

Preliminary Study on Thermodynamic Urban Design Based on Prototype Research of Tropical Rainforest

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Abstract. Under the background of contemporary global design and all-sided sustainable development, traditional architectural design methods and the autonomy of architecture are being challenged. Energy and thermodynamics now provides a more complete perspective on the future based on archeology and science. Before attempting to find a city paradigm for Singapore, a tropical island nation facing an energy crisis, this article, from the perspective of natural learning, examines the ecosystem of tropical rainforests, conducting the prototype analysis with four aspects, climate and microclimate, vertical structure, energy flow and ecological community. Correspondingly, four important strategies that run throughout the thermodynamic urban paradigm design are summarized: climate adaptation, self-organization, community system and regeneration succession. Afterwards to plus the further design from four different levels: region, city, architecture and experience, this article is to explore new thermodynamic urban paradigm.

1. Introduction

The research on “energy” has been the clue throughout natural science and social history since the recent half century. In the energy context, architecture can be considered as a kind of “open and unbalanced system”. According to Prigogine’s point view, it also can be deemed as the “dissipative structure” of thermodynamics. Therefore based on this perspective, architecture, a dissipative structure, is featured with energy exchange maximization and entropy maintenance, which would raise the repeated consideration on architecture based on the consideration on energy within the overall thermodynamic system. The process, extensive and sustainable development of globalization, is another background of current issue about the energy and thermodynamics, which puts forward new requirements for the autonomy and revaluation of architecture from the perspective of energy.[1-7]

2. Prototype research on tropical rainforest

In order to seek for a thermodynamic vertical city design strategy especially in tropic, this paper firstly turns to nature learns from nature to explore the organization form in the natural ecosystem which is different from the modernism Le Corbusier’s Delirious New York. The tropical rainforest, as the ecosystem in the tropical zone, has survived and grown the natural selection for twenty million years, ancient and mysterious, efficient and friendly. Its open system and organization form definitely become the outstanding objects for prototype research by taking energy as the perspective.

2.1. Climate adaptation feature

2.1.1. Tropical climate response. Nearly all the features of the tropical rainforest ecosystem are formed due to the response to the tropical climate, in other words, the tropical rainforest is a climate-



orientated ecosystem, and completely complies with the natural environment locality (figure 1). The climate features of tropical rainforest different from other ecosystems mainly include three following aspects. 1. The tropical rainforests are generally located between the 23.5 parallels enjoys perennial direct sunlight, which provides the possibility of severe photosynthesis for rainforest and provides prerequisite for its biomass up to $2.9\text{kg/m}^2\cdot\text{y}$. 2. The rainfall is extremely abundant, basically higher than 1800mm and even reaching to 3500mm, which no doubt intensifies the respiratory and transpiration of plants, heavily promoting the metabolism; 3. Keeping at high temperature level without cold winter and obvious diurnal temperature variation, therefore, makes tropical rainforest always in the energy circulation of producing, consuming and reproducing.[7,8]

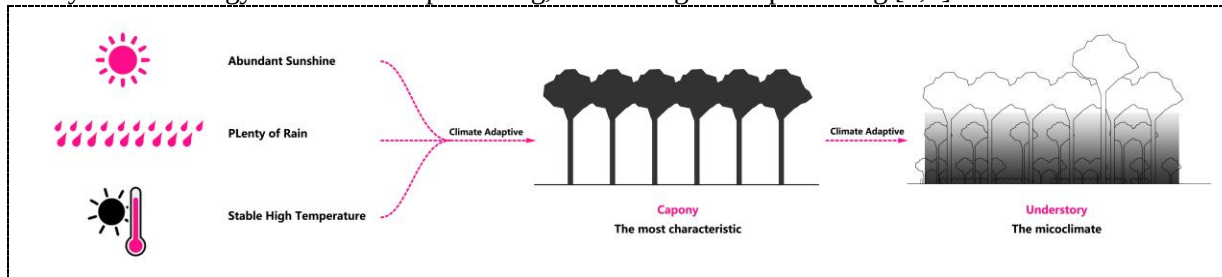


Figure 1. Climate orientation ^a

^a drawn by the author

2.1.2. Microenvironment and microclimate establishment. Under the environment of sufficient direct sunlight, abundant rainfall and constant high temperature, the crowns are all striving for growth to enjoy more sunlight and rainfall. So that the canopy forms a continuous expansion surface to blot out the sky like a cove. At that time, the dwarf tree, other dwarf tree species, shrubs and mosses as well as almost all animals completely live in an environment different from the canopy expansion surface. In other words, the canopy establishes a microenvironment and microclimate for the understory part (figure 2). The characteristics are as follows. 1. Breezy environment. 2. Weak light environment. The canopy blocks almost all sunlight. 3. Light quality. The light spectrum penetrating into the bottom environment cannot promote blossom and fruit yielding. 4. Sharp increase in humidity. 5. Interception of Rainfall. 6. Weak temperature variation. [7,8]

