Interaction between Parametric Modelling and Criteria of Product Development in China’s Non-standard Practice

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This paper questions the ideal digital paradigm of its applicability for non-standard architectural practice in China. Streamlined multi-disciplinary cooperation may constrain when facing a challenging construction context which notorious for its high speed, lack of craftsmanship, low budgets, and poor detailing. Living with this, however, a group of digital practitioners has successfully been able to complete several non-standard architectural projects with a complex form. An argument raises suggesting an essential part of their success lies in their alternative use of typical parametric models, which are adapted to create tolerance space between design, development, and implementation process in response to local challenges. Here, we study two non-standard cases from Chinese architectural practice HHDFUN. By analysing the project delivery processes, this paper ambitious to extract higher-level knowledge that will contribute to the professional practice and facilitate the extension of an expanded, yet purely digital design solution space into the challenging material world of local construction.

Keywords: HHDFUN, parametric model, solution space, product development, China’s context

INTRODUCTION

When Carpo (2011) argued that an architect’s authorial role in the modern design process may not survive the digital turn, he was indicating a potential shift of the architect’s professional responsibility from the radical segregation between drawing and making. In this paper, we stand with the notion that design is a problem-solving process (Lawson, 2006), and these problems are normally ill-structured in architectural practice due to its uncertain goals and involved immeasurable variables (Hudson, 2010). For the architect, design exploration describes a space where he seeks feasible solutions to accommodate design problems and constraints. Parametric modelling, furthermore, visualises this exploration space while bringing precision to a project’s design-to-materialisation process. By allowing him to manipulate design variables and describe involved design problems with algorithms, the adoption of this computational medium is able to increase the architect’s control over implementation uncertainties and acts as the facilitator to his role shift in the current digital trend.
Design problems in architectural practice are structured with form and functional requirements, which we see as constraints that constantly shaping each project participant of whose design solution space. According to participants' diversity and problem characteristics, Lawson (2006) categorised these constraints into two types in the 'model of design problem' (Figure 1). In architectural practice, internal constraints (problems) refer to the essential requirements related to building design such as functionalities, circulations, and systems; and external constraints (problems) are limits like collaborators' technical capacities and material performance. For an architect, these two constraint types define the boundary of a feasible exploration space. Each type contains radical, practical, formal, and symbolic problems (Figure 1), which may be raised by various participants at different times along project development. Here, we focus on a pure architect's design solution space that may impact an architectural practice of its materialisation success. Radical requirements raised by the client, user and legislator are beyond the scope of this study.

Among four major debates of parametric in architectural practice: 1) “all design is parametric”, 2) “change is parametric”, 3) “tooling is parametric” and 4) “Parametricism (Schumacher, 2008) is parametric”, three have created a bias due to the separation between a model's ‘creation’ and ‘use’ (except Parametricism presents a design style) (Davis, 2013). Davis (2013) suggested the notion that both the ‘creation’ and ‘use’ of a parametric model contribute to an architect in solving above-mentioned problems. The ‘creation’ describes the strategy of an architect defining a problem structure and parameter values, while the ‘use’ refers to the manipulation of these inputted values and information exchanges. The effectiveness of this integration lies in how an architect relates his modelling strategy to both internal and external design constraints, also in what design decisions he made in response to gained knowledge. This paper case studies two non-standard building projects by Chinese architectural practice HHDFUN. We argue that, by creating the design tolerance via parametric means, an architect may increase the feasibility of his design exploration. Here, we discuss one approach which interacts parametric model with the corresponding criteria in the realisation of building components.

**PARAMETRIC MODELLING & PRODUCT DEVELOPMENT CRITERIA**

Parametric models are the commonly preferred medium to manage and convey the copious amounts of project information affecting design decision making and to collaborate with project participants. Friction appears when either the precision provided by the model beyond available implementing capacities or a model may lack needed details for the craftsmanship on-site. Hence, the structure of a parametric model not only represents an architect's design intention but also his problem-solving logic and expected multi-disciplinary collaborations.

**Rationale behind parametric modelling and its control strategies**

The parametric model is a tool for an architect to accommodate his solution space to others’. Here, we present an abstractive diagram (Figure 2) showing the fundamental logic of creating a digital model and how its parametric capacity is defined. The model creation process is called governing geometry, which involves three hierarchical levels: 1) building scale, 2) system scale, and 3) component scale (Cárdenas, 2007). In each level, computational definitions of building parts are either described with global ge-
ometries, which present only formal information of the designed parts, or local geometries that contain sub-elements of the parts from the next hierarchical level. The model structure illustrates how an architect organises design constraints and what parameters he may use to explore design options.

