instrument for the economic transaction, CE has changed the image of China from various perspectives. Existing research recognised the enormous achievements of implementing industrial symbiosis. A couple of newly published documents revealed an ambitious objective of China's next movement, which is transforming the metropolitan area into eco-city based on CE. Contrary to the industrial symbiosis, closing the loop in an urban area will affect urban fabric and citizen's daily life significantly. The efficiency and possibility of achieving urban symbiosis mainly rely on the location of associated facilities and the spatial configuration of infrastructure.

In the field of deterring the chaotic urban sprawl and resources misuse, Coordinated Development has shown its advantages and capability. Studies over the past one decade have provided valuable information on the fundamental principles and approaches of CD and implied the strong correlation with the innovative conception, Polycentric Urban Structure.

Indubitably, a sustainable future city needs a smooth economic transaction and compatible spatial structure, which provides a platform supporting all the flows in a CE-based ecological city. In other words, the conventional Urban Metabolism model should be spatialized to detect the impacts caused by various spatial layouts and determine a relatively better configuration of settlements and facilities.

However, few studies have investigated the outcomes of applying CE into metropolitan areas with different spatial structures. Most articles, whose topic related to CE and eco-city planning, are mainly emphasising the importance of economic transaction and listing several common standards. As for the study of the spatial structure and Polycentric Urban structure, although, the topics such as land price, commuting patterns and settlement patterns have been thoroughly studied, there still are inadequacies about the interdisciplinary research between CE and urban spatial structure.

The primary 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.

source: www.EurekaKing.com

01.5 RESEARCH QUESTION:

Both of Circular Economy and Spatial Structure are the topics with a vast range of knowledge and numerous aspects that are worthy of careful considerations, which gives a fact that it is almost impossible to include everything in a single work of research. The critical method to conduct this study is to find a specific angle to start experiments, which may become a fresh inspiration for further analysis. Therefore, determining a core player in the urban symbiosis is the start point of this project. Then both of the locations of tested facilities and material flows will be projected into several spatial structures.

The primary research question of this study is following:
Which spatial structure has more potential to facilitate urban symbiosis? What is the most compatible approach for allocating associated facilities in the metropolitan area?

Given the fact that the cornerstone of this project is to intertwine the knowledge of the circular economy and spatial structure, the primary objective is pointing in two directions. First, this project is trying to find a better spatial layout for the processing of closing the material and energy loop in a metropolis. From this angle, empirical data will be conducted to reveal the distinctive characteristics of different spatial structures. Second, this project is eager to determine a way of allocating CE-related facilities in an eco-friendly manner, which will smooth the path of the economic transaction by utilising the merits of the corresponding spatial structure. The hypothesis of the following research method is a technique called approximation where the study initiates from two remote points and keeps marching towards an obscure joint that may have the potential of being the optimum solution. Several sub-questions are listed below to answer the primary research question:

1. What is the relatively crucial role in the chain of urban symbiosis?

2. What are the most typical urban structures? Also, how are the characteristics affecting the relationship between various urban elements?

3. What is the performance when different types of spatial structures accommodate the same CE-related facilities?

4. What is the performance when different CE-related facilities (core variable is the capacity) are provided in the identical spatial structure?

5. Which method would facilitate the evaluation to make a convincible assessment?

6. What is the conclusion that can assist the process of urban planning as a set of guidelines?

01.6 THEORETICAL FRAMEWORK

Although this project started from a single event occurred during Chinese spring festival, the rationale behind this phenomenon is extremely complicated. Therefore, a broad scope of knowledge is the foundation, which would provide the technical expertise and references of appropriate methodology for coupling the research question.

The way to mediate the side effects caused by rapid urbanisation is never easy. During last half centuries, numerous theories, strategies, attempts and initiatives emerged and were aiming to solve all the problems embedded in the city. Among them, most widely recognised terms are Sustainability, Eco-city, Garden city and so forth. All those notions may obtain their distinct propositions, but deep down, they are interrelated and share the same objective. Therefore, at the early stage of research, several classic theories about 'sustainable development' were studied to show a clear vision of the ideal living environment.

After studying the theories above, the scope of this research has been narrowed down by paying more attention to Circular Economy and Urban Spatial Structure. At this phase, one of the primary objectives is to determine the reason for causing environmental damages and resources squandered. Secondly, the core principle and associated approaches will be the focal point and this part of the study will answer sub-question one. In parallel, the theory of spatial structure will give the insights for sub-question two.

Based on the obtained knowledge from previous research, the more specific study will be conducted, which is about the existence solutions practised in China. This part of the survey can project the general knowledge into a site-based environment to investigate the feasibilities of mentioned initiatives.

Next, which is also the most fundamental work for the subsequent research, several core theories will be summarised to facilitate the process of finding the correlation between practical actions with theoretical work. For Circular Economy, which is the promising offspring from the Urban Metabolism Model, mainly developed based on the 'system thinking theory' and the 'complex system theory'. With regard to spatial structure, 'location theory', 'spatial network' and 'polycentric urban structure' are the primary targets for studying. During this chapter, sub-question three and four will get the logical answers that should be tested or proved by the following work.

The main content of this project is forming an experimental model to generate empirical evidence. The outcome of this part of work will be referred back to theories and then lead to discussion and comparison. Because of the complexity that this project possessed, the generated data will inherit the similar level of complexity. Therefore, 'Multi-Criteria Analysis' will be employed to direct the way to a conclusion.

Finally, the firm conclusion should assist the process of urban planning as guidelines such as spatial logic or suggestions. I also hope that this project could inspire further study.

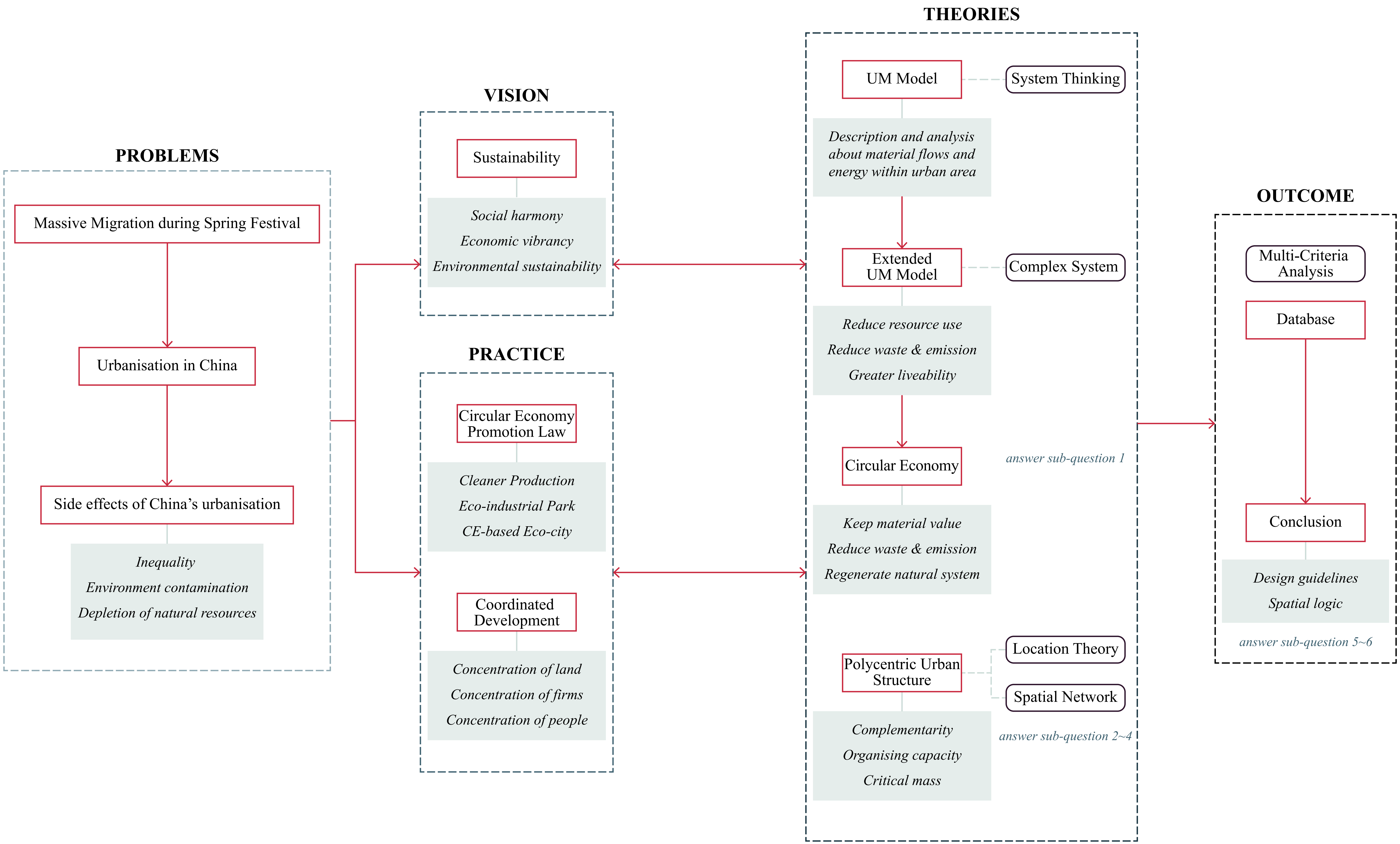


Figure 12. Theoretical framework (Made by author)

01.7 RESEARCH APPROACH

In order to answer all sub-questions, several methods was used, namely: literature review, case study, parametric modelling, evolutionary solver (Galapagos), GIS cartography.

Literature review

Reviewing literature is the major method in this project and related to all the questions. First, the literature review about eco-city and sustainability is conducted. The conclusion of this part is the standards of eco-city with several design principles. Secondly, the literature review is about the significance and path of development of Circular Economy. After CE, articles about Polycentric Urban Structure were the primary resource of reading. Following is literature about 'location theory' and 'spatial network'. The outcome of this section is the summary of existing urban planning model from the most simple one 'Thunen's Isolated State' to most current one 'Polycentric Urban Structure'. Several theories also assisted this project. In next chapter, only the most important and highly relevant theories will be introduced.

Case study

The case study is an essential method of answering the first sub-question. In China, there are already several pilot projects launched as eco-city. For instance, the Tianjin Eco-city project cooperated between China and Singapore is a valuable case. From studying existing case, their solutions may have a sufficient impact on this graduation project. Besides, most of the research about Material Recovery Facility is based on the study case. Associated statistics were picked and generalised for the following use. Also, methods of statistical analysis are vital, such as Linear Regression.

Parametric modelling

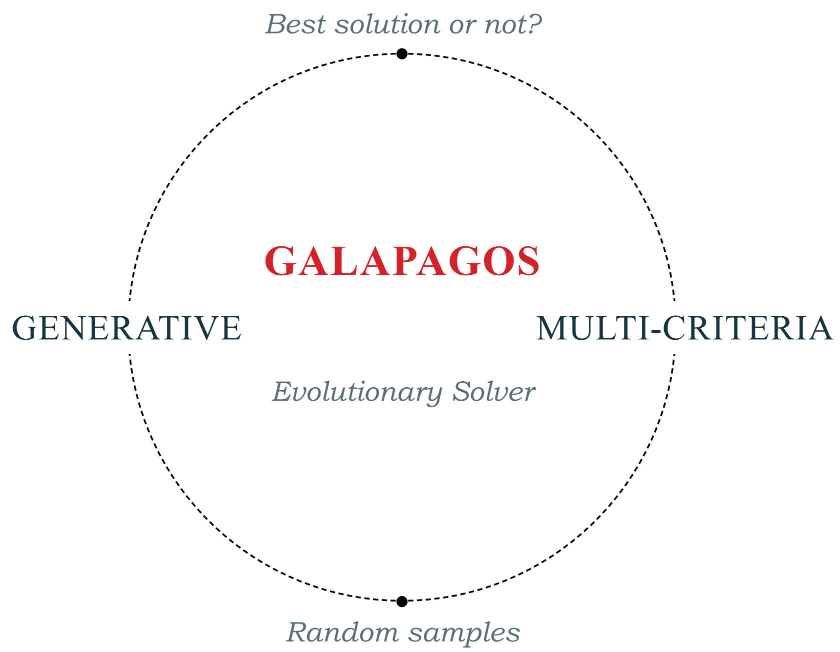
This term, in this project, mainly refer to build model parametrically in Rhino/Grasshopper environment. Compared to the mapping or modelling in GIS, parametric modelling provides a better flexibility and computing speed. This method will be used primarily to answer question three and four. During this stage, the abstract model for computing is the primary working object, which has little connection with geographic conditions. In a parametric model, it is easier to alter the model and assess the performance. Further, this model could generate urban planning design after several modifications. For more detail, I will explain in the methodology part.

Evolutionary solver: Galapagos

Galapagos is a utility embedded in Grasshopper and based on the Genetic Algorithm, which is a scheme that imitates evolutionary processes through simulating procedures of population, crossover and mutation of competing solutions(Rakha & Reinhart, 2012). In Rhino environment, this evolutionary solver uses the variables (genes) to choose the random location (genome) within the test area (solution domain). After several generations, the outcome will close to the optimum based on the evaluation system.

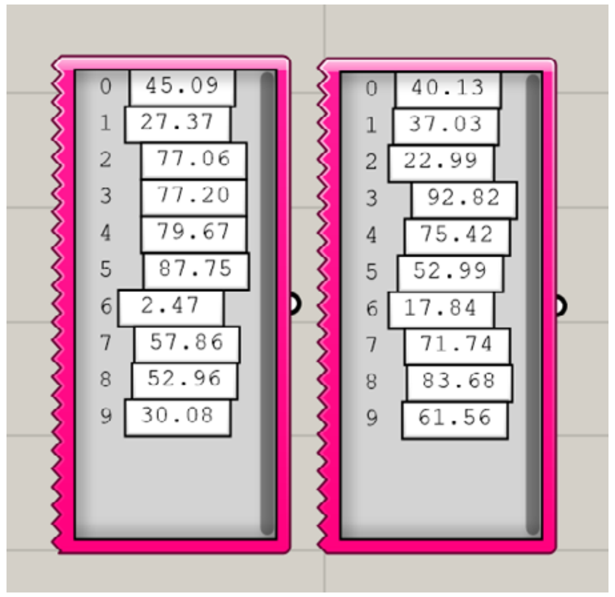
GIS cartography

A geographic information system is a system designed to capture, store, manipulate, analyse, manage and present spatial or geographic data. Besides, GIS is an essential platform in Geo-design. In this project, GIS is the tool for mapping which can visualise the current site conditions, the evaluation results and final design proposal.



The core of the generative design is the real-time feedback loop, which can instruct the successive actions of inputs. In the Evolutionary solver, Galapagos, there are two primary components. The first one is the Gene Pool, which is a container of a group of sliders. Since in the digital model, all the attributes of geometry have direct correlations with numbers, the Gene Pool is a useful tool to manipulate the geometries in Rhino. Another most crucial component in Galapagos is the Fitness component. This component is the primary interface of the solver. The right graph in Figure 13 shows the Fitness component. There are two knots, Genome and Fitness. The genome is connecting to all the gene pools while the Fitness is linking the entity which represents the goal for this model. Usually, the goal is a number that calculated based on multi-criteria. This number is the real-time feedback in the whole model and will give instructions for changing the numbers in Gene Pool. After several iterations, this solver could find the optimum.

Figure 13. The core components in Galapagos.

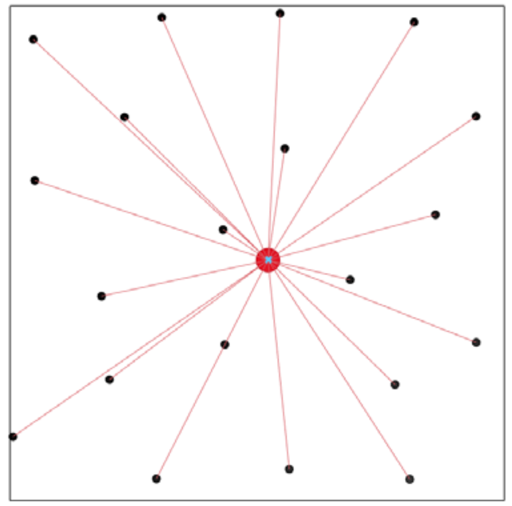


Gene Pools

Which can control the attributes of geometries, such as Area, Height,Color , Coordinate and so forth.

Fitness & Solver

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



20 random points & 1 red point

The black points could represent the residential blocks while the red point is the facilities. All the connections are the transport routes when transfer essential material flows.

Figure 14. The screenshot of an example of the Generative design method.

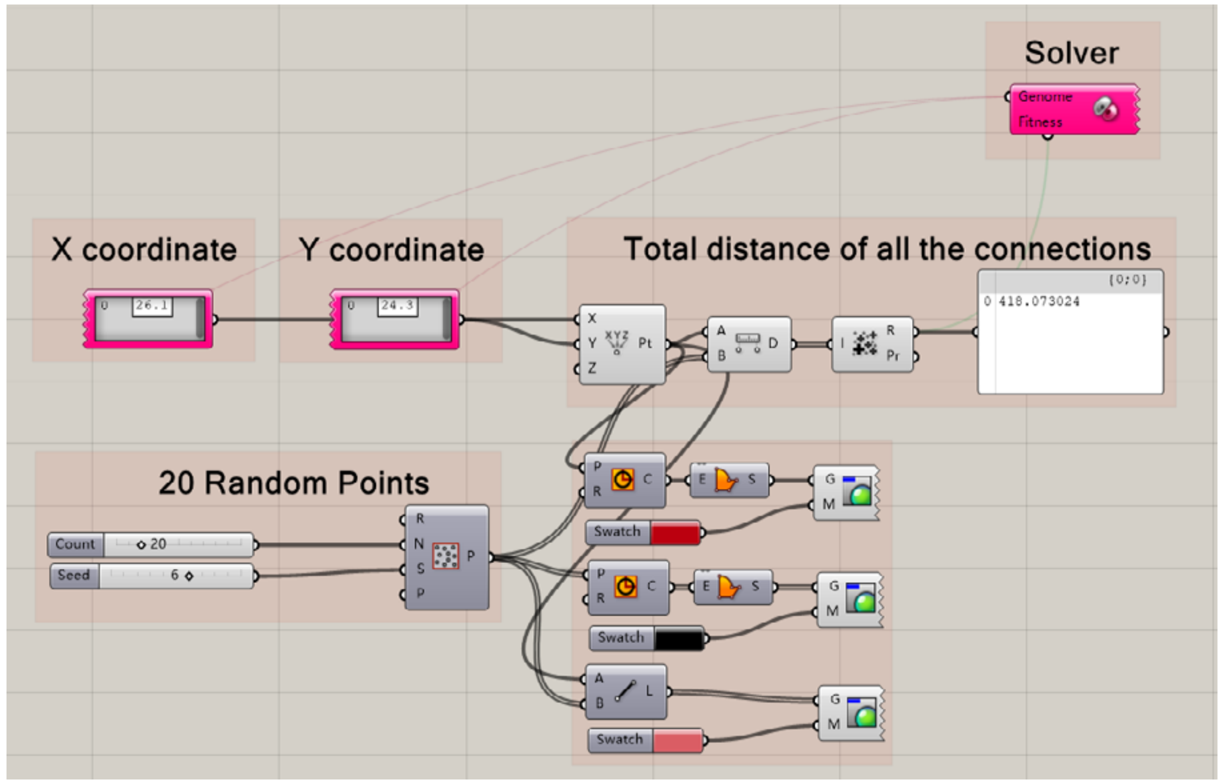


Figure 14 shows a simple example of Galapagos. 20 randomly generated points site within a rectangle. The goal is to determine the location of a red dot which has the minimum distance of all the connections. In this example, the coordinates of the red dot are the main parameters, and the total number of all the connections' length is the fitness. After several iterations, the evolutionary solver can yield the best solution.

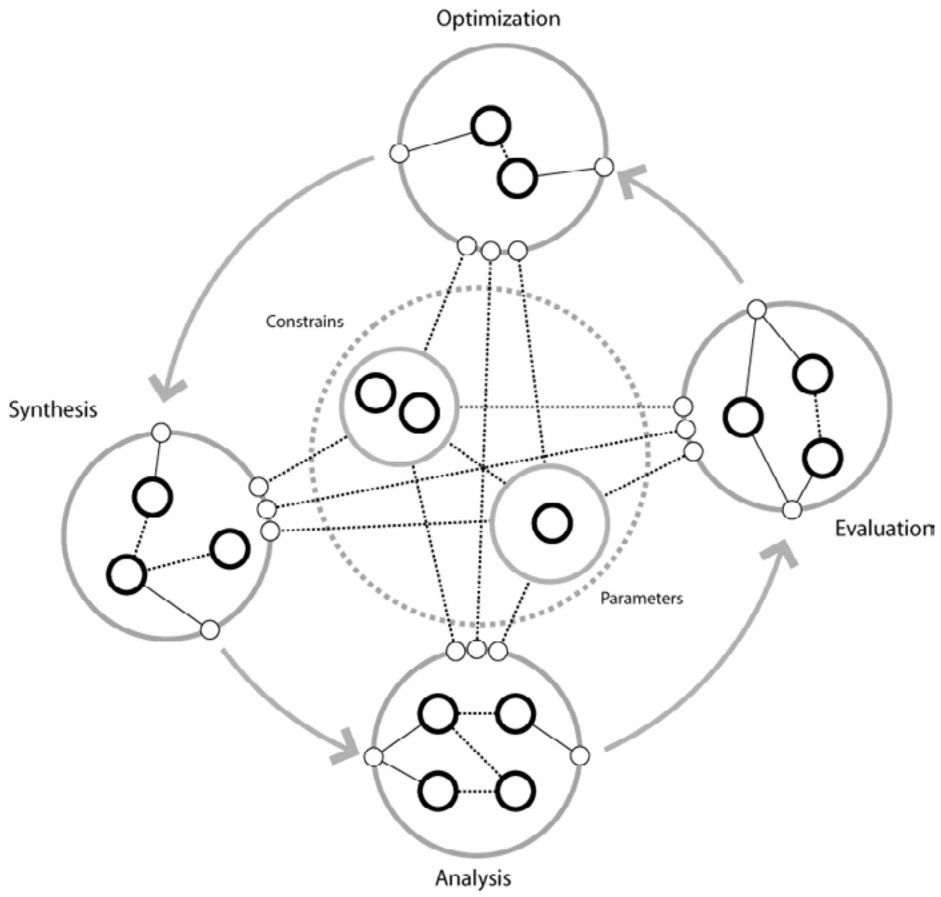


Figure 15. Diagram of generative multi-performance design system
Source: Alfaris, A., & Merello, R. (2008). The generative multi-performance design system.

Methodology:
This project is aiming to have an empirical understanding about how to integrate CE in urban planning. At the first couple of months, the author had a hypothesis that the Polycentric Urban Structure is a perfect spatial layout for implementing CE. Eventually, these two advanced theories would entail a possible framework for building eco-city. However, that questionable assumption needs several concrete proofs.

This project followed the road of 'The quantitative revolution', which was an attempt made in the 1950s by the new generation of urbanists to transform the 'soft' descriptive study of cities into a 'hard' analytical science(Burton, 1963). Similarly, this research started with a non-geographic-based model. The reason for doing this is the complexity of city will increase the difficulty of modelling. By contrast, an abstract model is concise and more accessible to understand the underlying mechanism. For further research, this abstract model possesses the ability for providing empirical insights of urban planning by inputting the geographic information. In this project, forming an abstract model is the primary work.

Although this experimental model starts from an imaginary metropolis within a territory of square shape, there are three major barriers. First, how to simulate the urban fabric based on the various properties inherit from different types of spatial structure, namely, monocentric and polycentric, requires proper consideration. The second problem is to distribute the CE-related facilities in the previous generated urban fabric. The last task is trickiest and vital, which is to assess the performance of aforementioned works and optimises the outcome based on the feedback.

The main parametric modelling technique of this project is based on 'A framework for an integrated computational design system' from Anas Alfaris and Riccardo Merello(Figure 15). Their generative multi-performance design system builds on the strengths inherent in both generative synthesis models and multi-performance analysis and optimisation (Alfaris & Merello, 2008).

Sharing the same philosophy with system thinking, the process of forming this model begins with a top-down decomposition. First, generate a basic grid as the imaginary metropolis. Second, simulate the land price and density based on the knowledge from the literature review of spatial structure. Then, generate the corresponding urban spatial layout for different types of structure. Next, distribute the same amount of household into this metropolis. At this stage, the work of spatial configuration is completed. Next step is to distribute CE-related facilities and evaluate the performance of each attempt. Within this procedure, different disciplines are decomposed into modules that simulate the respective mechanisms. The result of evaluation will affect the parameters and then be altering the way of facility distribution. All the modules in this experimental model are connected to a data flow network that includes clusters and subsystems. Finally, this integrated system acts as a holistic structured functional unit that searches the optimum of satisfactory solutions.

All of those empirical data will lead to the conclusion of this project. Figure 16 shows the whole workflow.

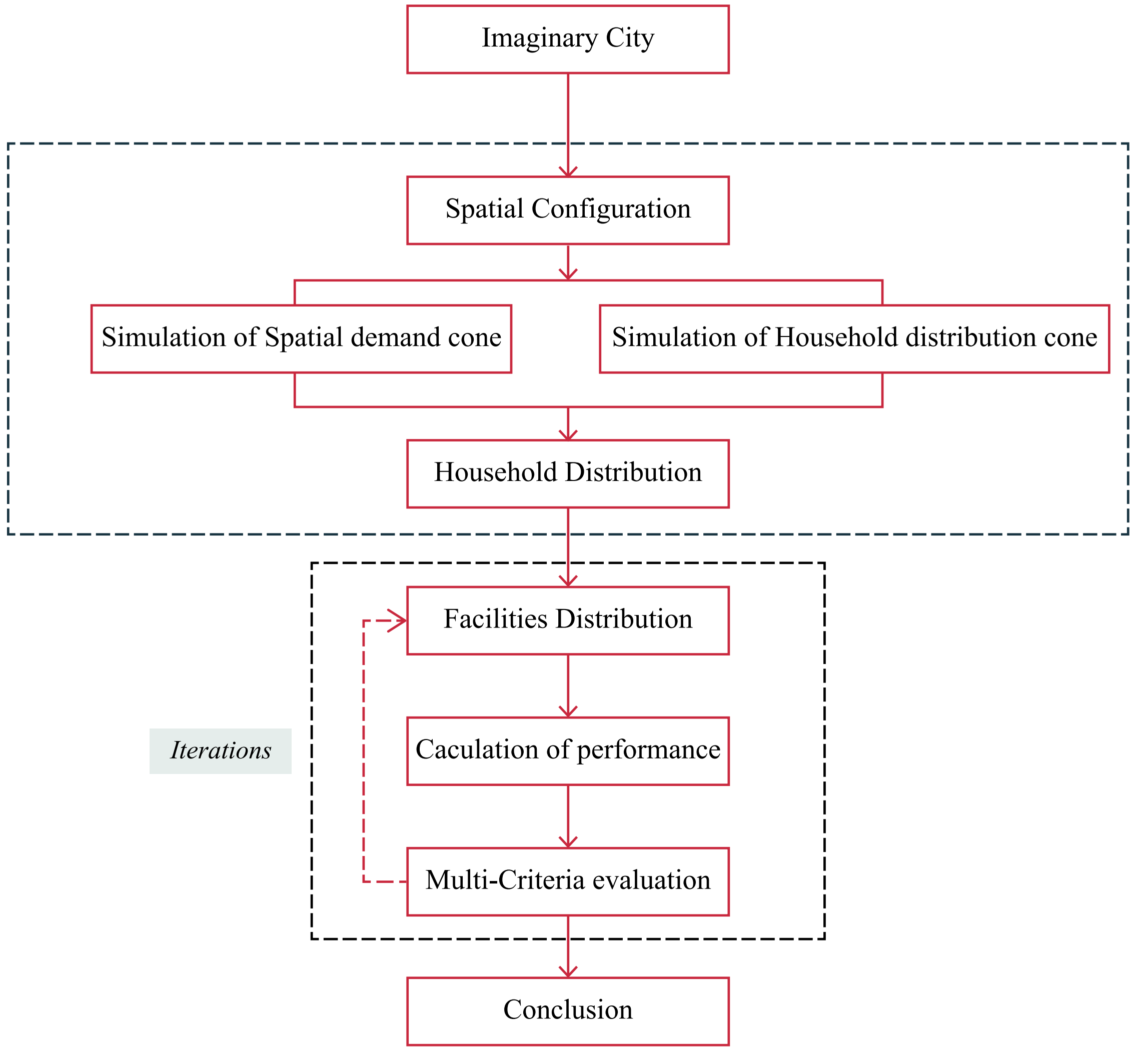


Figure 16. Methodology of the graduation project (Made by author)

01.8 RELEVANCE :

1. Social relevance:

The motivation of this project is a social problem which is the massive migration during the spring festival in China. This problem revealed the situation of the imbalanced regional development. In the introduction part, the reason for the side effects of rapid urbanisation and the related solutions launched by the Chinese government has been introduced. The ultimate objective of all the actions in China is to achieve the eco-city where can provide harmonious society and maintain economic prosperity without compromising the mother nature. This graduation project inherits the same objective in a broader scope of perspective.

From the estimation, the process of urbanisation in China will not stop in 50 years. As the shrinkage of resources and increase of the population, the social problem will strongly influence the national security and cohesion. The circular economy provides an alternative economic model to minimise the threats of environmental contamination and resources depletion.

In China, the industrial symbiosis is the major represents of CE, and this industrial transformation has already made a significant achievement. The eco-city project will not only focus on the industrial sectors, but the daily consumption from citizens is also essential. This will need the awareness of the importance of protecting the environment and the change in citizens' behaviour. Therefore, this research has a direct impact on society. To some extent, the outcome of this project will contribute to social harmony in China and increase the cohesion.

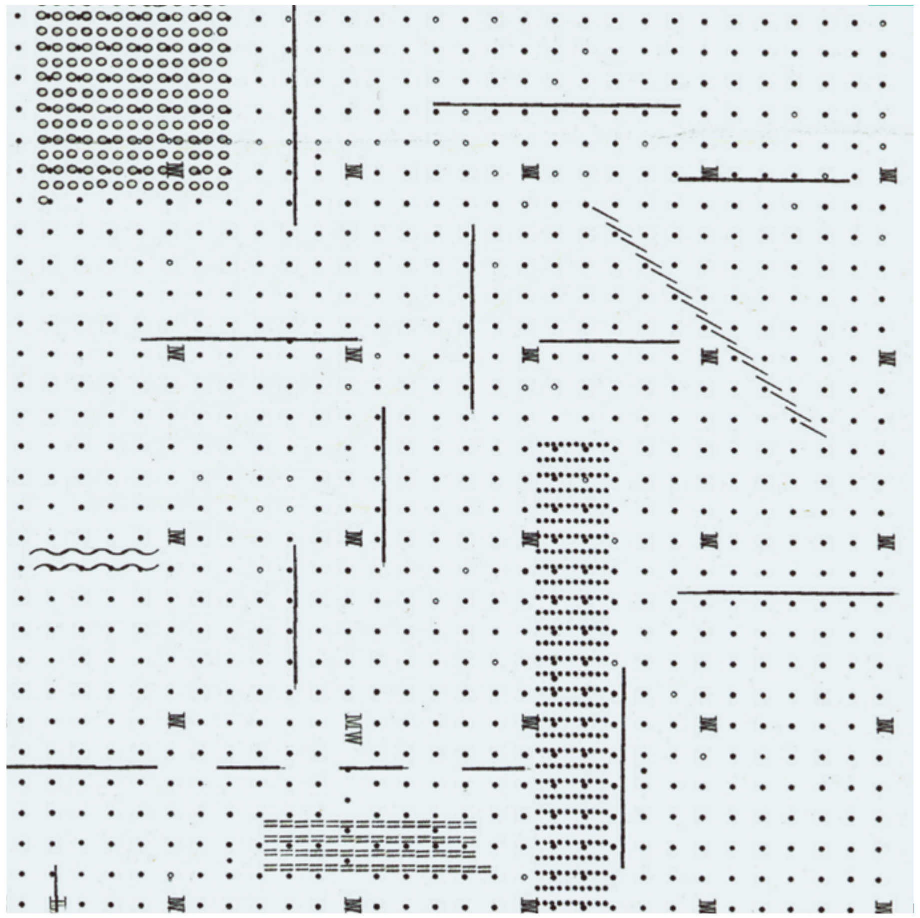
2. Scientific relevance:

Most of the researchers about CE are talking about the principles, flows, and interventions while lots of scholars who are the experts in urban planning focus on the structure, function, and land use. However, the combination of CE and spatial structure such as 'polycentric urban region' may become a feasible approach for achieving the smart urbanisation. Therefore, this project may contribute to the planning department of China for future development by finding the joint of two essential theories.

The core theoretical foundation for this project is the 'location theory'. During the quantitative revolution in the 1950s, a group of urbanists have revolutionised the urbanism field by adopting location theory from the economic model into geographic context. That was the start point of transforming the study of cities from soft description to hard analytical science. This project follows the spirits of quantitative revolution and is trying to make a model based on the empirical statistics. The outcome of this project could provide insight into the relationship between land-use planning, spatial network and the principle of CE. Eventually, general strategies and conception can be materialised in the layout of urban planning.

Also, the methodology of this project is pretty innovative. 'Generative design' is more popular in architecture design regard with the form finding. Applying this method in urban structure study is still rare. The outcome shows that this method and the whole workflow is efficient and effective. It has the potential to facilitate future researches.

02
LITERATURE REVIEW



02.1 SUMMARIES OF THEORIES

This section is about the review of various theories supporting this project. The first one is the concept of sustainability, which is the ultimate objective for China's government regarding the future development. The second one is the theory about Circular Economy, which is the alternative model of the linear economy to maintain the value of products, materials, and resources as long as possible and reduce the waste significantly. The third one is Polycentric Urban Structure, which is a significant framework for current urban planning in most developed countries and is the theoretical foundation for the Coordinated Development in China. Following is the 'location theory', which provide the theoretical foundation for this project.

1. Sustainability

During last two decades, the Chinese governments and scholars have presented several policies and concepts as the guidelines or blueprints for the future of this nation, such as 'ecological civilisation', 'scientific outlook on development', 'harmonious society' and so on. Above all, there is an ultimate aim, which is achieving the sustainable development. In this vision, citizens of China can enjoy the better social cohesion, environmental resilience and economic prosperity. Therefore, having some understanding and insights of sustainability is essential to this research.

The term 'sustainability' originates from the French verb 'soutenir', which means to hold up or support(Brown, Hanson, Liverman, & Merideth, 1987). Gradually, the mean of this term was transferred to the field of ecology, which imply the principle of respecting the ability of nature to regenerate itself. There are tons of definitions and explanations of sustainability. It refers to the situation where human activities are regulated within certain rules to conserve the functions of the earth's ecosystems(Ding, 2008). With the increasing concerns of global environmental risks, more and more countries were seeking a feasible approach to achieve the sustainable development. This situation stimulates a series of international discussions about the complex and dynamically interconnected nature of the environment, society and economy(Kates, Parris, & Leiserowitz, 2005). Later a most commonly accepted definition of sustainability has been presented at the Brundtland Commission. This description described that the development should meet the need of the present without compromising the ability of future generations to meet their own needs(Brundtland, 1987). Since then, the scope of sustainable development widened from environmental concerns to a more overall desirable progress with a variety of expectations. Gradually, the perceptions and regulations on sustainable development became more specific and detailed. Instead of merely setting common goals, it also has many expectations, such as what should be developed and what needs to be sustained, for how long, and for the benefit of whom(Acero & Savaget).

Despite the divergence among many perceptions of sustainable development, all of them reflect the best wish and desire for better future. Based on above understanding, in this paper and for the graduation project, the sustainable development is framed as better social cohesion, environmental resilience and economic prosperity.