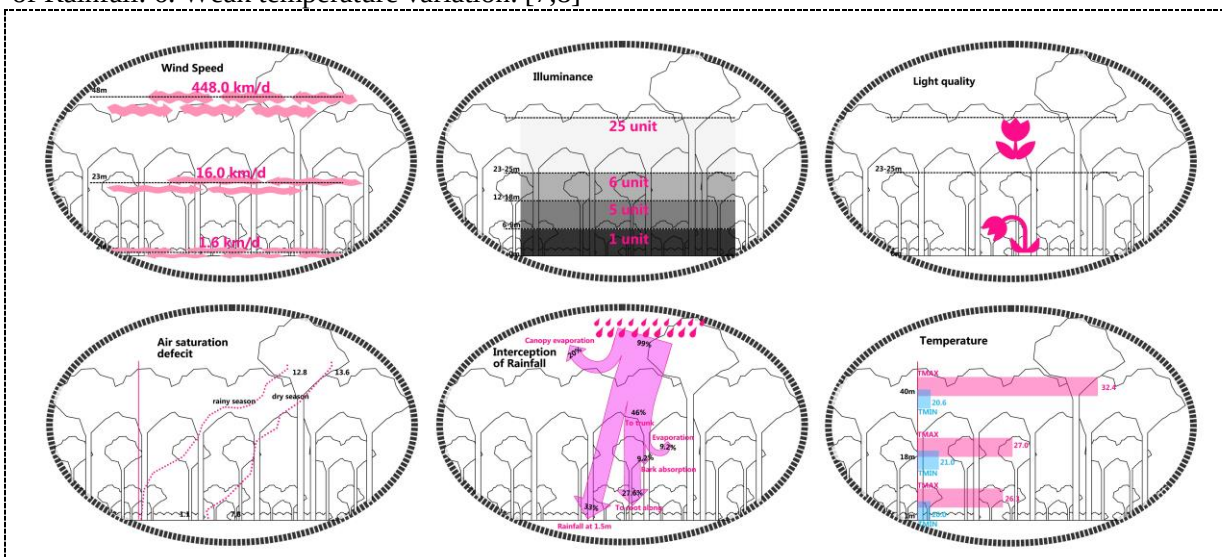


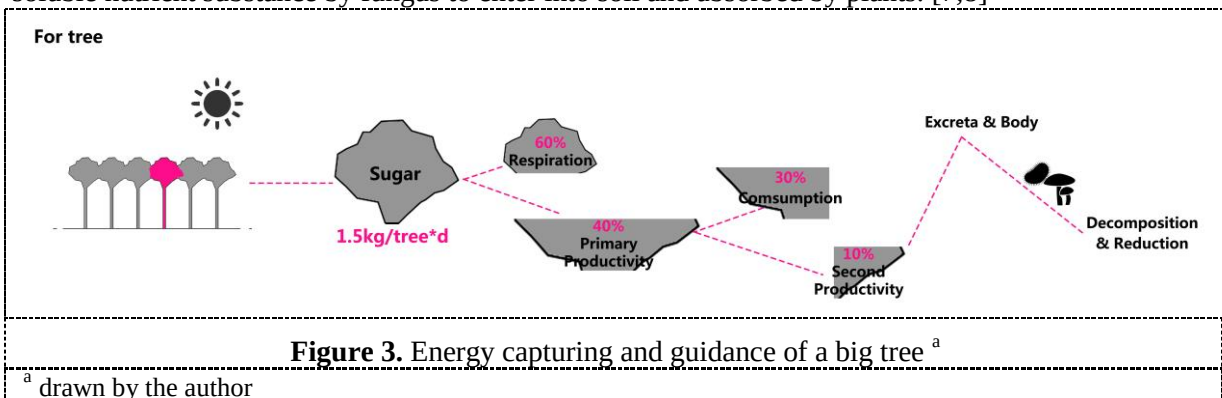
Figure 2. Undergrowth microenvironment and microclimate ^a

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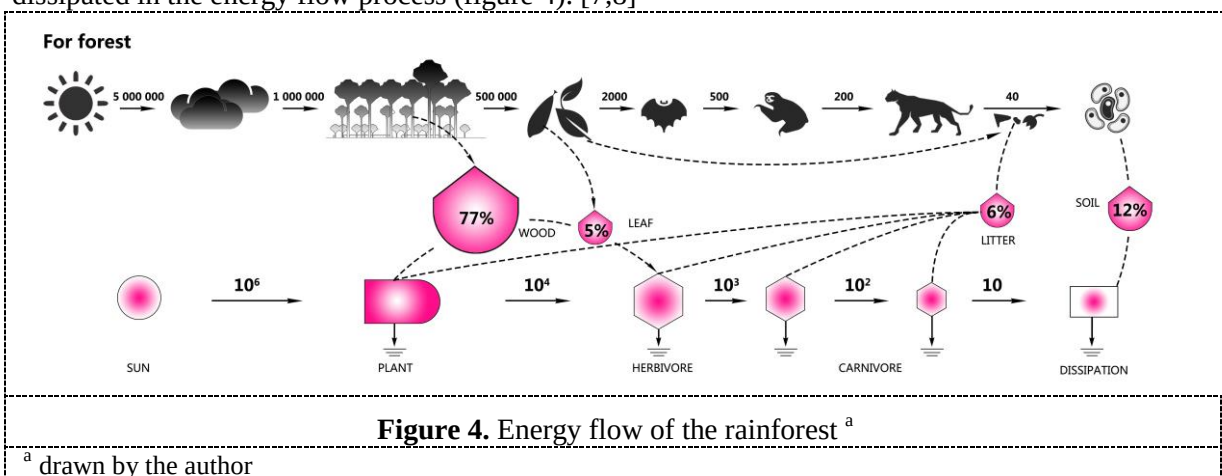
2.2. Energy flow feature

