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Regional Opportunities: The Seeking of Feasible Modes for Chinese Architects to Deliver Non-standard Building Envelope

Abstract: The architectural industry has been pervasively engaging with computation. In mostdeveloped countries, designers adopt digital applications in virtual representation, simulation, and information exchange in order to expand design vocabularies and simultaneously pursue a higher production efficiency. These trends have impacted China's architecture as well. In the past two decades, computation has interacted with domestic design generation and project delivery (PD). However, facing a dominative "Design-Bid-Build" (DBB) system and a rigid labour environment, pioneering Chinese architects are currently experiencing digital incompatibility among collaborating parties —the increasing design complexity versus effective methodologies of project delivery. This paper firstly questions the applicability of a Western PD paradigm in non-standard domestic practices and discusses shortcomings in current building and manufacturing industries. It then introduces a digitally enhanced PD hierarchy, in which process-based philosophy and modelling strategy are elaborated. Furthermore, the paper uses two cases of non-standard building envelopes to illustrate opportunities computation brought to architects. It aims to seek the possibility of an architect-led PD mode which fits a Chinese context and argues its peculiarities in comparison with the Western paradigm.

Keywords: Non-standard envelope; Architect-led; Project delivery; Computation

1 Introduction

Beyond virtual simulation, computation in architecture has been amplified in design generation, representation, and evaluation. Pioneering designers such as Zaha Hadid Architects, UNStudio, and Coop Himmelb (1) auhave been exploring formal potential in a digital environment without which such experiments would have been inaccessible. Here, the digital paradigm shift refers to another level of integration — the ideological and procedural developments in project delivery. Historically, the Western architect stands at the peak of an authority pyramid, following the epistemology that produces architecture top-down, also known as the "Design-Bid-Build" (DBB) mode. Architecture's monumental and semantic attributions are reasons behind its sluggish technological advancement when compared with other design-related industries. Also, the risk-avoiding nature of its multi-disciplinary collaboration often leads to insufficient innovation in workflow[1]. Nevertheless, computation-based algorithmic or parametric design reshuffled this order, breaching the dichotomy between form and function, and enabling an architect with both a micro and macroscopic relation to his discipline.

Here, we discuss this macro-micro relation via two perspectives. From a single nail to complete, prefabricated assembly parts, architecture can be described as a composition of sub-components. Here, in a conventional paradigm, the architect has to go through a redundant process from conceptual design to technical drawings in to achieve buildable result. Where this pathway has limitedmanipulating flexibility, algorithmic/computational tools can facilitate direct collaborations among disciplines, enabling the architect to seek design iterations while simultaneously e. g. fulfilling engineering and structural needs.

Macro-micro relations can also refer to the inner relations of a building's digital model. From fundamental-input variables, including points, lines, and surfaces, the digital complex is constructed with a selection logic. Architecture is virtually represented by levels of geometrical definitions in a "parent-children" relation.

This evolution, involving both digital epistemology and technology, has triggered a paradigm shift in project delivery among pioneering Western firms. Not only did the notable slogan of a streamlined "CAD-CAM" industrial workflow surface: new professional specialists emerged consisting of architects, engineers, and computer scientists. A holistic development in the architectural industry became a necessity to cope with increasing design explorations. China, on the contrary, just witnessed a pervasive urbanisation where a rigidified industrial system dominates. Domestic architects, consequently, are endowed with less authority in this current circumstance. Nonetheless, architectural digital thinking has been imported to China since the 1990s. New generations have started to challenge an imbalanced atmosphere where mature manufacturing capacity and an integrated system are yet to come. Today, pioneering architects are seeking alternative strategies to deliver non-standard practices.

This paper studies computational strategies and processes in delivering non-standard building envelope and discusses the architect's changing role in information exchange. The research goal is to generalise a computational process-based project delivery (PD) mode that enables domestic architects to integrate available resources and bypass constraints.

2 Domestic Argument

Since the "Open Door Policy" in the 1970s, China has jumped onto a fast track of urban development, following a so-called "Chinese Characteristic" Western mode. Well-trained returnees from Western developed countries facilitate this process. The term "Home-grown" architects[2] refers to practitioners who are aware of a domestic socio-economic and industrial context. Among them, a digital sub-group has emerged that is exploring the latest ideology and cutting-edge techniques.

