Towards Thermodynamic Architecture: Research on Systems-based Design Oriented by Renewable Energy

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Abstract. The research presented in this paper, "Thermodynamic Architectural Prototype", hopes to put forward a new way from systems-oriented view to interpret renewable energy issue in buildings. It also helps to develop the concept of energy flow in architectural field in both theoretical and practical aspects, through a series of specific design studies. From prototype to paradigm, those design studies aims to provide an effective method for systems-based design through four phases: case studies, complex knowledge production, prototype generation and implementation, energy formation.

Preface

"An alternate agenda for energy—one that is more specific to architecture—becomes methodologically possible once the principles of these energy systems and hierarchies are more fully understood."—Kiel Moe, 2013

1. Context and Challenge

In 21st Century some pioneers of architectural education and practice begin to pay close attention to the role that energy and thermodynamics play in buildings. By introducing thermodynamics into architecture, it emphasizes two urgent tasks: one is to know what kind of architectural form can be used as a system to effectively organize the relationship between architecture and environment, the other is to learn how to channel the energy flow among the subsystems of a building[1].

1.1. Big new task

As eco-crisis and climate change have become the ubiquitous agenda within the contemporary urbanization in China, the development of "green buildings" characterized by energy saving and renewable energy utilization has turn to be a research tendency in architecture. "Thermodynamic Architecture" has tried to redefine the relationship of matter, energy, space, material and system[2]. It takes maximum energy conservation and sustainable energy supply as the principle to guide the form generation.

1.2. Integrated / Systems perspective / Multi-disciplinarity

The energy issues of contemporary architecture require complex scientific perspectives. The task of "Thermodynamic Architecture" is to study what kind of architectural form would efficiently organize the relationship between buildings and climate, as well as the energy flow in a whole building system and its internal subsystems. In this process, it needs a shift in thought patterns to remedy the alienation between technology and design methods.

1.3. Climatic responsive design

The development of modern artificial environment technology has made buildings losing their characteristic which caused by regional climate. We believe that the architectural form as an interpretation of climate and environment, can feedback the thermodynamic performance of the site by special shape, material and spatial organization. How to continually utilize the renewable energy on the site and reconnect the link between climate and design is a critical topic in this study.

2. Research by Design

Since 2014, the research team led by Professor Li Linxue from Tongji University has been studied in the renewable energy agenda with the integration of interdisciplinary specialists. They are trying to deal with three dilemmas: how can thermodynamic science drive buildings as a system from different scales? How can interdisciplinary tools be integrated on the same platform within a site's condition? How, as John. T. Lyle said, "*shape the forms to show the processes*"?

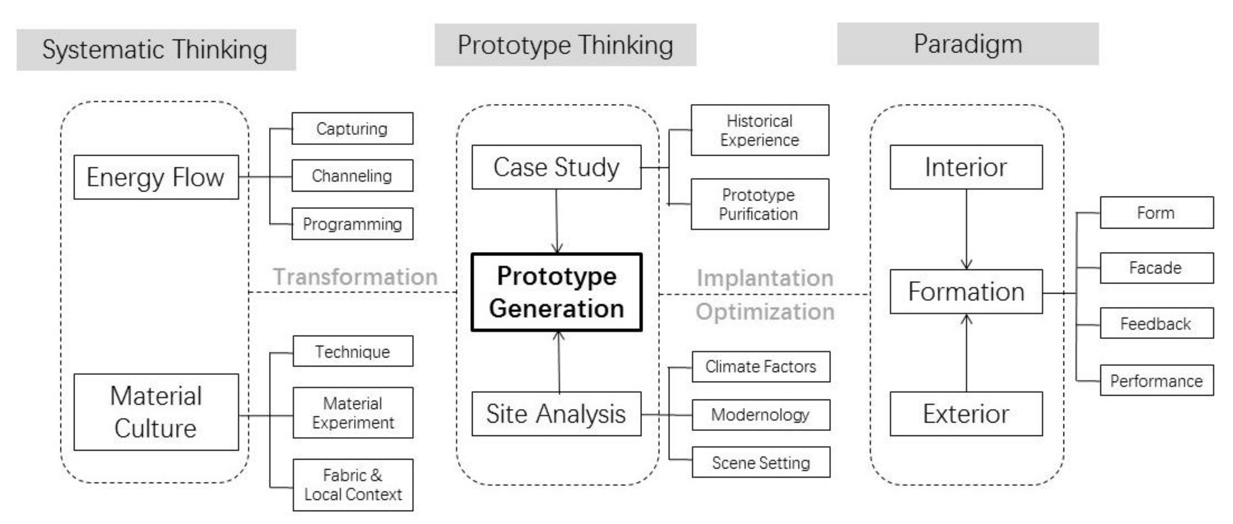

Figure 1. The general framework of "*Thermodynamic Architectural Prototype*" (Source: Tao Simin)