Among the terrestrial ecosystems, the tropical rainforest is no doubt the most productive ecosystem with the net primary productive force of $2.9\text{kg/m}^2\cdot\text{y}$, compared with $1.5\text{kg/m}^2\cdot\text{y}$ for the agriculture in temperate regions, $1\text{kg/m}^2\cdot\text{y}$ for the tropical grassland, even negative for the ocean and land ecosystems. The primary production of tropical rainforest accounts for 13.76% in the earth, while it reaches to 40.4% in the total biomass. [7,8]

2.2.1. Energy capturing and guidance of a big tree. One adult tree in the tropical rainforest can produce pure sugar of 1.5kg within one day, where the direct breathing of plants and life consumption account for 60%, while the left 40% are used for chemical matrix synthesis, such as the vegetable protein and fiber for wood, and only 10% are converted to secondary productivity, namely, the protein eaten by animals. Complex carbon molecules, namely, the organic matters retained in the animal waste and corpses of animals and plants, fall onto the ground to provide food for fungus and germ which decompose and restore them (figure 3). There is a mystical phenomenon in the tropical rainforest, which is the soil is relatively infertile. It is the fast energy circulation that causes the thin humus layer of soil. Therefor the tree roots rely on fungus to absorb and circulate energy, that is to say, a kind of symbiotic relationship, mycorrhiza. Hyphae makes the dead organic substances to be absorbed by tree roots, while only small part of organic substances are decomposed, restored to be soluble nutrient substance by fungus to enter into soil and absorbed by plants. [7,8]



2.2.2. Energy flow of the rainforest. The 4 000 000 of the 5 000 000 units solar energy are absorbed and reflected by clouds with only 1 000 000 shine left at the canopy layer. Wherein, half of the energy are absorbed and converted by the canopy and even the leaf with only 2000 units energy are absorbed by phytophagous animals. Through the stage shedding of biological food chain, the final 40 units energy can be fallen to the ground, converted or absorbed by fungus. The energy is being constantly dissipated in the energy flow process (figure 4). [7,8]



2.3. Vertical Spatial Heterogeneity

Due to climatic reasons, tropical rainforest forms a thick layer of continuous canopy, which then creates a sub-forest micro-environment with gradient differences. Furthermore, this micro-climate, in turn, makes the under-forest environment vertically layered, forming a unique spatial heterogeneity in the tropical rainforest (figure 5). [7,8]