2.1 Paradigm Confliction

Process-based PD philosophy emphasizes the necessity for developing technological integrity. Rather than a single discipline's evolution, this paradigmatic change involves both technical and systematic improvements among all corresponding industries, including engineering, manufacture, assembly, and implementation[3]. A streamlined PD mode is the success of a holistic social development.

2.1.1 Domestic Explorations

Under the circumstance of an economy-driven "Design-Bid-Build" mode, "home-grown" architects have come up with multivariate strategies to realize innovations regarding design complexities and scales. *MAD Architects*' early "Hutong Bubble 32" in Beijing for example shows a small-scale non-standard installation demonstratingan architect's control over the PD process. Collabourating with a local art design institute for construction, the architect could output geometry and implementation information directly from the computational model. However, in larger-scale projects such as in "China Wood Sculpture Museum" and "Harbin Opera House", more typical Western consultants were involved in formal optimisation and structure rationalisation. With sufficient financial means available, *Gehry Technologies* and *Inhabit Group* could be invited as consultant to provide CAD-CAM services to realise the non-standard curtain walls.

"Home-grown" pioneers have adopted both approaches in the current environment. In non-standard design materialisation, an international collaboration with high-end consultancy is comparatively more reliable. However, it is not always the case that the developer and investor prioritise a design's completeness to its financial efficiency. Also, self-developments and investments of an architectural firm occur within this recent Western paradigm, resulting in multi-disciplinary team compositions with a research-oriented purpose. So, the question is raised whether within a Chinese context the needed ideological changes of an architect's digital workflow can increase PD's feasibility in explorative designs while integrating a local industrial environment efficiently.

2.1.2 Deficiencies in Manufacture Industries

The progress of China's economy and social development has fostered a building industrial mode whose manifesto of urbanisation is rooted in a hierarchy dominated by "low-cost" competition. Furthermore, building construction related manufacturing industries remain labour-intensive within a labour-focussed demography. The industry is comparatively less developed because of:

1) Deficient manufacturing precision. The trend to import CNC machinery and operation workflows does not match the sluggish developments in professional knowledge and operating techniques. Many industry plants are equipped with advanced machinery, but, compared to Western developed countries, product outcomes remain unstable in quality, pass rate, lifespan, and accuracy.

2) Insufficient Computer Aided Engineering CAE) competence. Product innovation requires follow-up updates in materialisation workflows and computational validations of its manufacturability. Currently, most domestic manufacturers continue operation in a traditional work mode, with communications between accessible machinery and design generations staggered. In large-scale non-standard practices, high-end consultants will be involved in pre-manufacture rationalisation (leading to higher financial cost).

3) Long innovation process. The lack of necessary engineering capacity among manufacturers stretches the time duration for new productions. Without the early-stage validation and rationalisation in a design's manufacturability, new product design requires exessive and often redundant testing processes before starting the production line.

4) The need for flexible manufacture system (FMS). Most of the manufacturers in China have adopted Computer Aided Process Planning (CAPP) in project delivery — a top-down digital managing method integrating CAD, CAE, and CAM with fabrication details including material selections, processing techniques, and production lines. An FMS, however, is key to ensuring production variety. Production lines in flexible manufacturing cells (FMC) are capable of mass-customisation only if a FMS integrates all operations. Currently, in China, most manufacturers continue doing this process manually.

3 Digital Opportunities

Digital progresses, i. e. computational capacity in design, communication, and management, can amplify Chinese architects' authority in intent realisation while simultaneously fitting the rigid context. This leads to elaborate discussions on each project phase where an architect can strategically control design input and output in search of effective results.