The use (control) of a parametric model interacts with an architect’s creation strategy. In the diagram (Figure 3) we illustrate two major types of parametric control: direct and staged. A fully direct parametric control is commonly applicable to small-scale architectural practices where less computation capacity is needed comparing to a large-scale building. On any hierarchy level, a change made to variable value may affect the form and details of an outcome and its correlated materialisation strategies. A direct para-
metric control endows an architect the most freedom in design exploration as his design decision may change anytime to accommodate materialisation requirements. On the contrary, staged strategy separates model into sub-problems, continuously shrinks an architect’s exploration space and design freedom while project progresses. Architects adopt this approach mostly for large-scale building practices due to contractual needs and excessive computation involved. In non-standard architectural practice, including geometric, functional, and material processing complexity as well as an architect’s past experience play the key role in determining a model’s ‘creation’ and ‘use’ strategy.

**Criteria for product development in architecture**

Product development in architecture concerns the designing, developing, and examining of building components and defines technical and material processes for both off-site and on-site products. These criteria interact with both internal and external design problems and may also affect an architect’s modelling strategy. Here we discuss five categories measuring the complexity of developing a non-standard building and its components: 1) production environment, 2) product type, 3) product complexity, 4) product frequency, and 5) product newness (Eekhout, 2008).

Production environment rates the industrialisation level from a traditional construction (the least flexible) to a flexible industrial production. Product type and product complexity refer to a building component’s materiality and characteristics in regard of its fabrication and implementation requirements. For example, we see a component’s standardisation level as its product type, which ranges from a super standard product to a super special product. Also, product complexity describes a building component’s internal organisation including its sub-elements and their product types. Product newness and frequency are the indications for industrial design, engineering, and production, which describes a product’s maturity and needed investment for design development (Figure 4).

These criteria shape an implementer’s design solution space. For example, once committed to the project, a component manufacturer will start planning and the related industrial design process. In order to fulfill a design intent, the manufacturer will provide different solutions of the composition of a component’s specification, product architecture, manufacturability, and development economics. In the non-standard architectural design, however, geometric complexity may increase the uncertainties during its component developments. When there is no intersection found between the architect’s and the manufacturer’s original solution space, either or both of them have to redefine the boundary to seek a feasible outcome. In the discussion of an architect’s pure design solution space, this adjustment is what we called creating design tolerance.

**CASE STUDY - HHDFUN**

The founding partner Zhenfei Wang and Luming Wang are the key figures of Chinese avant-garde architects who have been challenging a domestic construction context and have successfully delivered non-standard building practices. We argue that one critical factor to their success is the design tolerance, which HHDFUN creates via parametric means, allowing collaborating parties to find intersections among their solution spaces. Here, we study two building complexes, Tianshui Tourist Center and Dichi Tourist Center of Shandong Qingdao 2014 International Horticultural Exposition, to compare the delivery process of two non-standard buildings; discuss failures and learnt knowledge by the architect; and analyse the interaction between the architect’s modelling strategy and building components’ materialisation. Both Tianshui and Dichi Tourist Center are developed from the same logic: using a non-standard building form to fulfill topographical and functional requirements. Finished buildings have integrated circulation pathways, gardens, and event spaces with the surrounding context.
The insufficient tolerance in Dichi Tourist Center

This project was successfully implemented and exhibits an eye-catching effect of its landscape (Figure 5 left). Nevertheless, the construction process has encountered setbacks due to the difficulties in materialising its non-standard forms. In this paragraph, we discuss the friction found during the implementation of outdoor steps, which was caused by the internal design problems led by the architectural design conflicting with external constraints such as material characteristics and installation logic.

The design was created based on the geometric rationale that a flexible diagrid can be deformed to match the topography of its contours (Figure 5 right). The architect has adopted a staged modelling strategy to avoid excessive computation (Smith, 2007), and to fulfil administrative needs of a conventional design-bid-build work mode. The digital model structure has been built top-down, where the first level of geometric definitions described the building design with global geometry. The key driving parameters are
the inputted reference curves that follow the landscape ridges and blend elevation differentiation (Figure 6 left). The architect has established direct relations between an overall geometric definition with its dependents in the first modelling level. Information including step divisions and tread heights were related to the manipulation of the desired envelope form (Figure 6 middle). By the end of governing an overall building geometry, a reference model has been frozen in order to determine the building footprint and geometric control points (Figure 6 right). Henceforth, no more global changes were allowed in the building scale since design information has been passed on to collaborators.