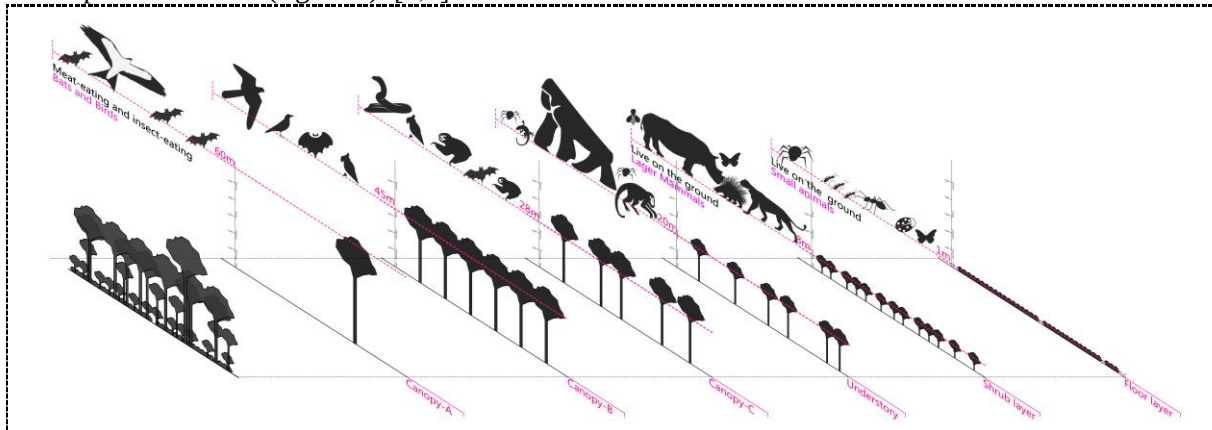


Figure 5. Vertical spatial heterogeneity of flora and fauna ^a

^a drawn by the author

2.3.1. Overview of flora vertical layering. There are vertical stratifications in the tropical rainforest, including the canopy-A layer, the canopy-B layer, the canopy-C layer, the understory leaf layer, the shrub layer and the floor layer. Among them, the canopy-A layer refers to the part outside the edge of canopy, which is the highest canopy, even reaching to 84 meters in South America. The canopy-B and the canopy-C layers are closely spaced trees and their ripe dense top crowns. Understory leaf layer refers to the more widely separated, smaller tree species and young plants that form the fracture layer under the canopy. The shallow shrub layer consists only of shrubs and young trees growing less than 10 meters above the ground. The floor layer includes tree seedlings, fungi, and low-growth plants. The vertical structure of flora divided into 6 layers, nonetheless, is not always obvious for the vertical structure will change due to differences in climate, soil and other factors. [7,8]

2.3.2. Overview of fauna vertical layering. Corresponding to the phenomenon of six levels of flora stratification, Harrison (1962) believed that in the rainforest, the fauna vertical stratification seems to be more apparent. He also summarized and classified the animal's vertical stratification into six levels. 1. The space above the canopy, that is, the canopy at low altitude, mainly including insectivores and carnivorous animals, dominated by bats and large birds. 2. Both in the canopy-A and B layers, there are herbivorous mammals, as well as insectivorous animals and omnivores, such as various types of birds and fruit-eating bats. 3. Under the canopy, there are mainly flying animals and insectivorous bats in the middle area between the trunks. 4. The space full of rattan vines on the trunks, there are climbing carnivorous animals and insects that feed on the epiphytes on the trunks, such as the big spider. 5. On the ground, there are large mammals who can run. 6. And small ground animals. Overall, more than half of the mammals inhabit the canopy, and 70%- 80% of these lives live on trees. [7,8]

2.3.3. Causes and significance of spatial heterogeneity. In an ecosystem, the position occupied by time and space and its functional relationship with related populations are the niche. When there are spatial differences in resources, and moreover each species settles in a position where it has a competitive advantage, there is a possibility that the species will coexist. In tropical rainforest, the canopy shields the undergrowth environment like a shell, which forms a micro-environment with a gradient that allows the plants to be vertically stratified. As a result, the animals that depend on it also vertically occupy different niches. In this way, plants and animals in the ecological niche with advantageous differences in time and space are continuously producing new species. Therefore, a huge variety of

species lives together in the rainforests. In other word, the spatial heterogeneity has successfully allowed these diverse species to co-exist. [7,8]

2.4. Ecological communities symbiotic

2.4.1. Overview of community diversity. The biological species of tropical rainforests account for 70% of the earth. The study found that such a large number of organisms survived in the tropical rainforest with extremely rich diversity. The tropical rainforest that developed from the age of dinosaurs 20 million years ago has 30,000 advanced plant species. However, the competition among rich species is relatively weak, and thus it is possible to coexist with each other. [7,8]

2.4.2. Four hypotheses of causes for the coexistence of various species. How do such rich and diverse species form and why do they coexist? There are four hypotheses (Figure 6). 1. Niche Differentiation hypothesis is that when there are spatial differences in resources, and each species settles in the position with its competitive advantage, a large number of species can coexist. As the rainfall in the tropical rainforest increases, the plant species density increases, soil fertility decreases, spatial heterogeneity increases, and diversity increases. 2. Grazing or Pest Pressure hypothesis means that if there is a high probability of being fed and destroyed for species rich in diversity or competitiveness, these harmful feedings will promote the coexistence of multiple species. Predators control the structure of the community through damaging to the prey. 3. Life History Trade Off hypothesis means that negative correlations between abilities (communicative ability, competitive ability, and growth ability after settlement) may promote the coexistence of multiple species. If this assumption is strictly followed, then infinite species can coexist. 4. Lottery Competition hypothesis refers that on the one hand, most plants in tropical rainforests occupy the same ecological niche and have the same ecological needs as the ecological equivalent species. On the other hand, even if the differences in the competitive ability between species are not obvious, the chance of competition is small and there is no competition exclusion, then species can coexist. [7,8]