Therefore, the research group took "Thermodynamic Architectural Prototype" as the topic, and selected three independent keywords - Wind, Light and Heat - as the main targets of renewable energy utilization to develop design projects in three semesters. Through abstract or figural methods such as monographic study, prototype establishment and software simulation, they chose a specific site in China and proceeded from architectural design(a large-scale public building such as a commercial complex or a museum)to explore the relationship between forms and energy(figure.1). By focusing on the utilization and transformation of natural energy sources in a specific environment, a new epistemology of thermodynamic architecture is put forward and the systematic research on the design methodology is carried out.

3. PHASE 1-2-3-4 :Prototype to Paradigm

The research process includes four phases, and each phase requires corresponding modelling study and diagram analysis.

3.1. PHASE 1: Case study: reading, observing, analyzing and illuminating
"Prototype" represents the underlying and historical experience, it indicates a fundamental contribution[3]. The case studies expect to recall the energy clues in those buildings and reveal the typical inherent architectural laws by prototypes extraction. It may include fragments and the entireties, small and large scales, single building and settlement. And it may also concern with technics, materials, spaces, surfaces, devices and organizations[4]. The aim is to refine their significant "prototypes" by analysing the strategies in the selected cases, about how they capture, channel or program energy. The step may provide references for the subsequent design process and expand them to a wider field.

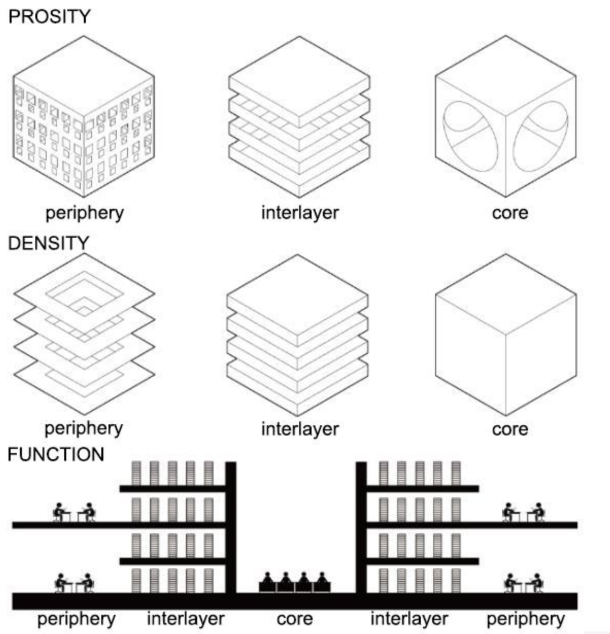

Figure 2. "Peel" the Phillips Exeter Academy Library for prototypes (Source: Zheng Xin, Zheng Siyao, Lyu Xinxin. Tutors: Li Linxue, Zhou Jianjia)

Take "light" as the topic, the research group selected Phillips Exeter Academy Library for a case study in this phase. They peeled the whole library into three sections: periphery, interlayer and core (figure.2). The periphery provides a homogeneous facade, the two sizes of windows guarantee the ample sunshine for the reading place; the interlayer as a relation between hall and reading place ensures suitable light intensity; the core is not just a simple hall, in fact it is a centrality, a symbolism, meanwhile it can be the reflection of light. After that they exacted the prototype in each section with three keywords - porosity, density and function - to answer the question according to the local climatic characteristics: how the case represents significance in the architectural energy agenda?

3.2. PHASE 2: Interdisciplinary and trans-disciplinary approach: a complex production of knowledge
Through the construction of new knowledge systems, research in energy and thermodynamic architecture will provide an opportunity to restore an autonomous instrumentality in a wide range of discourses of sustainability. In this phase, the researchers concern about all the natural elements in a built environment. Within the interdisciplinary knowledge system of architecture, environment, energy and material science, the research group is trying to do a discourse re-construction. For example, a set of quantitative analyses were carried out by a group member in order to take the middle-east wind

tower as his prototype, and some experiments were conducted to discuss the influence of the air flow angle and the opening form of a wind tower on ventilation performance (figure.3).