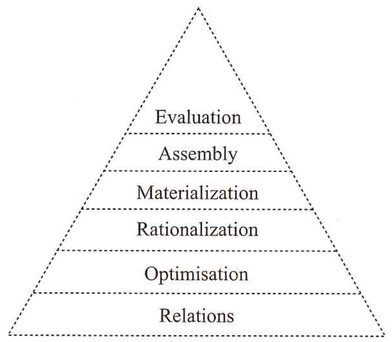

Figure 1 Digital PD hierarchy

One can see a building as consisting of its "information" and "matter" — a "parts" to "whole" relationship embedded in each level. A project's digital model is crucial to the role an architect plays in the materialisation approach, revealing the corresponding workflow in the PD hierarchy (Figure 1).

3.1 Parametric Modelling

With universally available digital tools, Chinese practitioners are endowed with the same level of information control as their colleagues in the Western. Parametric models are fundamental to this "parts to whole", "information and matter" ideology in project delivery. A parametric model from the PD hierarchy involves two levels of geometrical definition (Figure 2.): "governing geometry" and "construction system"[4]. When cross-referencing the above hierarchy and diagram, we can define the first level of "digital relations" as the generation of "construction geometry". Similarly, the "optimisation" and "rationalisation" process equals the transition from a "control geometry" to a buildable "reference geometry". Then in the second phase, the parametric model produces needed datafor materialisation, assembly, and as-built evaluations.

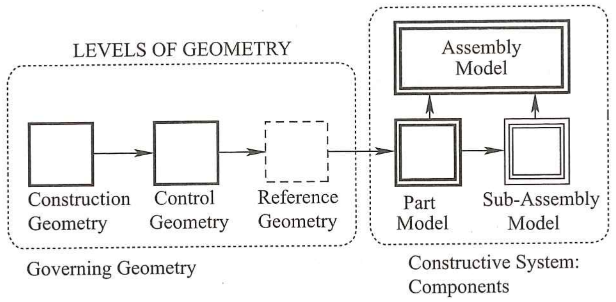

Figure 2 Levels of geometry (Cardenas, C. A)

In a digital environment, an architect changes his/her role of presenting space from non-perspective drawings to constructing a virtual logic of variables. A process-based design is rooted in its parametric model and proceeds bottom-up. The current DBB mode in China disconnects designers from following PD participants (even the current nationwide BIM promotion is there merely to facilitate post-design integrity). In order to regain the weight of their corresponding role, strategic parametric modelling becomes essential.

3.2 Operation Rationales

3.2.1 Digital Relations

In a parametric context, the tone of a design's feasibility is set by constructing proper relations among model parts and disciplinary communications. For digital modelling, this connection begins at manipulations of the fundamental "base model", which consists of basic geometries including point, line, and surface in any software environment. This level of digital modelling can be interpreted as a "parent and child" relation, based on which a project's materialisation logic builds up. In this phase, an architect uses theparametric model to control flexibility affected by both subjective design requirements and objective constraints.

In effective parametric modelling, two major strategies are adopted by architects in constructing digital relations: "top-down" and "bottom-up". Top-down defines the base geometry as an overall form, from which subordinating elements including individual components, manufacturing details, and assembly logic are developed along with input parameters. On the other hand, a "bottom-up" approach constructs the overall form from detailed components. The aggregation of these parts then reveals a materialisation logic of its whole.

3.2.2 Computational Optimisation and Rationalisation

The complexity of "child" geometry is developed from parametrical manipulations of its "parent". The second and third phase aims to achieve a reference model for further materialisation. In non-standard designs, these two phases often involve both geometrical and structural engineering of curved surfaces. Thus, the optimisation phase is focusing on interpreting various surface types to manufacturable comprehension.

Geometric analysis is essential to a design's realisation solution. For non-planar geometries, a first category is ruled surfaces, which includes both developable (unrollable) and non-developable (cannot be flattened without stretching and cutting) surfaces (Figure 3). With digital tools, designers nowadays can easily engineer non-developable ruled surfaces for the planar manufacturing. A second category of freeform geometry increases the realisation difficulties. Analysis tools enable designers to evaluate both synclastic (positive Gaussian curvature) and anticlastic surface properties (negative Gaussian curvature) allowing efficient subdividing solutions (Figure 4).