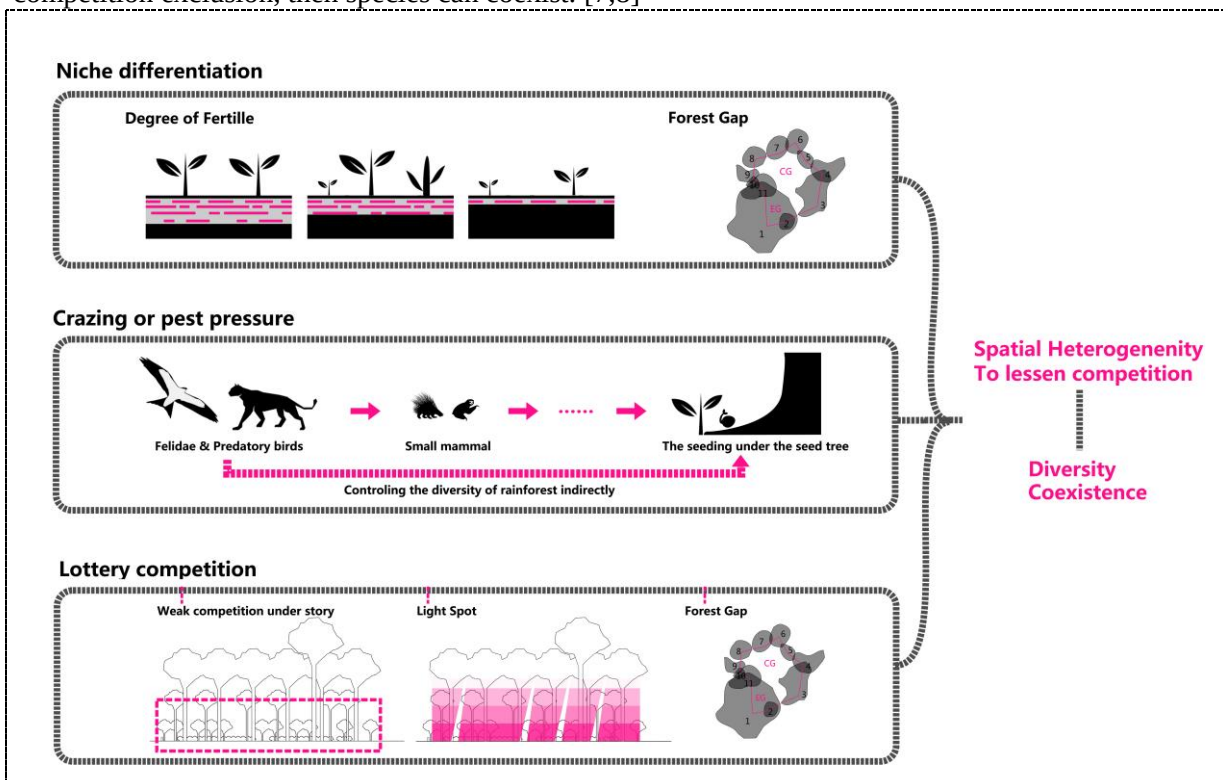


Figure 6. Hypothesis of Diversity Cause ^a

^a drawn by the author

2.4.3. Growth and metabolism. The Lottery Competition hypothesis points out an interesting phenomenon - Forest Gap. Because of the existence of Forest Gap, it is randomness rather than competitiveness that determines which species can be successfully established under the forest. The tropical rainforest experienced the periods of pioneering succession, early secondary succession, late secondary succession and current climax succession. Lottery competition caused by forest gaps, etc. not only promotes the establishment of biodiversity, but also brings the tropical rainforest a stable and benign metabolism during its growth. [7,8]

3. Thermodynamic urban design strategy based on Singapore

Singapore is a city-state walking in the forefront of the world. In the face of various crises in the development of globalization today, although Singapore is an island nation, it has contributed a lot to the strategy of solving various crises. In the current global context of sustainable development, we should pay more attention to the flow of energy under the order of things. As the biologist, Odom said, energy flow can be extended to the environment, energy in society can be used to shape the landscape of culture and thought. In this context, we propose a prototype of a rainforest thermodynamic city to create an urban paradigm that not only contributes to Singapore but also as a solution facing the current global energy and environment crisis especially for cities in Asia that are rapidly developing. Therefore, based on the four important characteristics of the research on tropical rainforest prototype, we accordingly propose four important strategies for the tropical rainforest thermodynamics urban prototype.[1,7]

3.1. Climate response

The energy is the deep level order for the organization of things and the energy is closely related to the climate. The growth and four characteristics of tropical rainforests are all due to the climate oriented. The biosphere uses the most basic principle - climate adaptation, to shape the ecological system that with regional differences, and shaped the mysterious and ancient ecosystem like the tropical rainforest. For tropical cities, like Singapore, the climate response from the urban perspective, on the one hand, is reflected in the utilization and enrichment of the forest to form a green lung system for the city, making the overall effect is greater than the local sum. On the other hand, the design of the road system conforms to the main wind direction to form wind tunnels for the city, so as to capture the energy of the forest and water resources with the maximum efficiency. From the point of view of architecture, the design idea that changed from the design of space to the "guidance" of the energy in the sunshine, rain and wind, moreover to some extent the air has become the leading role in the design (figure 7 and 8).[4-6]