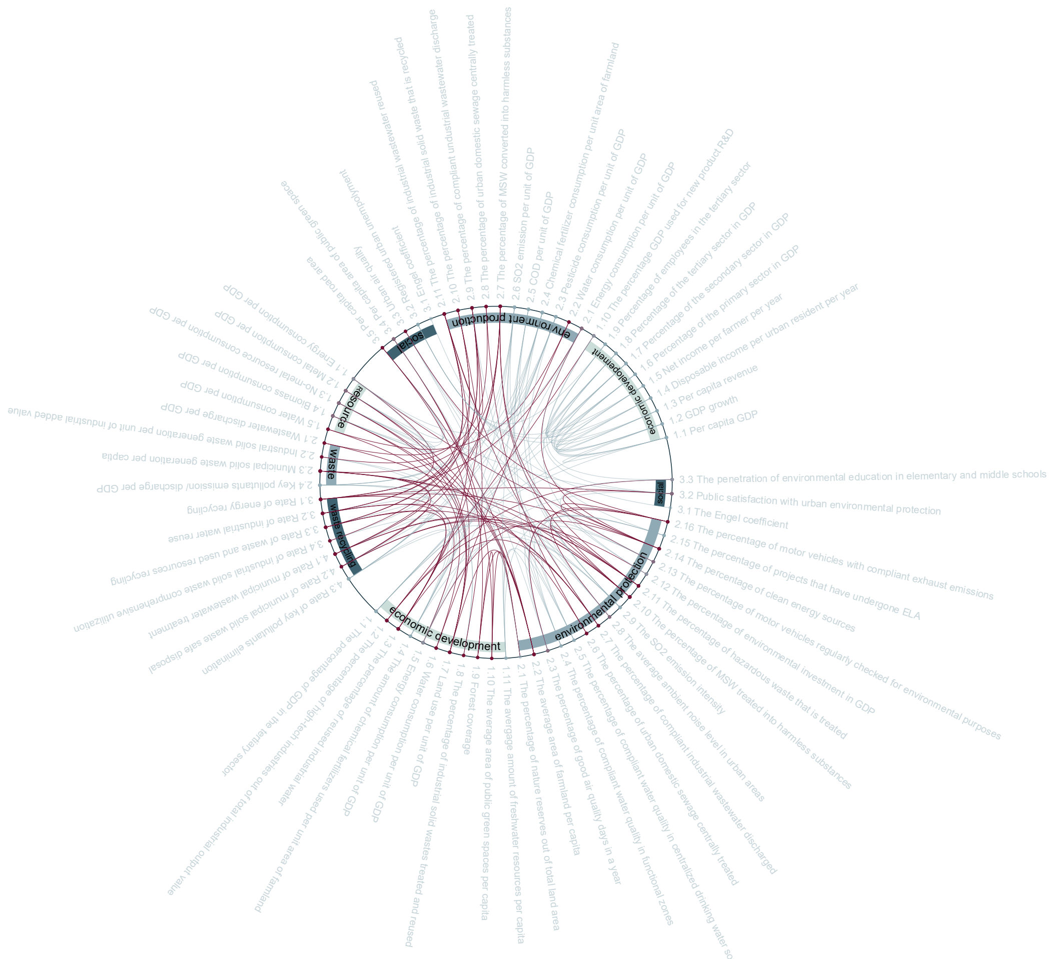


Figure 17 . indicators which have indirect influence on spatial layout

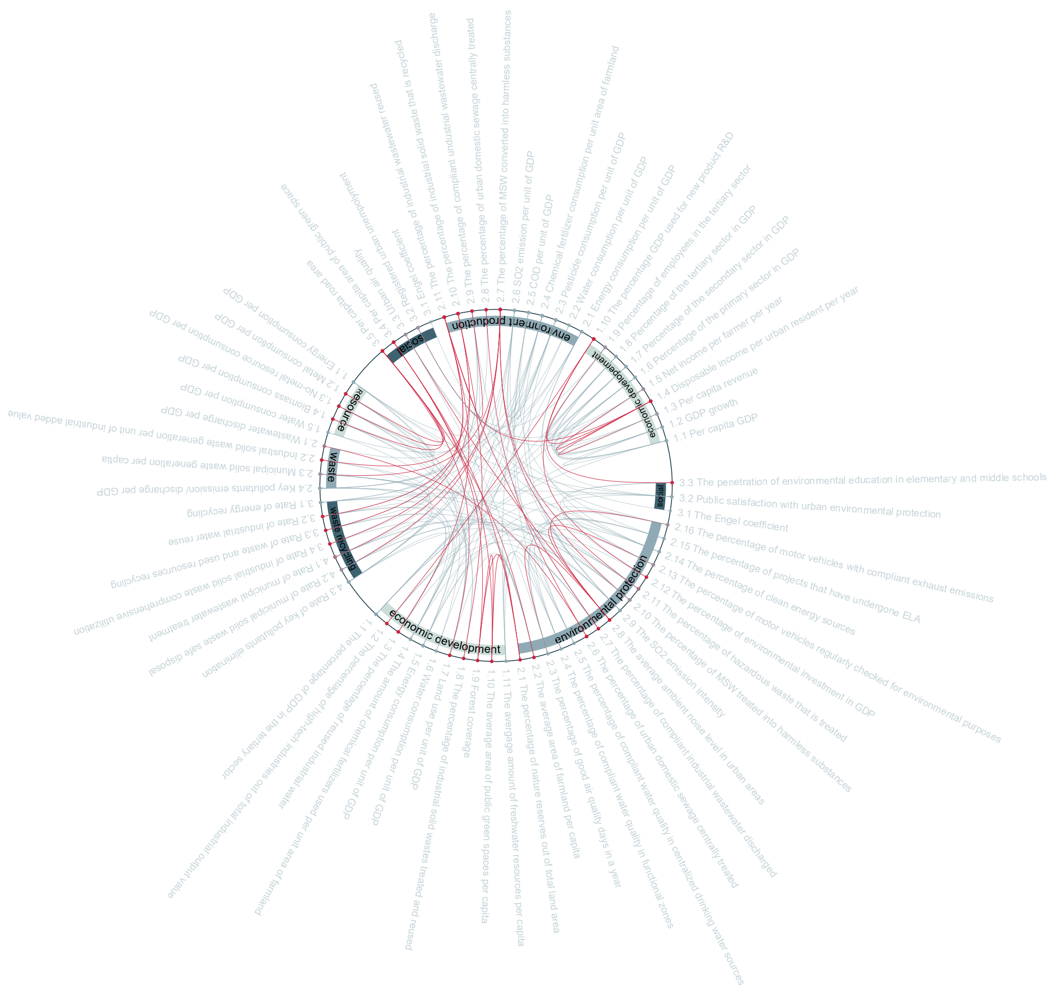
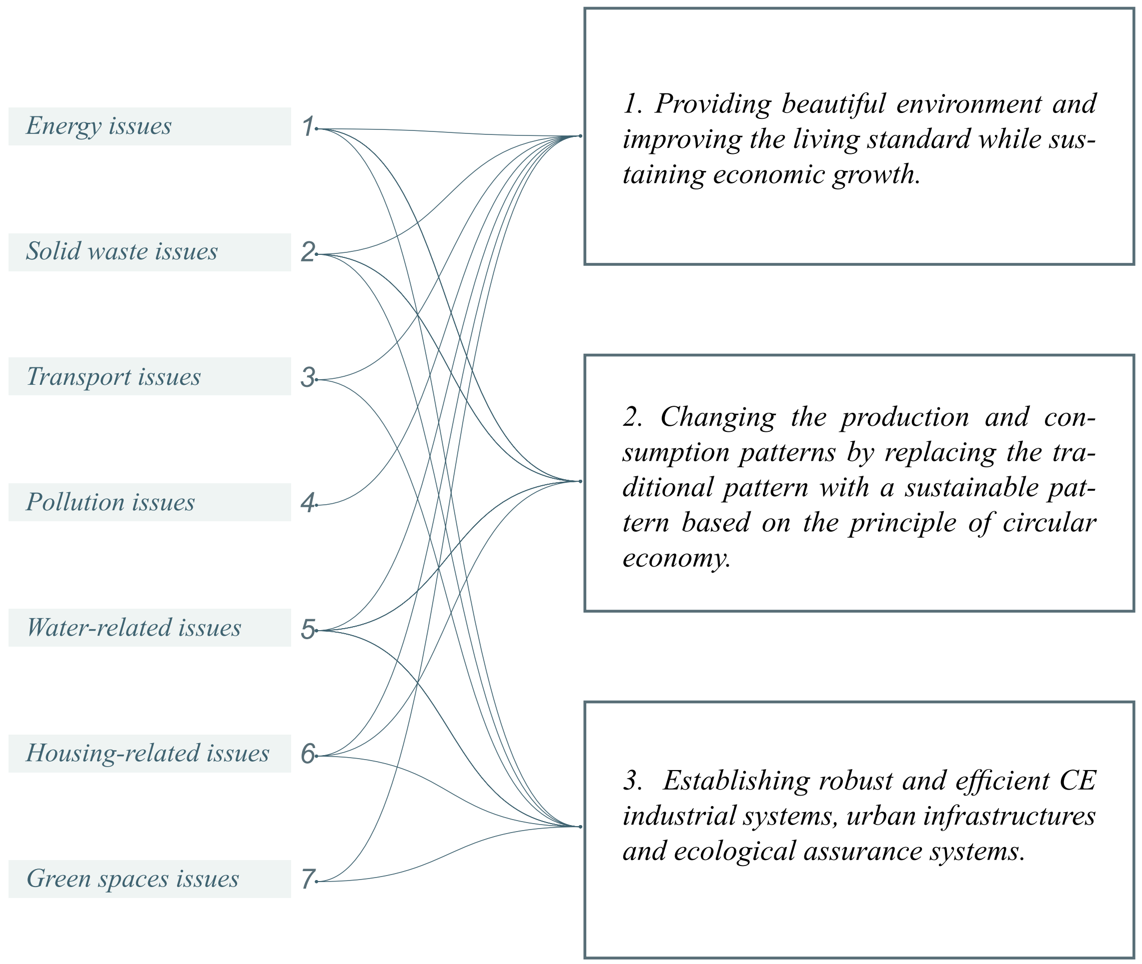


Figure 18 . indicators which have direct influence on spatial layout

The principles of CE-based eco-city



Because there are several evaluation systems published by different institutions and tons of indicators from various literature, how to choose them is the most challenging question. Among them, many indicators may have unique terms, but they actually are saying the same issue. Therefore, conducting an elemental analysis of those evaluation systems is crucial. Diagrams in left page show the interrelationship between all the indicators listed in several kinds of literature and government documents. These analyses lead to the principles of CE-based eco-city.

2. Circular Economy

The concept of CE has been drawing world's attention since the late 1970s(MacArthur, 2013). Stahel and Reday introduced several notions about CE with a focus on industrial economics. They abstract a loop economy to describe the strategies for waste prevention, regional job creation, resource efficiency and dematerialisation of the industrial economy(W. Stahel & Reday, 1976). Later, Stahel presented that selling utilisation instead of ownership of products is the most sustainable business model for a loop economy(W. R. Stahel, 1982), which has a fundamental influence on current approaches of CE in practices.

The contemporary perception of CE has evolved to integrate various concepts that share the idea of closed loops. Some of the most influential theories are cradle-to-cradle(McDonough & Braungart, 2010), ecological laws(Commoner, 2014), regenerative design(Lyle, 1996), industrial ecology(Graedel & Allenby, 1995), and the blue economy(Pauli, 2010). The most famous definition of CE is from the Ellen MacArthur Foundation, where they perceive CE as 'an industrial economy that is restorative or regenerative by intention and design'(MacArthur, 2013). Based on the various literature, we see CE as the alternative model for the linear economy, because CE provides a regenerative system in which resource input and waste, the emission during production, the leakage of energy are minimised by closing the material and energy loops. Therefore, the value of products, materials, and resources is maintained for as long as possible, and waste is significantly reduced or even eliminated'(Herrschel & Newman, 2003). Besides, the circular economy is not a pure product or service that any single institution and company can do alone. The circular economy requires cooperation and thereby fostering connections across individual stakeholders and sectors. Therefore, the contribution of CE does not limit with the environmental and economic aspects; it could improve the social cohesion as well.

To project the benefits into environment, economy, and society, CE would lessen the environmental impact, creating new opportunities for growth and innovation and creating more jobs across various skill levels(Herrschel & Newman, 2003).

However, the most significant achievement of CE is still within Europe where most developed countries are located, because the transition from linear to the circular economy has high requirements. For instance, advanced technology, sufficient initial investment and efficient policies. Therefore, applying the CE in the process of urbanisation in the western area of China is quite tricky. However, China might be capturing the latecomer advantages through its systematic promotion of eco-industries initiatives within a circular economy framework.

3. Polycentric Urban Structure

Metropolis both in developed and in less developed countries have expanded rapidly in economic strength, built-up area, and population/ labour force(Han, 2005). Both public and private sectors have invested substantial amounts of money in establishing suburban centres, new residential communities, services and amenities, highways, and other infrastructure. The immigrants and various type of business play crucial role in redistributing or reshape the urban fabric. As results, several features appeared increasingly, such as interdependent economies, joint labour markets and shared infrastructures. Along with this trend, the notion of Polycentric Urban Region Structure (PURs) has been the hot topic in urban planning for a long time and always compared with its counterpart, the monocentric structure.

The broad idea is that PURs can develop new sources of competitive advantage and to market better city region(E. Meijers, 2008). Because of their specific spatial structure, PURs have the potential to enjoy economic development similar to their monocentric counterparts without incurring the same cost or 'agglomeration shadow'(Cardoso & Meijers, 2017). Besides, the concept of 'borrowed size' is another trend for urban planning. This trend refers to the situation where smaller cities located within larger metropolitan complexes do perform more favourably due to their access to the agglomeration benefits of larger neighbouring cities(E. J. Meijers & Burger, 2016). Both of those two theories emphasise the importance of significant agglomeration where the highest-valued economic activities and cultural functions are found. The difference is how to connect to that vast agglomeration. However, both methods could alleviate the pressure of central city and other side effects of developed urban areas.

To be summarised, the polycentric urban structure is a more advanced model for future development and urban expansion compared to the city sprawls and monocentric structure. The more efficient network of infrastructures and more even distribution of amenities contribute a lot to mitigating the pressure of central city and reducing the disparities as well. The more intensive and efficient land-use planning can alleviate the shortage of resource. That is the rationale that Chinese government has designated PURs as the primary principles for the future urban planning after several large coastal cities such as Beijing, Shanghai, and Guangzhou have experienced rapid polycentric urban development(Yue, Liu, & Fan, 2010).

4. Location theory

A book called 'complexity, cognition and the city' gives a systematic introduction of most profounding theories associated with urban planning. In the second chapter, the author introduces how the urbanist perceives and scientifically model the city. In the 1950s, a group of new generation urbanists were urged to find a better way to describe the city instead of subjective feelings. They started the great quantitative revolution. During this movement, they adopted the location theory from 'spaceless' economic models into geographic context, which could be used to explain settlement patterns. Since then, many urbanists were following this road to elaborate the theory of cities and settlements. The description model became complicated by involving more elements to consideration. This section will introduce several important theories and models.

4.1 Thunen's Isolated State

The author imagined a large town at the centre of a fertile plain. A non-navigable river is cross this plain. Throughout the plain, the soil has the same fertility, while the plain is surrendered by uncultivable wilderness far from the town. Besides, the uncultivated land cuts off all the communication between the town and the outside world.

Therefore, the central town must supply the rural area with all manufactured products, and in return, it will obtain all its provision from the surrounding countryside. The problem the author wanted to solve is this: what pattern of cultivation will take shape in these conditions, and how will the farming system of various areas be affected by their distance from the central town?

From the economic perspective, the answer is obvious. Those products, which have a strong correlation between distance and value will be grown near the town. With increasing distance from the town, the land will progressively be given up to products cheap to transport in relation to their value. For this reason, concentric rings with its particular staple product will be formed.

4.2 The 'Isolated City'

Thunen's type urban land-use system has been transformed from the verbal model into a visible diagrammatic model. Businesses are prepared to pay high rent at the centre of the city, but are reluctant to "live" far from it. Their spatial demand curves (or RBC – rent-bid curves) are thus the highest and steepest. Industrialists are exactly the opposite and residents are in between: they cannot afford to pay the high prices at the centre but are prepared to live far from it, and so on. Each land use thus occupies a ring where it can pay (bid for) the highest rent.

4.3The Best Location

Alfred Weber was the first to produce an explicit theory of location for its own sake. In the introduction to his dominant work Theory of the Location of Industries(Weber, 1929) he writes the following: "We have a theory of the location of agricultural production by Thunen, . . . However, we do not as yet have any theory of the location of industries . . ." (p 5–6)

Similarly to Thunen, he starts to formulate his theory with an imaginary uniform isolated plain. Then Weber created his locational triangle and illustration of agglomeration.

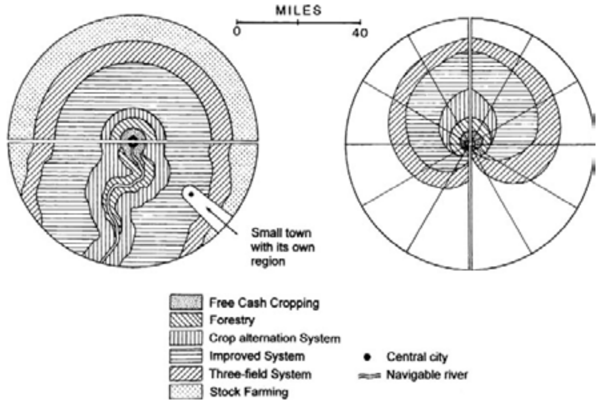


Figure 19 . diagram for 'isolated state' (Hall, introduction to Thunen 1996, XXII)

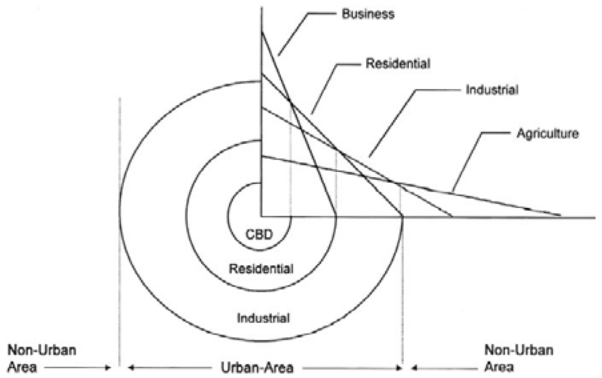


Figure 20 . spatial demand curves(location theory by Alonso (1964))

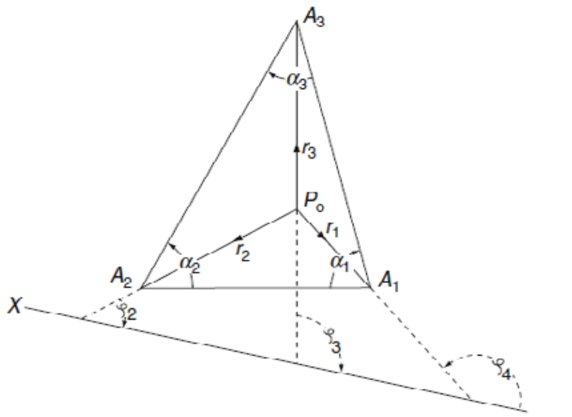


Figure 21 . location triangle
Source: Portugali, J. (2011). Complexity, cognition and the city. Heidelberg: Springer-Verlag Berlin Heidelberg.

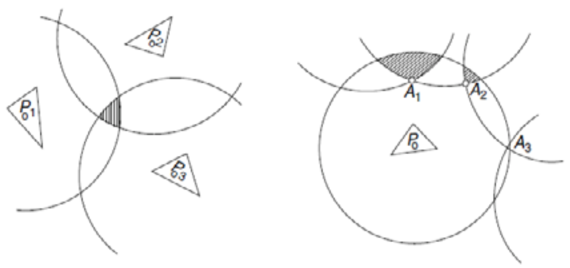


Figure 22 . illustration of agglomeration
Source: Portugali, J. (2011). Complexity, cognition and the city. Heidelberg: Springer-Verlag Berlin Heidelberg.

03
PREPARATION FOR EXPERIMENTAL MODEL

03.1 VITAL FLOW IN URBAN SYMBIOSIS

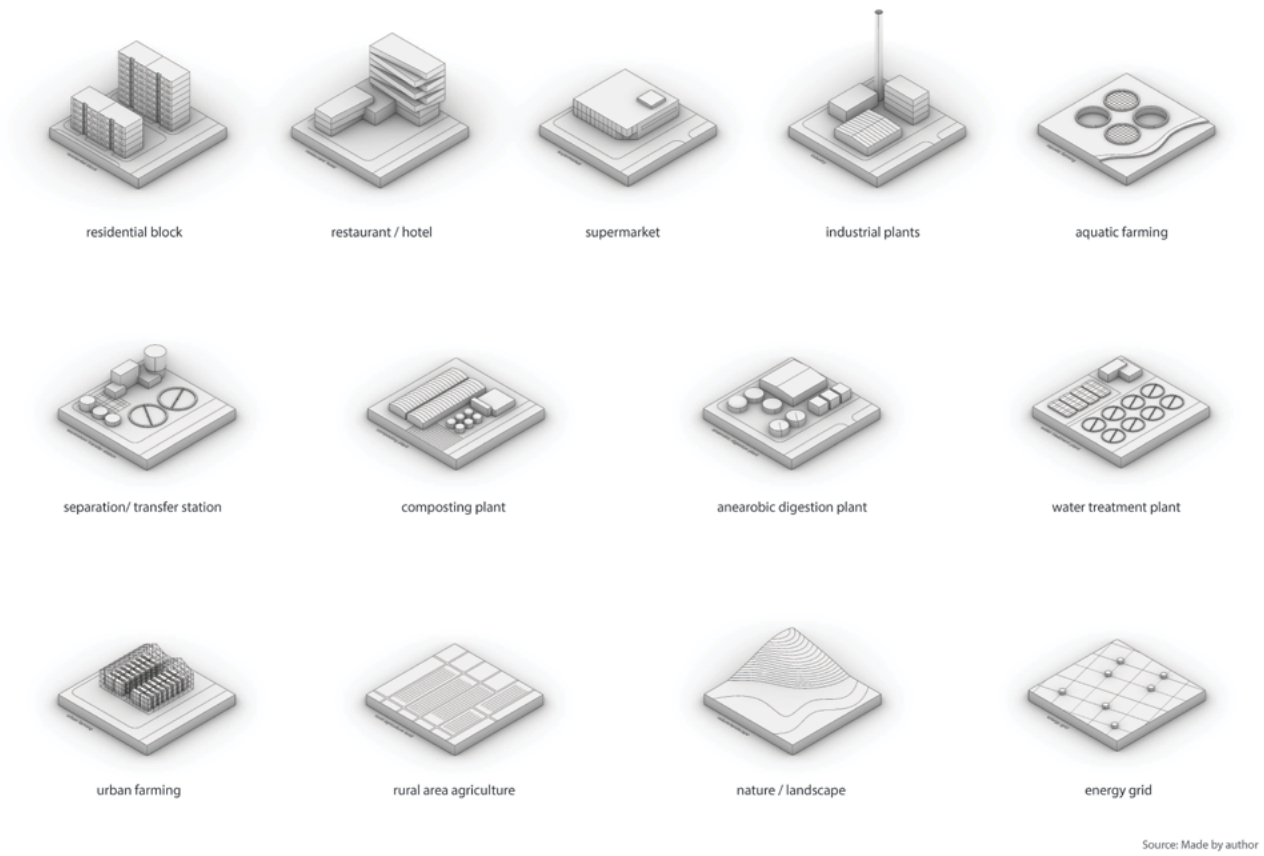


Figure 23. Vital sectors in Urban Symbiosis (Made by author based on literature review)

Urban symbiosis involves designing and operating systems to survive and thrive over time. To understand the urban symbiosis, we must use the approach of System Thinking.

A system is an assemblage of elements or parts that interact in a series of relationships to form a complex whole that serves particular functions or purposes. The theory of system thinking has a profound effect on many fields of study, such as computer science, business, psychology and ecology. The Urban Metabolism is also an offspring of system thinking. Determining the essential elements and their relationships within an urban area is significant in a CE-based eco-city. In the modern world, many systems are open unintentionally, into which materials and resources are consistently brought in from the outside, used in some way, and then released outside the system in some form of waste. By contrast, there are no open systems in nature. Dead animals and decaying matter become food and nutrients for something else, and everything is recycling. The primary mechanism of urban symbiosis is to mimic nature and design closed systems by slowing the passing and using of materials and resources through the system and linking elements to form new symbiosis and functions.

In this project, one crucial step of work is to understand the whole cycle of urban symbiosis, the leading sectors and their relationships. Then the flows of resources and energy could form a quantifiable model to calculate all the inputs and outputs. This evaluation model is essential for further analysis and optimising. Because it provides feedback loops helping explain how system work. This kind of feedback loop is the information flows within a system that allows that system to organise itself.

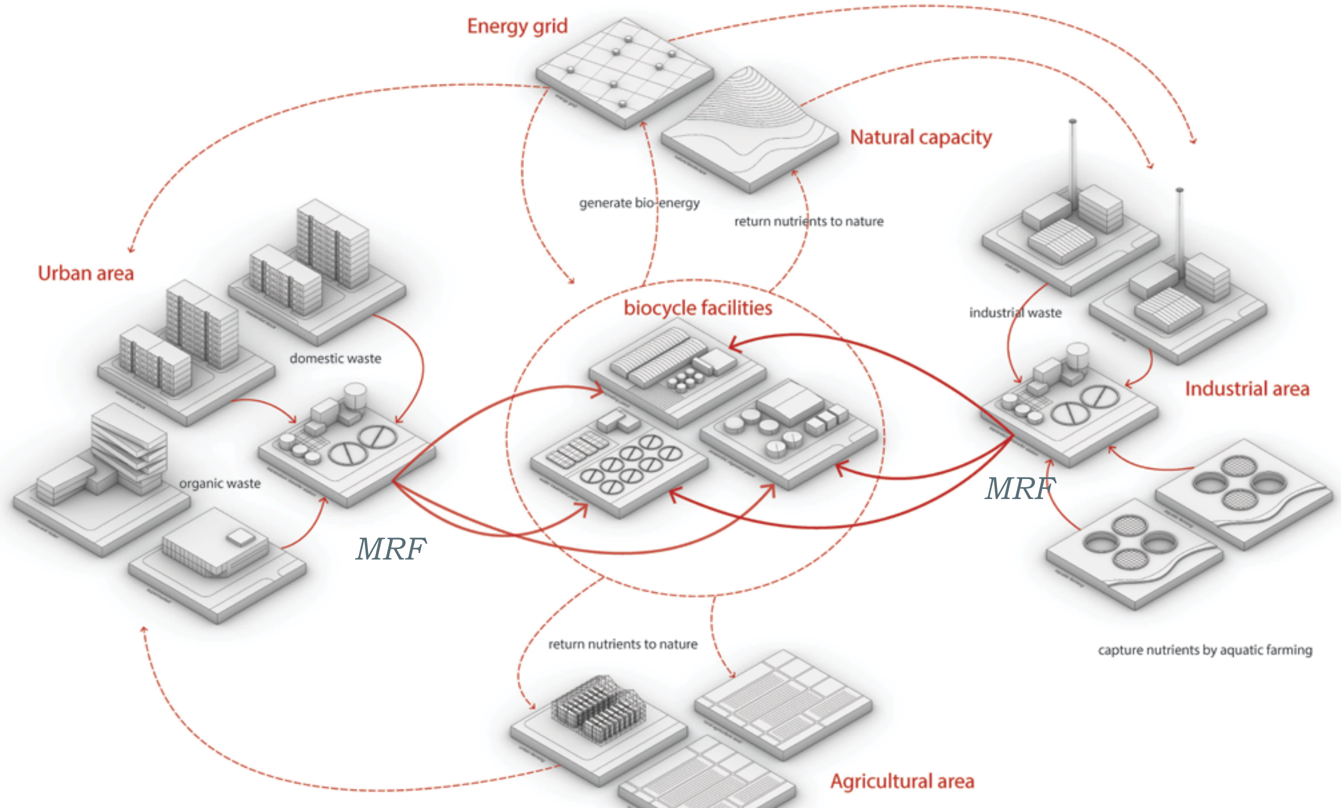


Figure 24. Spatial relationships between major sectors (Made by author based on literature review)

This graph shows the spatial relationship between various urban element when urban symbiosis closes the loop of material and energy flows. It reveals that the material recovery facility (MRF) is the most critical sector to connect the residential blocks with industrial clusters. Therefore, in the following experimental model, MRF is the only CE-related facility for testing. The function of all MRFs is to separate a waste stream into streams of saleable recyclables and a residual stream for final disposal that contains non-recyclable materials and non-recovered recyclables.

However, before all the calculations, this chapter will first list most of the vital sectors in urban symbiosis and abstract their relationship(fig.23). Then, one of the most crucial sector from the perspective of urban planning will be picked as the test item for the following study. This sector is the 'leverage point' in system thinking theory. The leverage point is a small intervention can yield significant changes.

In this project, the Material Recovery Facility(MRF) is the leverage point, because it has a close relationship between both the residential area and the industrial area(fig.24). This facility is also the crucial sector in the whole urban symbiosis chain. It determines how many municipalities solid wastes can be processed. To some extent, MRF decides the recycling ratio.

The graph(fig.25) at next page explicitly demonstrates the flows of urban symbiosis. It also shows the importance of MRFs.

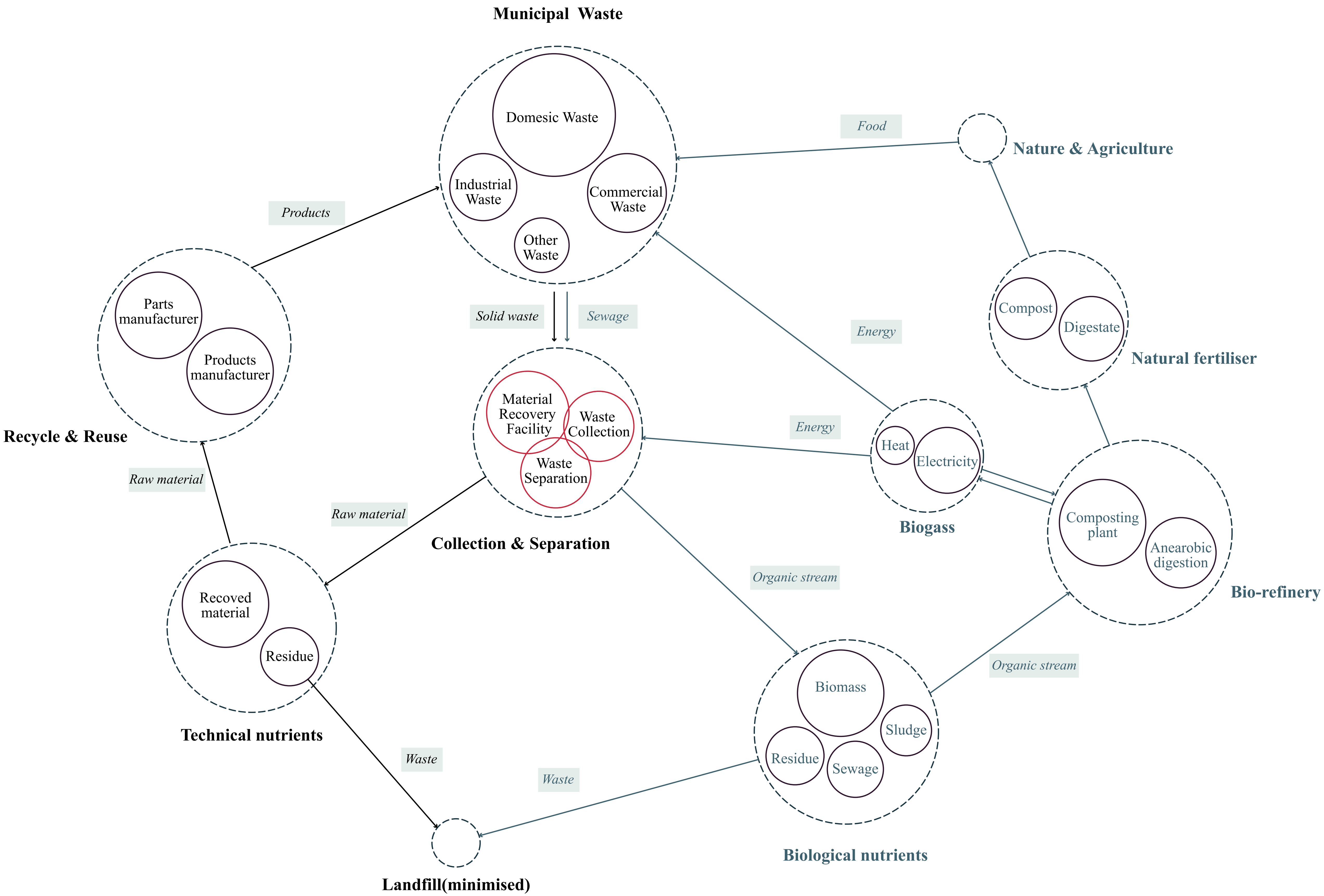


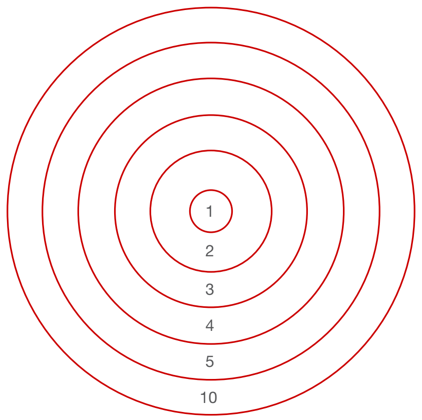
Figure 25. Diagram for Urban Symbiosis (Made by author based on literature review)

03.2 THEORIES OF SPATIAL STRUCTURE

1. Classical theories of spatial organization

Concentric-ring theory

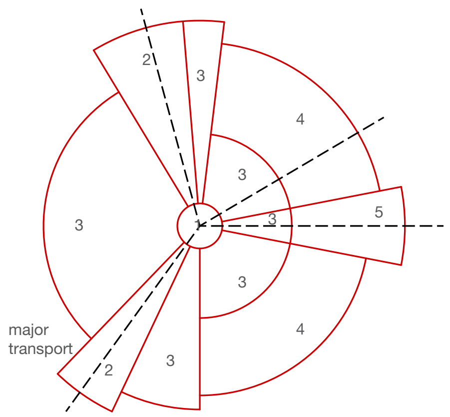
by Burgess (1927)



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

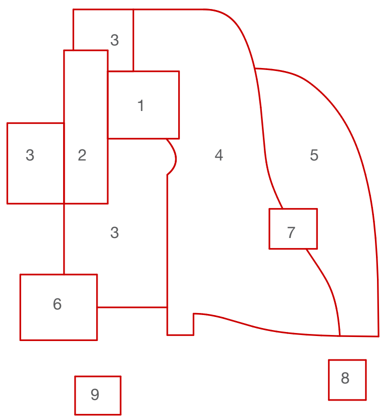
by Hoyt (1939)



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)



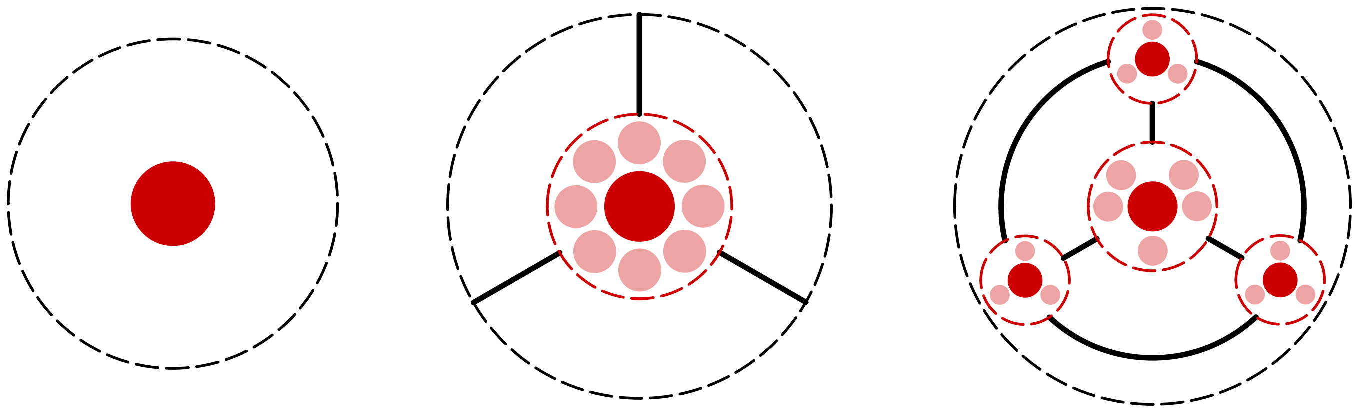
1. central business district (CBD)
2. wholesale light manufacturing
3. low-cost housing
4. medium-cost housing
5. high-cost housing
6. heavy manufacturing
7. outlying business district
8. residential suburb
9. industrial suburb

Those theories were constructed to examine single cities and had their limitations as they do not reflect the current situation of our cities. Therefore, they do not adequately explain the distribution of social activity around urban areas.

2. The Evolution of the Spatial Structure of a City

A: Pre-industrial era | *B: Industrial revolution* | *C: Contemporary era*

Source: Rodrigue, J., Comtois, C., & Slack, B. (2017). The geography of transport systems. London: Routledge.



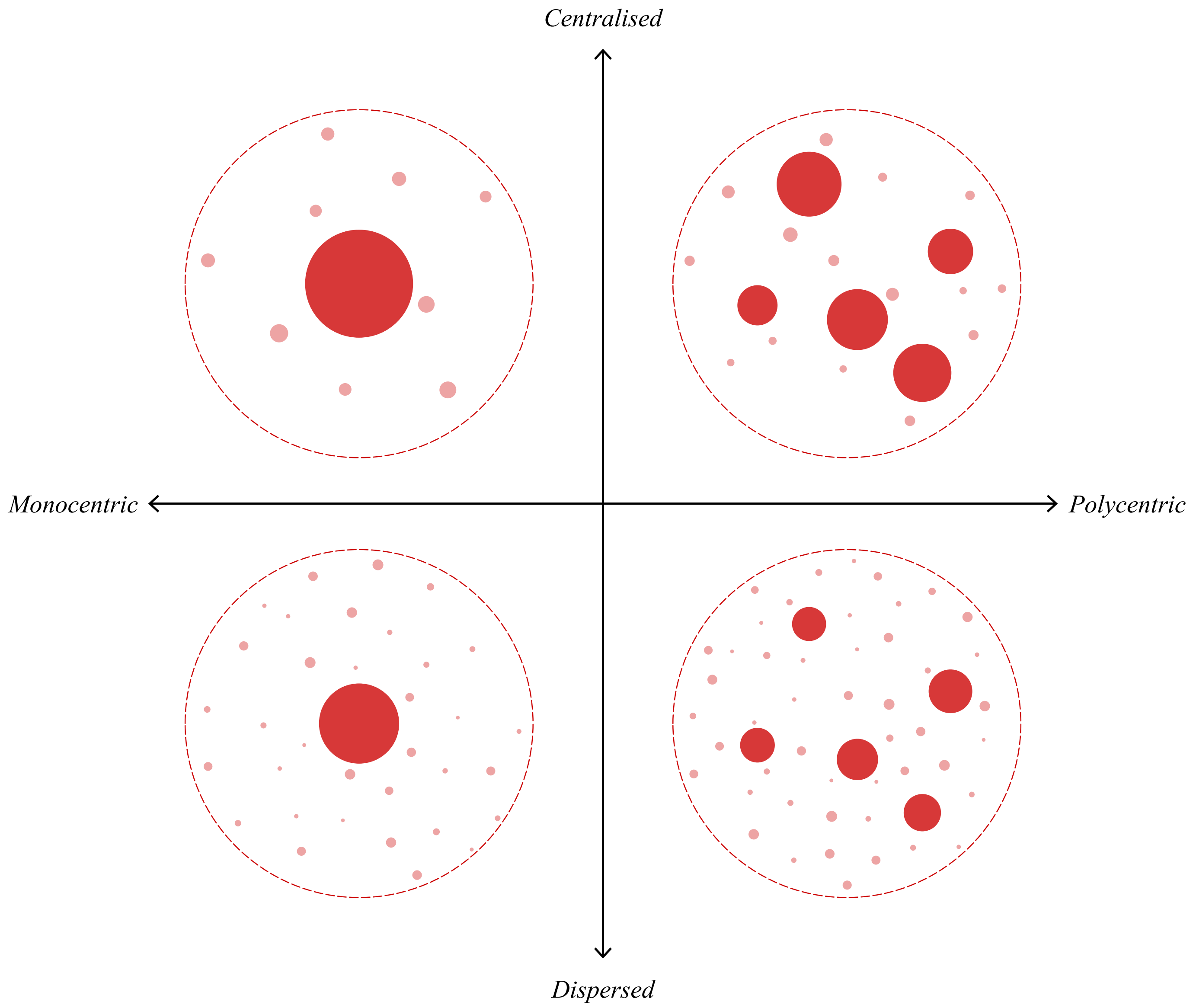
core activities | *core activities* | *major transport route*
central activities | *peripheral area*

A: The CBD was limited to small section of the city generally nearby the waterfront, the market and a site of religious or political importance. These were locations where major transactions took place and thus required financial, insurance, warehousing and wholesale services.

B: Part of the manufacturing located outside the core. Major terminal facilities (ports, railyards) were located in proximity to the city core. As the industrial revolution matured, major transportation axis spurred from the central area towards the periphery.

C: After the Second World War, industries massively relocated away from central areas to suburb, leaving room to the expansion of administrative and financial activities. Because of the increase of rent in the central area and the improvement of road accessibility, new retailing sub-centres emerged in suburban areas to service these new areas. Warehousing and transportation have also relocated to new peripheral sites close to modern terminal facilities.

3. 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.