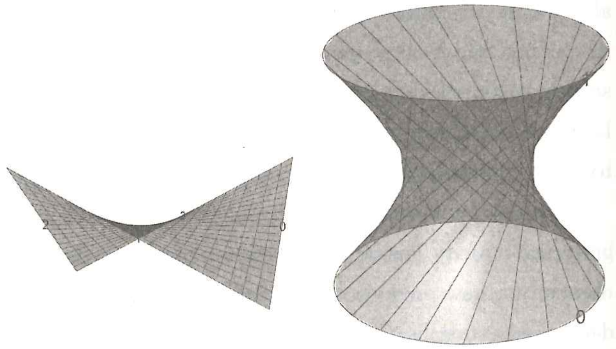

Figure 3 Examples of developable (left) and non-developable (right) surfaces

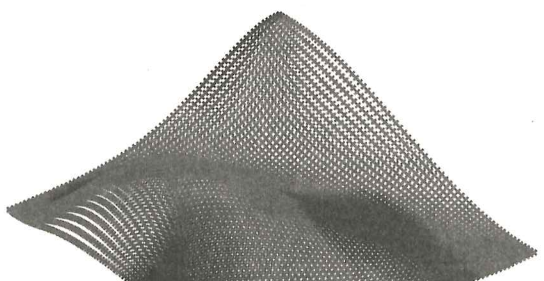

Figure 4 Gaussian analysis of freeform surface

Two strategies are involved in the next PD phase: "post-rationalisation" and "pre-rationalisation". In the "post-rationalisation" strategy, "reference geometry" is fixed prior to "optimisation" and "rationalisation", possibly by third-party specialists. In the "pre-rationalisation" mode, architects and engineers integrate accessible productivity and resources while defining the form. The subdivision of non-standard surface aims to seek manufacturable dimensions that fit a material and machine requirements. Following a geometrical analysis; and integrating material performance, non-standard surface subdividing methods can be categorised as 1) subdivision of continuous surface (grid projection); 2) surface from strips; 3) faceted surface (figure 5).

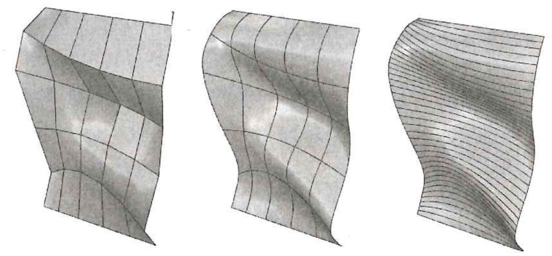

Figure 5 Surface rationalisation methods: grid project (left); surface from strips (middle); faceted surface (right)

3.2.3 Materialisation and Assembly

When settling all input parameters, a reference model is ready for information output. In a digital environment, this process can be interpreted in various ways. In developed countries where labour cost is high, the output from a digital reference model (information model) is often directly translated to machine languages such as G-code (a numerically control programming language) for direct manufacturing. In less-developed contexts such as China, this data can also be incorporated in common labour-intensive manufacturing processes and implementations. Then, an architect is responsible for elabourating building components in order to match the accessible manufacturing techniques, including forming, contouring, tessellating, folding, and sectioning[5]. In this situation, either the off-site pre-fabrication or the in-situ implementation is under a manageable environment where an architect oversees the information exchange.

4 Case studies

Digital opportunities allow Chinese practitioners to balance regional pros and cons, and regain project authority by controlling various formats of data exchange. Especially in non-standard practices, a new workflow paradigm is needed due to the extra cost of working in a conventional mode. Consequently, Chinese digitally-driven architects have been seeking a characteristic spectrum where innovative design intents fit the developing context.

4.1 Increasing Role

The current industrial environment is characterised by an imbalanced digital competence among project parties. Architects are frequently facing a restricted PD mode. In digital environments, process-centric flexibility and parametric modelling strategies help an architect to output information matching a given materialisation context. As a result, his/her role of authority rises.

4.1.1 Case 1: The "Greenland Huxiang Center"

This building was designed by CCTN Architectural Design with architect Hongtao Bo in 2014 and completed in 2015. The project is a renovated sales centre covered with a non-standard envelope (Figure 6.), whose opening dimensions were parametrically designed in response to daylight requirements. Similar to the aforementioned rigid PD system, the project architect encountered manufacturing constraints, and locally available engineers and production centres were not able to proceed with a full CAD-CAM workflow. Adaptations were needed during the process.