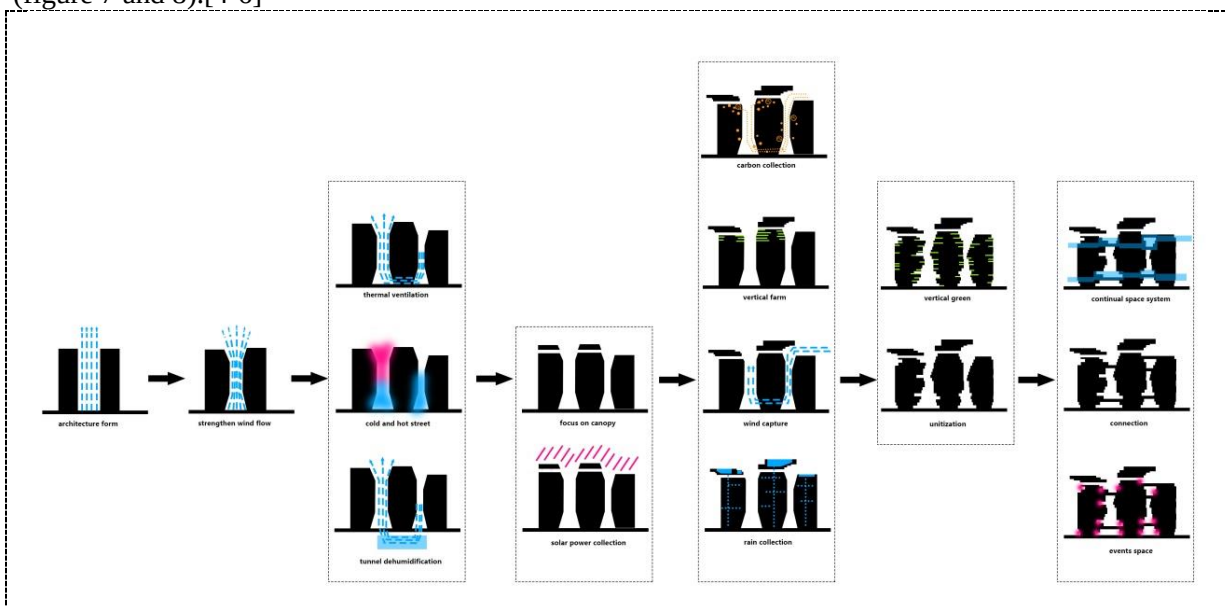
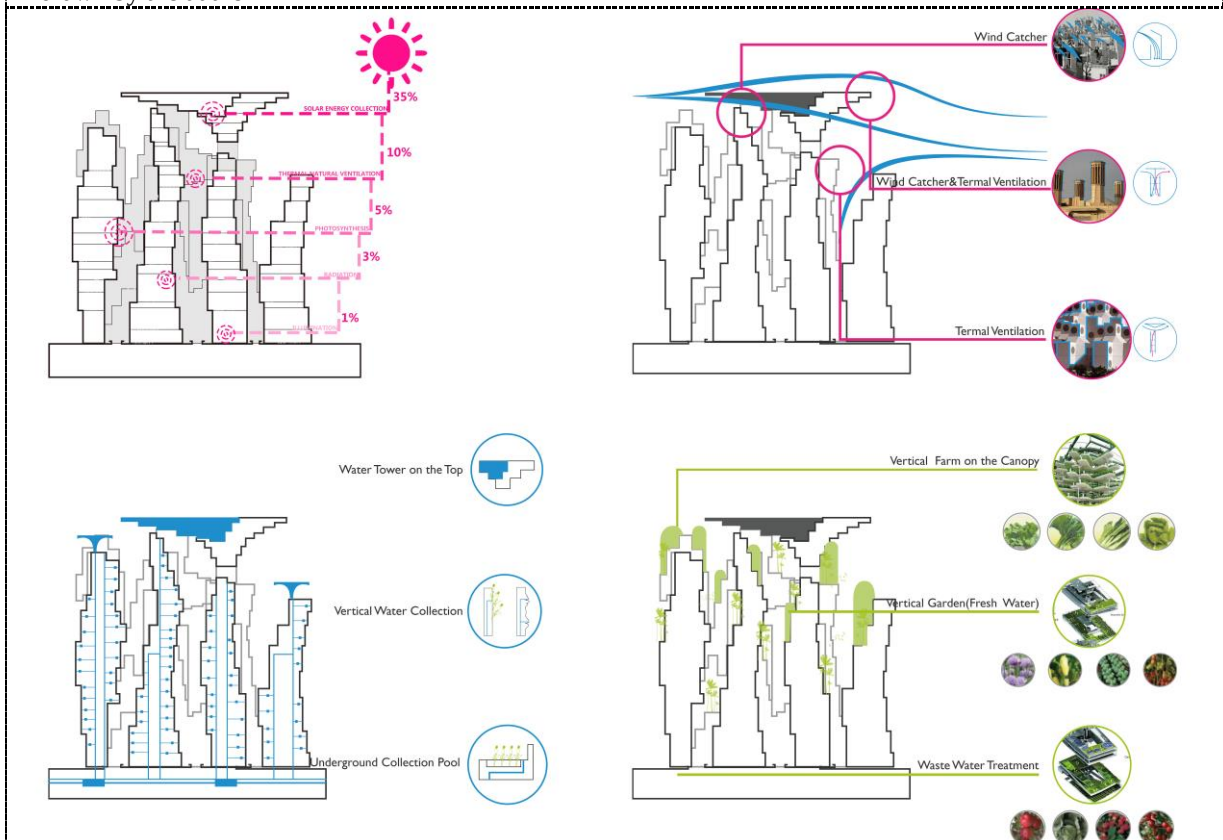