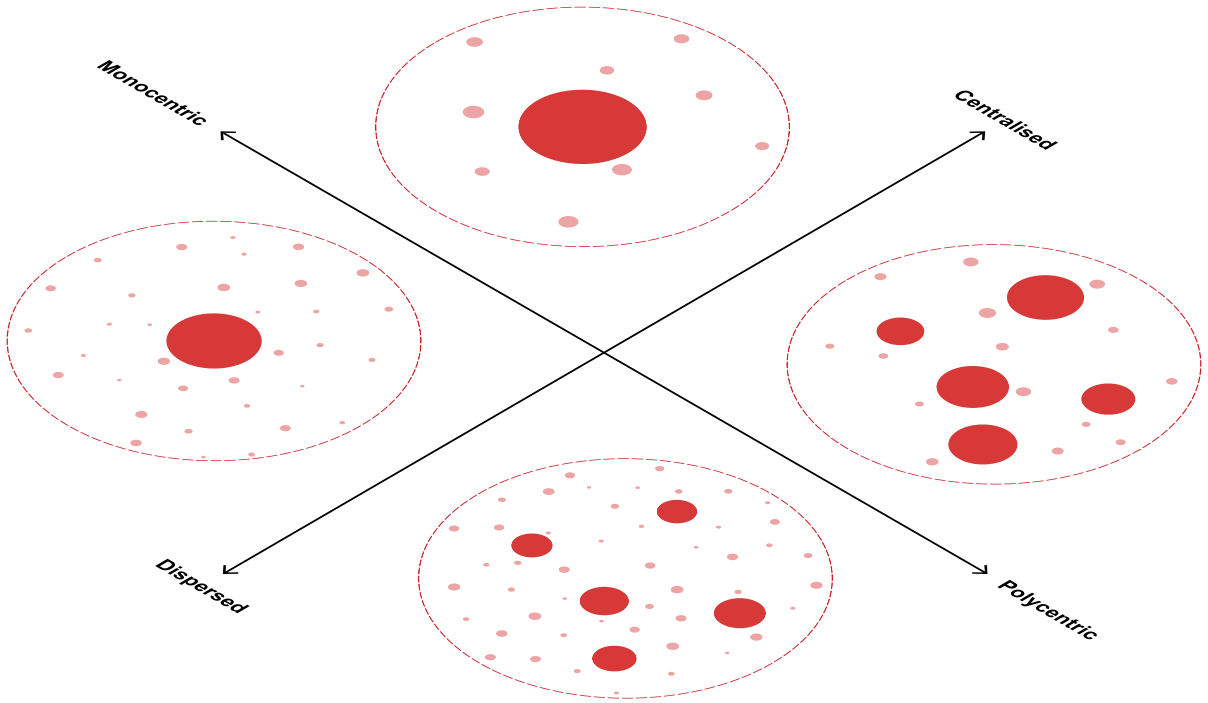
Currently, it is hard to abstract the spatial structure for most of the cities into a single model. Most of them obtained several characteristics both from monocentric and polycentric regional structure through the long-time development. However, each city has its own tendency which can be illustrated in this diagram.

The diagram at previous page shows the dimension of urban form. It summarises various spatial structures into four categories, namely, monocentric centralised, monocentric dispersed, polycentric centralised and polycentric dispersed. Those four types of layout are the foundation of the experimental model. All of the following works are conducted upon those four layouts.

04
ABSTRACT MODEL

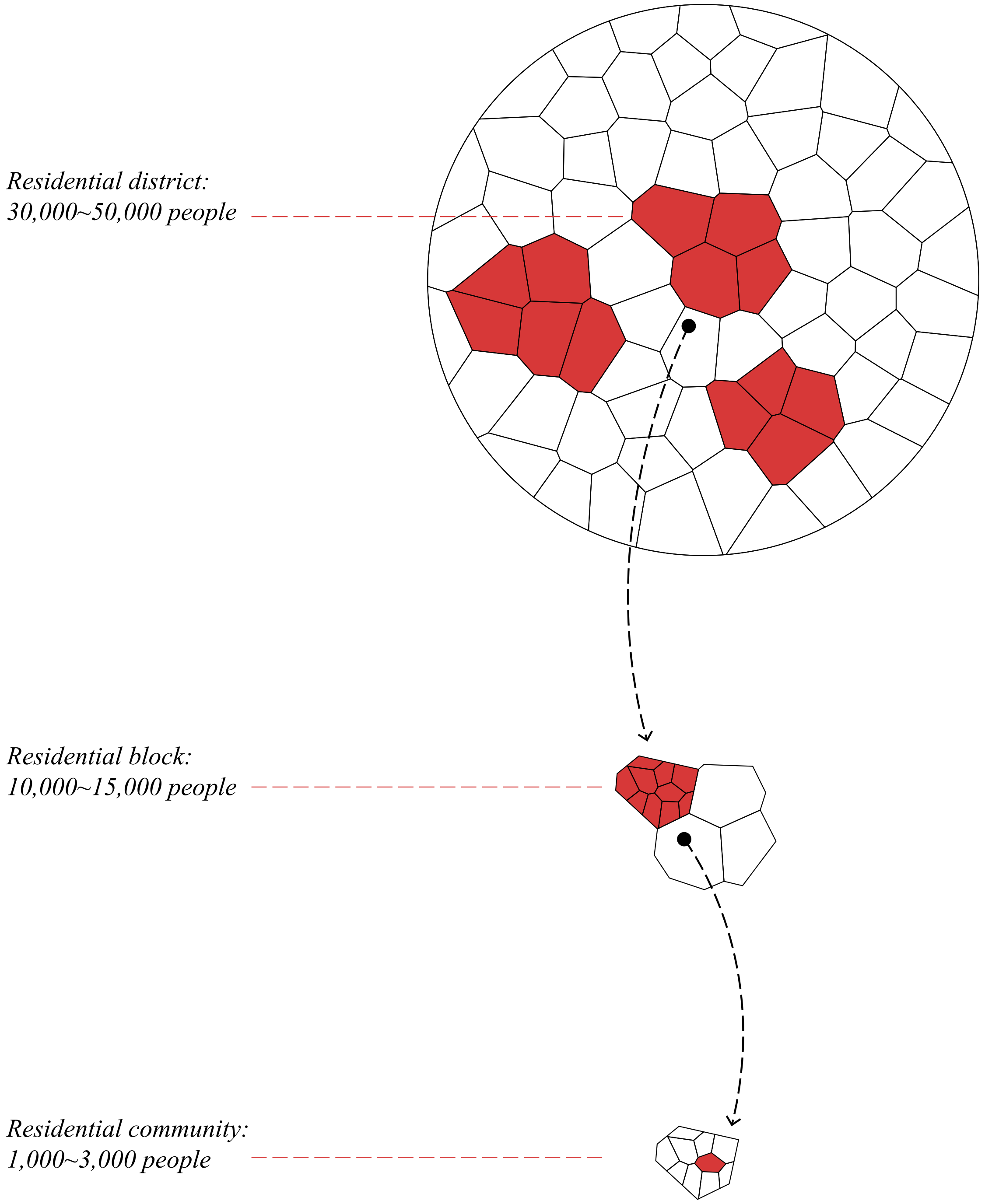
04.1 PREREQUISITE OF MODEL

1. Metropolis with 10 Million people



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

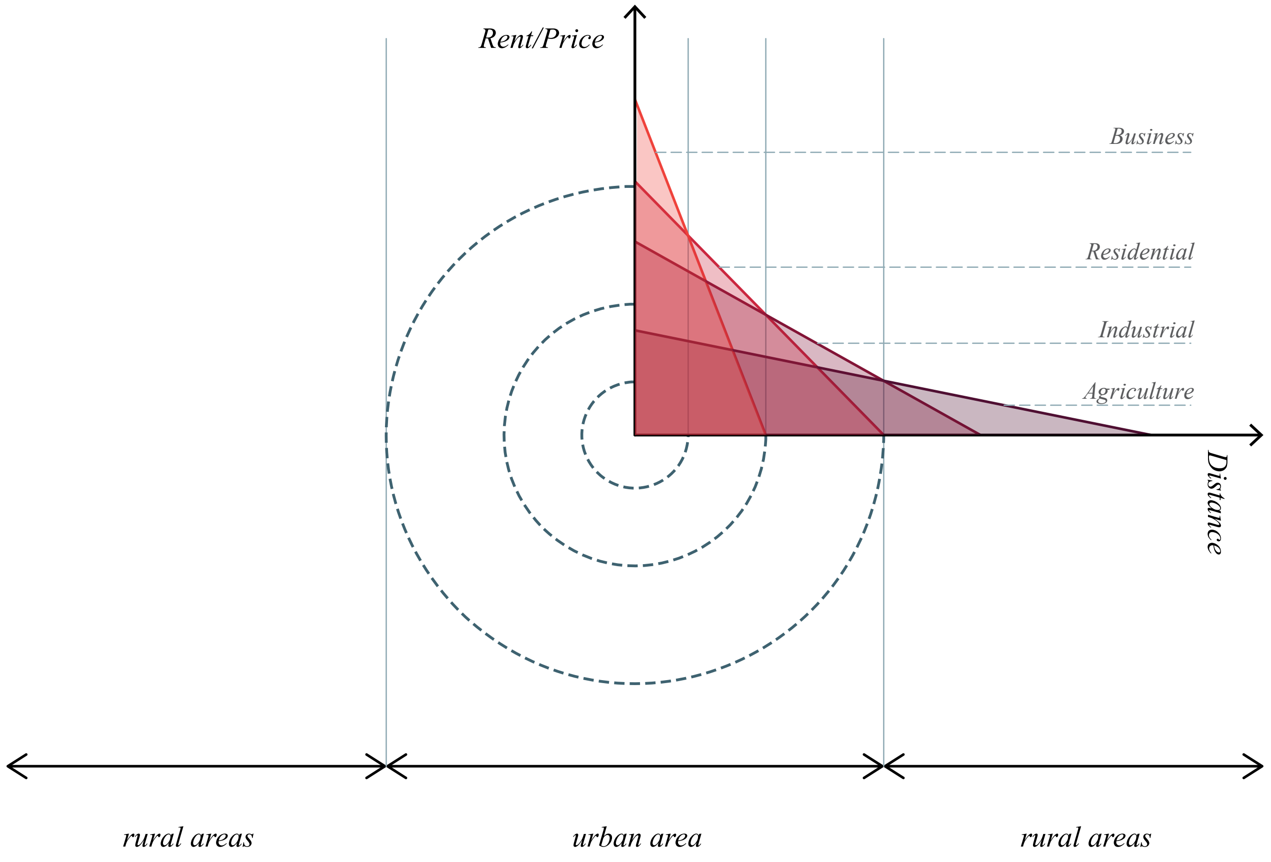
2. Three types of Chinese residential area



In this project, the residential district is used as the unit for distributing 10 million people in the metropolis. To simplify the calculation, I choosed the upper limitation of how many people can a general residential district accommodate, which is 50,000 for each district. At the following part, residential district will be represented by RD.

04.2 SPATIAL DEMAND CONE SIMULATION

1. Density and Land Price: Spatial demand curves

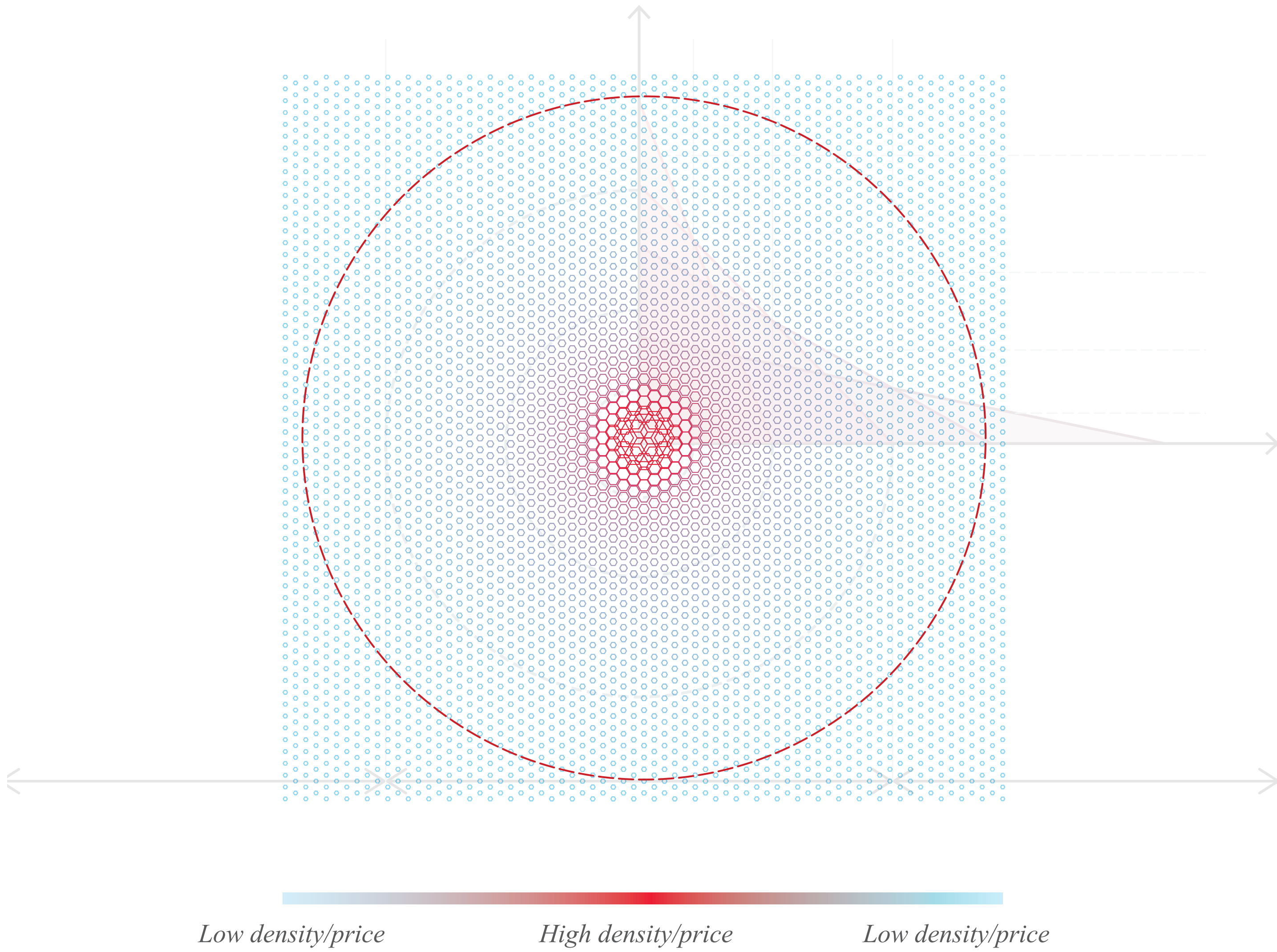


Source: spatial demand curves(Made by author based on the location theory by Alonso (1964))

The graph above shows the spatial demand curve or the rent-bid curves. Businesses are prepared to pay high rent at the centre of the city, but they are reluctant to locate far from it. As for industrial areas, they are the opposite compared by business area. Nevertheless, residential area is in the middle. Each land use, therefore, occupies a ring where they can pay the highest rent. This diagram is a visualisation of 'location theory', which explains the reason for allocation of different land use. Except showing the land price, this diagram also could indicate the density of urban fabric. Because most of the residential districts, commercial districts and offices are relatively near the city centre, the density around the centre is also higher than in surrounding areas.

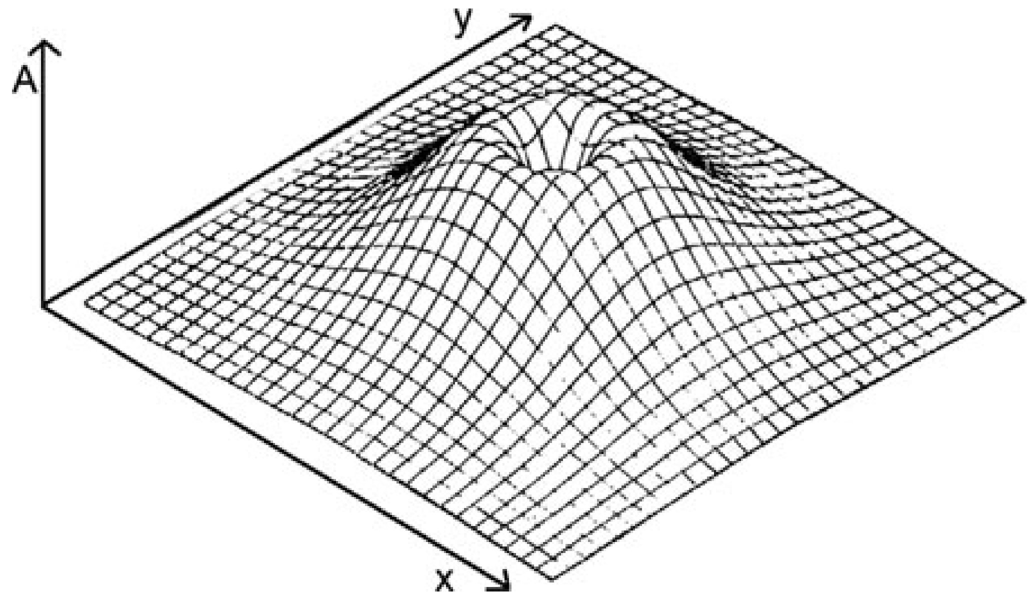
The limitation of this diagram is that it only shows the situation of an urban area with one centre. For polycentric urban structure, this diagram would become more complicated.

2. Magnetic field simulation



The limitation of traditional spatial demand curve could be overcome by using a magnetic field to simulate the influence of city centre. This graph shows the result of a basic simulation. The red colour represents the more substantial strength of influence caused by the city centre.

Theoritical basis : Gravity Cities



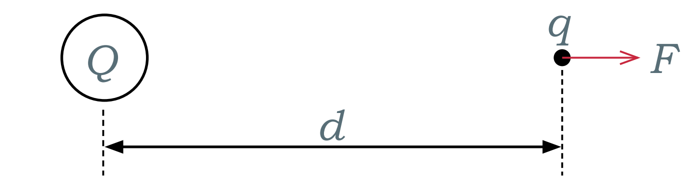
Source: Angel and Hyman (1972)

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



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

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

$$F = \frac{kqQ}{d^2}$$

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

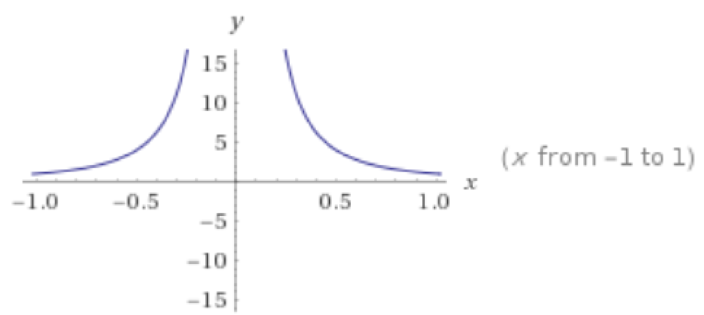
where d=separation distance between charges (meters)

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

kQ ⇢ *Influence power of urban centre*

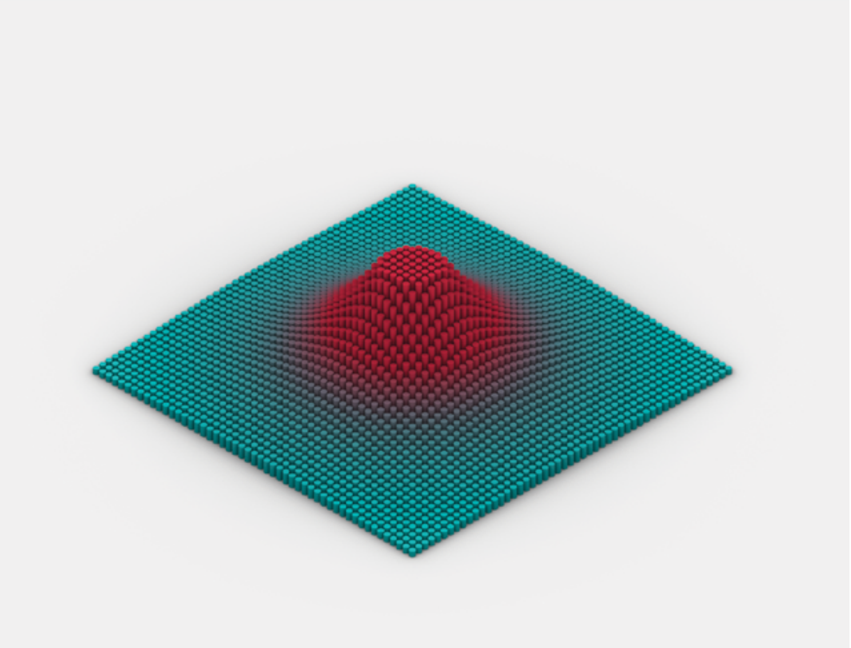
d^2 ⇢ *Distance to urban centre*

An inverse square law

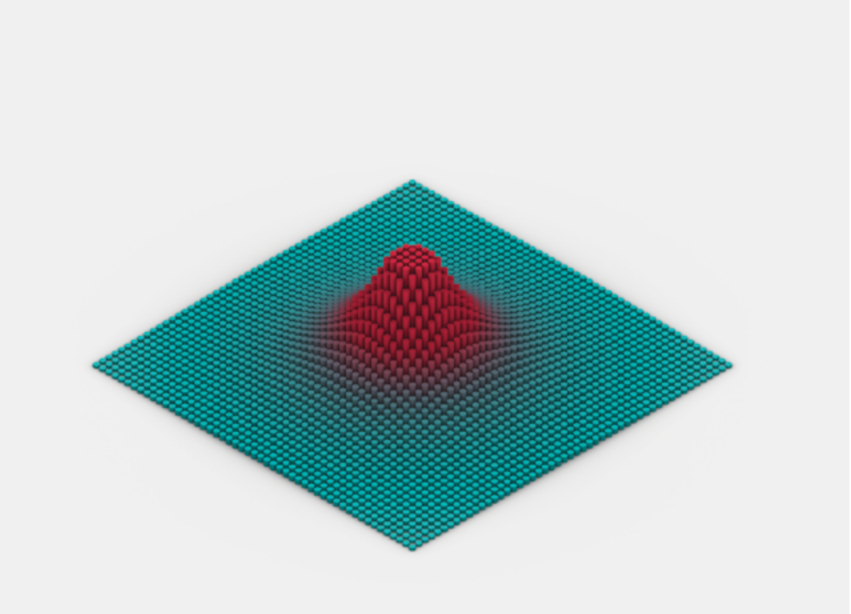


Source:http://www.wolframalpha.com/input/?i=y%3D1%2Fx%5E2

3. Results of megnatic field simulation

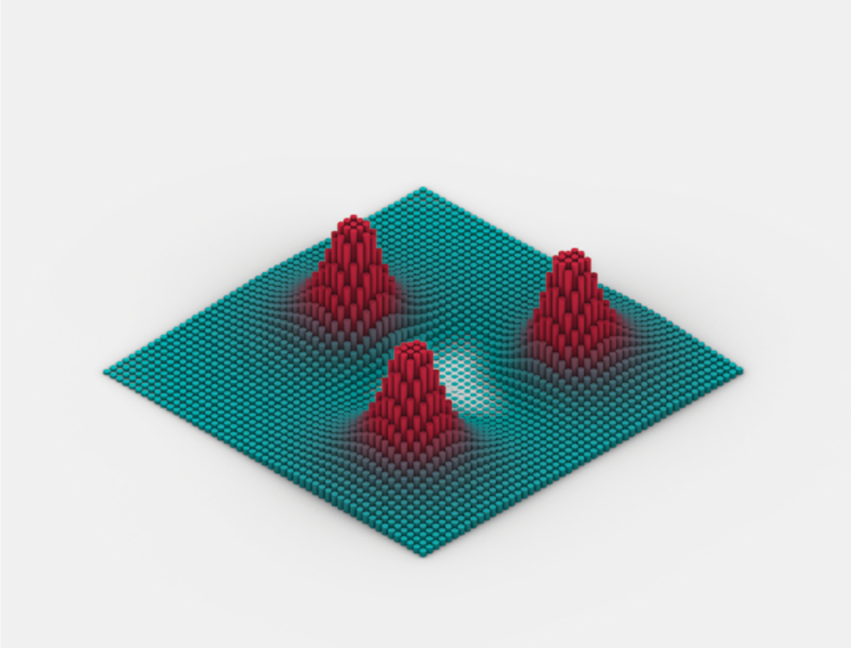


Monocentric-Centralised

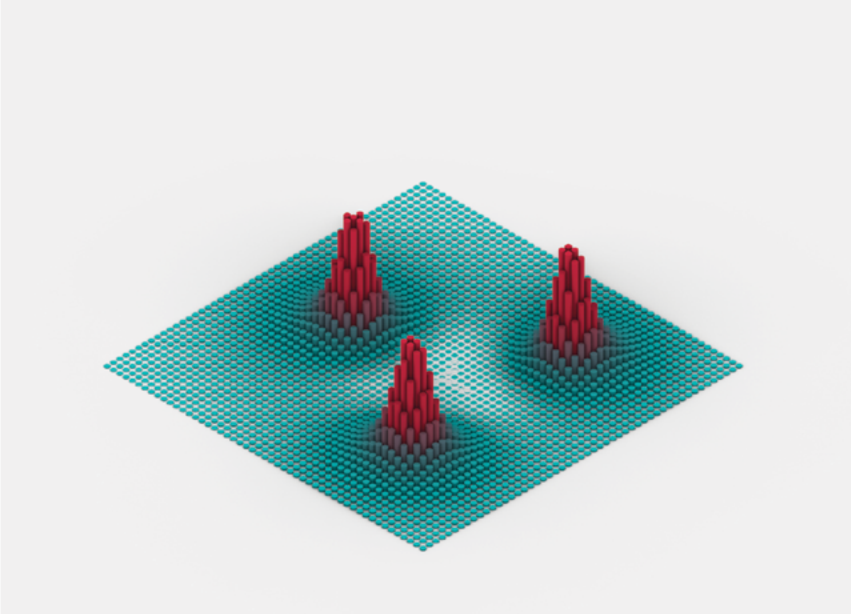


Monocentric-Dispersed

These four graphs are the results of spatial demand cone simulation. The reason for calling it spatial demand cone instead of the curve is that 2D graph has been converted into three dimensions. For the left two cones, they represent the situation of centre's influence in a monocentric urban form. The difference is that for monocentric centralised model, the strength of centre is higher than dispersed model. By contrast, the strength of decay is lower than the dispersed model.



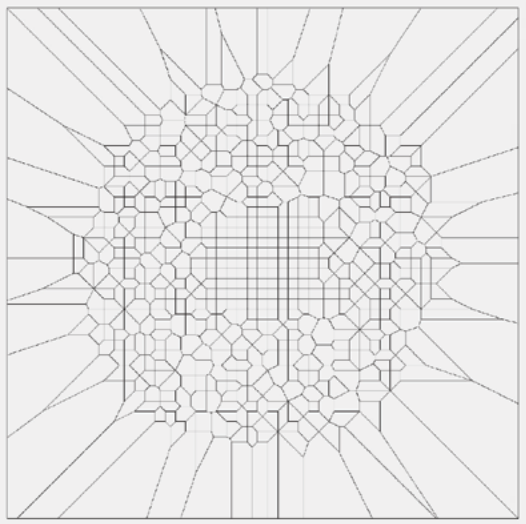
Polycentric-Centralised



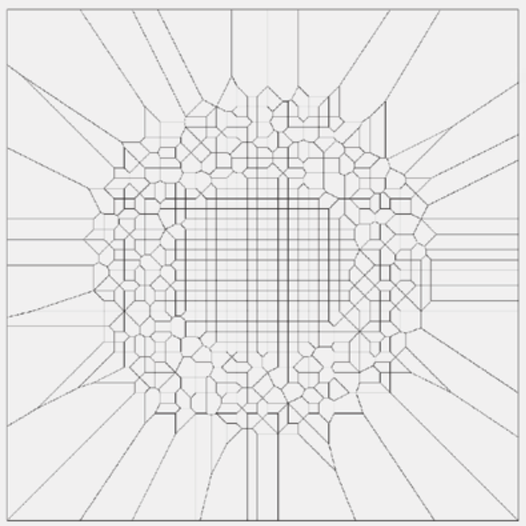
Polycentric-Dispersed

For polycentric model, the result is more complicated. Because the field centres have been merged, they show a collective influence on the whole region. Compared to the monocentric model, due to there are three centres, the strength of each centre is lower than the monocentric centre. Similarly, the centre in the dispersed model has weaker power to affect surroundings. The grasshopper scripts of this simulation are included in the appendix chapter.

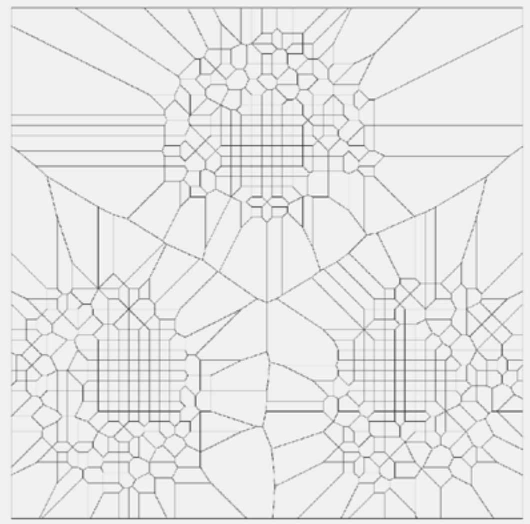
4. Urban fabric based on the previous simulation



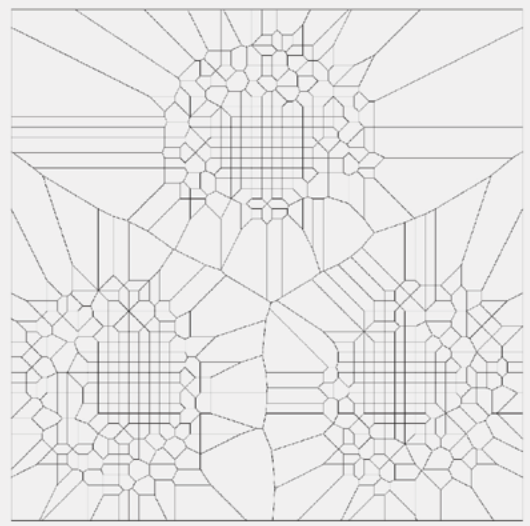
Monocentric-Centralised



Monocentric-Dispersed

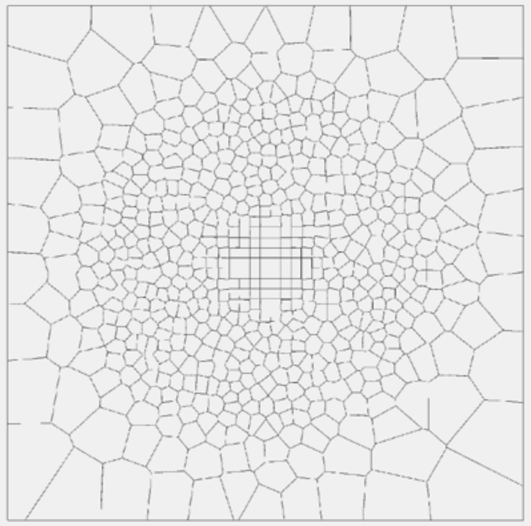


Polycentric-Centralised

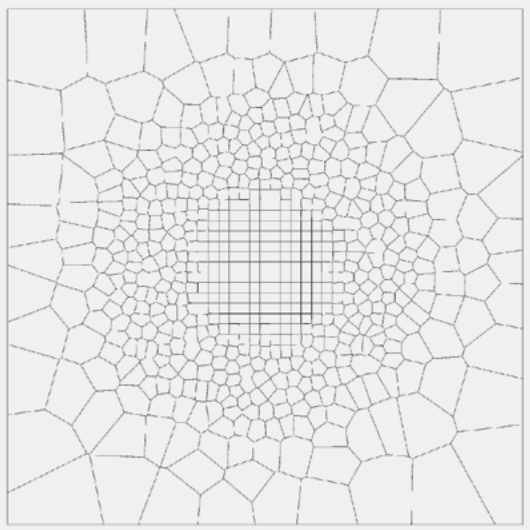


Polycentric-Dispersed

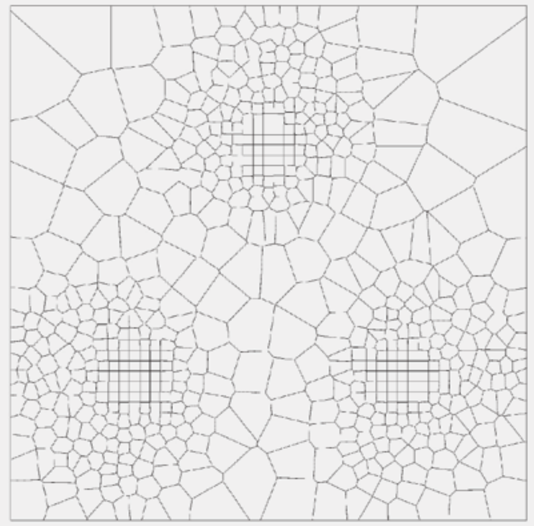
5. Urban fabric after Vornonoi relaxation



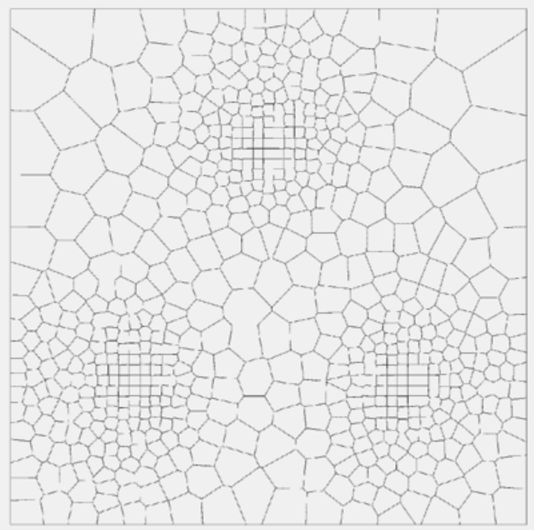
Monocentric-Centralised



Monocentric-Dispersed



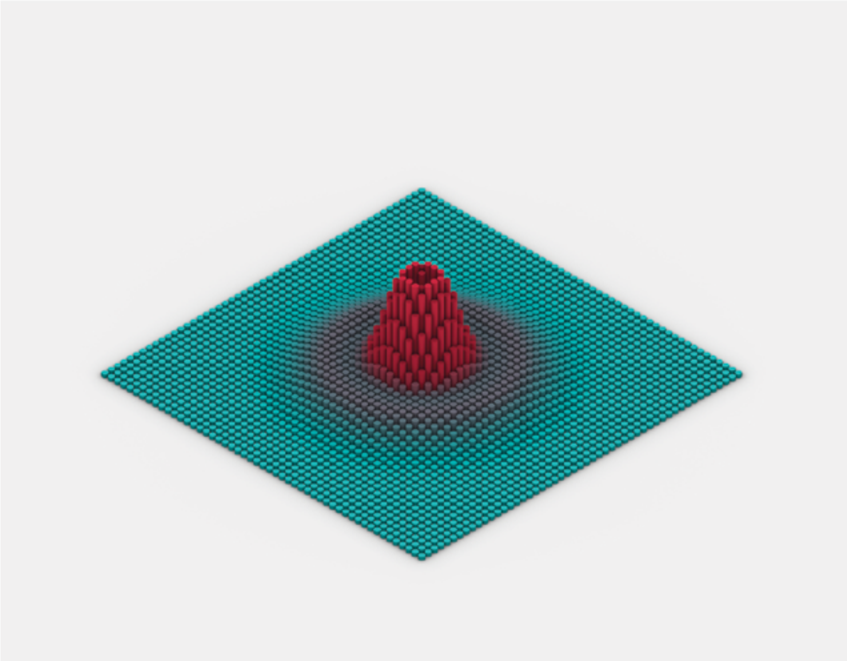
Polycentric-Centralised



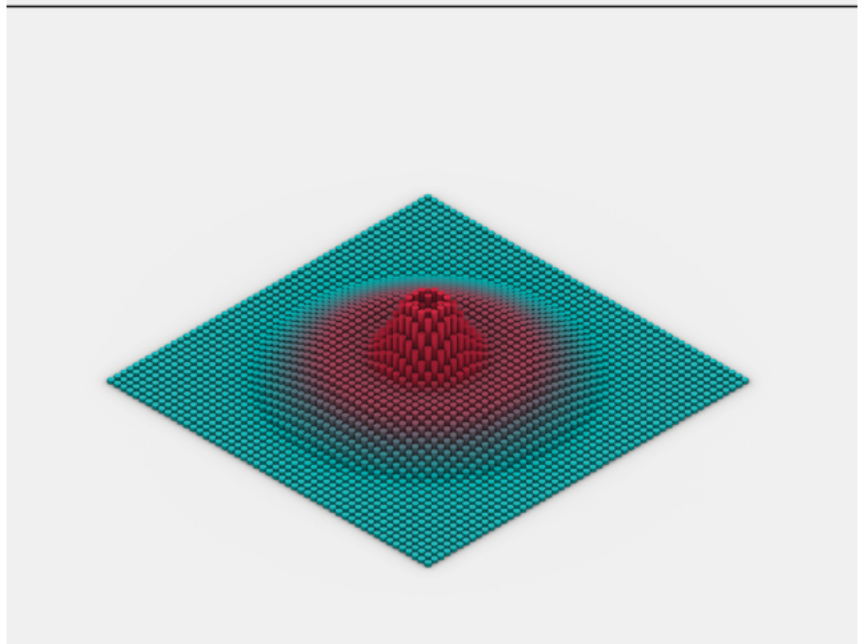
Polycentric-Dispersed

04.3 HOUSEHOLDS DISTRIBUTION CONE SIMULATION

1. Results of megnatic field simulation

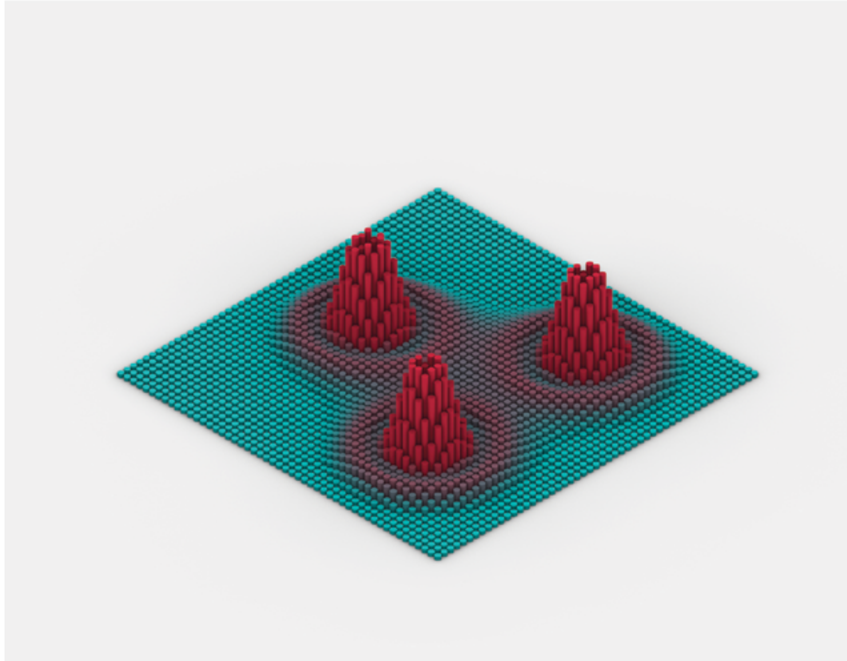


Monocentric-Centralised

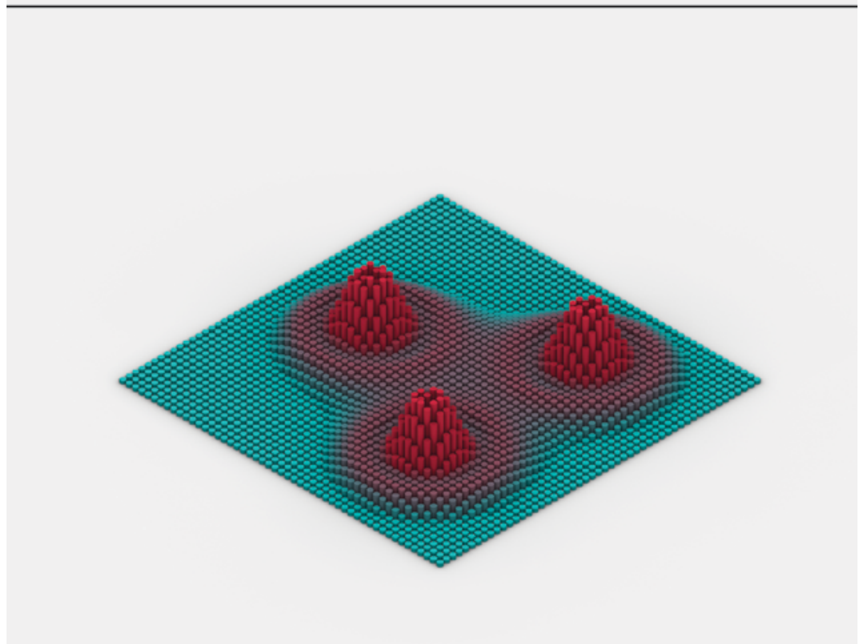


Monocentric-Dispersed

While the spatial demand cone could indicate the land price and density of a given urban form, the household distribution cone is aiming to show the frequency of which area are more popular for settling down. The purpose of this simulation is to distribute the entire 200 RD into previously generated urban fabrics.