In addition, we also need to pay attention to “material culture” which closely related to the climate and historical context on site. Material interacts with the environment in the form of energy flow. The redefinition of material pedigree, tectonic and perception is actually the aggregation of visible matter and invisible energy[5]. The research group once took a series of drain ability test: since it rains frequently in Shanghai, the facade drainage is quite important. Clay can be gradually eroded and stained if immersed in water for a long time. Different types of texture are tested under water to optimize the drain ability. The V shape texture, though very simple, works efficiently. Base on the texture, the technique for this facade was also explored (figure.4).

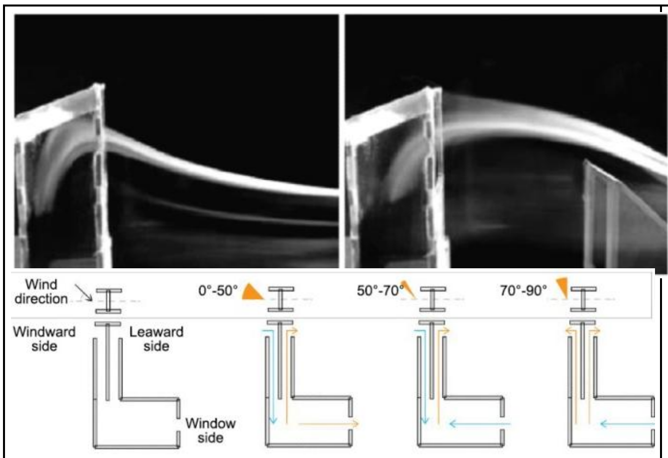

Figure 3. Analysis for Wind tower (Source: Zhang Runze. Tutors: Li Linxue, Zhou Jianjia)

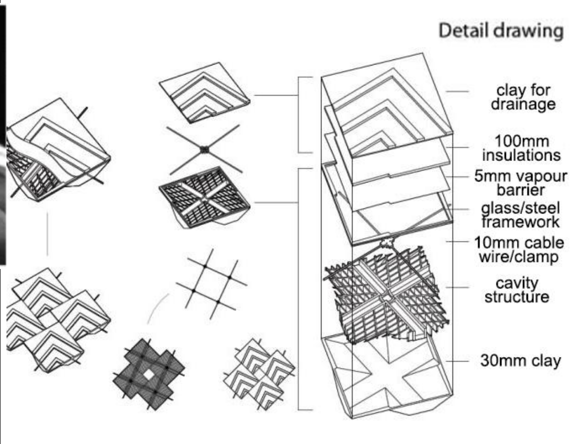

Figure 4. Material experiment (Source: Liang Qianhui, Lin Jingzhi, Wang Jingkai. Tutors: Li Linxue, Zhou Jianjia)

3.3. PHASE3: Prototype generation and implementation

Looking for original energy clues in buildings from the perspective of prototype is to reveal the most typical thermodynamic rules in its design. Base on the experience of thermodynamic abstraction from case studies, the research group embeds the initial prototype into the climate, environment and context of the site. By the process of angling, segments, addition, merging, overlapping or distortion, the prototype can be evolved and evaluated to fit a specific environmental mechanism.

As mention earlier, a group member took the middle-east wind tower as the original prototype. In this scheme he focused on the sustainable utilization of wind energy on the site. According to the wind direction and speed of the site, prototype transformation steps like geographic control, volume division and contour test for 3D facade were taken by software simulation for better wind energy utilization in the local environment (figure.5).

The “light” scheme came from photosynthesis. The prototype generation took a composition of several factors into account: porosity, layers and channel. In order to test and optimize the performance of the prototypes in the light environment of site, we tried to produce many variations of the original prototype by different dimension, thickness, height, direction and form, and used the prototype models to simulate a whole day’s natural light condition in the light laboratory (figure.6). The most reasonable prototype could be selected in this process and applied to the next phase.

In the “heat” study our research group was inspired by ant colony. We started with the inner cavity section analysis, tried to explore the combination modes of different channel branches, heights and cross section forms, and considered the optimization method by simulation. The final prototype

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generation combines the climate on site and the required functional elements (in this case it is an industrial museum) and it represents a better heat regulation (figure.7).

3.4. PHASE 4: Energy formation: systems-oriented design

Kiel Moe put forward the concept of "energy formation" in his book *Convergence: an Architectural Agenda for Energy*, and he explicated materials, energy systems and amortization as three factors that should be converged through design to maximize the architectural and ecological power of buildings[6]. In this view, the basic way of generating architectural form is the capture and guidance of energy. The process from prototype to paradigm can be seen as a systems-based integral translation. Therefore the resulting form may be called "energy materialization".