Figure 7. Formal following energy on the architectural scale ^a^a drawn by the author**Figure 8. Energy capture on the architectural scale ^a**^a drawn by the author

3.2. Self-organization

In its own evolution process, there is no need for the specific interference of the outside world. An open and unbalanced system flows and transforms the energy at the fastest speed, with the strongest feedback and the maximum amount. It can achieve a certain goal by the mutual coordination of its own elements, that is, that is to say, forming the Self-organization of the system. Self-organization is a way to understand and interpret the world in the context of complex science, also considered as an ideal mathematical and physical model. The energy flow of the tropical rainforest already approaches the self-organization to a large extent. How to let the operational pattern of the thermodynamic city model to fit the law of energy flow, the "hexagonal" structure that can be seen everywhere in the tropical rainforest even the whole nature has inspired us, together with the research of the architect Otto also concluded, that the hexagon is the most efficient and intensive structure for the boundary of a system and the core service range. Using this kind of organization mode in the thermodynamic urban design, on the one hand, can arrange and organize the social activities such as the road network and industries of the city, which makes energy circulate and transforming more sufficiently and conveniently between each system and reduces the energy loss caused by traffic and waiting time. On the other hand, it can pave the infrastructure deep into the community and even family households, such as the distributed smart power grid, distributed sewage treatment and biogas power generation, distributed rainwater collection based on new energy, to utilize the wind, rainwater, solar energy and even garbage to the maximum efficiency, thereby to complete the "self-sufficient" energy flow (figure 9 and 10). [9]

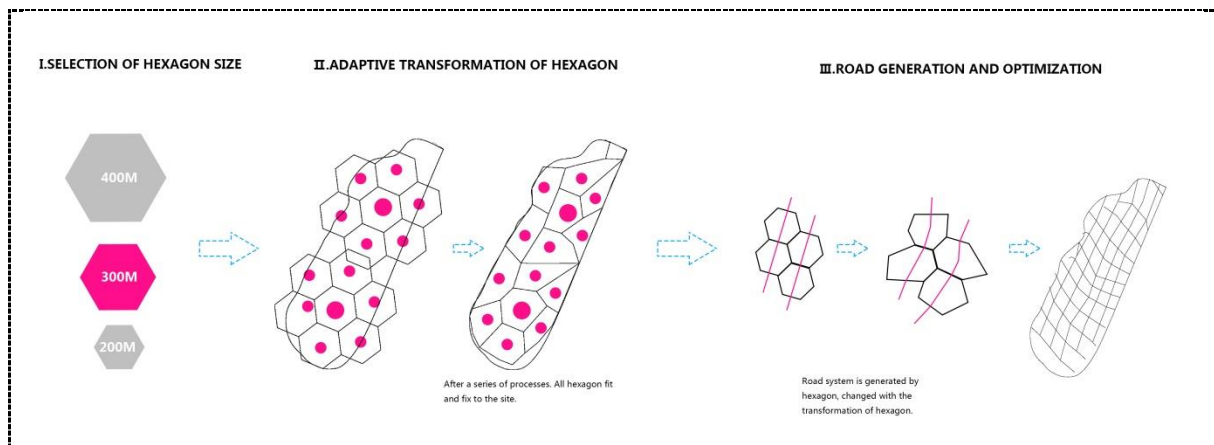


Figure 9. The "hexagon" structure acts on the urban form ^a

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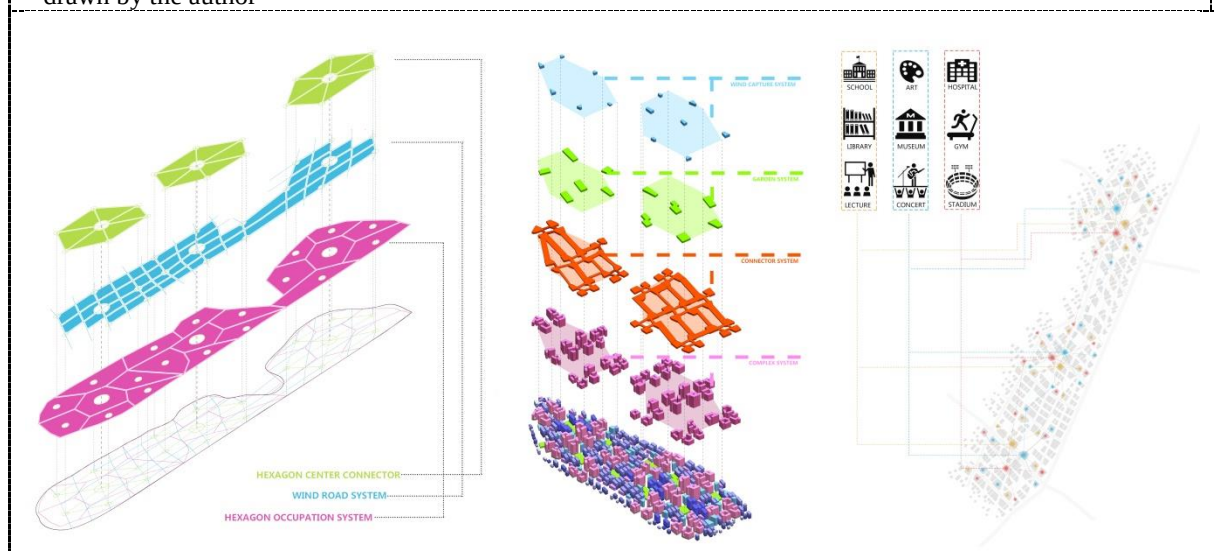