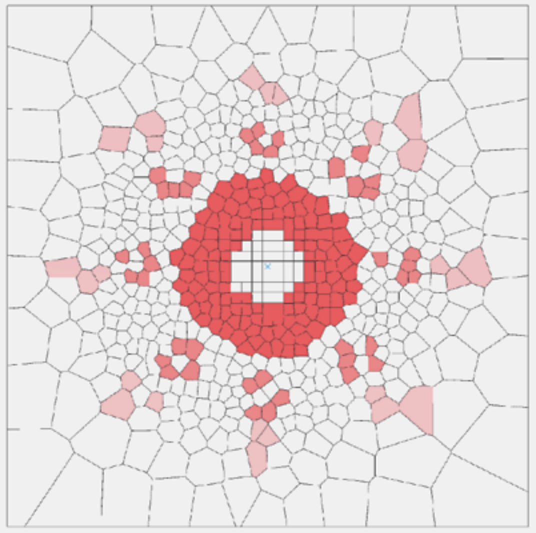
Polycentric-Centralised



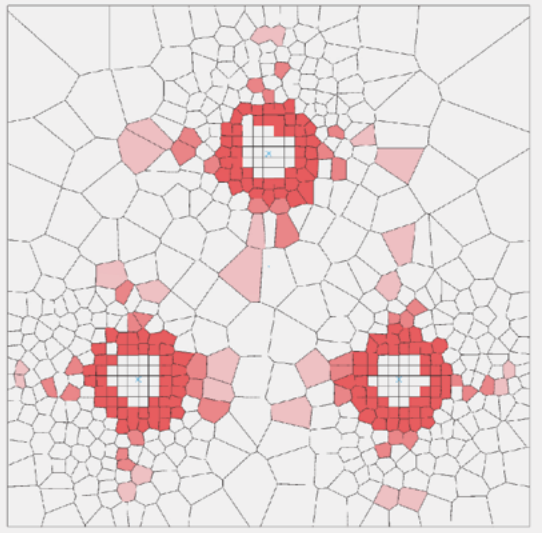
Polycentric-Dispersed

04.4 DISTRIBUTION OF 200 RESIDENTIAL BLOCKS

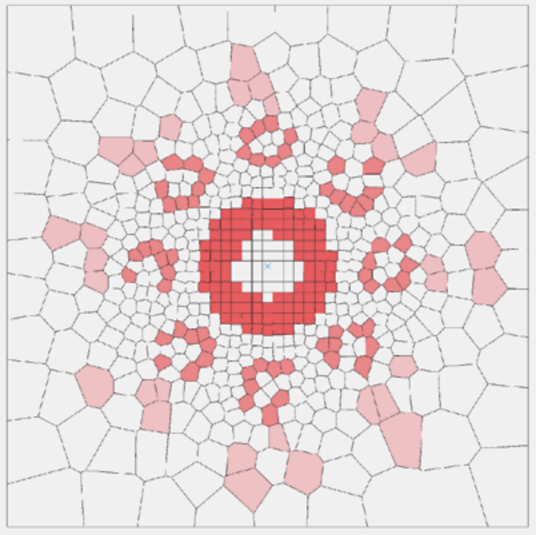
1. Results of distributing entire household



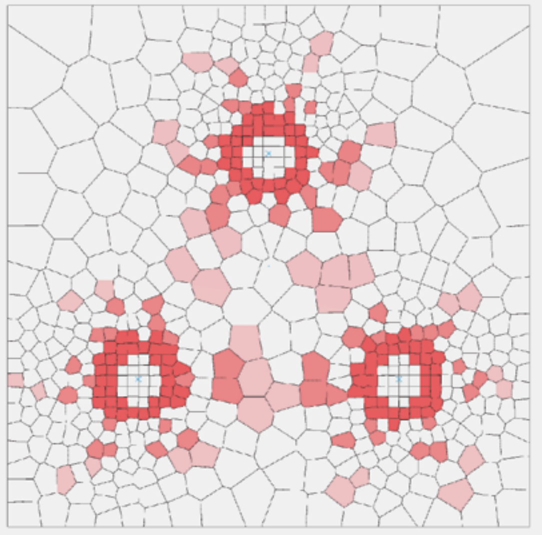
Monocentric-Centralised



Polycentric-Centralised



Monocentric-Dispersed



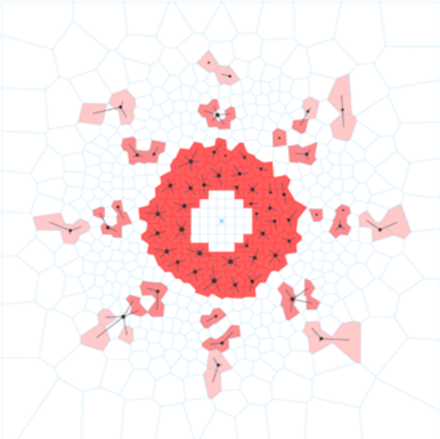
Polycentric-Dispersed

04.5 DISTRIBUTION OF MATERIAL RECOVERY FACILITIES

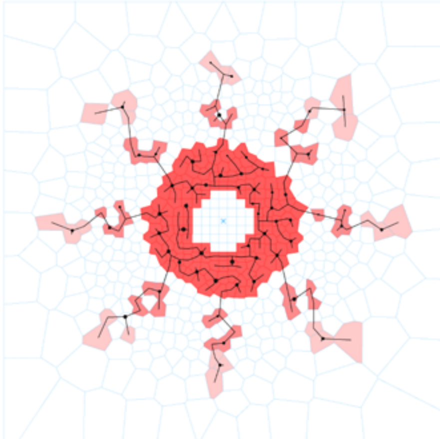
1. Distributing MRF in Monocentric-centrialised model

After distributing the entire 200 RDs into previously generated urban fabrics, how to allocate MRF is the primary task. Because there is a wide range of capacity of MRF, the approaches of distributing all the plants are almost countless. Therefore, seven different average capacities have been selected as the inputs for this model. During the iteration of finding the best locations for all the plants, the goal for optimisation is the minimal transportation distance, which is roughly equal to the total distance of all the linkages between facilities and their served residential blocks. At this stage, the correlation between the spatial configura-

1. Average capacity:200TPD (60 facilities)

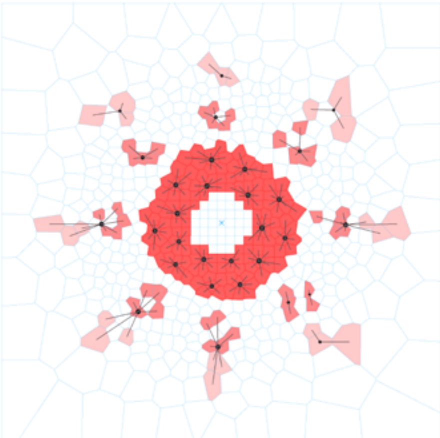


linkeages between facilities and serverd cells

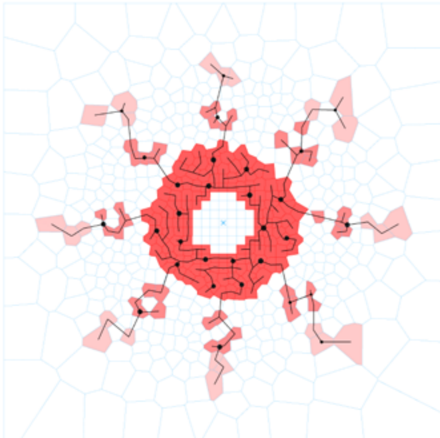


'minimal spanning' among entire cells and plants

2. Average capacity:400TPD (30 facilities)

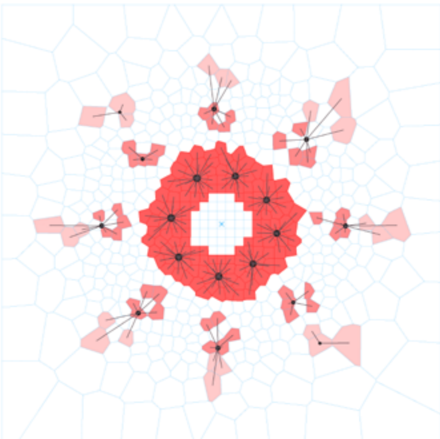


linkeages between facilities and serverd cells

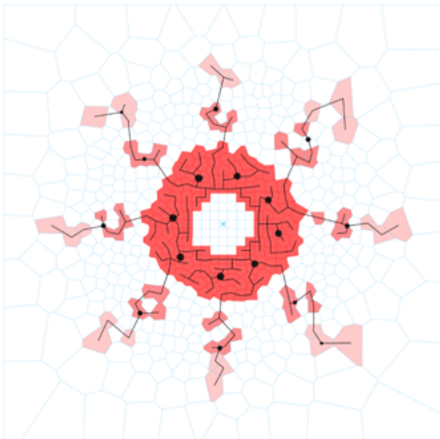


'minimal spanning' among entire cells and plants

3. Average capacity:660TPD (18 facilities)

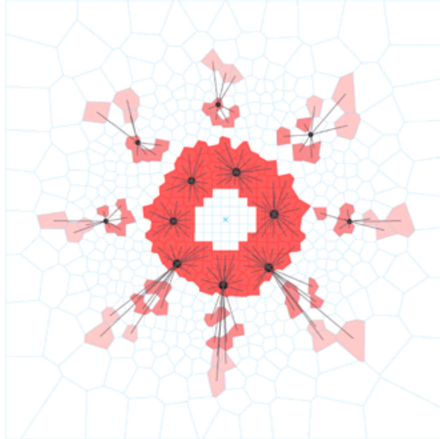


linkeages between facilities and serverd cells

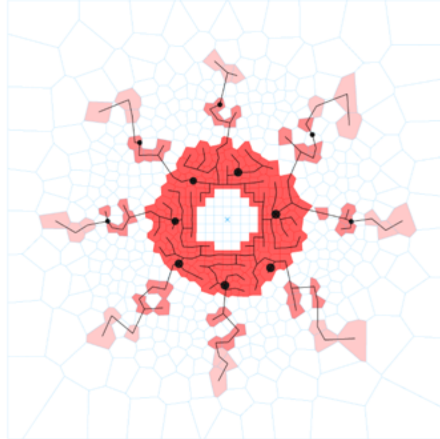


'minimal spanning' among entire cells and plants

4. Average capacity:1000TPD (12 facilities)

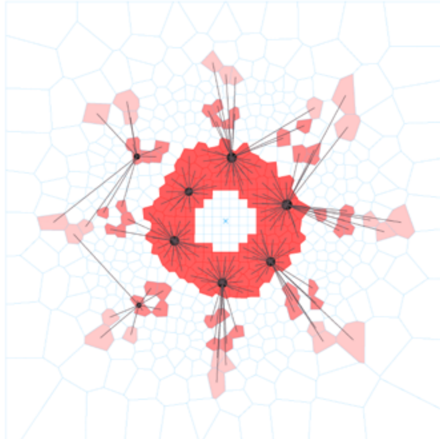


linkeages between facilities and serverd cells

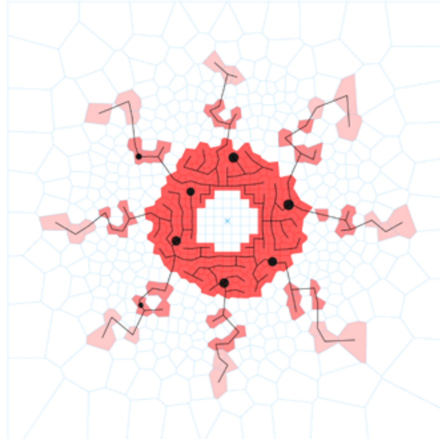


'minimal spanning' among entire cells and plants

5. Average capacity:1500TPD (8 facilities)

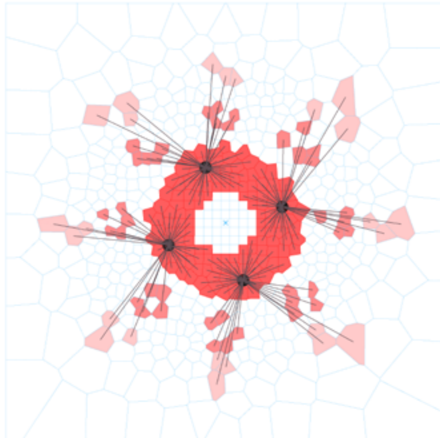


linkeages between facilities and serverd cells

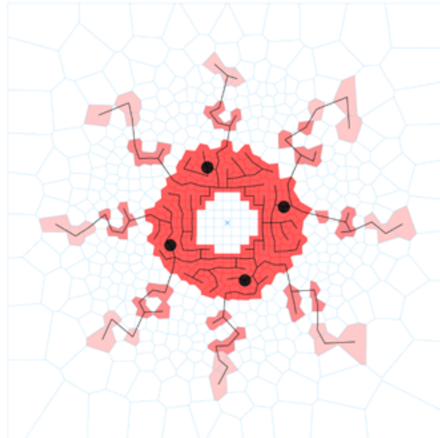


'minimal spanning' among entire cells and plants

6. Average capacity:3000TPD (4 facilities)

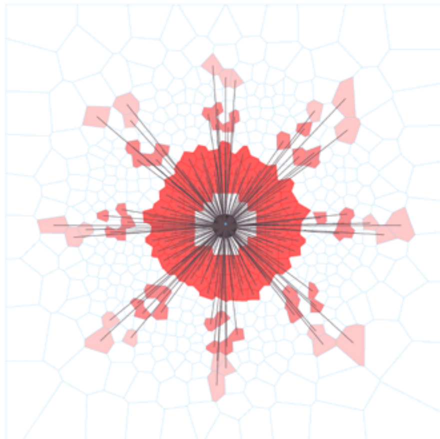


linkeages between facilities and serverd cells

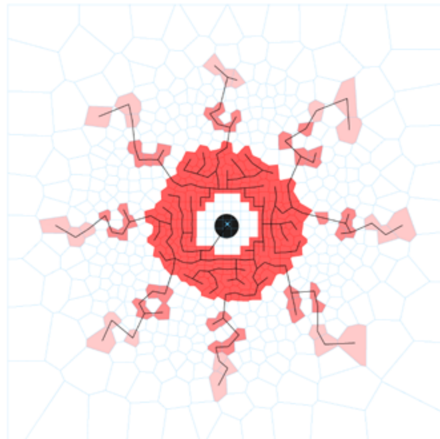


'minimal spanning' among entire cells and plants

7. Average capacity:12000TPD (1 facilities)



linkeages between facilities and serverd cells



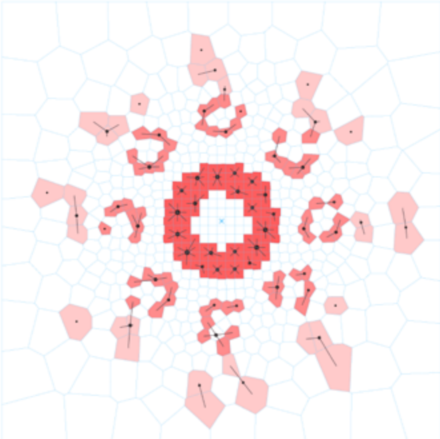
'minimal spanning' among entire cells and plants

2. Distributing MRF in Monocentric-dispersed model

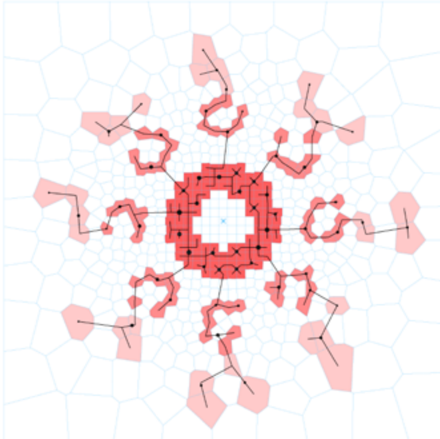
tion and the performance is still obscure. It will be way more complicated if including the land price as a consideration. Since this is the first experiment, this model should be as simple as possible to unveil some hidden logic.

Essential evaluation will be conducted after getting all the spatial configurations. The results of the analysis are the knowledge for the following works.

1. Average capacity:200TPD (60 facilities)

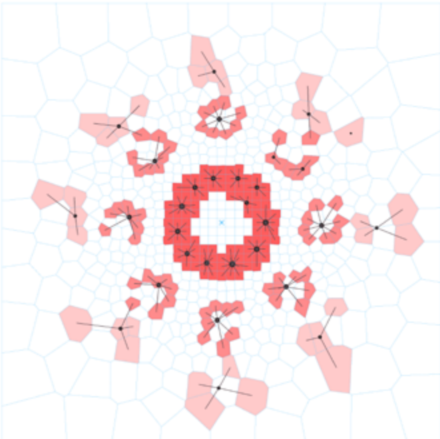


linkeages between facilities and serverd cells

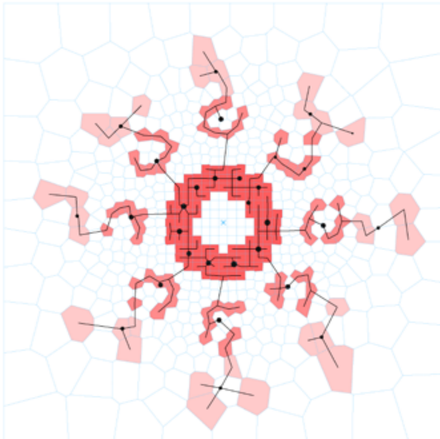


'minimal spanning' among entire cells and plants

2. Average capacity:400TPD (30 facilities)

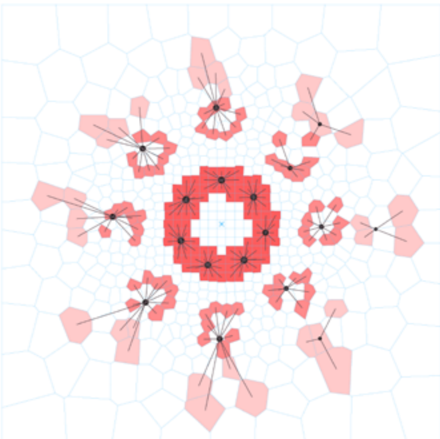


linkeages between facilities and serverd cells

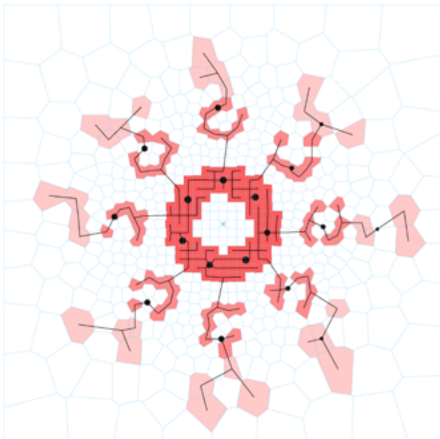


'minimal spanning' among entire cells and plants

3. Average capacity:660TPD (18 facilities)

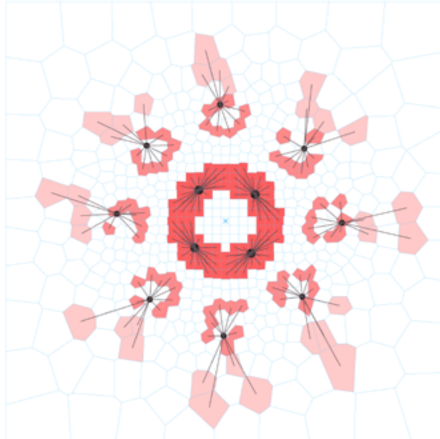


linkeages between facilities and serverd cells

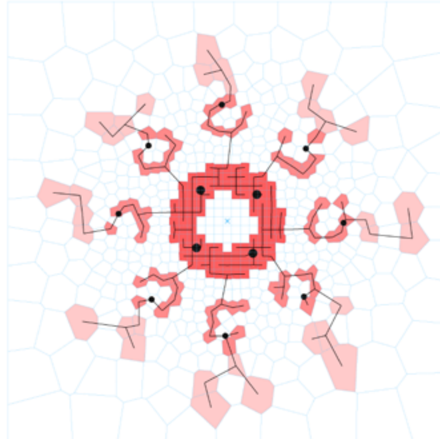


'minimal spanning' among entire cells and plants

4. Average capacity:1000TPD (12 facilities)

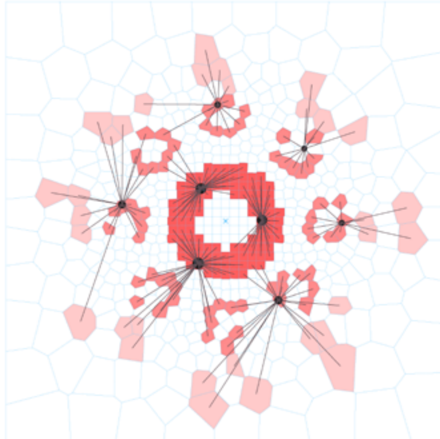


linkeages between facilities and serverd cells

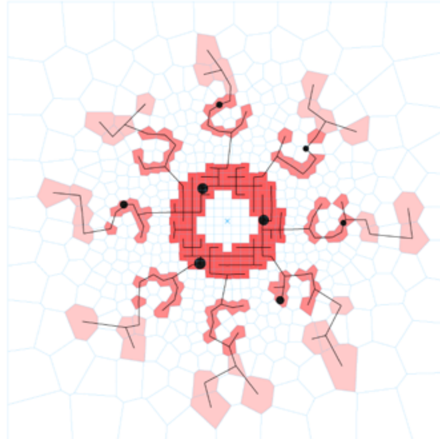


'minimal spanning' among entire cells and plants

5. Average capacity:1500TPD (8 facilities)

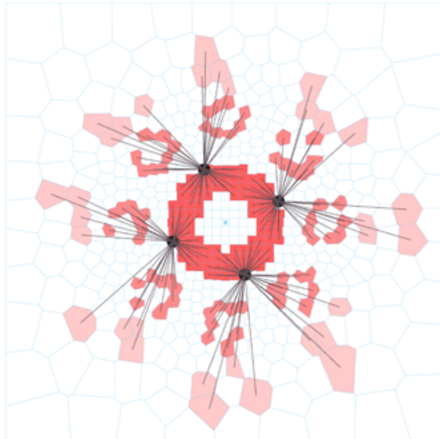


linkeages between facilities and serverd cells

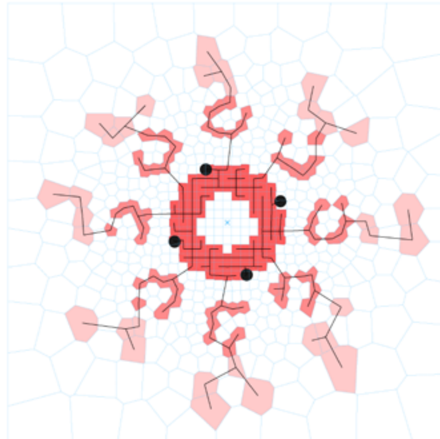


'minimal spanning' among entire cells and plants

6. Average capacity:3000TPD (4 facilities)

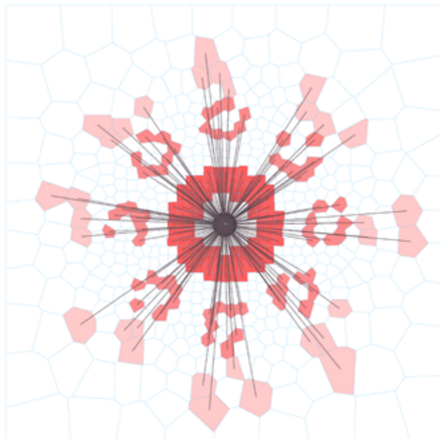


linkeages between facilities and serverd cells

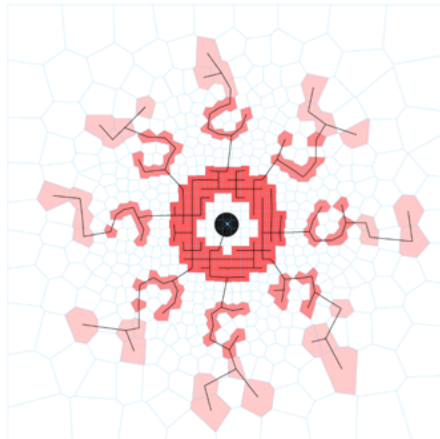


'minimal spanning' among entire cells and plants

7. Average capacity:12000TPD (1 facilities)



linkeages between facilities and serverd cells

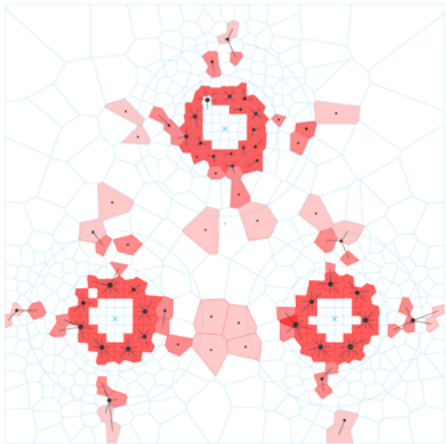


'minimal spanning' among entire cells and plants

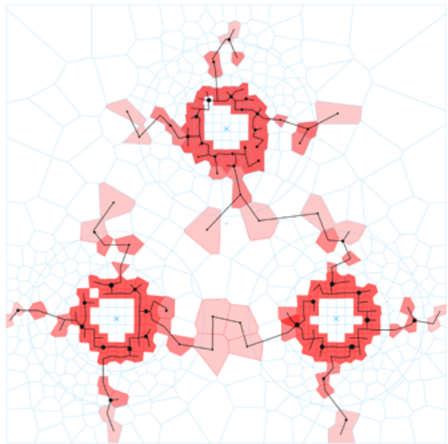
3. Distributing MRF in Polycentric-centrialised model

For each type of capacity testing, there are two graphs to show the results. The left one contains the location of all the facilities and the direct linkages between facilities and residential blocks. The total length of all the direct linkages is the key criteria for evaluation and optimisation. The right graph highlights the minimal spanning among entire facilities and residential blocks. Those routes represent the needed infrastructure for supporting all the flows. Although the total length of minimal spanning is more accurate in the term of transport distance, the code of generating those minimal spanning is way heavy than just connect-

1. Average capacity:200TPD (60 facilities)

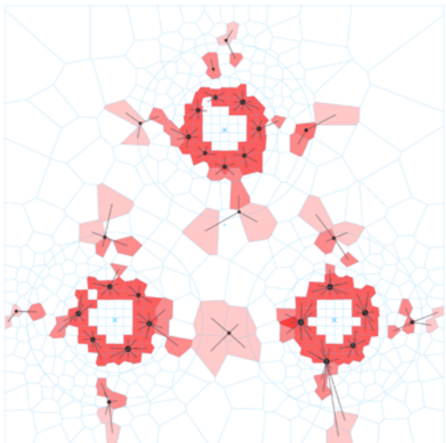


linkeages between facilities and serverd cells

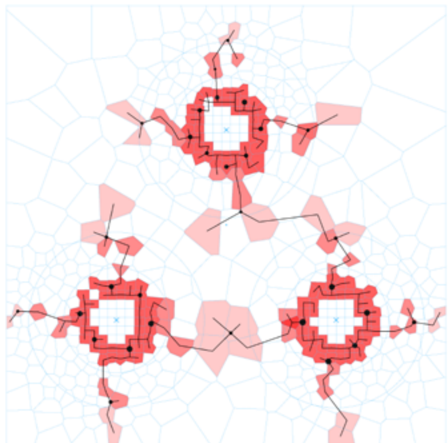


'minimal spanning' among entire cells and plants

2. Average capacity:400TPD (30 facilities)

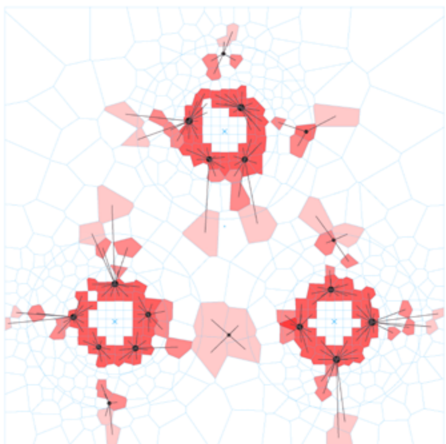


linkeages between facilities and serverd cells

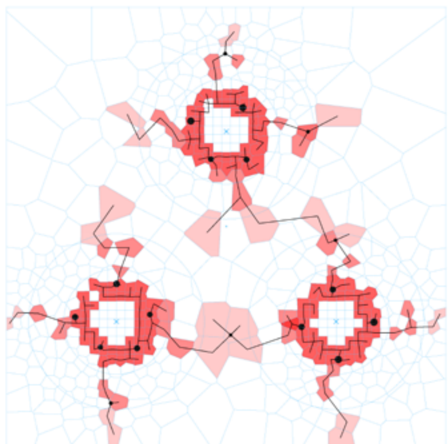


'minimal spanning' among entire cells and plants

3. Average capacity:660TPD (18 facilities)

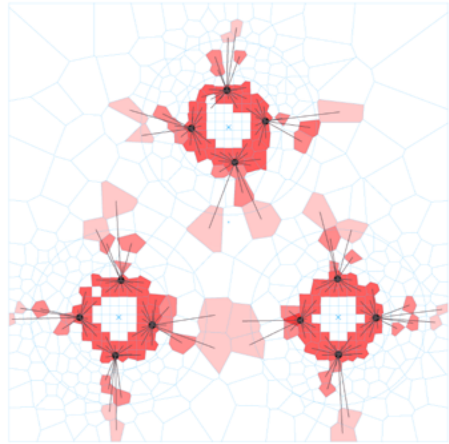


linkeages between facilities and serverd cells

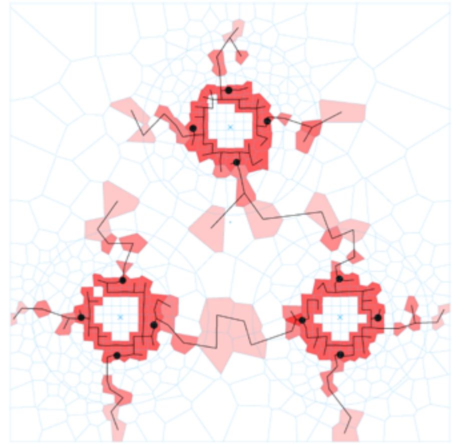


'minimal spanning' among entire cells and plants

4. Average capacity:1000TPD (12 facilities)

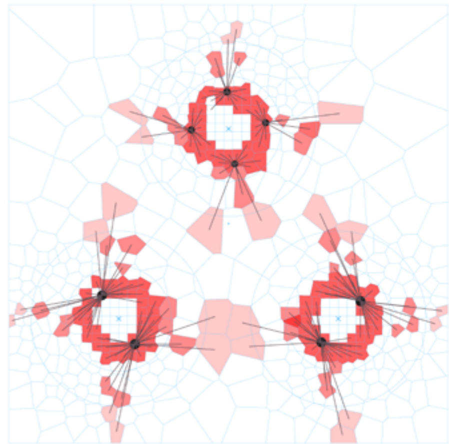


linkeages between facilities and serverd cells

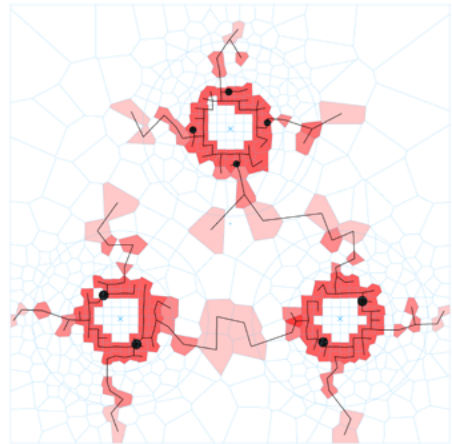


'minimal spanning' among entire cells and plants

5. Average capacity:1500TPD (8 facilities)

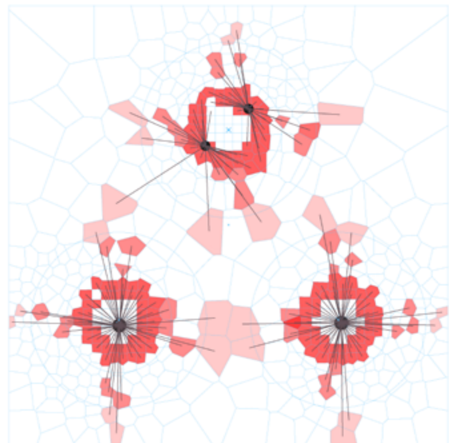


linkeages between facilities and serverd cells

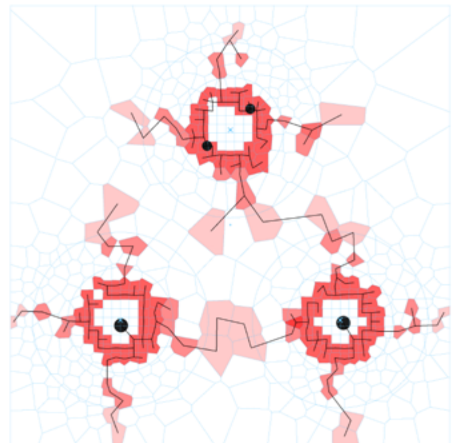


'minimal spanning' among entire cells and plants

6. Average capacity:3000TPD (4 facilities)

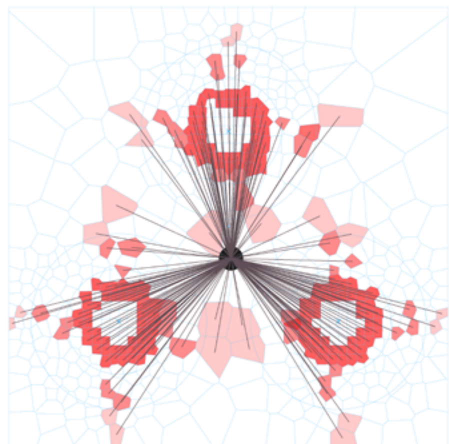


linkeages between facilities and serverd cells

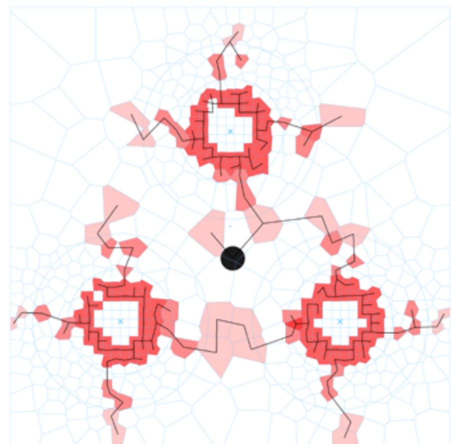


'minimal spanning' among entire cells and plants

7. Average capacity:12000TPD (1 facilities)



linkeages between facilities and serverd cells

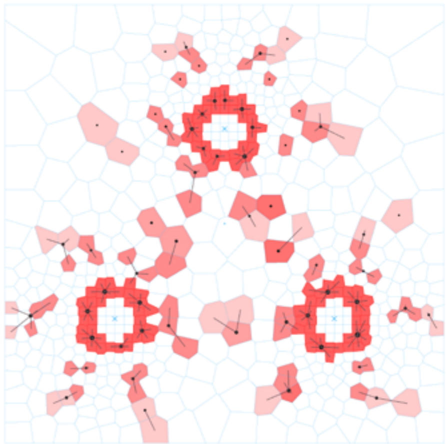


'minimal spanning' among entire cells and plants

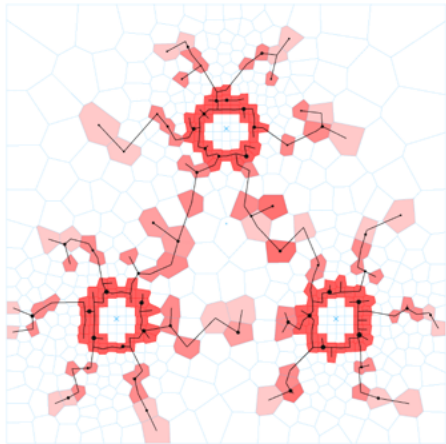
4. Distributing MRF in Polycentric-dispersed model

ing two points directly. Therefore, it will require much more time for calculating, which is not feasible due to the fact of limited time and computer quality. The compromised solution is to use the direct linkages for calculating and then multiply a constant (2 in this model). Then this model could have some roughly accurate results which are under a specific control.