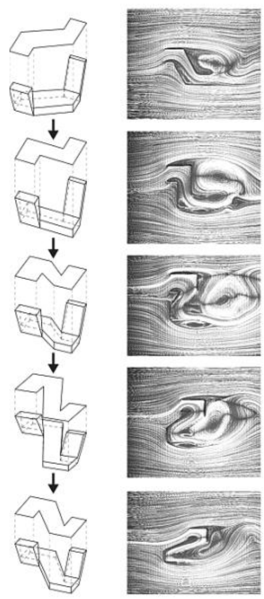

Figure 5. Prototype developing process oriented by wind (Source: Zhang Runze. Tutors: Li Linxue, Zhou Jianjia)

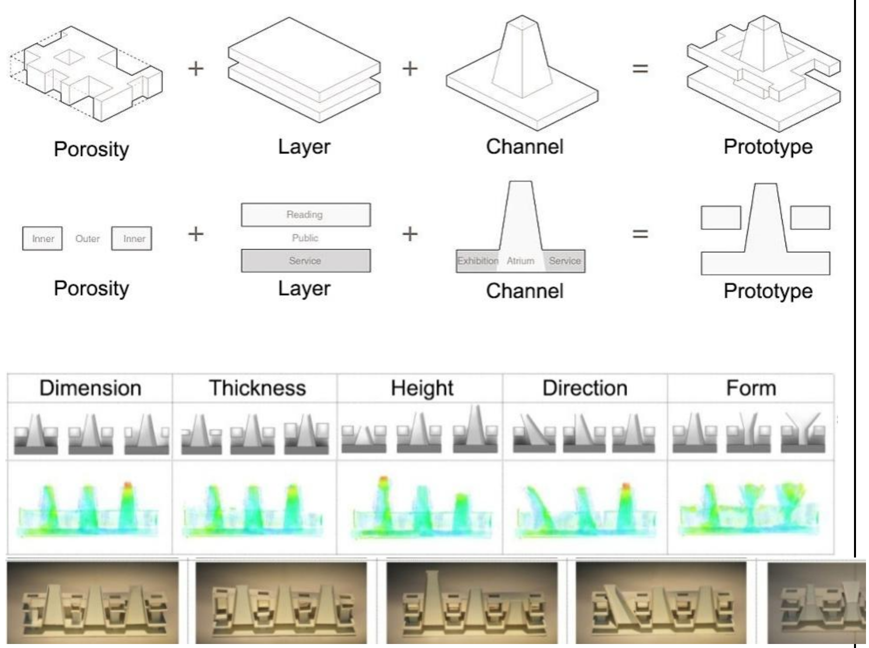

Figure 6. Prototypes test in "Photosynthesis" (Source: Zheng Xin, Zheng Siyao, Lyu Xinxin. Tutors: Li Linxue, Zhou Jianjia)

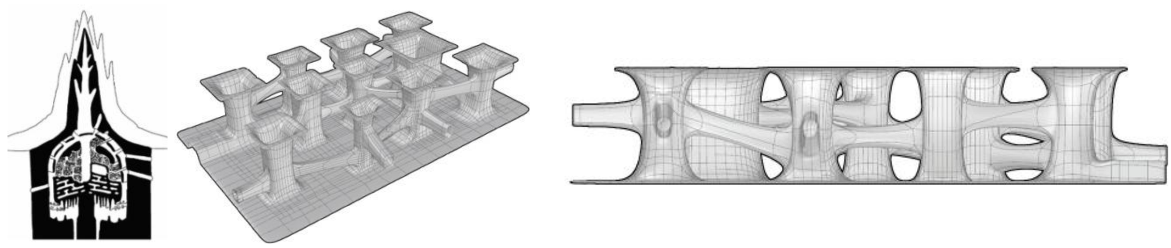

Figure 7. Ant colony and heat formation (Source: Li Hao, Gan Chongyu. Tutors: Li Linxue)

From prototypes to final design, it is a process of morphological and systematic transformation. First is a scale conversion on the prototype. Then taking into account the function, infrastructure, traffic organization, structure and the specific on-site climatic which need to be confront after prototype scaling, the energy formation begins to take shape, the interior and exterior space are naturally generated[7]. Finally, combining the adjustment by software simulation and detail structure models, the way to make use of on-site renewable energy can be expressed through the building form. The form appears to be open and able to fit in the local climate and context. Still take "Photosynthesis" as an example, the main objective of the design is to better guide and organize the natural light to meet the daily use of the building. In the final scheme, we can see the "chimneys" of varying size come from "channels" in the prototype, same as the spaces coming from "porosity", functions coming from "layers". They are massing into a whole building (figure.8).The building should be put into the site for environmental performance simulation, and the model also needs to be used for testing the feasibility of construction (figure.9).