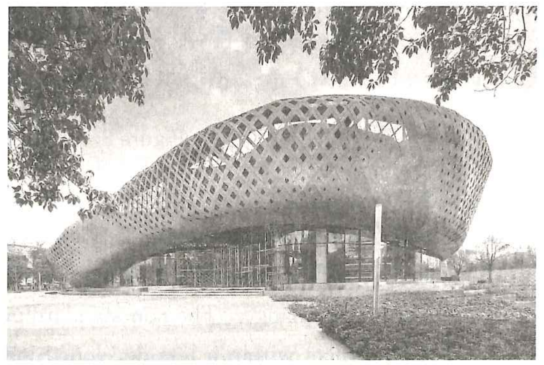

Figure 6 Non-standard envelope by CCTN Architectural Design

The parametric model was built with *Rhinoceros* and add-on *Grasshopper*, enabling the architect to flexibly manipulate the overall form (base geometry) in response to the desired performance. The non-standard envelope adopted a separate structural type: both the primary and secondary structural frames were pre-fabricated off-site in segments. The base skeleton was "isop-armed" (extracting geometry structural curves in both U and V direction), followed by simplification through reducing the number ofsurface subdivisionsplus converting curvy profiles to straight lines. Finally, all structural components were manufactured locally (Figure 7).

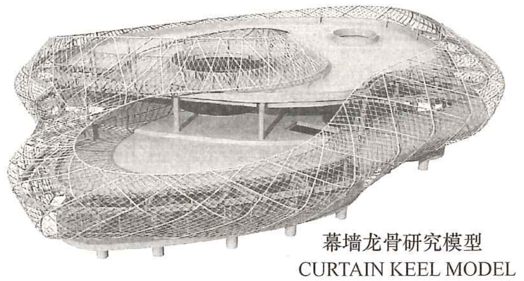

Figure 7 Separated structural system from straight segments

Here, the challenge was the PD strategy for surface panels. The non-standard envelope design led to variations of both panel profile and maximum curvature. Furthermore, a conventional DBB mode would no longer be effective due to the uncertain manufacturing capacity and implementing risk. Several contractors quit the bidding proce-ss. Eventually, a collaboration was established between a Shanghai-based ship manufacturer and the architect, as this manufacturer is more capable of materialising irregular components. The difficulty lay between formal performance and fabrication limitations. Locally available machines were only capable of producing convex panel whose maximum sectional chord is 200mm. This decisive parameter was brought back to the digital environment by the architect so that effective iterations were accessible. The architect provided panel layout and 2D drawings in *AutoCAD* in order tocope with a comparatively less-developed software environment (Figure 8).

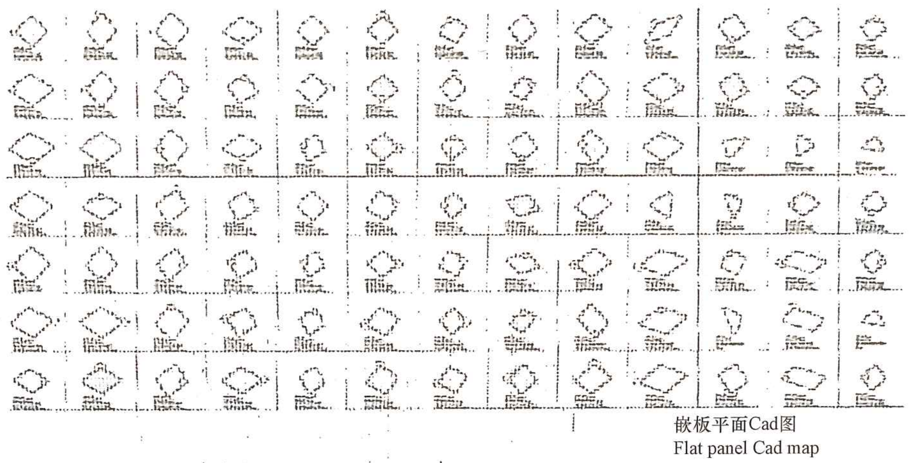

Figure 8 Architect's layout for panel fabrication

This case demonstrates the expansion of the architect's role, not only in process control and team composition, but also in his/her capability in design development and information exchange. The non-standard practice encountered conflicts within a less-developed industrial environment, requiring PD negotiation. With available digital tools, an architect nowadays is able to enlarge his/her responsibility by bridging gaps between needed information outputs and formal exploration.