1. Average capacity:200TPD (60 facilities)

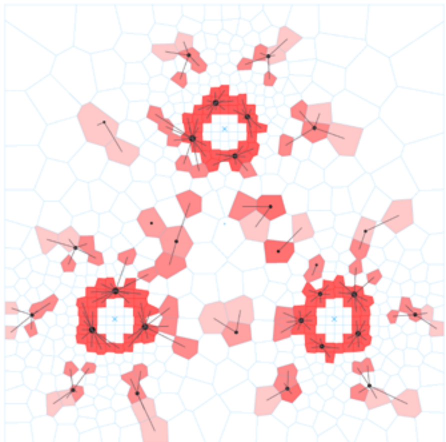


linkeages between facilities and serverd cells

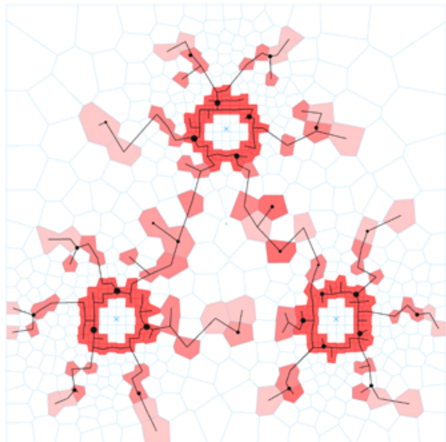


'minimal spanning' among entire cells and plants

2. Average capacity:400TPD (30 facilities)

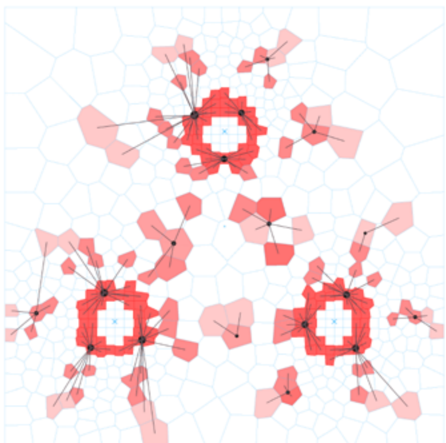


linkeages between facilities and serverd cells

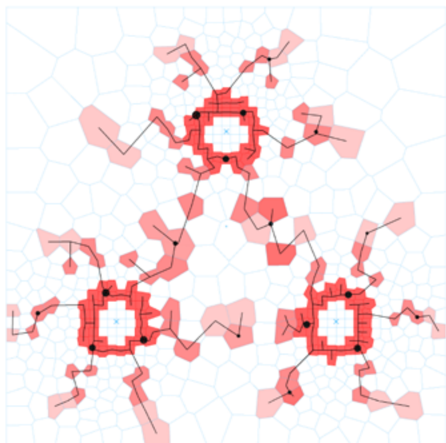


'minimal spanning' among entire cells and plants

3. Average capacity:660TPD (18 facilities)

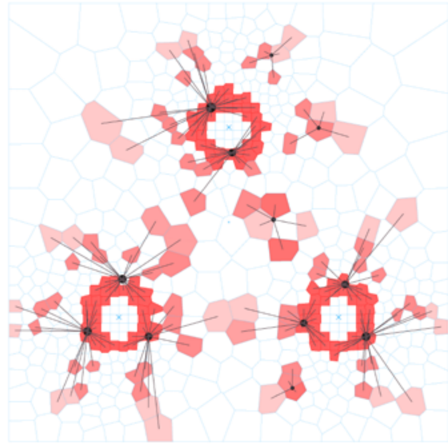


linkeages between facilities and serverd cells

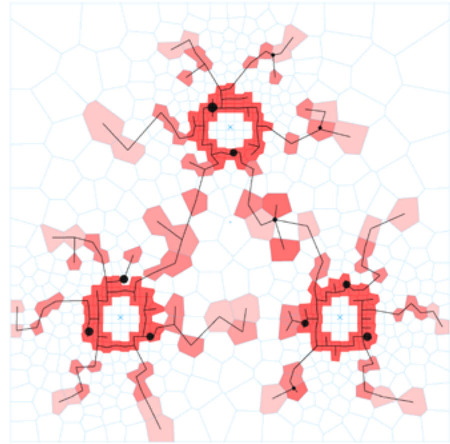


'minimal spanning' among entire cells and plants

4. Average capacity:1000TPD (12 facilities)

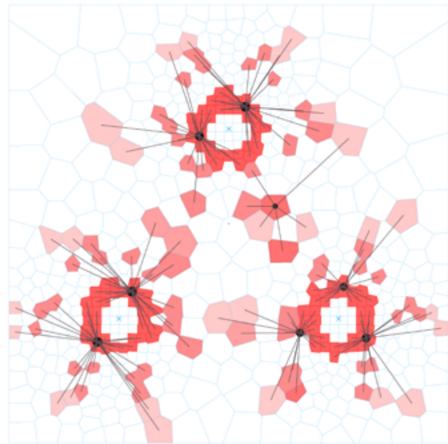


linkeages between facilities and serverd cells

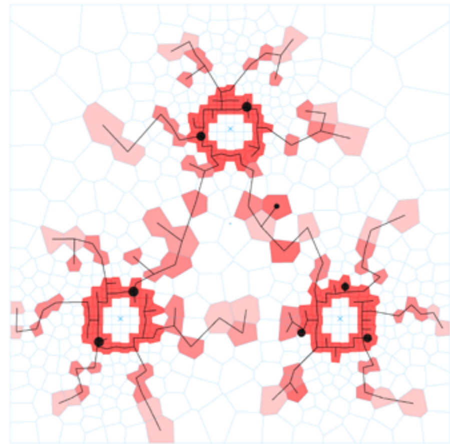


'minimal spanning' among entire cells and plants

5. Average capacity:1500TPD (8 facilities)

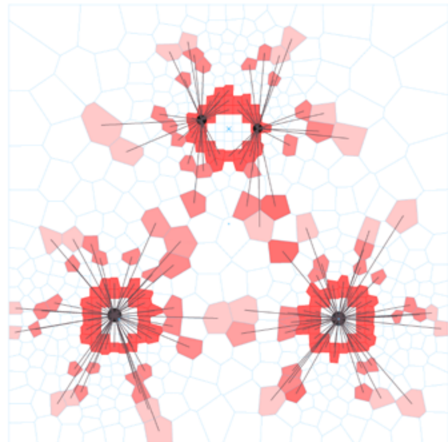


linkeages between facilities and serverd cells

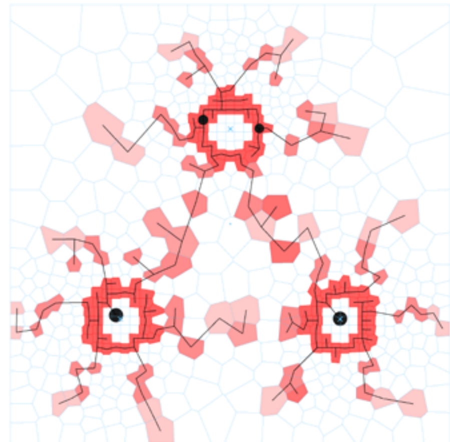


'minimal spanning' among entire cells and plants

6. Average capacity:3000TPD (4 facilities)



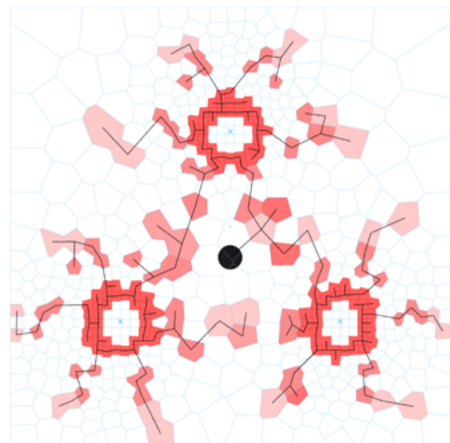
linkeages between facilities and serverd cells



'minimal spanning' among entire cells and plants

7. Average capacity:12000TPD (1 facilities)

linkeages between facilities and serverd cells



'minimal spanning' among entire cells and plants

04.6 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

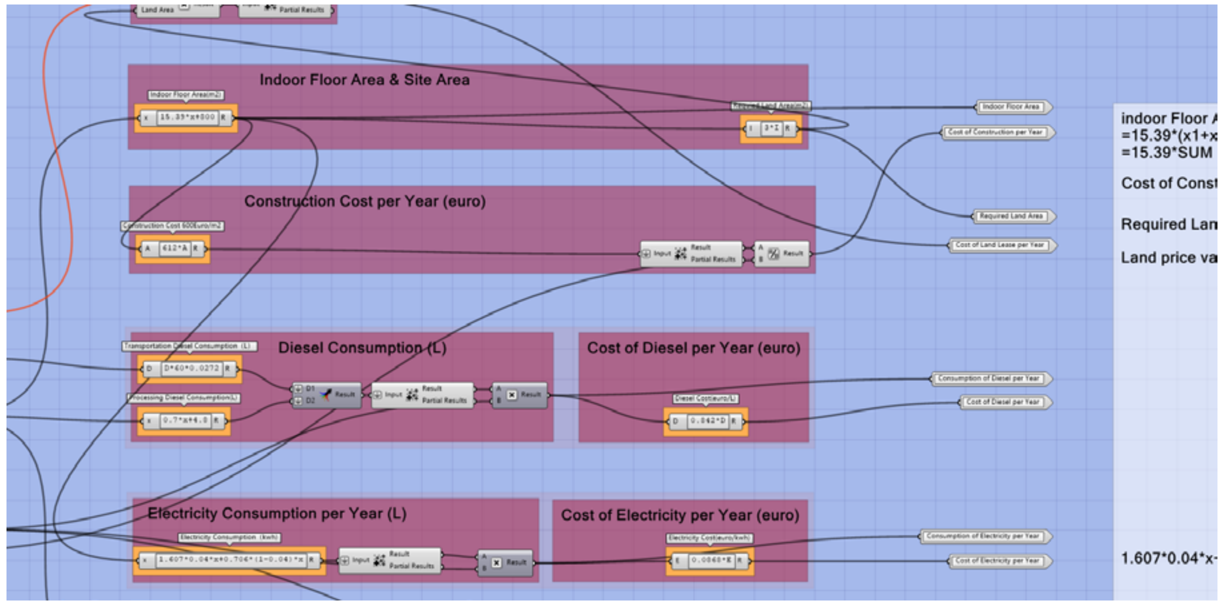
Ecological Cost

CO_2 emission
CH_4 emission
N_2O emission
Global Warming Potential

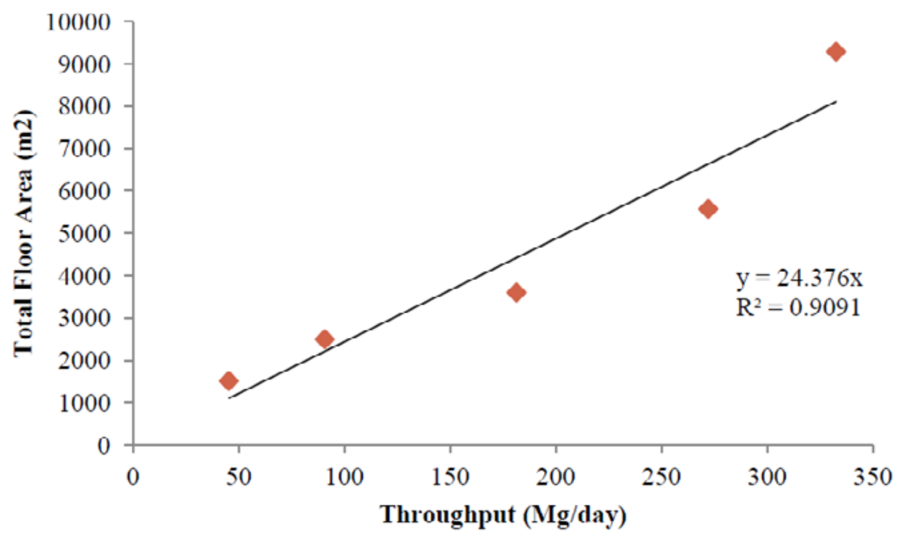
Revenue

Material revenue
Recovered organic waste

Script for all the calculations



Example: indoor area calculation



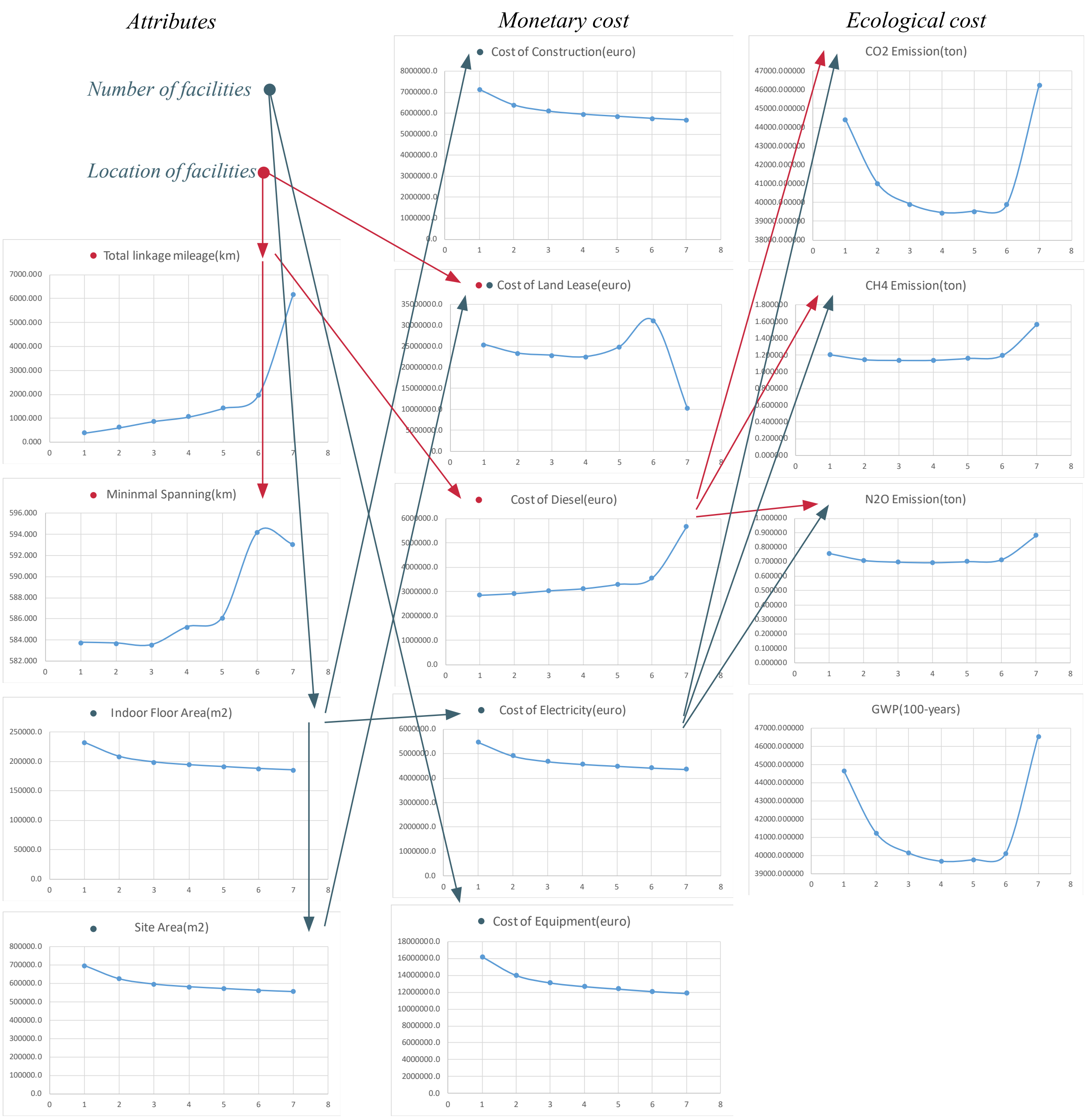
Source: Combs, A. R. (2011). Life Cycle Analysis of Recycling Facilities in a Carbon Constrained World.

$$y = 15.39x + 800$$

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.

The evaluation has three major aspects, monetary cost, ecological cost and revenue. All the calculations are using the equations published in the article called 'Life Cycle Analysis of Recycling Facilities in a Carbon Constrained World.' All the equations are in the appendix part. The upper graph in this page shows the scripts used for calculating in the Rhino environment. For the indoor area, the author of the mentioned article used the linear regression to summerise an equation. However, since that article published seven years ago and most of the data were in the US, in this project, a new linear regression work has been conducted to get a more proper equation. Moreover, all the other data such as the diesel price, electricity price and land price are based on the most current statistics in China.

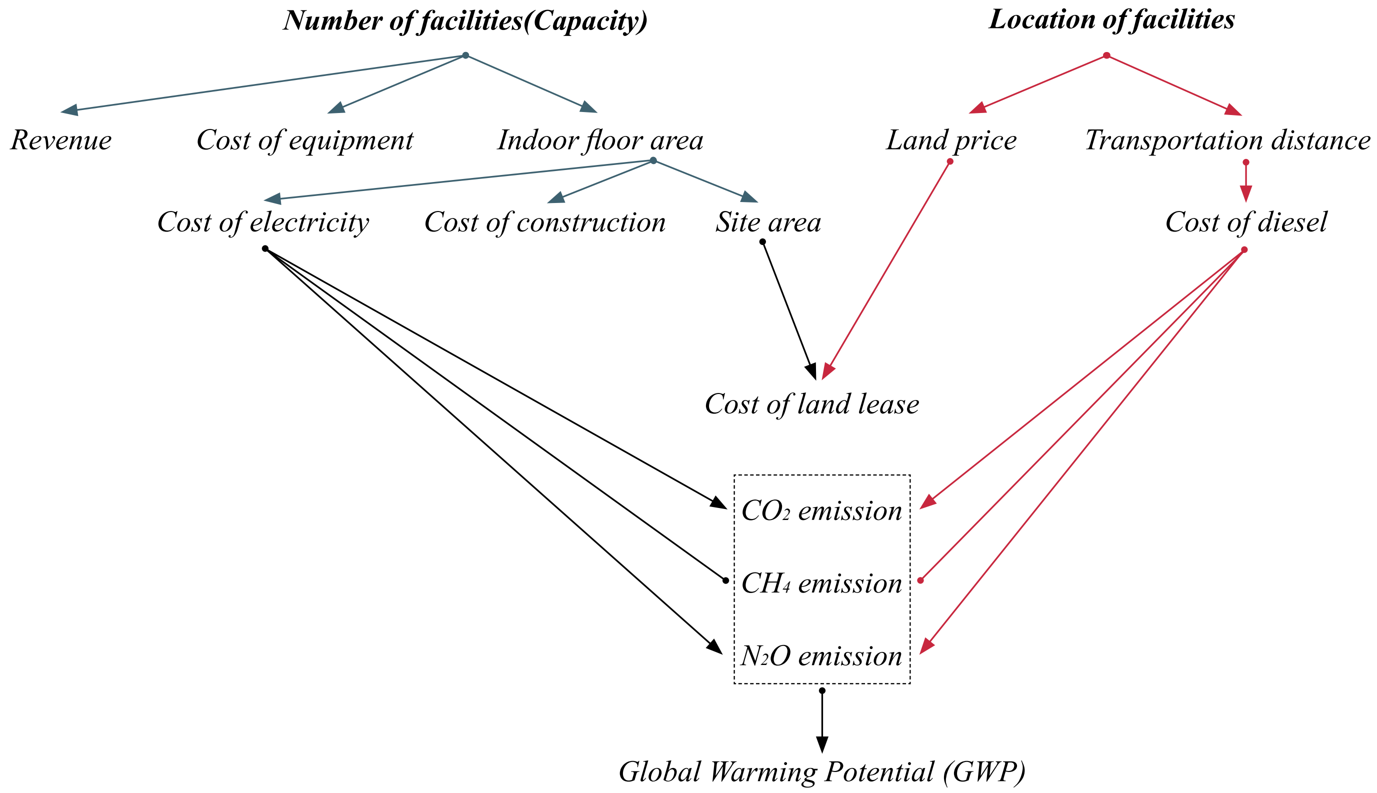
Relationships of all the results



The results have been visualised as line charts to help the necessary evaluation. All the charts above are the results for the polycentric centralised model. When we Ignoring the actual number, some of the charts have the same shape of lines, which indicates they are influenced by the same parameter. The diagram of the hierarchy for results helps to determine the most vital attributes for this abstract model.

Based on the theory of system thinking, all the elements are interrelated. Understanding their relationships is a primary work for the following study. In this evaluation section, several aspects

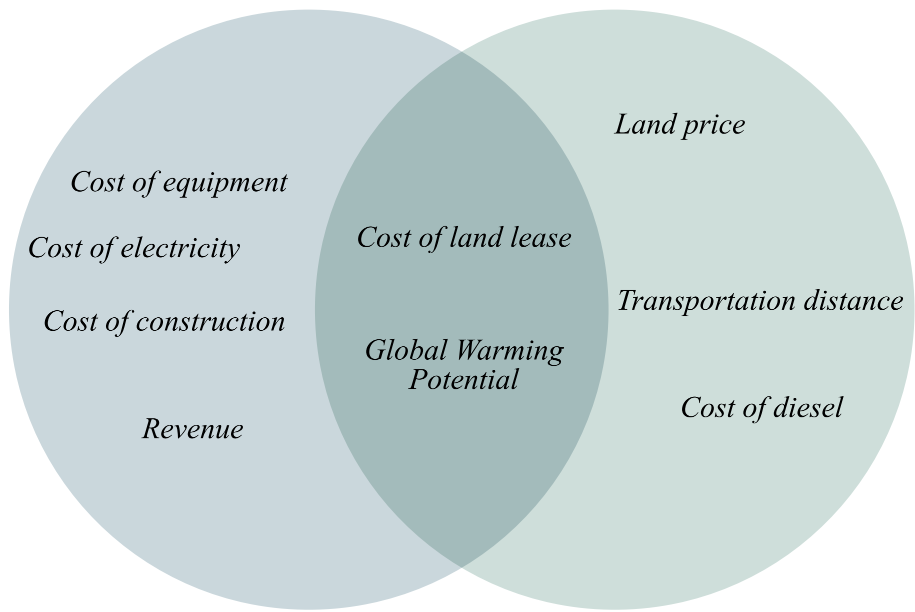
Hierarchy of all the results



Boolean Expression

Main parameters:

Number of facilities(Capacity) **Location of facilities**



have been assessed, such as the cost of equipment, cost of construction and cost of the land lease. The upper diagram in previous page shows the network of all the assessed factors. It demonstrates which elements have direct impacts on other elements. For example, a specific capacity of the facility requires a proper area of building for accommodating all the equipment and activities during the process. Then the indoor areas decide how much electricity will be needed in this facility, which will continue to influence how much GHGs will generate when producing and consuming that amount of electricity. At the same time, the indoor area of the facility has a direct relationship with the total occupied site areas. This number and the location of a facility together will decide the expenditure on land procurement. This diagram highlights that the most significant parameters are the capacity and location of facilities. It is evident that some 'costs' simply just rely on one parameter while there is also some situation that both parameters determine the final 'costs'.

The next diagram, which called 'Boolean expression', shows the three groups of cost influenced by different parameters. The capacity and location of facilities largely control the land cost and the greenhouse gases emission.

It has been widely proved that the greenhouse gases (GHGs) warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space. Because of the various attribute of different GHGs, they can have different effects on Earth's warming. The research from the United States Environmental Protection Agency states that there are two reasons in which these gases differ from each other. One is their ability to absorb energy (radiative efficiency), another reason is the time the can stay in the atmosphere.

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of gas will absorb over a given period, relative to the emissions of 1 ton of carbon dioxide (CO2). The larger the GWP is, it has more potential that a given gas warms the Earth compared to CO2 over that time. The time for assessment usually is 100 years. GWPs provides a standard unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases.

1. CO2, by definition, has a GWP of one regardless of the time used, because it is the gas being used as the reference.

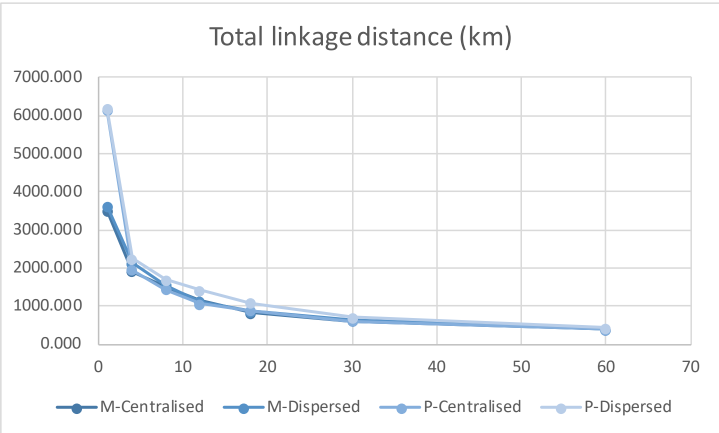
2. Methane (CH4) is estimated to have a GWP of 28–36 over 100 years

3. Nitrous Oxide (N2O) has a GWP 265–298 times that of CO2 for a 100-year timescale.

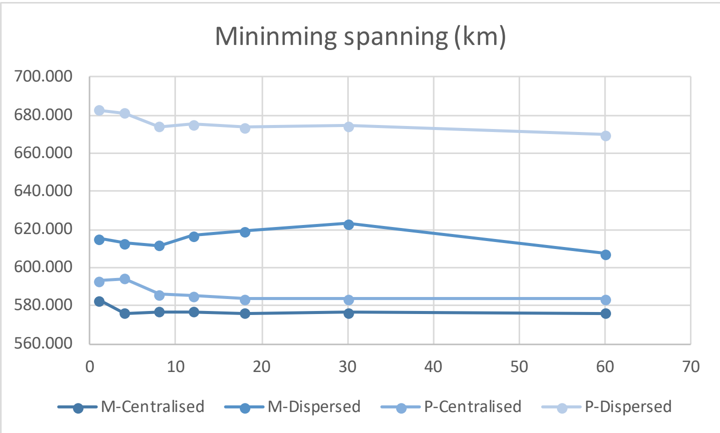
In this project, all the emissions are calculated based on the emission factors 2014 version (Appendix?). Most of the gases are generated during the production process of themselves and the consumption phase such as the motor engines. The final ecological cost is the figure of GWP in 100 years time span, which is more convenient for comparison. Regarding the economic cost, the final number is the addition of all the associated costs in the unit of Euro.

05
RESULT AND ANALYSIS

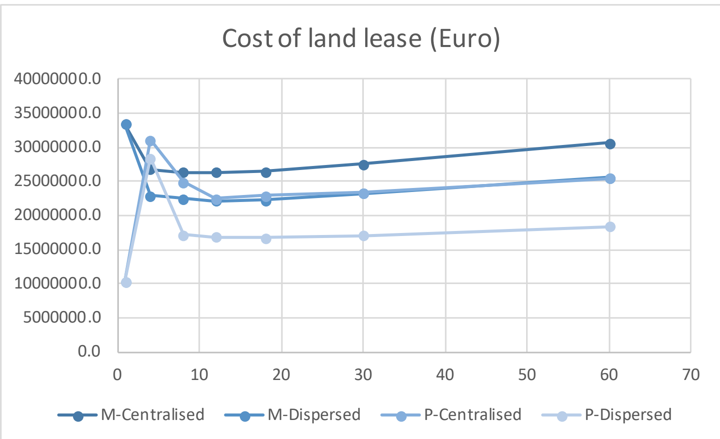
05.1 EVALUATION OF PERFORMANCE



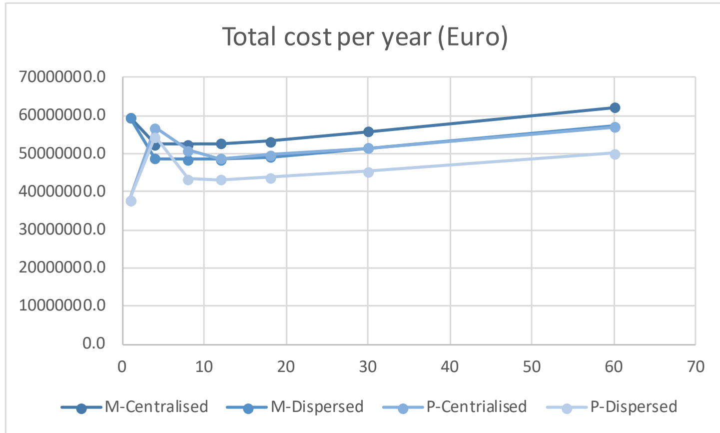
This chart shows polycentric model has less total linkage distance, which can represent the transportation cost. With the increasing of the number of facilities, the total cost of transportation will reduce.



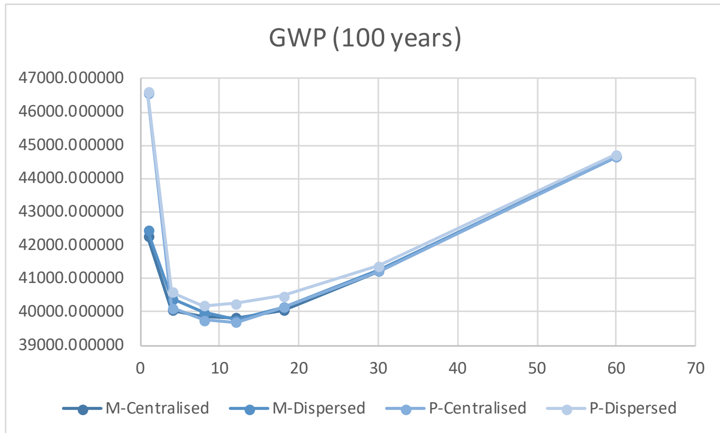
This chart shows the centralised model could use less infrastructure to cover all the cells and facilities. Within the centralised mode or dispersed model, the polycentric dimension will require more distance to cover the whole territory.



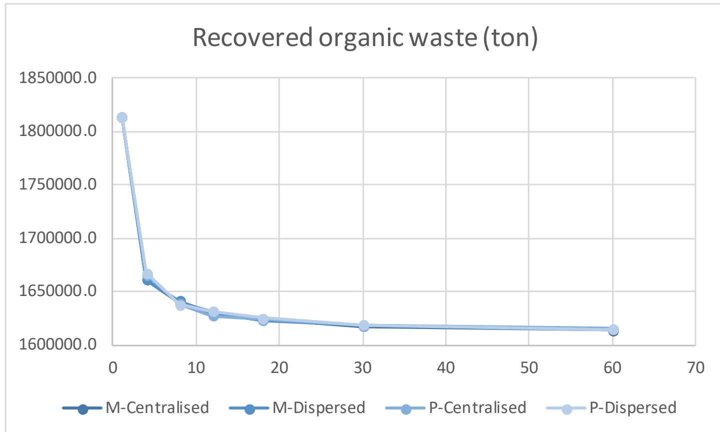
This chart indicates that the polycentric dispersed model needs the smallest amount of money for land lease while the monocentric centralised model is most expensive. With the increase of facilities number, the land cost will rise slightly.



Because the land cost and construction cost are the most significant part of the total cost, with the percentage from 40% to 60%, the trend of the 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 of six to twelve, all city will have the lowest influence on the environment.



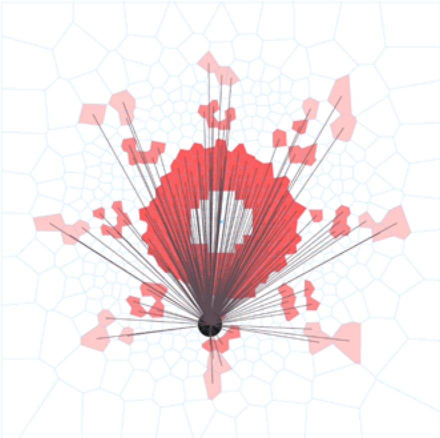
The ability to recover the organic waste rarely influenced by the different spatial structures. By contrary, the collective efficiency heavily relies on the number of facilities. With the decrease of capacity, the efficiency of MRF will also decrease.

05.2 OPTIMISING THE DISTRIBUTION OF MRF

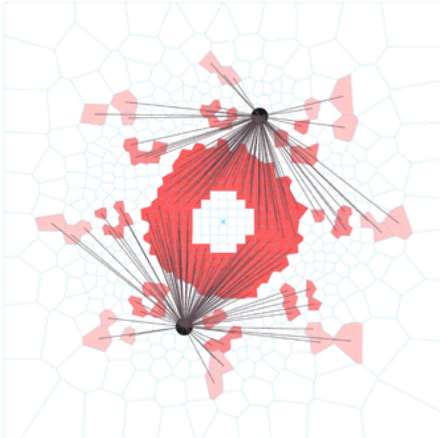
After previous analysis, it is evident that the capacity and location of facilities are the most dominant parameters, because the amount of material that is processed by the facility affect the overall processing costs. It is therefore essential to use the most cost-effective balance between processing an enormous amount of material and minimising transportation costs.

Another finding is that the when the number of facilities is around the range of 1 to 12, there may have the best solutions with a decent balance between monetary cost and environment. Those feedbacks has been used to alter the previous model, and this time, the goal is to find the best balance. For calculation, the Fitness was an equal weight to monetary cost and ecological cost. Below are the results.