Figure 10. Distributed infrastructure system ^a

^a drawn by the author

3.3. Community System

In the rainforest system, it is possible to say that the spatial heterogeneity of vertical stratification directly leads to the extremely abundant biodiversity, while the thermodynamic urban model should also encourage the sufficient community diversity as well. It is neither enough nor realistic to avoid competing for the society and state only directly by letting different communities occupy different time and space resources, and even by the negative correlation phenomena of life history. However when the different communities of the tropical rainforest occupy the common resources, different rules of symbiosis can be cultivated, like epiphytism, saprophytism, mutualism and killing, among which there are diverse forms of mutual benefit and coexistence models. For example in the relative barren soil humus of the tropical rainforest, mycorrhiza makes the root cells to absorb organic matter directly, thus the fungi gain the nutrition in this process as well. As an island state, Singapore possesses limited resources, and different ethnic groups and communities should find the living way of mutualism, which is the maximum utilization of resource energy efficiency. In the thermodynamic city paradigm, the canopy of high density vertical cities is responsible for capturing the energy and resource such as the sunlight, water and wind. Just like the dwarf tree layer and the tree trunk layer, the streets and the vertical public space of the city are the main carrier of urban life. Overall the different communities

occupy the suitable resources to live and work in the city, meanwhile to interact and communicate sufficiently in the common complex system (figure 11).[10,11]

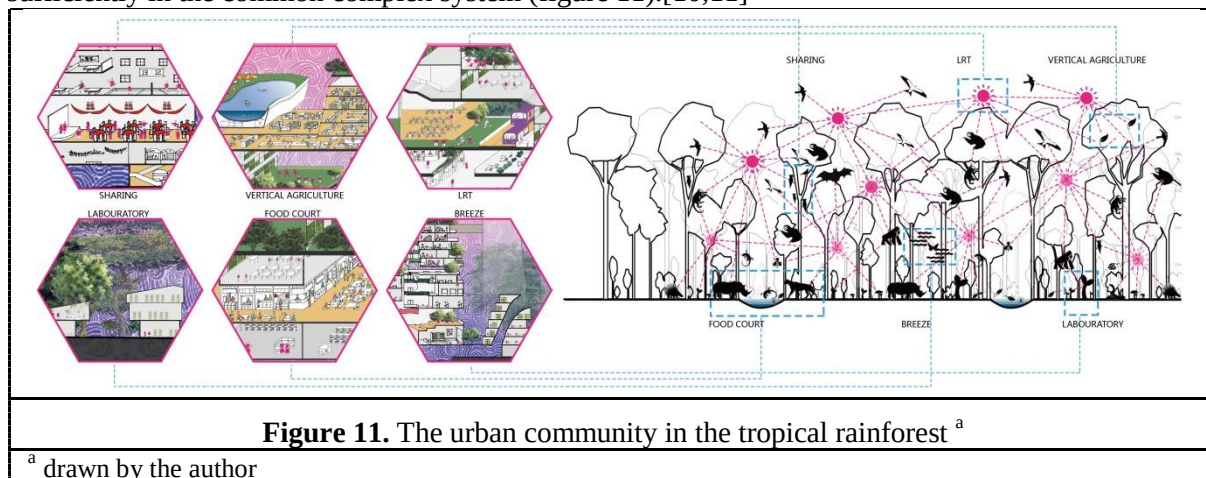


Figure 11. The urban community in the tropical rainforest ^a

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3.4. Regeneration and Succession

The same as the rainforest system, the city is not a certain state of time, but similar to an organism that undergoing metabolic process continuously. Urban morphology and social activity will be in different stage of regeneration. In the thermodynamic urban design, on the one hand, the city keeps growing, the stage planning and construction of the city, and the gradual and sustainable growth and succession of the industry and the living population. On the other hand, the urban canopy is abundant but will not shelter all the sunlight and sky but with the "Forest Gap" formed randomly, to provide possibility for the flexible activities on the ground and the vertical city.[8,10]

4. Conclusion

Indeed, the so called "city paradigm" is an ambitious conception, and the current four design strategies of the "thermodynamic city paradigm in tropical rainforest" cannot completely solve all the social problems of the city in the future. However, still, from the perspective of energy and learning from the nature and form the thriving and ancient ecological system of the tropical forest, thereby to put forward the design strategy of thermodynamic city will undoubtedly provide a new perspective to solve the current urban problems such as the urgent resource shortage and energy crisis.

5. References

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