4.2 Alternative Information Exchange

In the Western industrial paradigm shift, the way information is represented and exchanged among project participants has the most fundamental impact. This shift demands a holistic improvement, both technologically and organisationally, as more digital specialists and industrial automation are involved. Facing the challenge of financial constraints, domestic pioneers are seeking alternative solutions that bypass "high-end" collaboration while delivering explorative outcomes. Through parametric modelling, architects can manipulate the format of information exchange in order to level threshold differences. For example, in a different context, the requirements from administrative documents, industrial pre-fabrication, and labour-intensive implementation may lead to redundant operations. Yet, when able to control information exchange, architects nowadays can reduce unnecessary sluggishness in the process while simultaneously increasing product flexibility.

4.2.1 Case 2: The "Yan Ancestral Hall"

This project studies how an architect interprets the intended complexity and brings it to an operational comprehension and logic. The building is a 70-square meter brick architecture in which the client's family name "闫" was projected on the West elevation (Figure 9.). Onlya local vernacular labour force was available for implementation, meaning the criticality of the design's information needed to match labourers' comprehension.

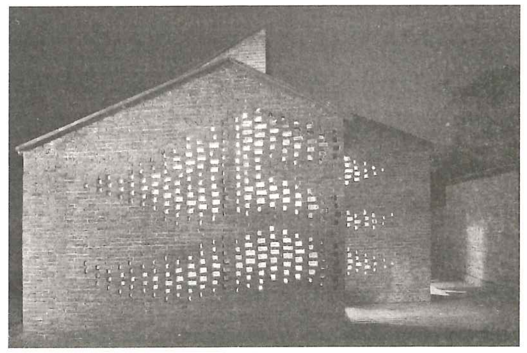

Figure 9 West elevation

Compared to advanced materialising approaches such as robotic automation and off-site prefabrication, the labour-intensive implementation required the relative location of each brick. Using the parametric environment of *Rhinoceros* and *Grasshopper*, the architect established an implementing logic with the "Flemish bond" —one header between two stretchers. The algorithm used header as the reference grid (Figure 10. left) while all stretchers were taken for length iterations (Figure 10. right). Conventional CAD drawings were abandoned as only a sequence diagram of brick layering was required.

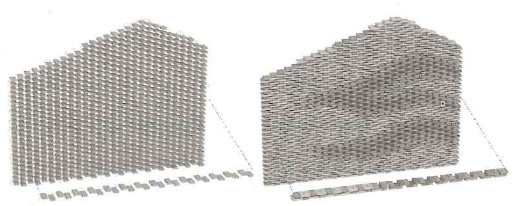

Figure 10 Header as a grid (left), iteration layouts (right)

From the parametric model, the architect extracted the total number of each cutting category, reducing material waste. The exchange format of construction information changed: the layering sequence was exported to *Microsoft Excel* rather than a 2-D drawing. It was comparatively much harder to present contractors a non-standard design with conventional layouts. Especially in this case, a holistic comprehension of the designed geometry was unnecessary for a precise implementation. As a result, the project was finished in 2 weeks with a deviation of 10 percent.

5 Conclusion

This paper affirms the increasing advantages that the Western digital paradigm shift brings to pioneering Chinese architects. Yet, the argument is made that in a less-developed industrial context like China, adaptations are needed from architects when delivering non-standard products. By elaborating on the capacity and rationale of parametric modelling, the paper aims to reveal the potential of Chinese architects gaining authority in project delivery. The two cases illustrate fundamental change sin the architect's role and in information exchange, from which the papers kick-off a future research goal of seeking peculiarities of "home-grown" architects delivering non-standard design.

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