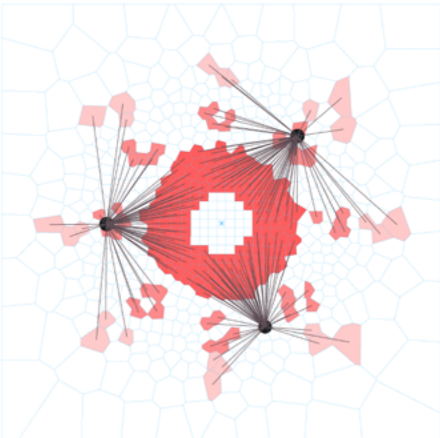
1. Monocentric Centralised



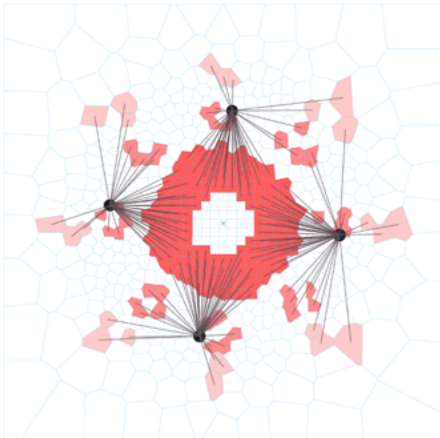
1 facility



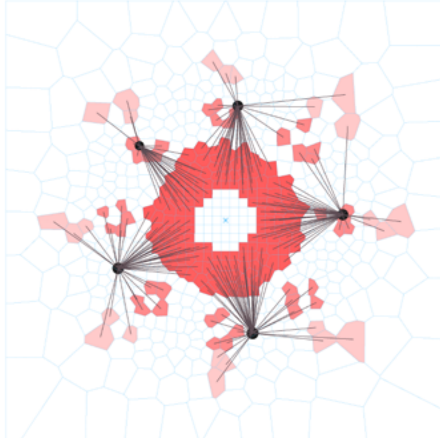
2 facilities



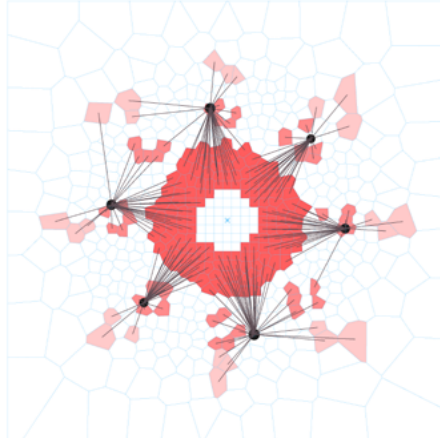
3 facilities



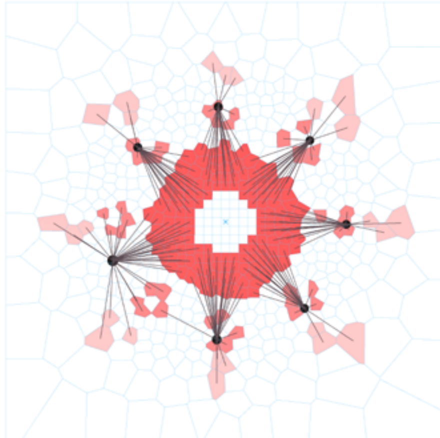
4 facilities



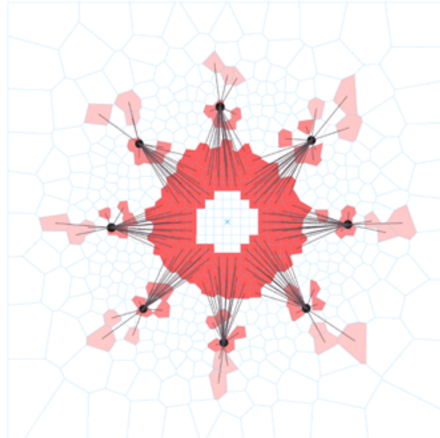
5 facilities



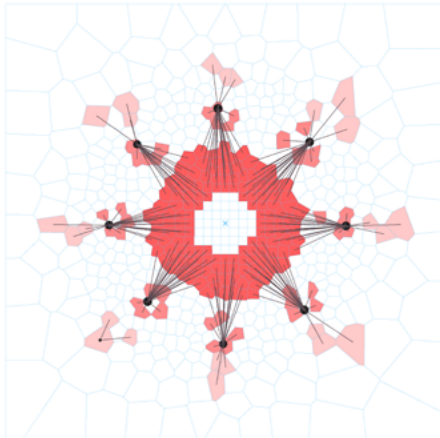
6 facilities



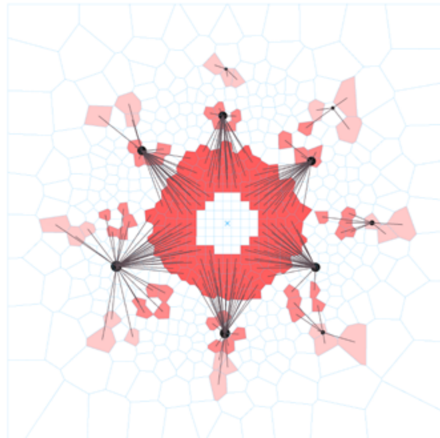
7 facilities



8 facilities

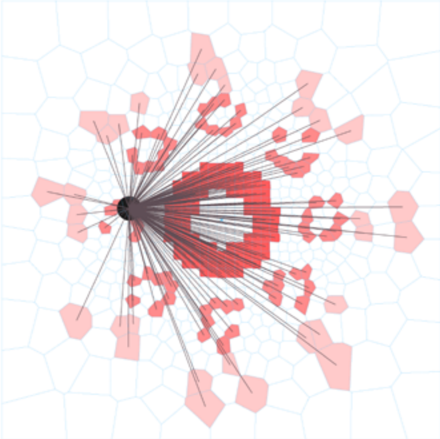


9 facilities

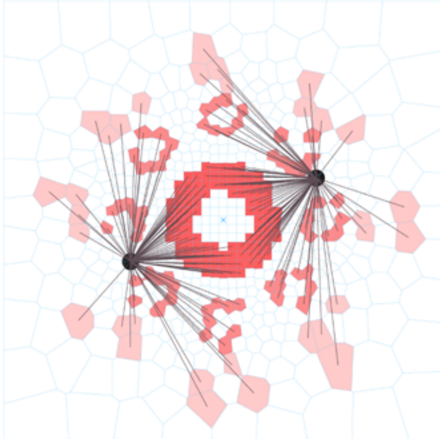


10 facilities

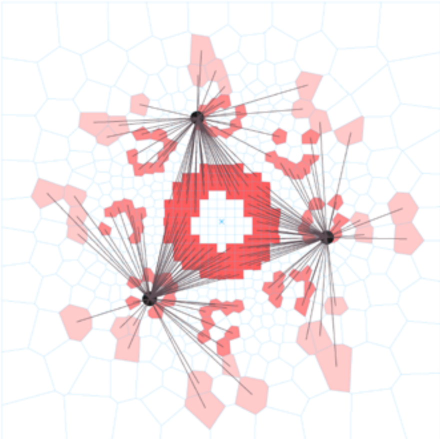
2. Monocentric Dispersed



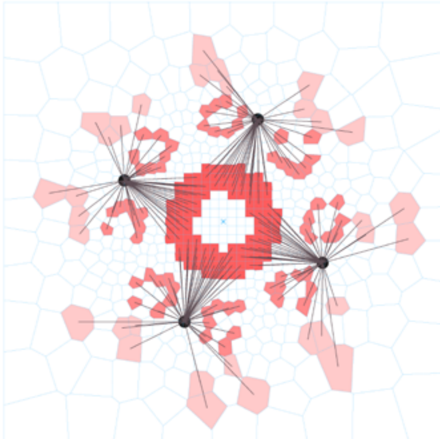
1 facility



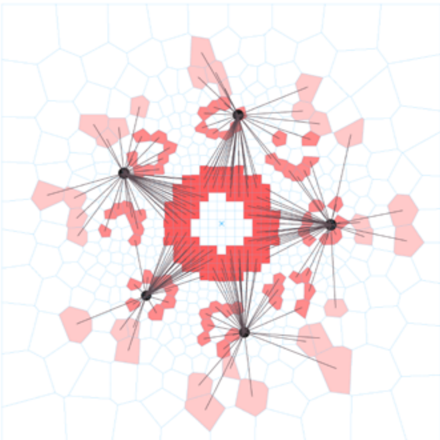
2 facilities



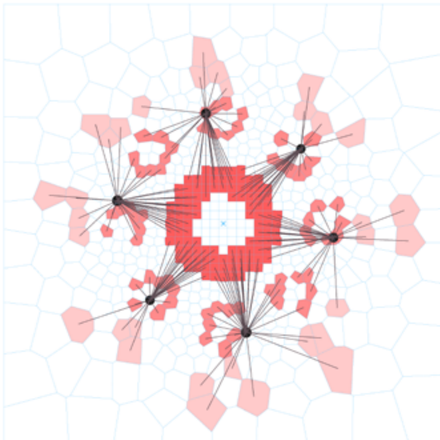
3 facilities



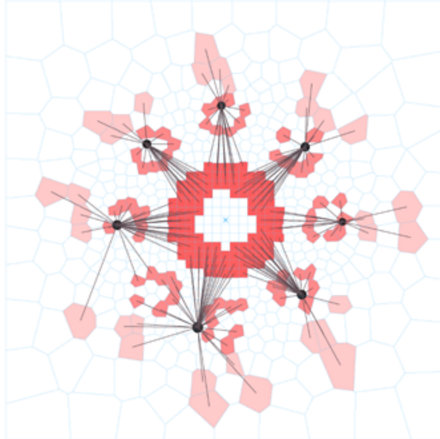
4 facilities



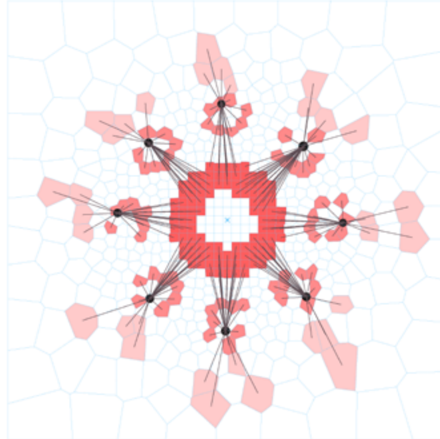
5 facilities



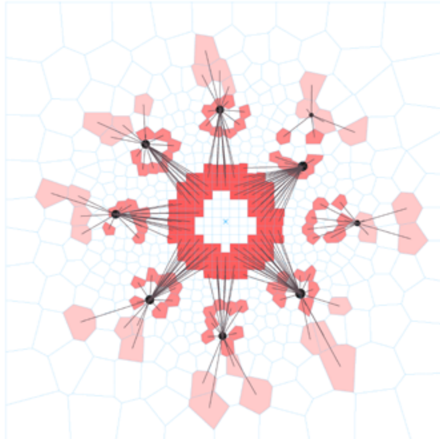
6 facilities



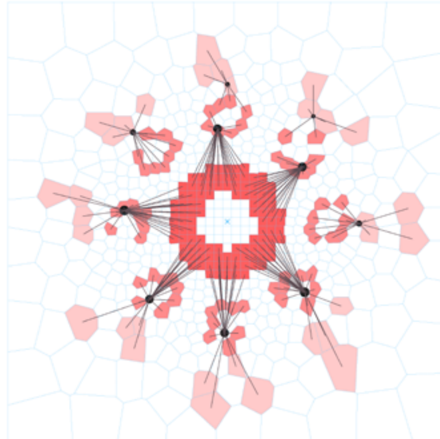
7 facilities



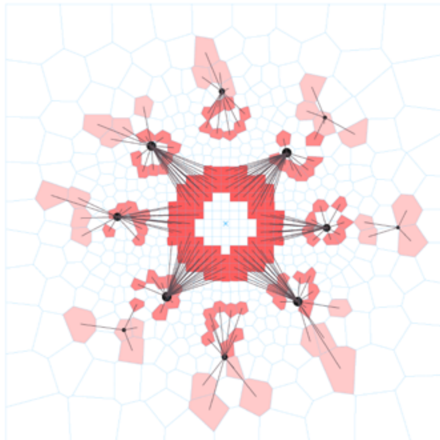
8 facilities



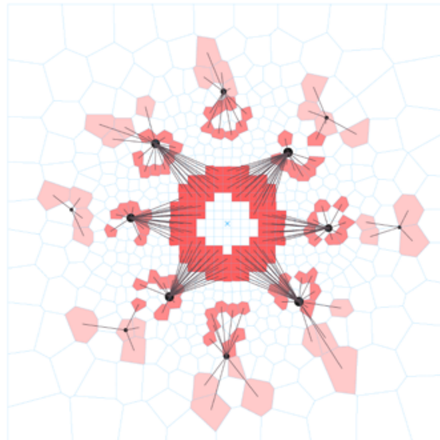
9 facilities



10 facilities



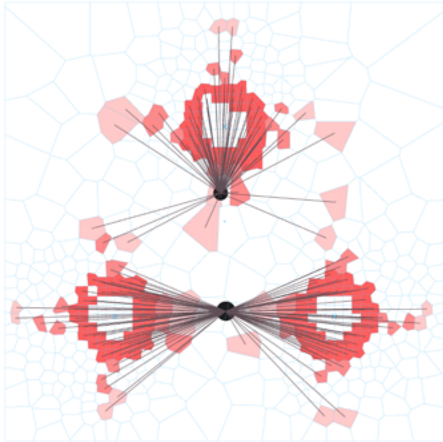
11 facilities



12 facilities

3. Polycentric Centralised


1 facility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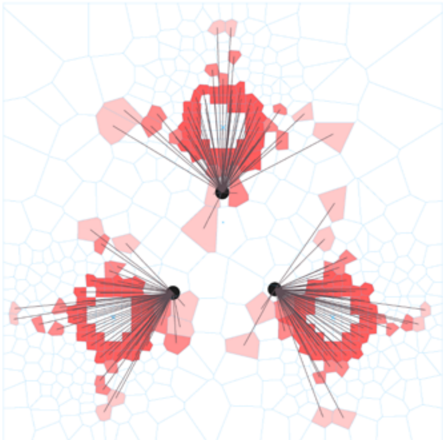
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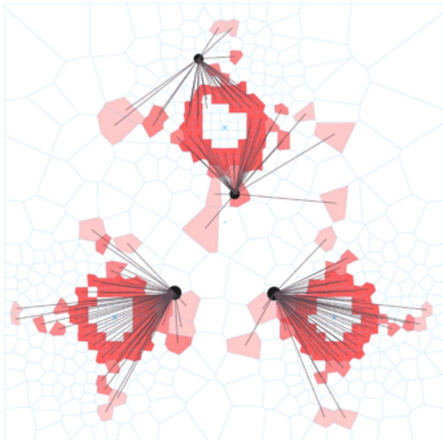
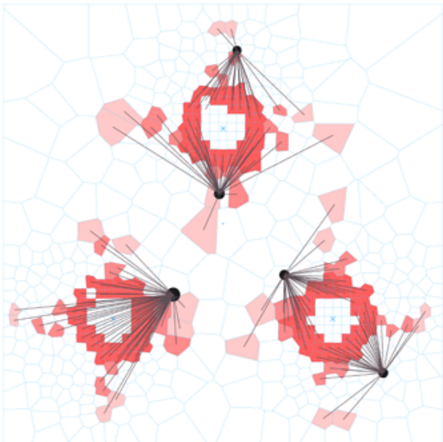

4 facilities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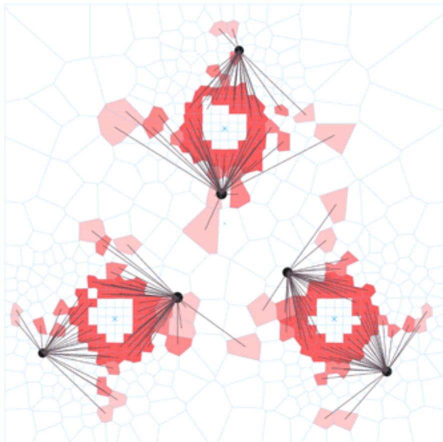
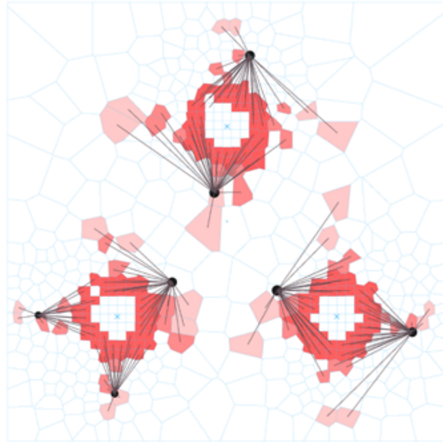
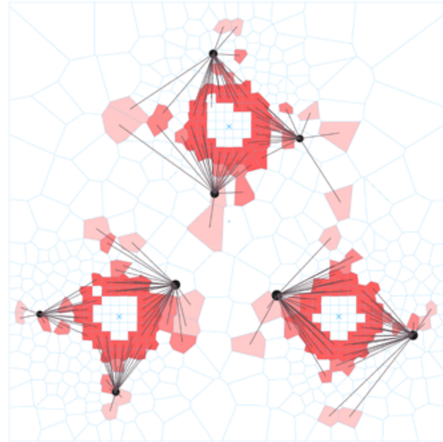
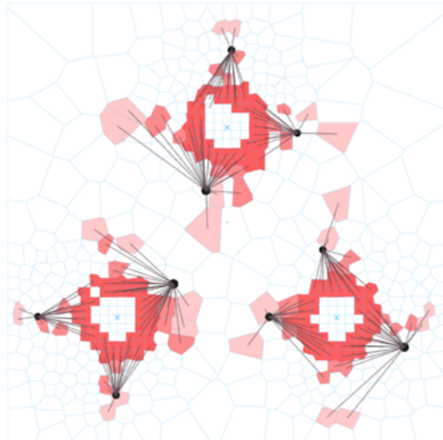
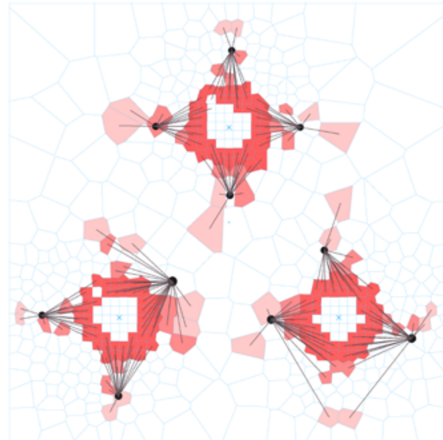
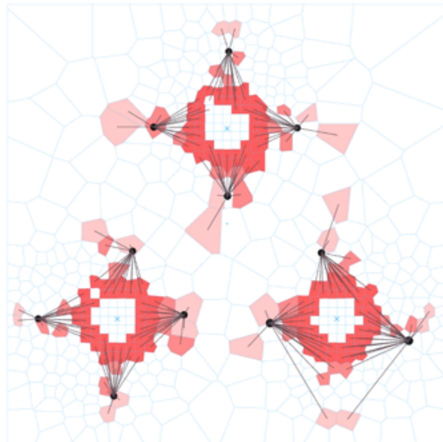

6 facilities

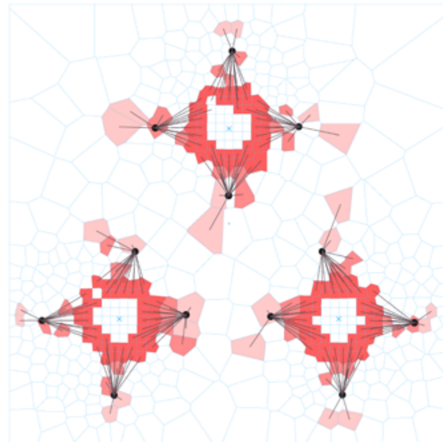

7 facilities


8 facilities

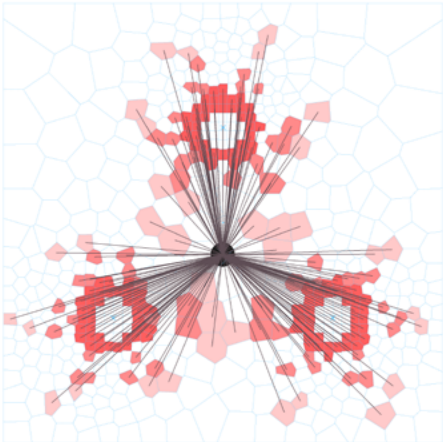

9 facilities


10 facilities

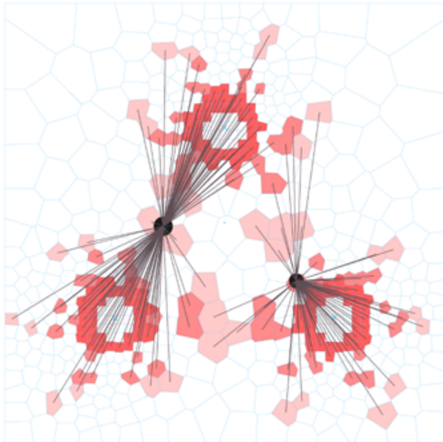

11 facilities


12 facilities

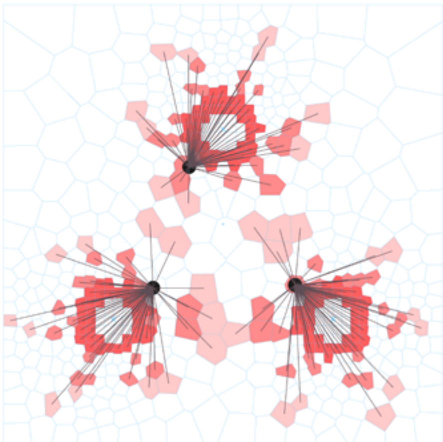
4. Polycentric Dispersed



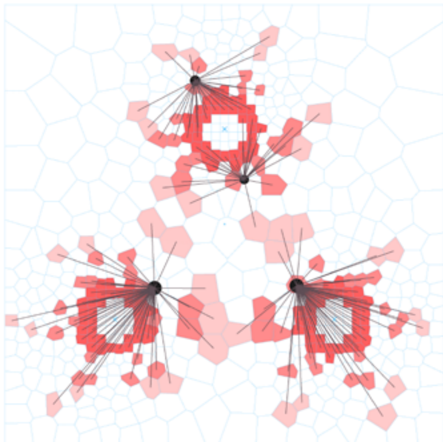
1 facility



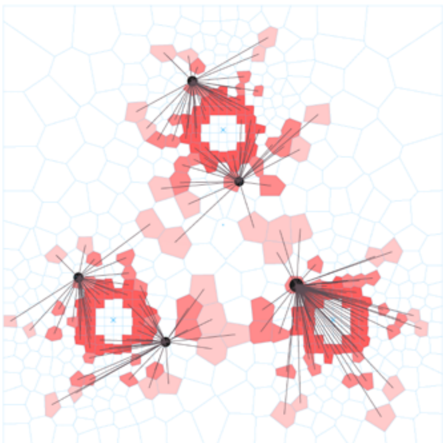
2 facilities



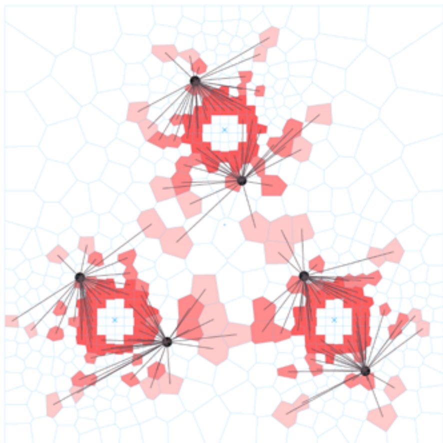
3 facilities



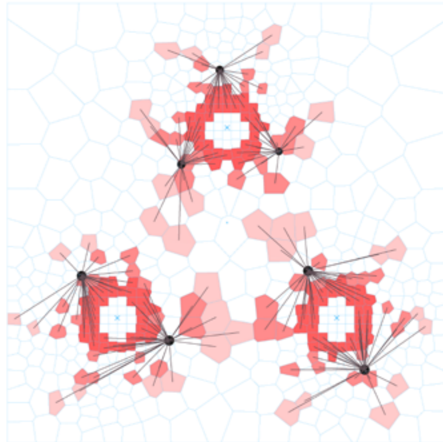
4 facilities



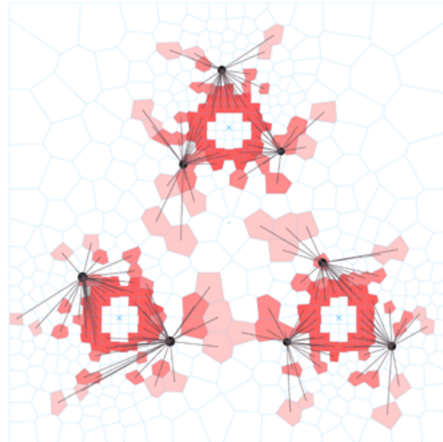
5 facilities



6 facilities



7 facilities



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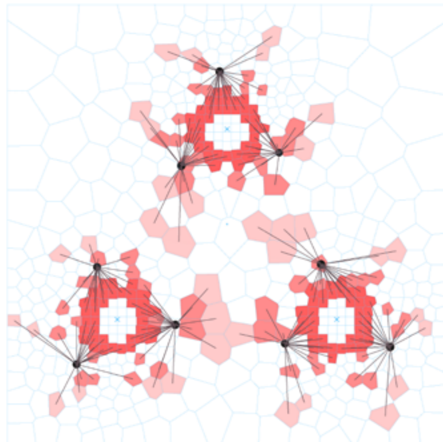
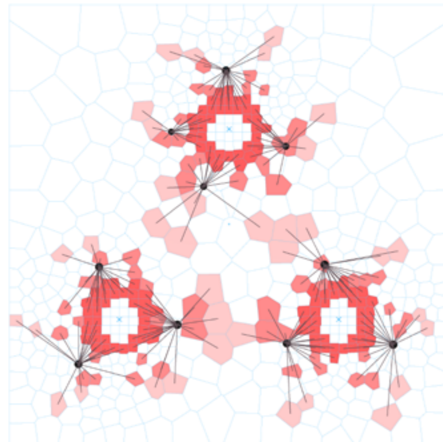
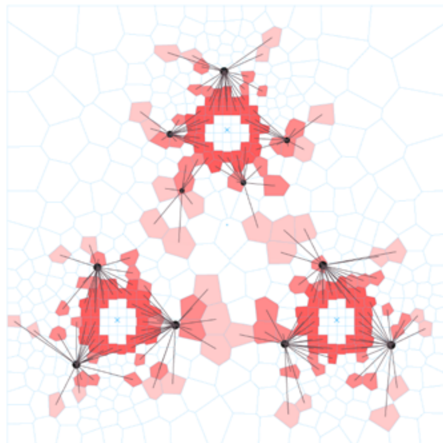


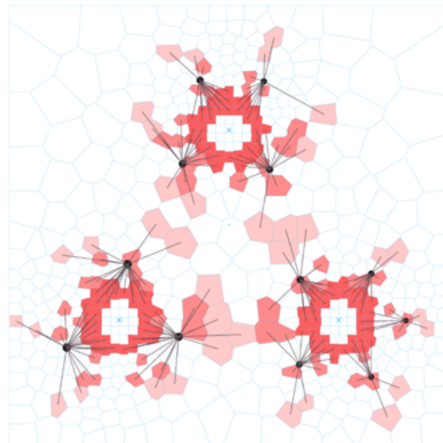
9 facilities



10 facilities

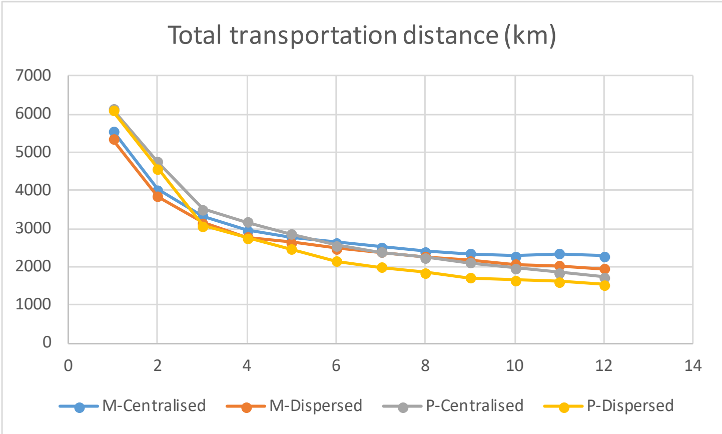


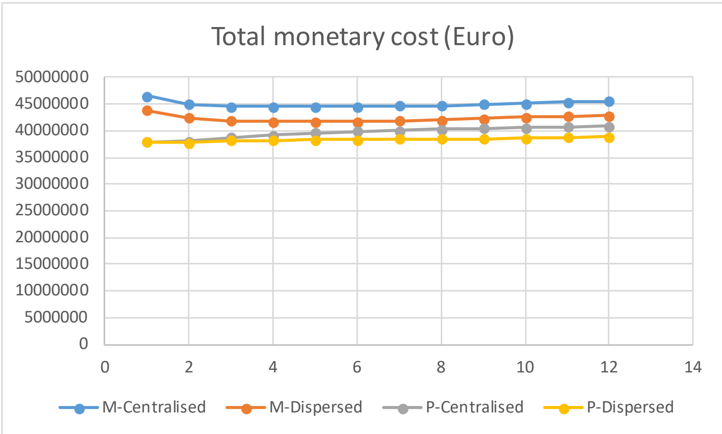
11 facilities

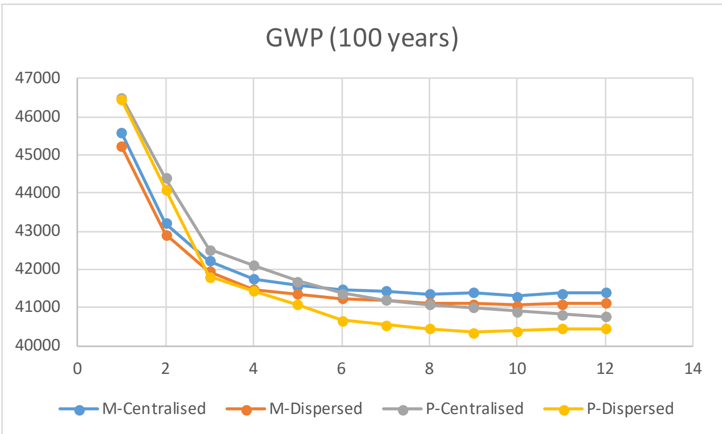


12 facilities

5. Evaluation of performance

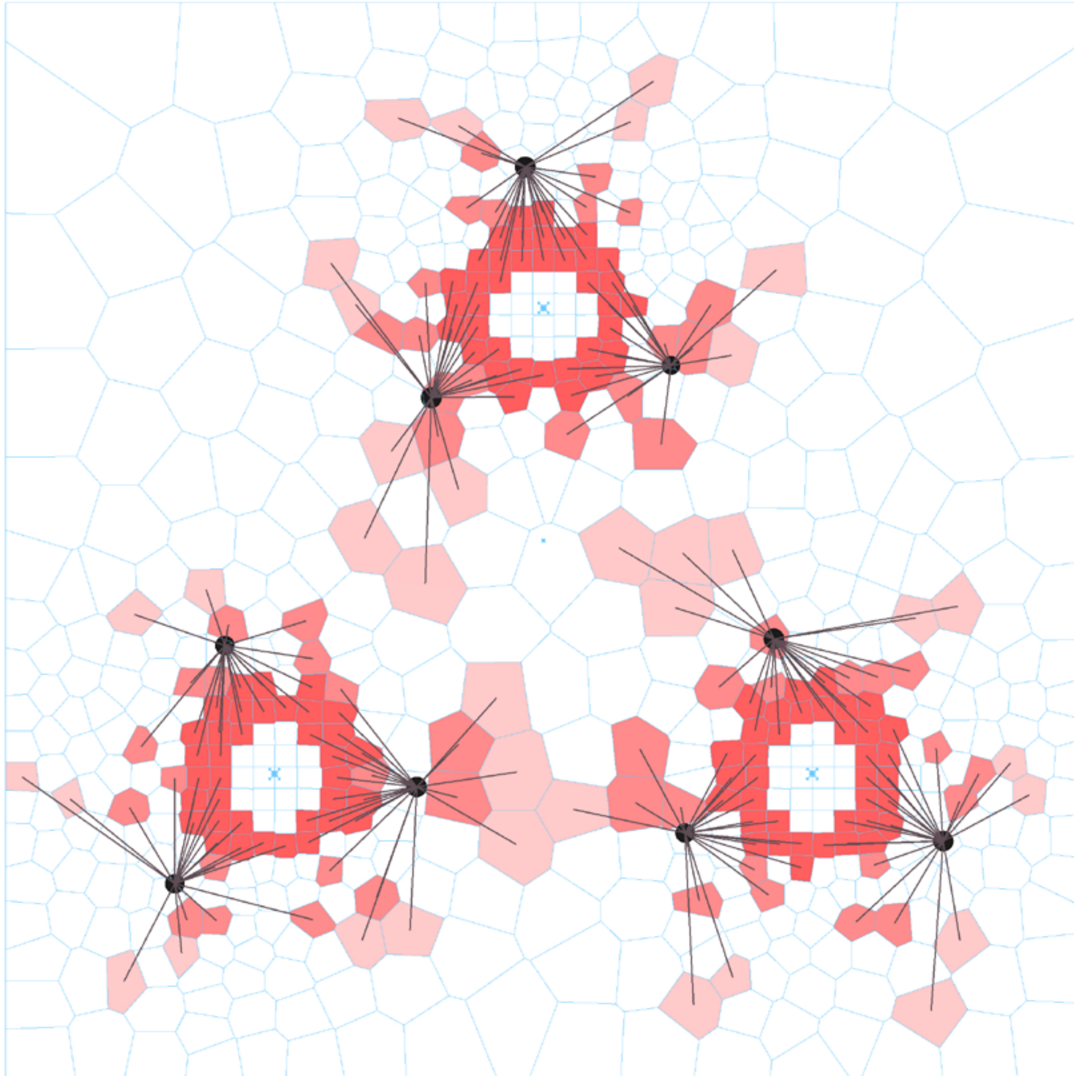






These charts are the analysis for the optimised model. During this optimisation, the goal is to find the best balance between monetary cost and ecological cost. This set of line charts shows that when there are more than three facilities, the polycentric dispersed model is the most cost-efficiency platform for allocating MRF. In the polycentric dispersed model, using nine facilities to serve the entire territory is the best balance.

6. Champion: 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.

At this stage, the general model has been finished, which is the essential part of research in this project. By analysing some empirical statistics, an optimum situation has unveiled itself. There are several conclusions, which may have the potential to assist in the process of urban planning and decision-making.

First, in a territory with the same area and total population, the polycentric spatial structure requires more investments of infrastructure than the monocentric structure. However, the benefits of polycentric are significant. When a metropolitan area has more than three centres, the distributions of utilities, residential blocks and infrastructures are more evenly. That leads to a better situation for allocating the MRFs. In this case, the total transporting distance of collecting MSW is smaller than monocentric model when more than three MRF servicing the whole territory. Therefore, the MRFs in a polycentric model could make a minimal impact on the environment than the monocentric model. Moreover, the polycentric-dispersed model is the optimum.

Due to the reason that in the polycentric metropolis, other centres have mitigated the importance of the city centre, the land price is slightly lower than the city area in the monocentric model. More interestingly, the area in the middle of two centres has a weak relationship with the distance to the city centre. Therefore, the land price for those areas is significantly low, and at the same time, it obtains the advantage of the proximity to the city centre. Thus, the middle area among several centres is the perfect location for MRFs, since the cheap land, not very far away from the city centre but far enough to the residential areas. Also, the results of all the final calculation prove that the polycentric-dispersed model has the smallest monetary cost. That could conclude the research that the optimum spatial structure for allocating the MRFs is the polycentric-dispersed model not matter in the perspective of ecological cost or the economic cost.

The second finding is that in the optimum model, each centre needs at least three facilities to cover the whole area. Moreover, three facility is the most cost-efficient way because it forms a triangle of the tangent of a circle.

Thirdly, finding the best location of the facility is a process of presuming the balance of land price and transport distance. In general, in a remote area, the land price is meagre than city centres, but it is impossible to put all the facilities as far as possible to the centre due to the increase of the transport distance. The previous study shows that the land price strongly determines the total monetary cost while the transport distance influences the ecological cost. Therefore, the final optimum model is a result when the economic and ecological aspects have an equal weight of importance. In this case, all the facilities should site 12 kilometres away from the city centre. If the weight of economic cost is increasing, those facilities should have a substantial distance to the city centre than 12km, maybe 15km or 20km. When from the ecological point of view, which means the land price, those facilities should be near the centre to minimise the transport distance.

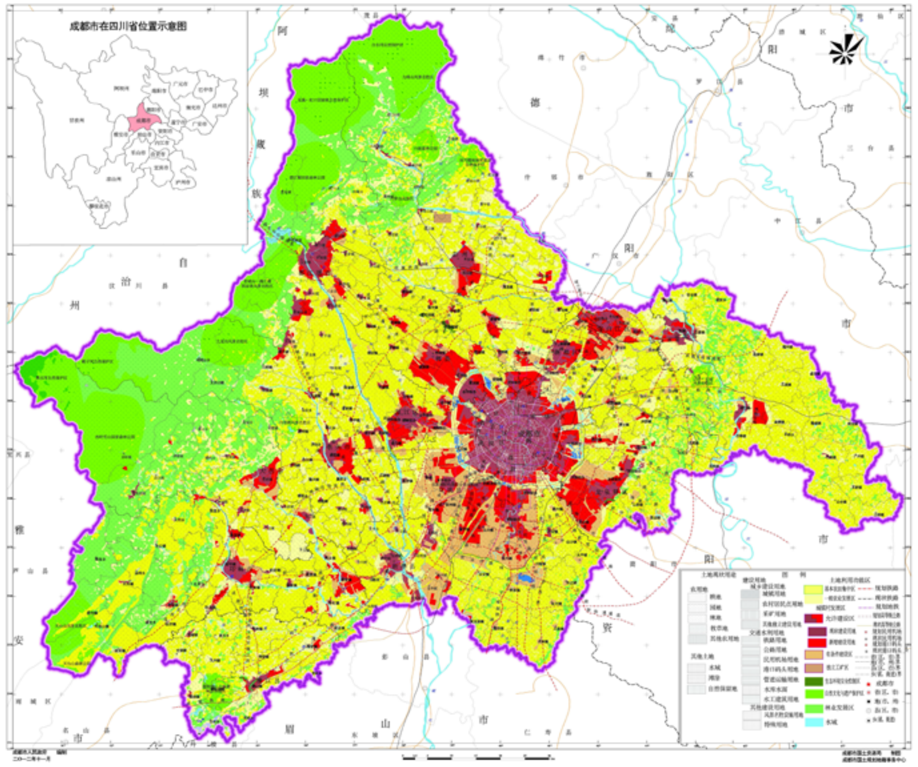
All the findings stated above are the conclusions from a general model, which is impossible in reality. However, it is still quite useful to make some suggestions for decision-making. In the real world, even a tiny city has a much more complicated situation than this abstract model. Moreover, most of the existing cities have a long history and it already embedded in the urban fabric. Therefore, when applying this general model or this workflow in a real situation, finding the optimum spatial structure and facilities configuration has a small chance. Nevertheless, it is feasible for optimising the existing situation based on all the current conditions. Next chapter is about how to apply this model in a real situation, in the case of Chengdu.

06
OPTIMISING THE EXISTING SITUATION

APPLYING THE GENERAL MODEL IN CHENGDU

06.1 MODELLING THE EXISTING SITUATION

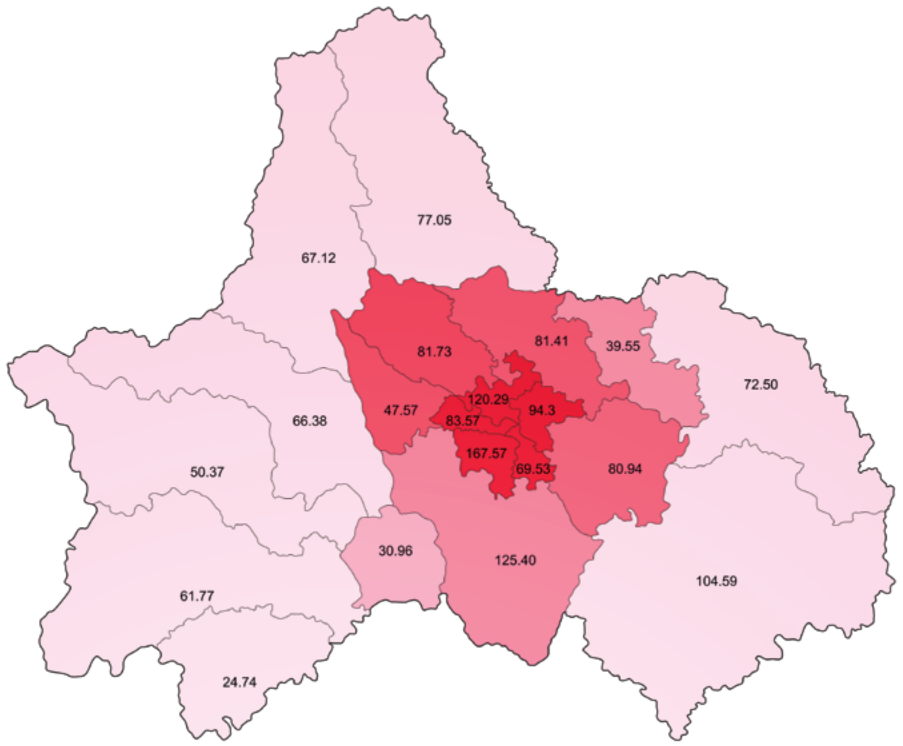
1. Land use of Chengdu



Source: The bureau of land and resources Chengdu. http://www.cdlr.gov.cn/Detail.aspx?ID=52414&ClassID=001002001007001001

Urban area
Farm land
Forest

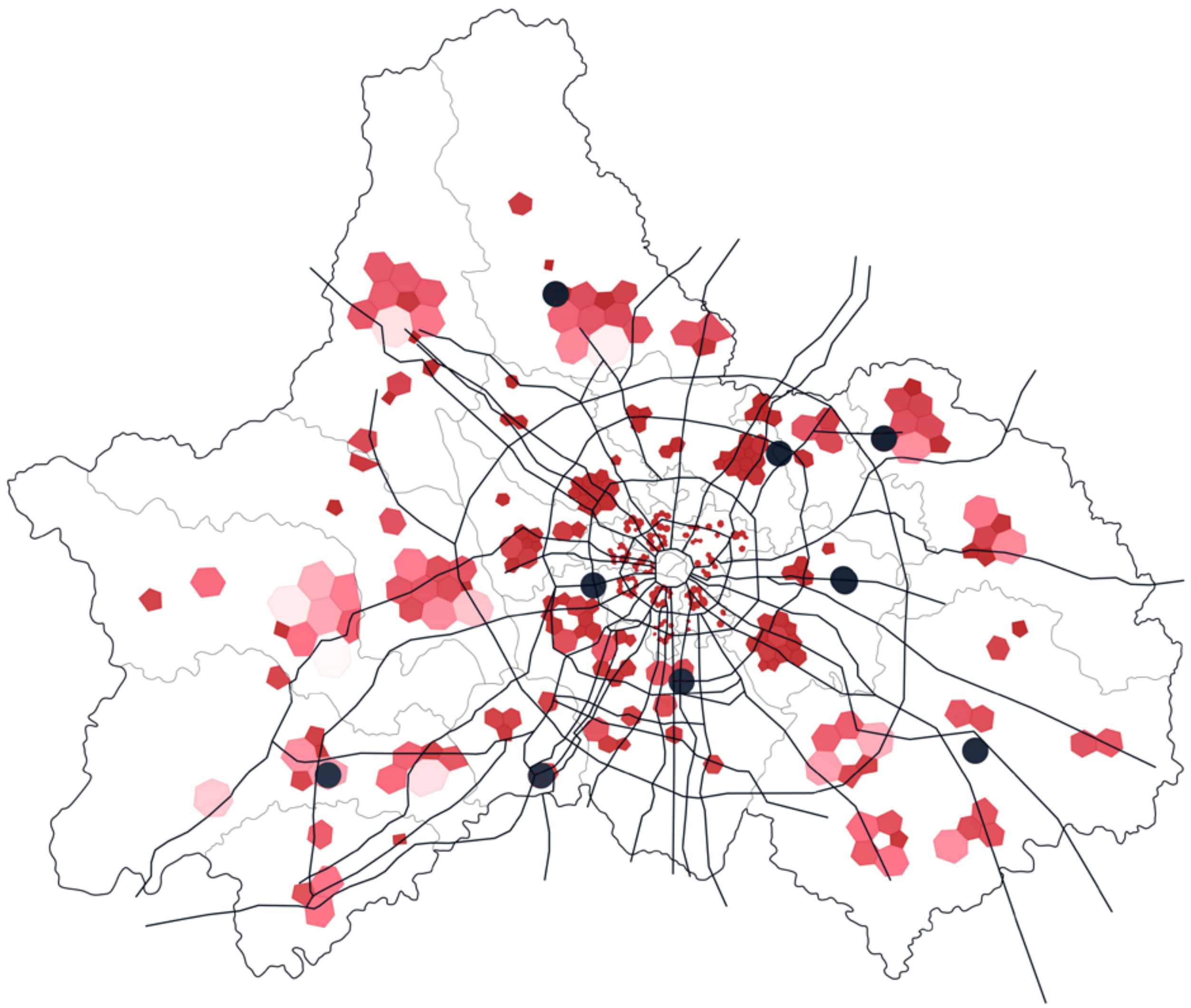
2. Population and density



Source: Chengdu statistic yearbook,2016

1 unit= 10000 people

3. Modelling the existing situation



1 RD cell contains 50,000 people

Residential Blocks
Infrastructure
Existing Waste facility

Before applying the general model on Chengdu, the existing information regarding the current residential blocks and infrastructures need to be picked. Those newly inputs modified the model environments and formed an updated model for the following study.