4. Conclusion: New paradigm for thermodynamic architecture

This study focuses on the thermodynamic principles of natural energy flow in the architecture and the utilization of the natural energy sources in specific climate environment. This project employs an innovative academic vision, integrates inter-disciplinary team, re-examines the guiding role of renewable energy in the initial design phase from a systematic perspective. And with the help of ecological simulation and digital design technology, the frontier method of "*Thermodynamic Architecture Prototype*" is built to provide a deeper theoretical support for the development of green buildings.

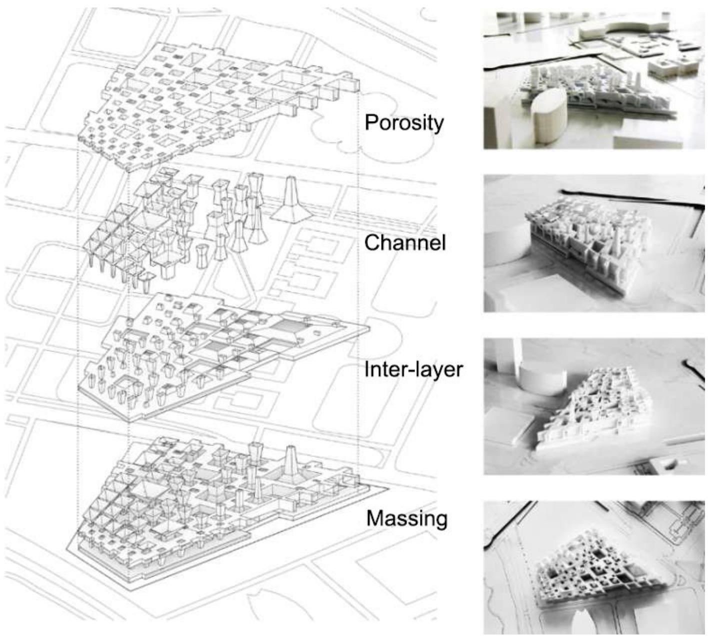

Figure 8. Prototype transformation and implantation (Source: Zheng Xin, Zheng Siyao, Lyu Xinxin. Tutors: Li Linxue, Zhou Jianjia)

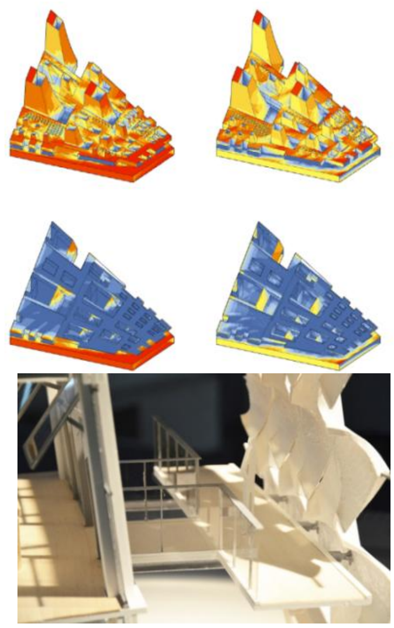

Figure 9. Performance and details (Source: Zheng Xin, Zheng Siyao, Lyu Xinxin. Tutors: Li Linxue, Zhou Jianjia)

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References

[1] Li L 2015 *Time+Architecture* **10** 142
[2] Li L and Tao S 2016 *South Architecture* **27** 173
[3] Moneo R 1978 *Oppositions* **13** 40
[4] Banham R 1969 *The Architecture of Well-tempered Environment* (Chicago: The University of Chicago Press)pp 89-92
[5] Hensal M 2013 *Performance-Oriented Architecture: Rethinking Architecture Design and the Built Environment* (UK: John Wiley & Sons Ltd.)p 121
[6] Moe K 2013 *Convergence: An Architectural Agenda for Energy* (London &New York: Routledge) pp 22-25
[7] Braham W W 2015 *Architecture and Systems Ecology: Thermodynamic Principles of Environmental Building Design* (London &New York: Routledge)pp 23-28