The first map on the left page shows the current land use published by 'The Bureau of land and resources Chengdu'. All the red area indicates the land for urban development where about 30% are the residential blocks. The rest of land is for agriculture activities and forest preservation. In the following work, all the residential cells are being put around those red-colour areas to respect the reality.

The second map shows the population and density for different districts in Chengdu metropolis. The city centre is hosting 71.6% population. Although, the urban planning for 2030 is aiming to achieve the polycentric urban structure; the current situation is that the city centre is dominating the whole areas at various levels. For modelling the existing situation, the population should be converted into the same unit as the previous model, which is 50,000 people per residential cell. The results are visualised in the map above.

This time, the calculation of transport distance is based on the existing infrastructure which are the thick black lines in the map above. Moreover, the black dots represent the current facilities related to the waste processing industry.

06.2 UPGRADES FOR MODEL

1. Bugs encountered

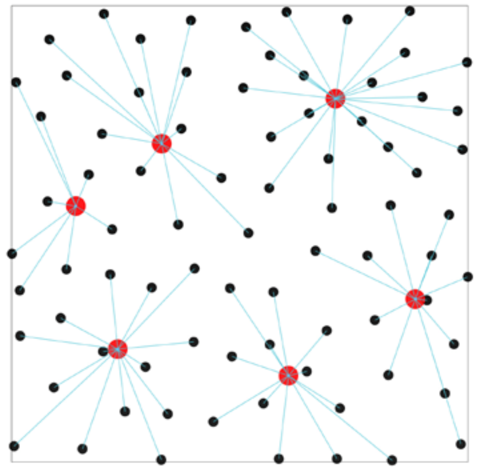


Figure 26

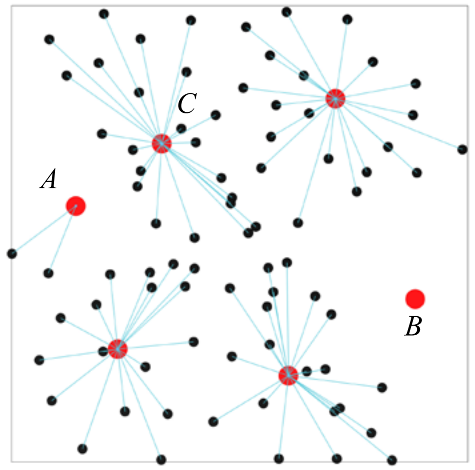


Figure 27

2. Finding the shortest path

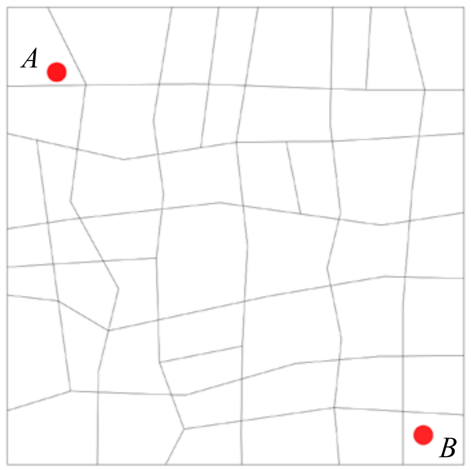


Figure 28

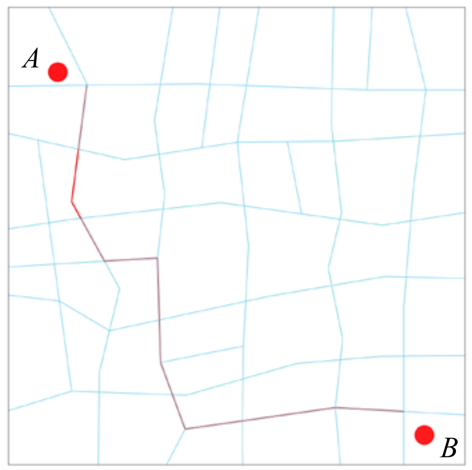


Figure 29

When applying the general model in Chengdu which has a specific condition, there are two critical problems surfaced. The code in general model defined an approach to find the nearest facility for each residential block. Figure 26 is a simple example of this process where the black dots representing the residential blocks and the red larger dots are the facilities. Blue lines indicate the relationship between the residential block and facility. In this diagram, all the black dots are evenly distributed with a rectangle; all the facilities serve a certain amount of residential blocks. However, in the model of Chengdu, the distribution of residential blocks is not evenly, which exposes two severe problems. Figure 27 shows the problem: when the black dots are not evenly distributed in the same rectangle, there are some situations that not a single or just a few black dots are connecting some unlucky red points, such as point A and B. At the same time, lots of black dots are linking to point C.

Those two problems significantly affect the process of finding the best locations. One is that the capacity of each facility is always different in an exceeding manner, such as one facility controls 60 blocks while another only serves two blocks. This fact increases the uncertainty and makes it harder for analysis. The second problem is the inputs number of facilities always is different from the results. For example, if the parameter of facility number is 12, the results sometimes only eight facilities are valid.

During the upgrades stage, the coding language of Python is used to overcome the mentioned problems. Finally, the model could control if all the facilities have the same capacity or not. Moreover, the number of valid facilities is always the same as the input.

The second significant improvement is about the transport distance. In the general model, all the transport distance are calculated by measure the length of the straight lines between facilities and blocks. In the model of Chengdu, the transport distance is the actual distance based on the existing infrastructure. Figure 28 and 29 demonstrate how to find the shortest path within a street network. For example, if a cat wants to use this street network to travel from point A to B, the red line is the shortest routes.

The next section is about the optimising model regarding the configuration of facilities. The work of optimising comprises two parts. In the first part, all the facilities have the same capacity, which eliminates the variables when facilities have different capacities. In this method, the analysis could quickly get some conclusions. Therefore, three different goals are being used for optimising. The first objective is to find a spatial configuration of MRFs where could have the minimal economic cost which is the addition of land cost, construction cost, electric cost, equipment cost and diesel cost. The second objective is to minimise the ecological cost which is measured by GWP. The last goal is to find a balance where the economic and ecological costs are both lower than before. In this 'balance' model, the monetary and ecological cost have equal weight. The results will be demonstrated in next section.
However, the drawback of the situation that all the facilities have the same capacity is apparent. First, this situation will never become a reality due to the complex of existing city. Second, when the residential blocks are arranged chaotically, it is not cost-efficient when all the facilities have the same processing ability. In this scenario, it is more reasonable if the capacity of the facility is determined by how many residential blocks are near this facility. That will lead to a result that each MRF has a unique number of capacity, which is the primary method in the second part of optimising.

06.3 RESULTS OF OPTIMISING MODEL(SAME CAPACITY)

1. Objective: minimal economic cost

1 Facility


direct links


used infrastructure

2 Facilities


direct links


used infrastructure

3 Facilities


direct links


used infrastructure

4 Facilities


direct links


used infrastructure

1. Objective: minimal economic cost

5 Facilities


direct links


used infrastructure

6 Facilities


direct links


used infrastructure

7 Facilities


direct links


used infrastructure

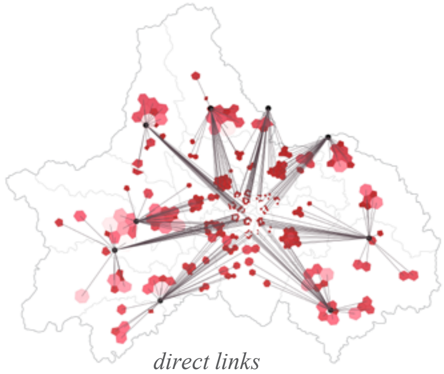
8 Facilities


direct links

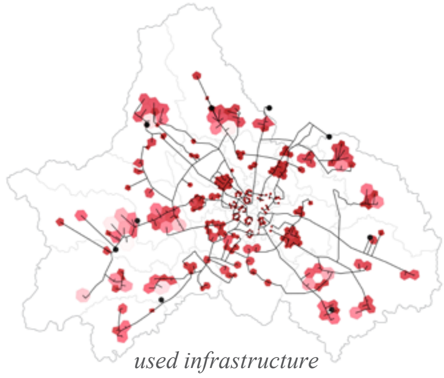

used infrastructure

1. Objective: minimal economic cost

9 Facilities

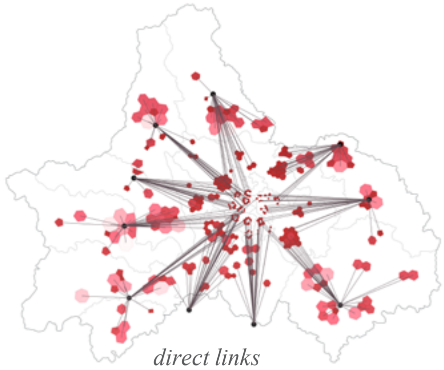


direct links

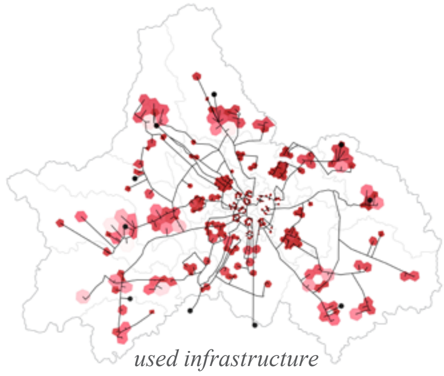


used infrastructure

10 Facilities



direct links



used infrastructure

11 Facilities

direct links

used infrastructure

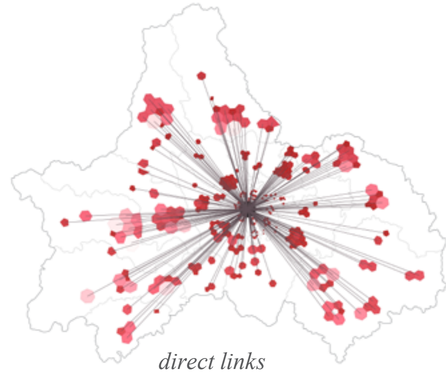
12 Facilities

direct links

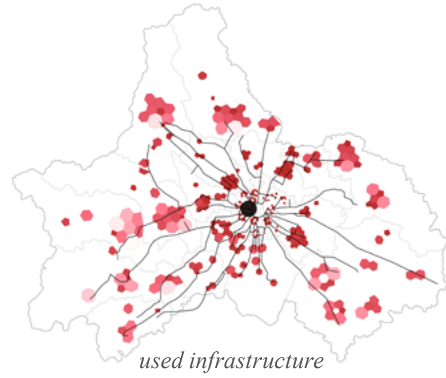
used infrastructure

2. Objective: minimal ecological cost

1 Facility

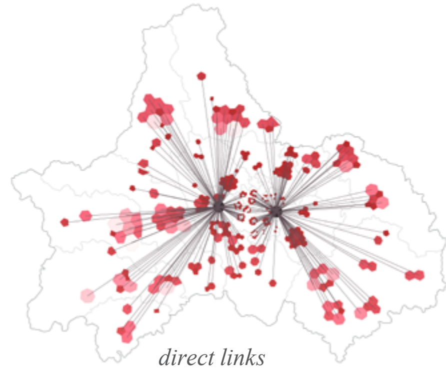


direct links

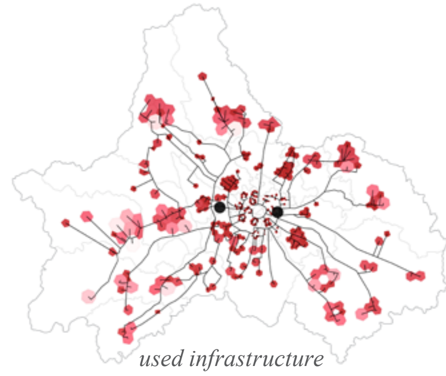


used infrastructure

2 Facilities



direct links



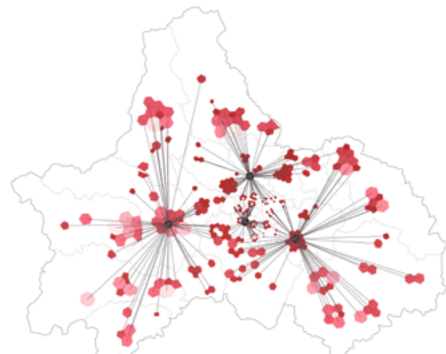
used infrastructure

3 Facilities

direct links

used infrastructure

4 Facilities



direct links

used infrastructure

2. Objective: minimal ecological cost

5 Facilities


direct links


used infrastructure

6 Facilities


direct links


used infrastructure

7 Facilities


direct links


used infrastructure

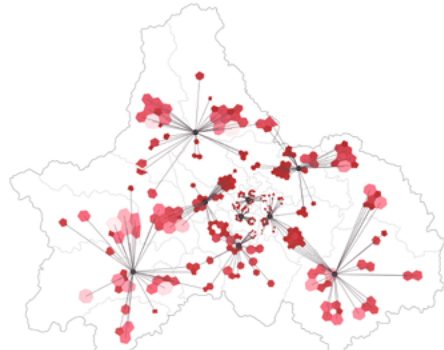
8 Facilities


direct links


used infrastructure

2. Objective: minimal ecological cost

9 Facilities


direct links

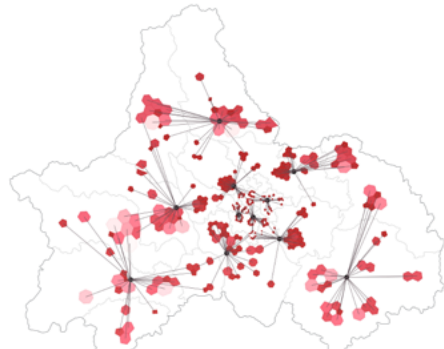

used infrastructure

10 Facilities


direct links


used infrastructure

11 Facilities


direct links


used infrastructure

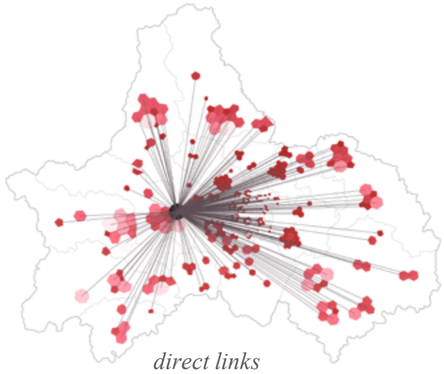
12 Facilities


direct links

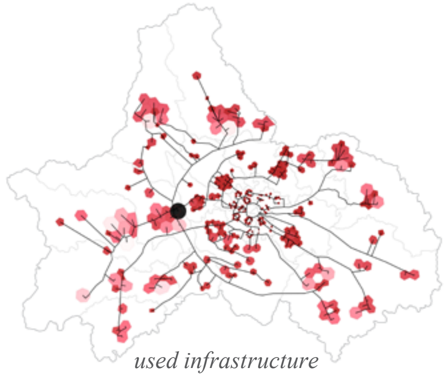

used infrastructure

3. Objective: equal weighted

1 Facility

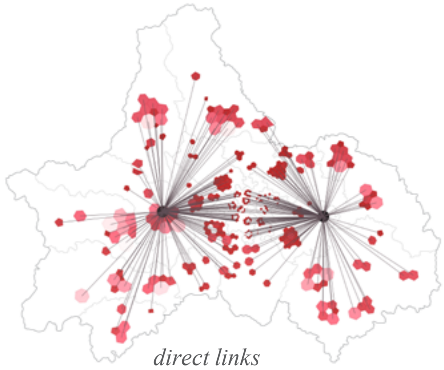


direct links

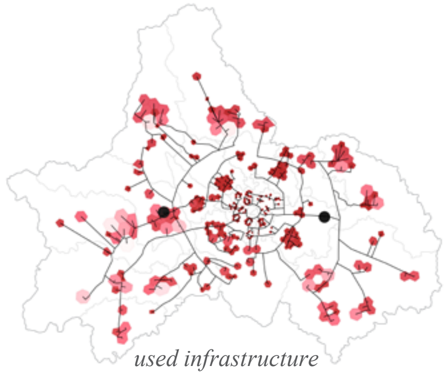


used infrastructure

2 Facilities

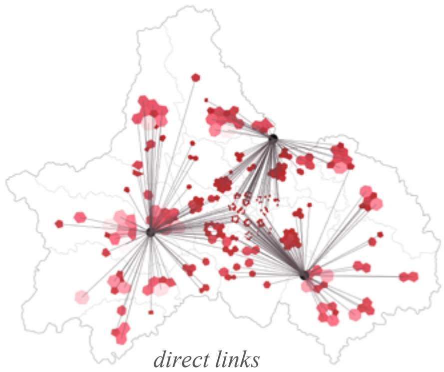


direct links

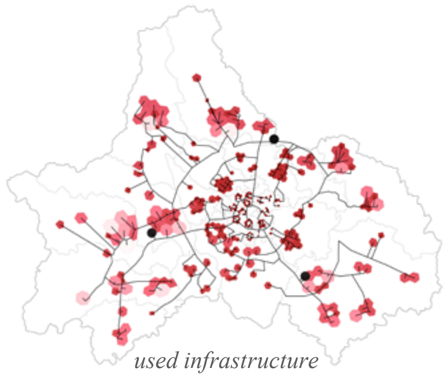


used infrastructure

3 Facilities

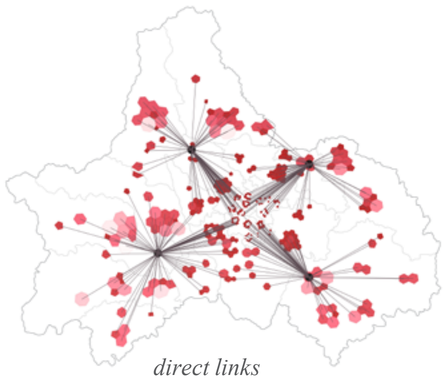


direct links



used infrastructure

4 Facilities



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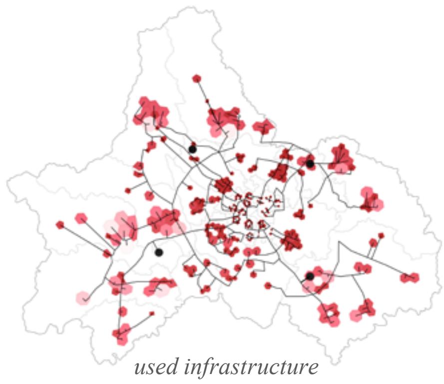
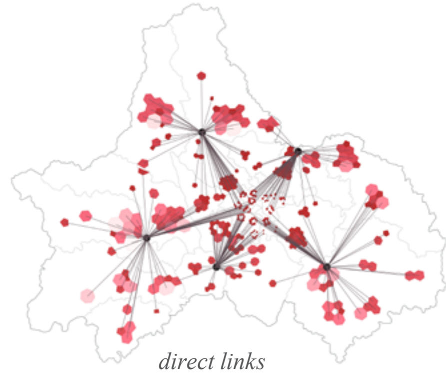


used infrastructure

3. Objective: equal weighted

5 Facilities



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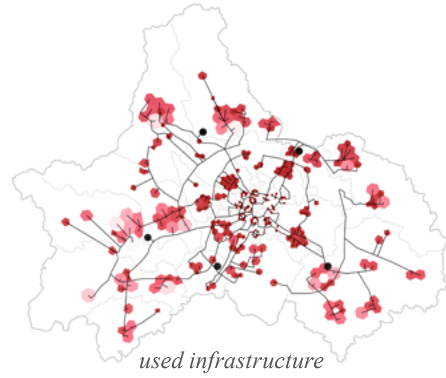
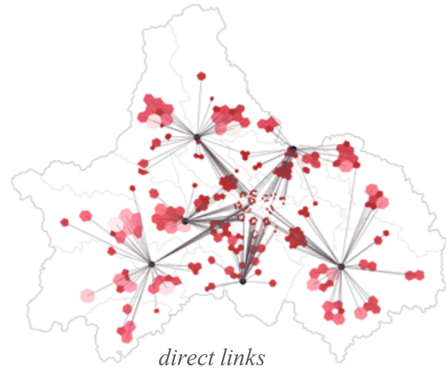


used infrastructure

6 Facilities



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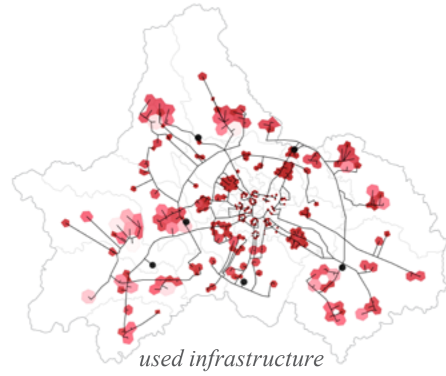
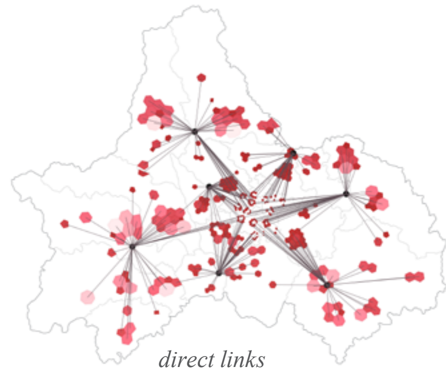
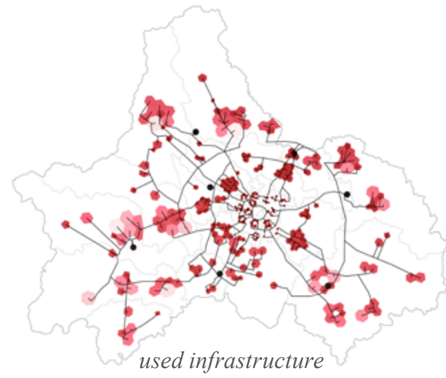


used infrastructure

7 Facilities

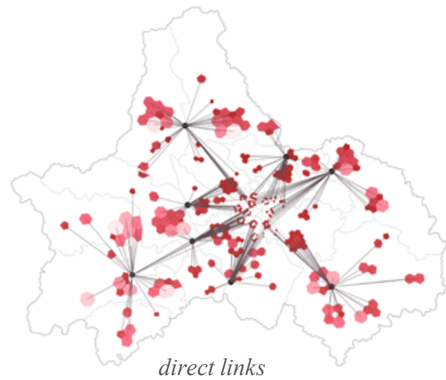


direct links



used infrastructure

8 Facilities



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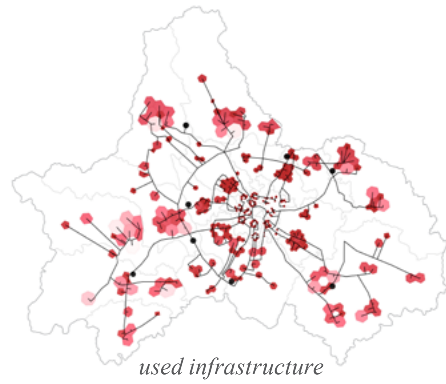
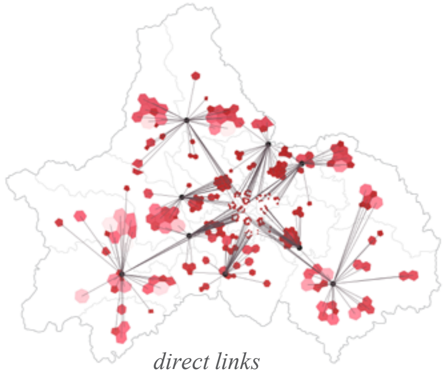


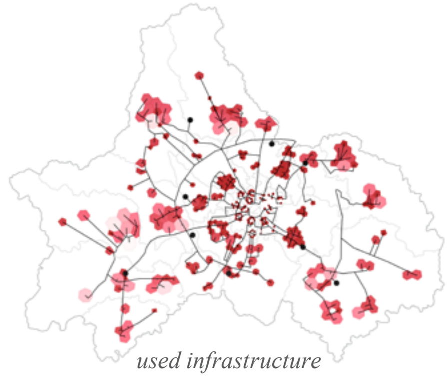
used infrastructure

3. Objective: equal weighted

9 Facilities

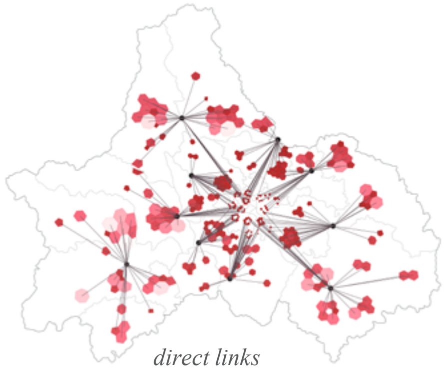


direct links

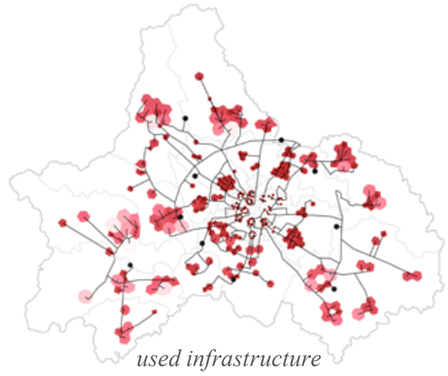


used infrastructure

10 Facilities

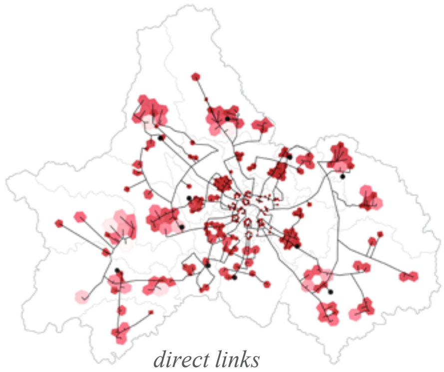


direct links

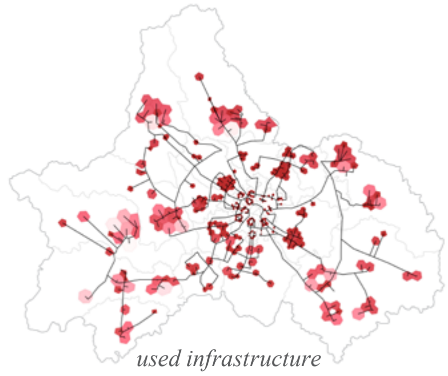


used infrastructure

11 Facilities

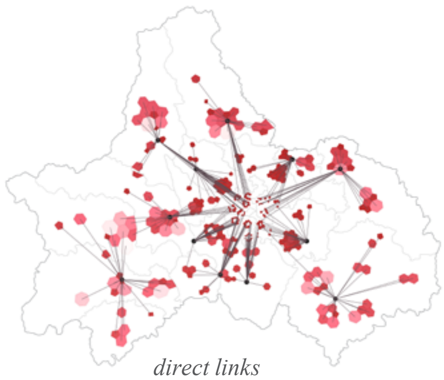


direct links

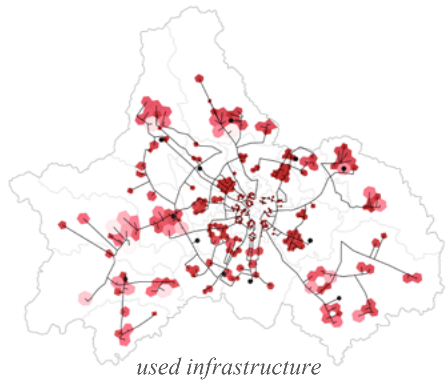


used infrastructure

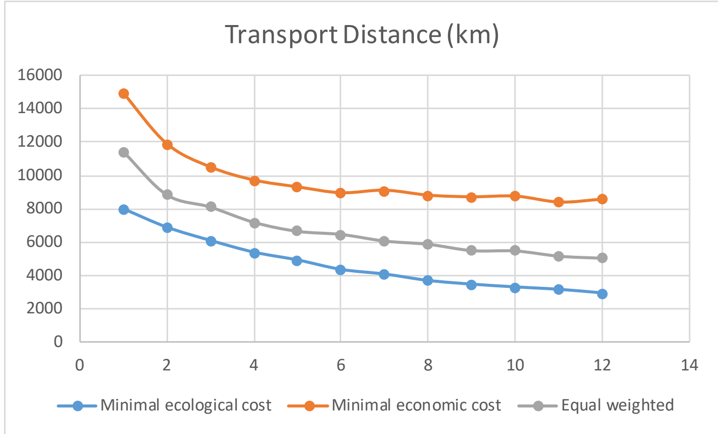
12 Facilities



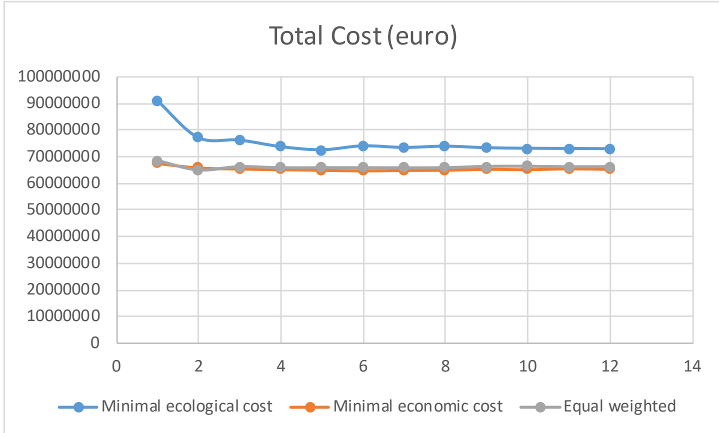
direct links



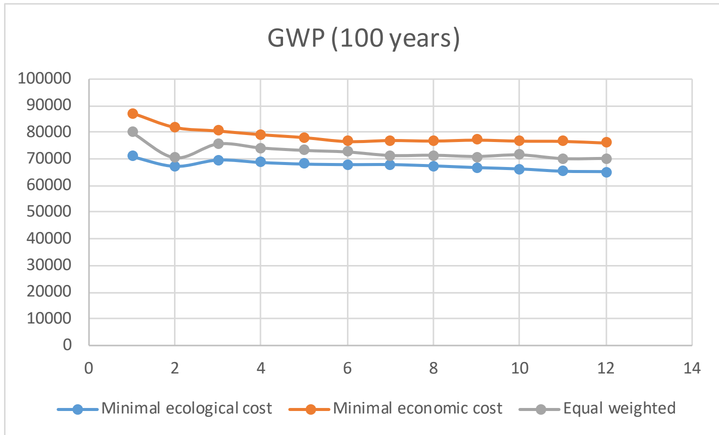
used infrastructure



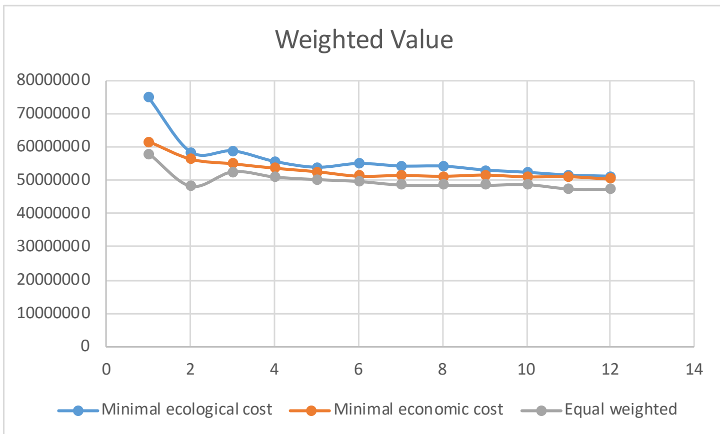
Because the transporting of waste generates tons of greenhouse gases, minimising the ecological cost equals minimising the total transport distance. The left chart shows when set the objective of optimising as the minimal ecological cost, the total transport distance is always shorter than that scenario that the economic cost is the most important. When the number of facilities increase, the total distance of transporting decreased. In this case, the configuration of 12 facilities is the best situation.



However, when minimising the transport distance, some facilities are way near the city centre where has a high land price. Therefore, when the objective is to reduce the ecological cost, the monetary cost is increasing dramatically.



The results of ecological cost have the same trend as the transport distance. When the objective is to reduce the economic cost, all the facilities are trying to locate as far as possible to the city centre to harness the advantage of the cheap land in remote areas. That is the reason that if we want to reduce the economic cost, the ecological cost will increase correspondingly.



In reality, finding the best location always involve the work of balancing the land price and transport distance. In this project, the best locations or configurations of facilities have to balance the economic cost and the ecological cost.

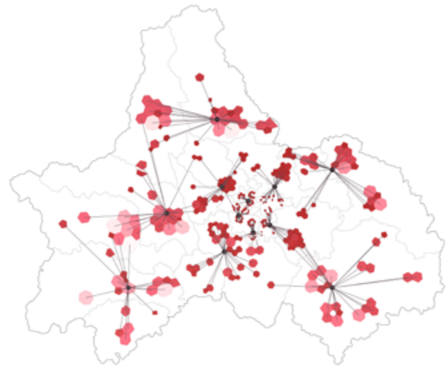
Conclusion One

Champion from the economic perspective

6 Facilities

Champion from the ecological perspective

12 Facilities



Champion from a balanced perspective

12 Facilities

06.3 RESULTS OF OPTIMISING MODEL(VARIOUS CAPACITY)

Objective: equal weighted

1 Facility

direct links

used infrastructure

2 Facilities

direct links

used infrastructure

3 Facilities

direct links

used infrastructure

4 Facilities

direct links

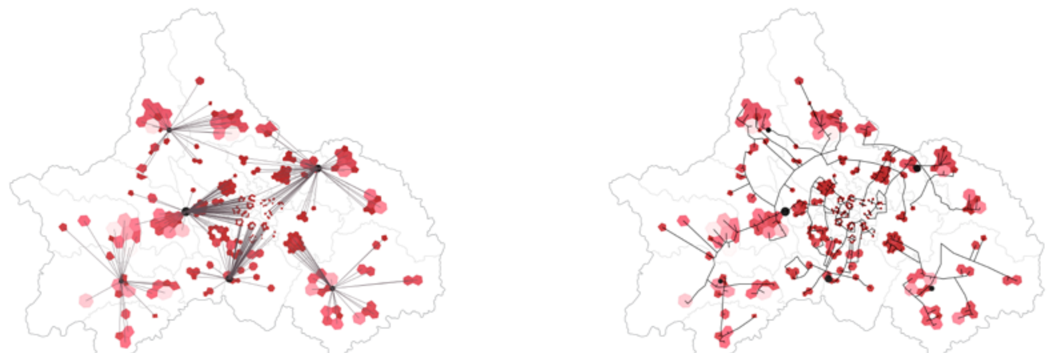
used infrastructure

Objective: equal weighted

5 Facilities

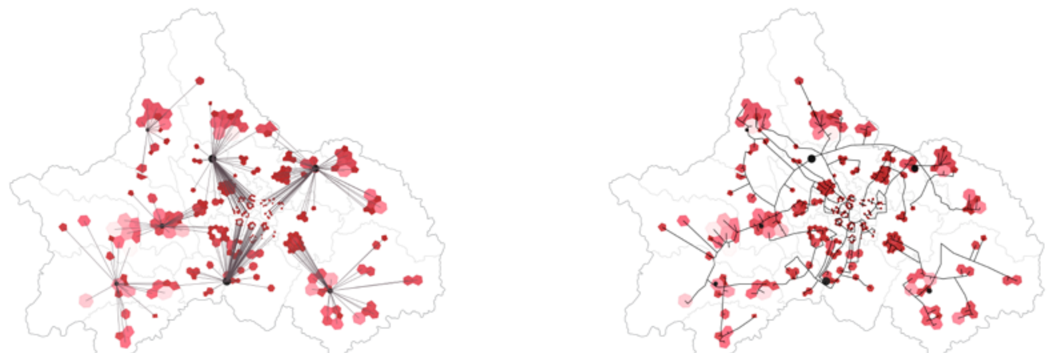
direct links — *used infrastructure*

6 Facilities



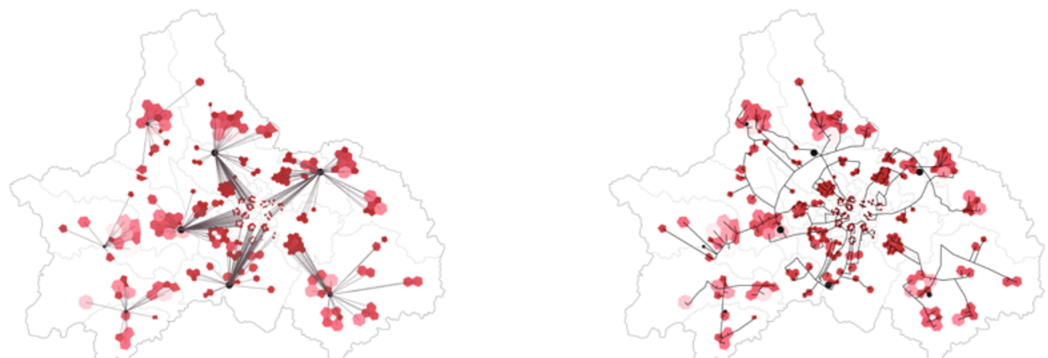
direct links — *used infrastructure*

7 Facilities



direct links — *used infrastructure*

8 Facilities



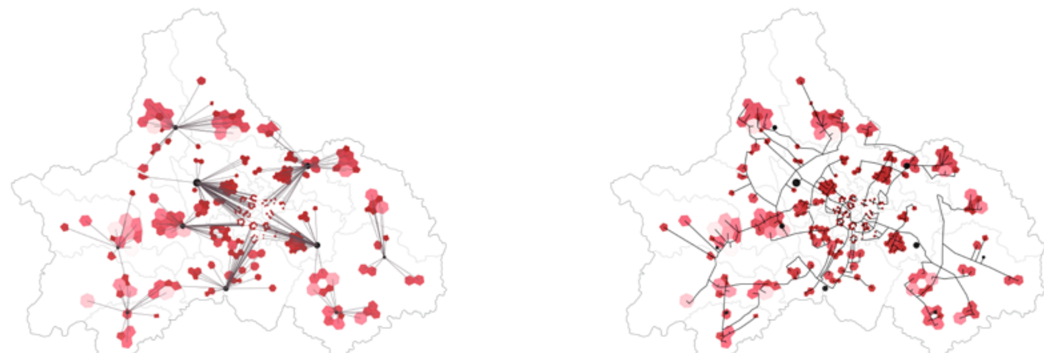
direct links — *used infrastructure*

Objective: equal weighted

9 Facilities

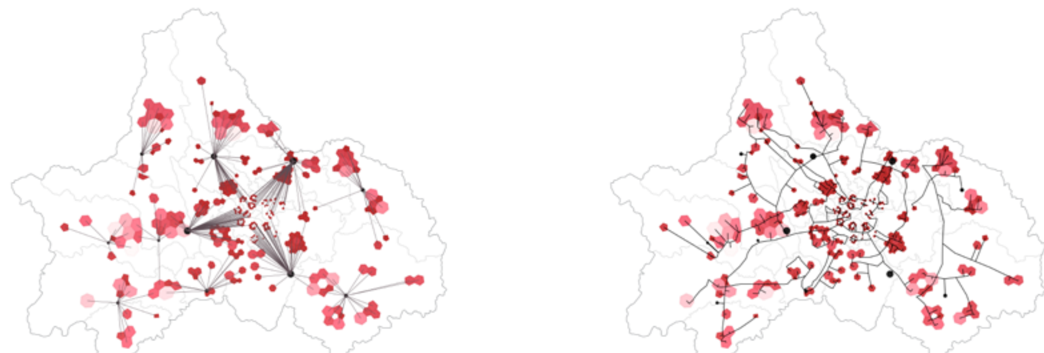
direct links — *used infrastructure*

10 Facilities



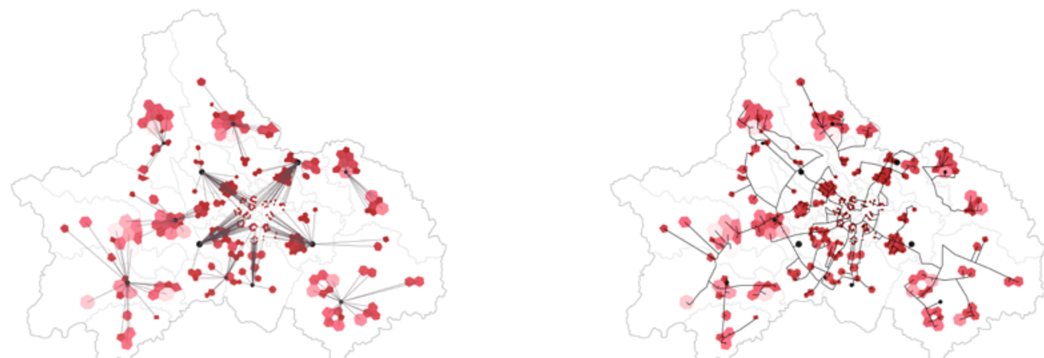
direct links — *used infrastructure*

11 Facilities



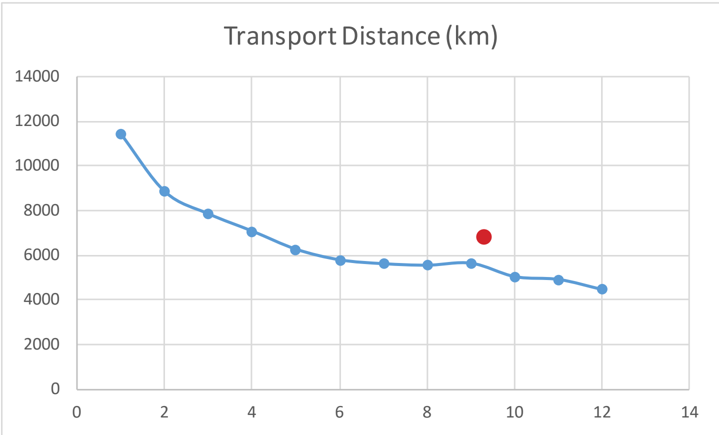
direct links — *used infrastructure*

12 Facilities

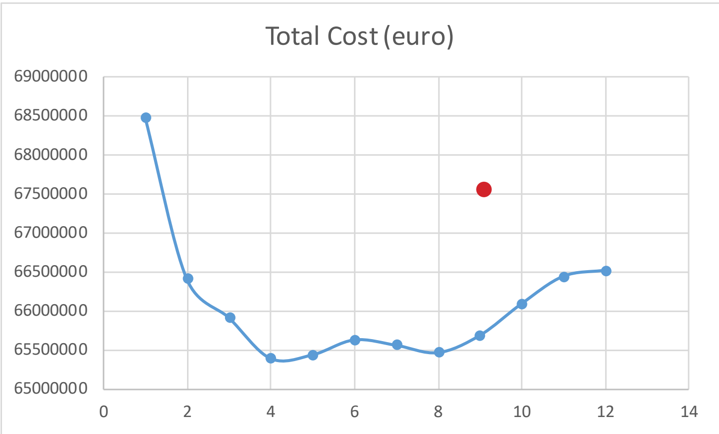


direct links — *used infrastructure*

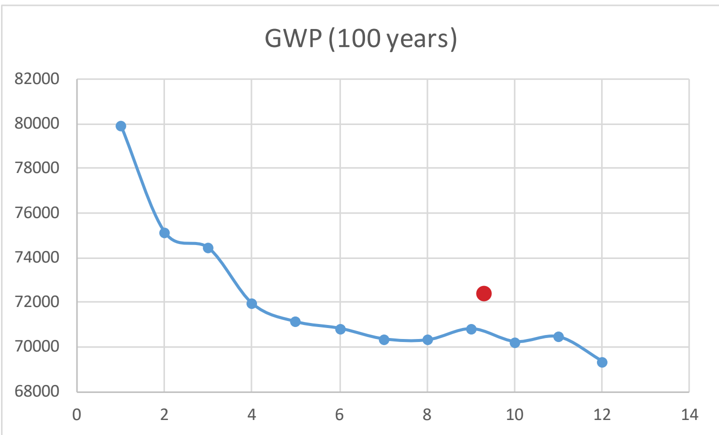
Analysis and Discussion



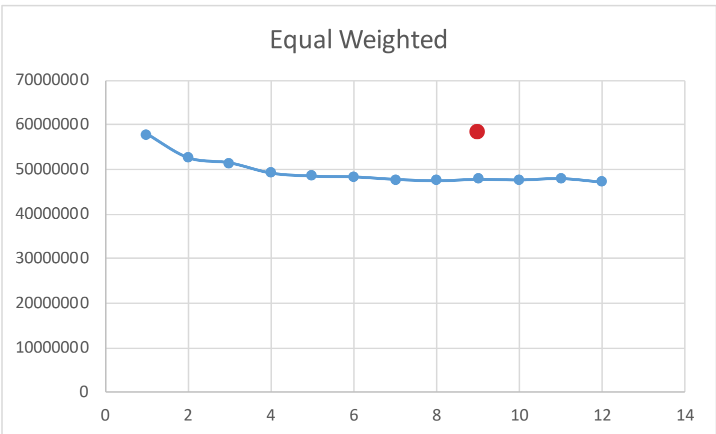
The trend of transport distance is the same as previous results. When the number of facilities increases, the total distance is decreasing.



Both in the situation that have 4 or 8 facilities can have the smallest economic cost.

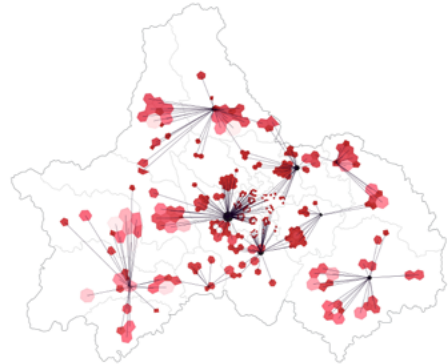


The trend is same as the results of transport distance. When the number of facilities increases, the total distance is decreasing.



When the number of facilities is larger than six, the results are good.

Evaluation of existing situation



The results in terms of economic cost, ecological cost are highlighted on the charts in previous page by red dots. Now, Chengdu has nine facilities related to the waste process. It is clear that all the optimised model have a better performance in differnt aspects. The champions are listed below.

The best configurations of MRFs

Champion from the economic perspective

4 Facilities

Champion from the ecological perspective
&
Champion from a balanced perspective

12 Facilities

07
REFLECTION

At the early stage of my graduation year, I had vague idea about which direction this project will be heading to. Because the motivation of this project is a phenomenon, I thought the most efficient way is to making a design as solution to easy the existing problems. After several group meeting and discussion with my mentors, I shifted my focus to the underlying reason instead of the symptoms of the problems. During this time, I began to read several classical theories about urban planning and urbanisation. Those reading cleared my mind and gave me more interests in finding the logic behind a complicated phenomenon. I thinking the relationship between research and design is quite simple and straight. There are several articles talking about how to use research as a tool to design and how to use design for research. In my opinion, as a student from urbanism track, research and design are closely intertwined. There is no sharp boundary. I proper to consider this two terms as the major sections in my workflow. They complement each other and inspire each other repeatedly.

My graduation group is Urban Metabolism and my graduation topic is about experimental modelling the CE-related facilities based on different urban spatial structures. I think my topic is with the research scope of our graduation group. However, the angle or position of my project is quite different. Basically, the study of UM is mainly about describing and analysing the material, energy flows within a region and find a solution to close the loop, eventually, keep our precious earth vibrant and healthy while increase the sustainability of economy. In my research, I put large efforts on spatializing the material flows in a given site. Because the complexity of reality, I abstracted some vital information and formed an imaginary city as the pilot project for exploring. I think the knowledge from our group gave me the foundation of my own project. In addition, I also hope my work could be a little be inspiring and meaningful. The primary research method in this project is parametric modelling. This method is flexible and powerful. It also gave me the accuracy for data analysing. At the early stage, I have tried several methods such as Geo-design, Cellular automation and so forth. However, both of them are not suitable for this project. For Geo-design, the reality of the chosen site is too complex and also lacking large amount of data, this situation made it quite difficult to proceed. By contrast, cellular automation is too abstract and to understand this method requires advanced knowledge about math and computer science. That made it not realistic for me to develop the graduation project. Regarding parametric modelling, I first, feel way familiar than other methods. The whole process was conducted in the Rhino environment which is a versatile software widely used by designers. It also provide the Grasshopper plugin that could be used as graphic coding tools. Although, I knew most of the functions in Rhino and Grasshopper, the way of doing parametric modelling was still a stranger for me. In the middle of this whole year, I spend quite long time in reading literatures and finally found an innovative method called 'generative multi-performance design system'. This method widened my eyes and inspired me to think the relationship between this method and Geo-design. I found out they actually share the same structure and workflow. From description model to evaluation model and change model. Their core principle is the same; the only different is their working environment. The value of parametric modelling is to give student who do not have the access to GIS software an alternative for conducting complex and precise work.

When I got the result from the abstract model, I feel quite convinced because most of the results could refer back to previous theories. Besides, I think the value of my graduation project can provide a tool for decision-making based on the empirical data. The enormous part of work in this project is calculating the cost for Material Recovery Facilities. All the calculation was based on existent research, survey and analysis. I do believe the result of my research could lead to further study and provide some fresh inspiration to others.
The main ethical issue in this project is at the final stage, which is the optimisation model. I have calculated the monetary cost, ecological cost and revenue from selling recovered materials. However, how to find the balance among them is a tricky question. There is always one or two parties have to compromise. I do believe the results could make some contribution in practice. For example, it can be used as guidelines for allocating the CE-related facilities and it can provide suggestions to decision makers.

However, there are huge limitation of this project. Problem one is that I am afraid I over-simplified this model. Therefore, it cannot reflect the true re-

sults. Second, urban symbiosis includes many different facilities, they have various characteristics, and in this project, I only tested the Material Recovery Facilities so far. I have no idea what is the results when integrate our facilities in this model. For the final part of my graduation period, I will first double check the abstract model. Then I will make the best use of the generated data and draw more conclusions that are useful. Finally, I would like to add a user interface for current model so people can play it without struggling with all the wires and components in Grasshopper.

REFERENCE:

Acero, L., & Savaget, P. Plural understandings of sociotechnical progress within the Organisation for Economic Cooperation and Development (OECD).

Alfaris, A., & Merello, R. (2008). The generative multi-performance design system. ACADIA 08 õ Silicon+ Skin õ Biological Processes and Computation, 448-457.

Bank, T. W. (1905). China 2030: Building a Modern, Harmonious, and Creative Society: World Bank Publications.

Bettencourt, L. M., Lobo, J., Helbing, D., Kühnert, C., & West, G. B. (2007). Growth, innovation, scaling, and the pace of life in cities. Proceedings of the national academy of sciences, 104(17), 7301-7306.

Brown, B. J., Hanson, M. E., Liverman, D. M., & Merideth, R. W. (1987). Global sustainability: toward definition. Environmental management, 11(6), 713-719.

Brundtland, G. H. (1987). Report of the World Commission on environment and development:" our common future.": United Nations.

Burton, I. (1963). The quantitative revolution and theoretical geography. The Canadian Geographer/Le Géographe canadien, 7(4), 151-162.

Cardoso, R. V., & Meijers, E. J. (2017). Secondary Yet Metropolitan? The Challenges of Metropolitan Integration for Second-Tier Cities. Planning Theory & Practice, 1-20. doi:10.1080/14649357.2017.1371789

Chen, A., & Gao, J. (2011). Urbanization in China and the coordinated development model—the case of Chengdu. The Social Science Journal, 48(3), 500-513.

Commoner, B. (2014). The closing circle: nature, man, and technology: Knopf.

Ding, G. K. (2008). Sustainable construction—The role of environmental assessment tools. Journal of environmental management, 86(3), 451-464.

Fan, C. C. (2007). China on the Move: Migration, the State, and the Household: Routledge.

Graedel, T., & Allenby, B. (1995). Industrial Ecology Prentice Hall. Englewood Cliffs, NJ.

Han, S. S. (2005). Polycentric urban development and spatial clustering of condominium property values: Singapore in the 1990s. Environment and Planning A, 37(3), 463-481.

Herrschel, T., & Newman, P. (2003). Governance of Europe's city regions: planning, policy & politics: Routledge.

Kates, R. W., Parris, T. M., & Leiserowitz, A. A. (2005). What is sustainable development? Goals, indicators, values, and practice. Environment(Washington DC), 47(3), 8-21.

Lan, S., & Zhong, R. Y. (2016). Coordinated development between metropolitan economy and logistics for sustainability. Resources, Conservation and Recycling.

Lin, G. (1999). State Policy and Spatial Restructuring in Postreform China, 1978–95. International Journal of Urban and Regional Research, 23(4), 670-696.

Lyle, J. T. (1996). Regenerative design for sustainable development: John Wiley & Sons.

MacArthur, E. (2013). Towards the circular economy. Journal of Industrial Ecology.

Mathews, J. A., & Tan, H. (2011). Progress toward a circular economy in China. Journal of Industrial Ecology, 15(3), 435-457.

McDonough, W., & Braungart, M. (2010). Cradle to cradle: Remaking the way we make things: North point press.

McDowall, W., Geng, Y., Huang, B., Barteková, E., Bleischwitz, R., Türkeli, S., . . . Doménech, T. (2017). Circular economy policies in China and Europe. Journal of Industrial Ecology.

Meijers, E. (2008). Summing Small Cities Does Not Make a Large City: Polycentric Urban Regions and the Provision of Cultural, Leisure and Sports Amenities. Urban Studies, 45(11), 2323-2342. doi:10.1177/0042098008095870

Meijers, E. J., & Burger, M. J. (2016). Stretching the concept of 'borrowed size'. Urban Studies, 54(1), 269-291. doi:10.1177/0042098015597642

Pauli, G. A. (2010). The blue economy: 10 years, 100 innovations, 100 million jobs: Paradigm Publications.

Rakha, T., & Reinhart, C. (2012). Generative urban modeling: a design work flow for walkability-optimized cities. IBPSA-USA Journal, 5(1), 255-262.

Schneider, A., Seto, K. C., & Webster, D. R. (2005). Urban growth in Chengdu, Western China: application of remote sensing to assess planning and policy outcomes. Environment and Planning B: Planning and Design, 32(3), 323-345.

Stahel, W., & Reday, G. (1976). The potential for substituting manpower for energy, report to the Commission of the European Communities. In: Brussels.

Stahel, W. R. (1982). The product life factor. An Inquiry into the Nature of Sustainable Societies: The Role of the Private Sector (Series: 1982 Mitchell Prize Papers), NARC.

Weber, A. (1929). Theory of the Location of Industries: University of Chicago Press.

Yearbook, C. S. (2012). National Bureau of statistics of China. China Statistical Yearbook.

Yong, R. (2007). The circular economy in China. Journal of material cycles and waste management, 9(2), 121-129.

Yue, W., Liu, Y., & Fan, P. (2010). Polycentric urban development: the case of Hangzhou. Environment and Planning A, 42(3), 563-577.

Zhang, K.-m., & Wen, Z.-g. (2008). Review and challenges of policies of environmental protection and sustainable development in China. Journal of environmental management, 88(4), 1249-1261.

Zhao, S., Zhou, D., Zhu, C., Qu, W., Zhao, J., Sun, Y., . . . Liu, S. (2015). Rates and patterns of urban expansion in China's 32 major cities over the past three decades. Landscape Ecology, 30(8), 1541-1559. doi:10.1007/s10980-015-0211-7

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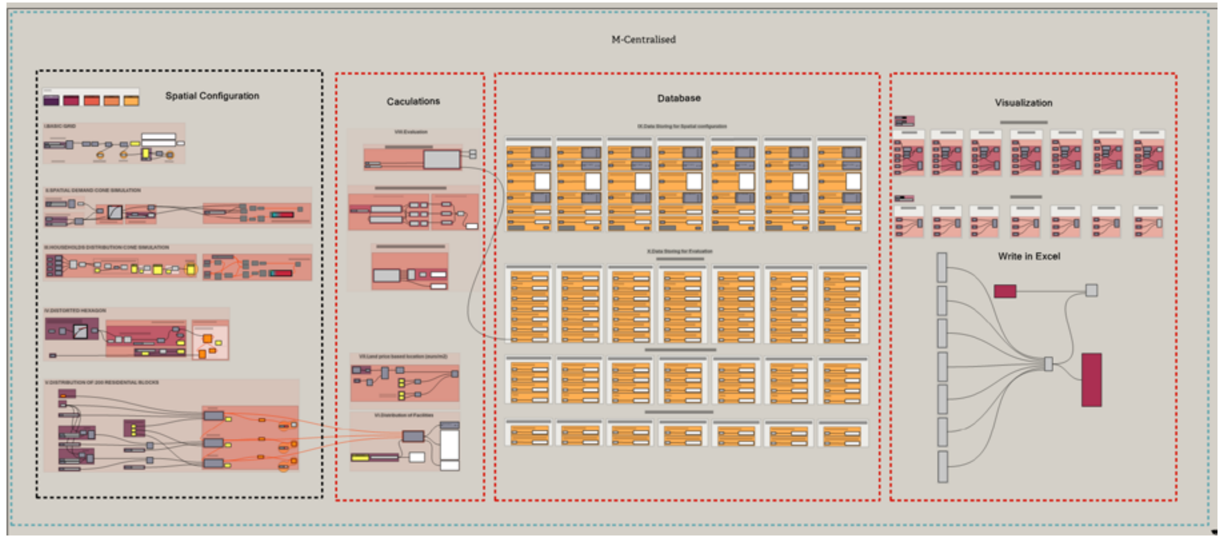
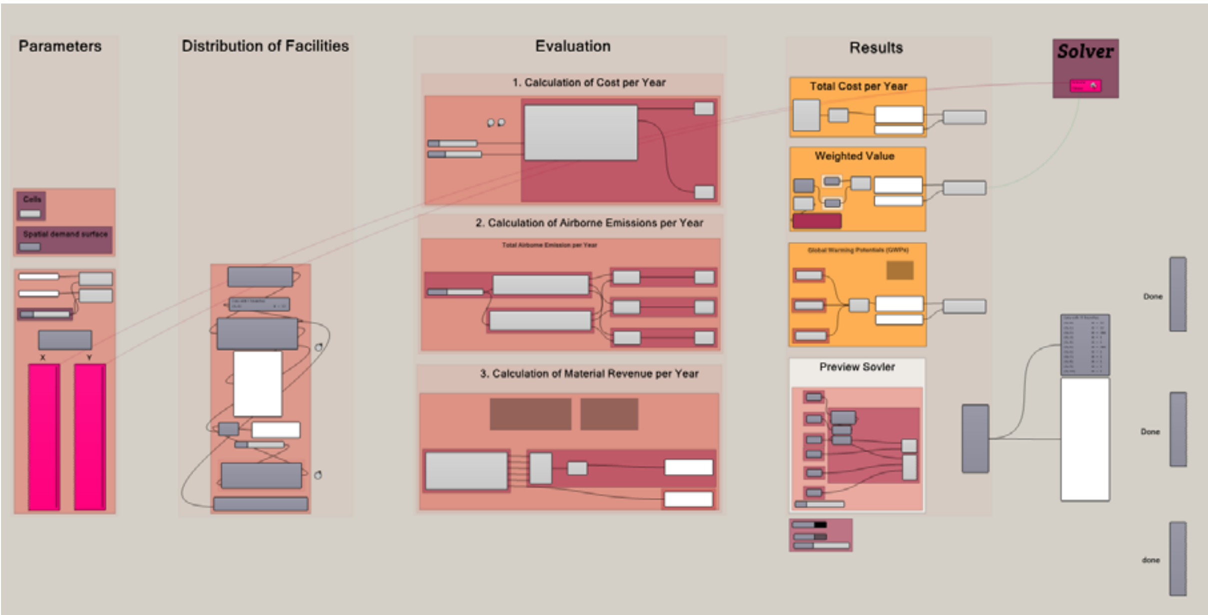
APPENDIX

APPENDIX A: SCRIPT OF MODEL



Grasshopper scripts for general model



Grasshopper scripts for the model of Chengdu

```
import rhinoscriptsyntax as rs
from collections import Counter


def FindClosestFPoints (ResidentialPoints,FacilityPoints):

def list_duplicates_of (seq,item):

def SortedPoints (links,CPs_index):

Total_links=[]
m=FindClosestFPoints(RP,FP)

while (m[0]>N):

    CPs1_index=list_duplicates_of(m[1],m[2]) #find the index for all the CPs1 in list CPs
        # and these index can help to find the corresponding RP and also those links
    a=SortedPoints(m[3],CPs1_index)

    #a is the RP_indexs which can be used to find links and points
    #print a
    FRlinks=[]
    for o in a:
        FRlink=m[3][o]
        FRlinks.append(FRlink)

    RP_useds=[]
    for u in a:
        RP_used=RP[u]
        RP_useds.append(RP_used)
    #print RP_useds

    for x in RP_useds:
        RP.remove(x)

    #print len(RP)

    FP.remove(m[2])
    #print len(FP)

    Total_links.append(FRlinks)
    m=FindClosestFPoints(RP,FP)

else:
    Total_links.append(m[3])


flat_list = [item for sublist in Total_links for item in sublist]
print len(flat_list)
```

Python scripts for model upgrades 1

```
__author__ = "W.Luo"
__version__ = "2018.06.23"


import rhinoscriptsyntax as rs
from collections import Counter


def FindClosestFPoints (ResidentialPoints,FacilityPoints):
    CPs=[]
    Ls=[]

    for i in ResidentialPoints:  # i is a item in list of RP for iteration
        Index=rs.PointArrayClosestPoint(FacilityPoints,i) #rhino function
        CP=FacilityPoints[Index]   # the closest point in the list of FPoints
        CPs.append(CP) # a list of closest points(FPoints)
        L=rs.AddLine(CP,i) # connect the RP and the closest FP
        Ls.append(L)  # list of all the lines
    # the end of for loop (already caculated all the RP in list)
    ccc=Counter(CPs)
    v=dict.values(ccc)
    print v
    return Ls,v

results=FindClosestFPoints(RP,FP)
links=results[0]
n=len(results[1])
print n

if n<N:
    Nlinks=[]
    for i in links:
        Nlink=rs.ScaleObject(i,x,[0.001,0.001,0.001])
        Nlinks.append(Nlink)
    links=Nlinks
```

Python scripts for model upgrades 2

Survey of MRF

Facility	Start-up date	Capacity(TPD)	Facility size	Recovery rate(%)
Single stream MRF				
Orange County MRF	2005	650	7200	94
Davis Street Station	2005	500	6960	88
Recycle Central at Pier 96	2002	2100	18600	83
CVT MRF	1991	6000	19500	88
GreenWaste MRF	2008	1400	8800	75
Athens Disposal	2002	5000	15800	30
Puente Hills MRF	2005	4400	20160	50
Sunnyvale SMaRT Station	2009	1500	4600	35
Western Placer Waste	2006	2000	6000	30

Projected MWPF Recovery Rates, by Commodity[85]

Material	Highly Automated Sorting System, %
Fiber	
Mixed Fiber	50-70
Cardboard (OCC)	65-75
Plastics	
PET	85-90
HDPE	85-90
Plastics #3-#7	75-80
Film	25-40
Metals	
Ferrous	90-95
Aluminum	90-95
Organics Foodwaste, Yardwaste	80-90

APPENDIX C: EQUIATIONS FOR CALCULATION

Equation 2.4 Calculation of airborne emissions per Mg of each waste fraction processed by the MRF.

$$\begin{aligned} AIRBORNE\_POLLUTANT_{f,i}\left[\frac{kg}{Mg}\right] = {} & TOTAL\_ELC\_CONSUMPTION_f\left[\frac{kWh}{Mg}\right] \bullet \left(ELC\_AB\_EMISS\_FACTOR_i\left[\frac{kg}{kWh}\right]\right) + \\ & TOTAL\_DSL\_CONSUMPTION_f\left[\frac{L}{Mg}\right] \bullet \left(\begin{array}{l} DSL\_PRECOMBUSTION\_AB\_EMISS\_FACTOR_i\left[\frac{kg}{L}\right] + \\ DSL\_COMBUSTION\_AB\_EMISS\_FACTOR_i\left[\frac{kg}{L}\right] \end{array}\right) + \\ & TOTAL\_PROPANE\_CONSUMPTION_f\left[\frac{m^3}{Mg}\right] \bullet \left(\begin{array}{l} PROPANE\_PRECOMBUSTION\_AB\_EMISS\_FACTOR_i\left[\frac{kg}{m^3}\right] + \\ PROPANE\_COMBUSTION\_AB\_EMISS\_FACTOR_i\left[\frac{kg}{m^3}\right] \end{array}\right) \end{aligned}$$

Where.

AIRBORNE_POLLUTANT$_i$: Emission rate of airborne pollutant, i, per Mg of waste fraction, *f* processed by the MRF

TOTAL_ELC_CONS$_f$: Total electricity consumption required to process 1 Mg of waste fraction, *f*

ELC_AB_EMISS_FACTOR$_i$: Emission rate of pollutant *i* resulting from 1 kWh of electricity production

TOTAL_DSL_CONS$_f$: Total diesel consumption required to process 1 Mg of waste fraction, *f*

DSL_AB_PRECMB_EMISS_FACTOR$_i$: Diesel airborne emissions of pollutant i resulting from 1L diesel production (i.e. precombustion)

DSL_AB_CMB_EMISS_FACTOR$_i$: Diesel airborne emissions of pollutant i resulting from combustion of 1L of diesel fuel

TOTAL_PROPANE_CONS$_f$: Total propane consumption required to process 1 Mg of waste fraction, *f*

PROPANE_AB_PRECMB_EMISS_FACTOR$_i$: Propane airborne emissions of pollutant i resulting from $1m^3$ of propane production

PROPANE_AB_CMB_EMISS_FACTOR$_i$: Propane airborne emissions of pollutant i resulting from the combustion of $1m^3$ of propane

Equation 2.7 Calculation of total equipment cost required in the MRF.

$$TOTAL\_EQUIPMENT\_COST\left[\frac{\$}{Mg}\right] = \sum_{f \in FRXN} \sum_{t \in TECH} UTIL_{t,f} \bullet INV_{t,f}\left[\frac{\$}{Mg}\right]$$

Where,

FRXN: Set of all waste fractions

TECH: Set of all separation technologies

UTIL$_t$: Binary utilization of a particular piece of equipment, *t* (0/1)

Equation 2.10 Calculation of the cost of construction per Mg of material processed in the MRF.

$$\begin{aligned} CONST\_COST\_RATE\left[\frac{\$}{Mg}\right] = {} & TOT\_FLOOR\_AREA\left[\frac{m^2}{tpd}\right] \bullet \\ & \left(\begin{array}{l} \left(1 + BUILD\_CONST\_COST\_RATE\left[\frac{\$}{m^2}\right]\right) \bullet \left(1 + ENG\_COST\_FACTOR[\%]\right) + \\ \left(LAND\_REQ\_FACTOR[\%] \bullet LAND\_ACQ\_COST\_RATE\left[\frac{\$}{m^2}\right]\right) \end{array}\right) \bullet \\ & MRF\_CRF / DAYS\_OP\_ANN\left[\frac{days}{yr}\right] \end{aligned}$$

Where,

CONST_COST_RATE: Cost of planning and construction of the MRF structure and land acquisition on a per Mg basis

TOT_FLOOR_AREA: Total floor area required to process one Mg if material

BUILD_CONST_COST_RATE: Construction costs associated with structure construction per unit floor area

ENG_COST_FACTOR: Fraction of construction cost associated with engineering and planning of structure

LAND_REQ_FACTOR: Multiple of indoor floor area to represent required land

Equation 2.11 Calculation of electricity consumed per Mg of material input into the MRF

$$ELECTRICITY\_CONSUMPTION\_RATE\left[\frac{kWh}{Mg}\right]=\sum_{f\in FRXN}\sum_{t\in TECH}\left(ELC\_CONS_{f,t}\left[\frac{kWh}{Mg}\right]\right)+$$
$$\left(OFFICE\_ELC\_RATE\left[\frac{kWh}{m^2-day}\right]\bullet TOTAL\_FLOOR\_AREA\left[\frac{m^2}{tpd}\right]\bullet\frac{PERCENT\_OFFICE[\%]}{100}\right)+$$
$$\left(WAREHOUSE\_ELC\_RATE\left[\frac{kWh}{m^2-day}\right]\bullet TOTAL\_FLOOR\_AREA\left[\frac{m^2}{tpd}\right]\bullet\left(1-\frac{PERCENT\_OFFICE[\%]}{100}\right)\right)$$

Where,

ELC_CONS_RATE: Electricity associated with processing a Mg of recyclables

OFFICE_ELC_RATE: Electricity consumption per unit floor area

PERCENT_OFFICE: Percent indoor floor area used as office space

WAREHOUSE_ELC_RATE: Electricity consumption per unit floor area.

APPENDIX D: RESULTS FOR GENERAL MODEL

M-Centralised Model

Average Capacity(TPD)	200TPD	400TPD	660TPD	1000TPD	1500TPD	3000TPD	12000TPD
Accounts of Facilities	60	30	18	12	8	4	1
Total Linkage mileage(km)	396.085	607.052	818.535	1147.295	1498.285	1908.017	3515.366
Mininmal Spanning(km)	576.232	576.501	576.020	576.820	576.906	576.134	582.703
Total Cost per Year							
Indoor Floor Area(m2)	232680.0	208680.0	199080.0	194280.0	191080.0	187880.0	185480.0
Site Area(m2)	698040.0	626040.0	597240.0	582840.0	573240.0	563640.0	556440.0
Cost of Construction(euro)	7120008.0	6385608.0	6091848.0	5944968.0	5847048.0	5749128.0	5675688.0
Cost of Land Lease(euro)	30611162.6	27598490.4	26408754.6	26298453.7	26389469.5	26783751.4	33386400.0
Cost of Diesel(euro)	2868744.4	2930302.1	3018671.8	3174714.4	3344857.1	3544462.6	4346223.2
Cost of Electricity(euro)	5470146.5	4905923.1	4680233.7	4567389.0	4492159.2	4416929.4	4360507.1
Cost of Equipment(euro)	16162200.0	13972200.0	13096200.0	12658200.0	12366200.0	12074200.0	11855200.0
Total Cost per Year(euro)	**62232261.6**	**55792523.5**	**53295708.1**	**52643725.1**	**52439733.8**	**52568471.5**	**59624018.2**
Airborne Emission per Year							
Total CO2 Emission(ton)	44418.411407	40982.010564	39811.674349	39584.862805	39645.464298	39800.455185	42005.679533
Total CH4 Emission(ton)	1.203168	1.143000	1.130335	1.144010	1.164951	1.191162	1.327447
Total N2O Emission(ton)	0.756044	0.707227	0.692901	0.694865	0.701568	0.710675	0.770708
GWP(100-year)	44673.791720	41221.339099	40046.417169	39820.532676	39883.655352	40042.015532	42268.536781
Material Revenue per Year							
Total Revenue(euro)	270873128.4	271858234.2	273649084.8	275390266.2	277661252.4	283607759.4	324996000.0
Recovered Organic Waste(ton)	1614068.1	1617694.8	1624287.7	1630697.9	1639058.4	1660950.3	1813320.0
Added Value(euro)	208640866.8	216065710.7	220353376.7	222746541.1	225221518.6	231039287.9	265371981.8

M-Dispersed Model

Average Capacity(TPD)	200TPD	400TPD	660TPD	1000TPD	1500TPD	3000TPD	12000TPD
Accounts of Facilities	60	30	18	12	8	4	1
Total Linkage mileage(km)	387.003	624.780	871.917	1110.028	1561.211	2130.215	3627.501
Mininmal Spanning(km)	607.227	622.986	619.157	616.958	611.478	612.793	615.175
Total Cost per Year							
Indoor Floor Area(m2)	232680.0	208680.0	199080.0	194280.0	191080.0	187880.0	185480.0
Site Area(m2)	698040.0	626040.0	597240.0	582840.0	573240.0	563640.0	556440.0
Cost of Construction(euro)	7120008.0	6385608.0	6091848.0	5944968.0	5847048.0	5749128.0	5675688.0
Cost of Land Lease(euro)	25533415.1	23286595.4	22313870.3	22169012.6	22534641.3	22908578.6	33386400.0
Cost of Diesel(euro)	2864189.3	2939193.8	3045446.2	3156022.7	3376418.5	3655908.8	4402465.9
Cost of Electricity(euro)	5470146.5	4905923.1	4680233.7	4567389.0	4492159.2	4416929.4	4360507.1
Cost of Equipment(euro)	16162200.0	13972200.0	13096200.0	12658200.0	12366200.0	12074200.0	11855200.0
Total Cost per Year(euro)	**57149958.9**	**51489520.2**	**49227598.2**	**48495592.3**	**48616467.0**	**48804744.8**	**59680260.9**
Airborne Emission per Year							
Total CO2 Emission(ton)	44403.818025	41010.496744	39897.451045	39524.980445	39746.576739	40157.493330	42185.863299
Total CH4 Emission(ton)	1.202353	1.144591	1.135124	1.140666	1.170596	1.211095	1.337507
Total N2O Emission(ton)	0.755672	0.707952	0.695085	0.693339	0.704143	0.719769	0.775297
GWP(100-year)	44659.067213	41250.081234	40132.964587	39760.112261	39985.676311	40402.261739	42450.339535
Material Revenue per Year							
Total Revenue(euro)	270975226.2	271918941.0	273276565.8	275128123.2	278331786.6	283607759.4	324996000.0
Recovered Organic Waste(ton)	1614444.0	1617918.3	1622916.3	1629732.8	1641527.0	1660950.3	1813320.0
Added Value(euro)	213825267.3	220429420.8	224048967.6	226632530.9	229715319.6	234803014.6	265315739.1

P-Centralised Model

Average Capacity(TPD)	200TPD	400TPD	660TPD	1000TPD	1500TPD	3000TPD	12000TPD
Accounts of Facilities	60	30	18	12	8	4	1
Total Linkage mileage(km)	386.869	611.030	875.050	1063.435	1426.599	1956.176	6157.229
Mininmal Spanning(km)	583.762	583.692	583.531	585.225	586.119	594.247	593.061
Total Cost per Year							
Indoor Floor Area(m2)	232680.0	208680.0	199080.0	194280.0	191080.0	187880.0	185480.0
Site Area(m2)	698040.0	626040.0	597240.0	582840.0	573240.0	563640.0	556440.0
Cost of Construction(euro)	7120008.0	6385608.0	6091848.0	5944968.0	5847048.0	5749128.0	5675688.0
Cost of Land Lease(euro)	25445100.7	23365605.6	22883444.2	22527642.8	24909460.3	31098712.1	10362725.1
Cost of Diesel(euro)	2864122.0	2932297.3	3047017.6	3132653.4	3308902.1	3568617.4	5671282.7
Cost of Electricity(euro)	5470146.5	4905923.1	4680233.7	4567389.0	4492159.2	4416929.4	4360507.1
Cost of Equipment(euro)	16162200.0	13972200.0	13096200.0	12658200.0	12366200.0	12074200.0	11855200.0
Total Cost per Year(euro)	**57061577.3**	**51561634.0**	**49798743.6**	**48830853.2**	**50923769.6**	**56907586.9**	**37925402.9**
Airborne Emission per Year							
Total CO2 Emission(ton)	44403.602707	40988.402601	39902.485296	39450.112632	39530.275878	39877.839320	46250.748641
Total CH4 Emission(ton)	1.202341	1.143357	1.135405	1.136486	1.158520	1.195482	1.564447
Total N2O Emission(ton)	0.755667	0.707389	0.695214	0.691433	0.698634	0.712646	0.878822
GWP(100-year)	44658.849961	41227.788570	40138.044072	39684.571745	39767.431941	40120.094980	46551.748719
Material Revenue per Year							
Total Revenue(euro)	271179421.8	272021038.8	273422814.0	274424476.2	277465335.0	285020572.2	324996000.0
Recovered Organic Waste(ton)	1615195.7	1618294.1	1623454.7	1627142.3	1638337.2	1666151.6	1813320.0
Added Value(euro)	214117844.5	220459404.8	223624070.4	225593623.0	226541565.4	228112985.3	287070597.1

P-Dispersed Model

Average Capacity(TPD)	200TPD	400TPD	660TPD	1000TPD	1500TPD	3000TPD	12000TPD
Accounts of Facilities	60	30	18	12	8	4	1
Total Linkage mileage(km)	425.888	710.639	1088.208	1412.981	1687.127	2252.073	6194.990
Mininmal Spanning(km)	669.581	674.570	673.805	675.076	674.234	681.222	682.718
Total Cost per Year							
Indoor Floor Area(m2)	232680.0	208680.0	199080.0	194280.0	191080.0	187880.0	185480.0
Site Area(m2)	698040.0	626040.0	597240.0	582840.0	573240.0	563640.0	556440.0
Cost of Construction(euro)	7120008.0	6385608.0	6091848.0	5944968.0	5847048.0	5749128.0	5675688.0
Cost of Land Lease(euro)	18444407.8	17106565.0	16750269.7	16820846.4	17236218.9	28424928.1	10361642.0
Cost of Diesel(euro)	2883692.5	2982257.4	3153929.7	3307972.6	3439573.2	3717028.2	5690222.2
Cost of Electricity(euro)	5470146.5	4905923.1	4680233.7	4567389.0	4492159.2	4416929.4	4360507.1
Cost of Equipment(euro)	16162200.0	13972200.0	13096200.0	12658200.0	12366200.0	12074200.0	11855200.0
Total Cost per Year(euro)	**50080454.9**	**45352553.5**	**43772481.1**	**43299376.0**	**43381199.3**	**54382213.8**	**37943259.2**
Airborne Emission per Year							
Total CO2 Emission(ton)	44466.300263	41148.459004	40244.997546	40011.779504	39948.904461	40353.300468	46311.424783
Total CH4 Emission(ton)	1.205841	1.152293	1.154527	1.167844	1.181892	1.222027	1.567835
Total N2O Emission(ton)	0.757264	0.711466	0.703937	0.705737	0.709296	0.724755	0.880367
GWP(100-year)	44722.110867	41389.283113	40483.633866	40251.285310	40189.821989	40599.828245	46612.970049
Material Revenue per Year							
Total Revenue(euro)	271044211.2	272203159.2	273864318.0	275668965.6	277360477.8	285302031.0	324996000.0
Recovered Organic Waste(ton)	1614698.0	1618964.6	1625080.1	1631723.9	1637951.1	1667187.7	1813320.0
Added Value(euro)	220963756.3	226850605.7	230091836.9	232369589.6	233979278.5	230919817.2	287052740.8

THE END. THANKS