Project implementors joined the team during the design development phase. By far, the design’s internal constraints such as functional and formal requirements have been determined using a reference model which was provided by the architect to each project participant. However, external constraints including components’ material processing and corresponded implementing strategy remain unsolved. The following modelling process was carried out to increase the detail level of building component descriptions. In this study, we discuss the architect’s parametric operations in delivering a non-standard landscape. The digital model not only represented his formal requirements but also a solution space he created for realising this design, and it was an agency for multi-disciplinary information exchange. The design’s feasibility was tested by if the intersection could be found, between the architect’s and implementer’s solution space, to cover the proposed design problems. In the case of Dichi Tourist Center, friction appeared during the implementation of the landscape steps and paving. The designed geometry and its component details have confronted with the standardisation of selected materials. The left photo in figure 7 shows contractor’s fabrication limits against the architect’s intent; the middle photo shows the formal discrepancy caused by using standard linear units to match non-standard curvatures; and the right photo illustrates the confliction caused by a paving orientation.

Figure 6
Form finding based on topography (left); local geometry definitions in building scale (middle); and outputs from the parametric model (right)

Figure 7
Construction imprecision (photos © Zhenfei Wang)
During the parametric design process, the architect has focused on internal design problems of formal and functional needs. Figure 8 left describes the architect’s research of seeking the best building geometry that integrates the landscape and pedestrian use. Landscape step components were described in *global geometries*. These definitions were accordingly generated based on the topographical condition and building footprint and contained parameters of riser height and tread count. As a result, the final digital model (Figure 8 middle) which the architect provided to the landscape engineers and consultants ended with the parametric depth of a system scale. Landscape implementer was able to extract information of step coordinates and dimensions. However, sub-component information such as unit division and layout was missing, neither did the final construction documents by the consultants contain sufficient implementing indications (Figure 8 right).

In this case, the non-standard envelope landscape has been constructed in the industrial environment between a traditional construction and an industrial prefabrication. The selected plastic extrusions were ready-made by the material supplier with a standard length and width, afterward customized on-site by contractors. As a matter of fact, this process was done arbitrarily as there was no clear information informing a cutting method. It was when an external design problem has caused construction imprecision. From figure 7 we can learn that the difficulty was realising the design non-linearity, which included curved treads and irregular paving, with standard plastic profiles. A better solution would be either the pre-fabrication of precise tread units that match the geometry or pre-designing sub-divisions to avoid unexpected outcomes. Hence, on-site contractors had to improvise and adjust the solution space based on their past experience. They have mapped the installation layouts on-site but resulted in material waste. Facing the design problem, there is no intersection found between the architect’s and implementer’s solution space. Has been only providing geometric descriptions of a system scale, the architect set the design tolerance too large to achieve a satisfying result. Consequently, he might lose control of the implementing process and uncertainties within.

**Parametric optimisation in Tianshui Tourist Center**

*Tianshui Tourist Center* (Figure 9 left) was also a non-standard design that dealt with the complexity of integrating formal ambition and functionality. Geometrically speaking, the design introduced a system of multiple ‘3-arm junctions’ where the intersections were defined as public spaces, and tangent lines among these public spaces represented pedestrian circulations (Figure 9 middle). Parametrically speaking, the system was driven by several ‘control points’ whose dependent variables such as ‘point coordinates,’ ‘circle size,’ and ‘length of tangent lines’ affected an overall computational form finding process (Figure 9 right).

In this chapter, we discuss *HHDFUN*’s design and modelling strategy for materialising a non-standard building envelope. The architect has created toler-
The building complex was divided into four zones (Figure 10 left). Taking building envelopes in Zone A and B as an example, the architect has fixed the building *reference models* before panel optimisation. Therefore, in the system parametric model, it allowed the architect to explore options for surface subdivision by changing the dividing amounts in U and V direction without affecting an overall form. An algorithm was created to analyse deviation between an optimised form to the original's, and to systematically reduce panel varieties. The colour gradient from red to green (Figure 10 middle) indicates the deformation of a panelised sub-surface to its original geometry, here, the maximum deficiency (in red) is 100.78mm. Panel information was directly extracted for generating shop drawings during the construction document phase (Figure 10 right).

Also, the architect has left a 16mm gap between each panel to create a tolerance allowing construction imprecision and on-site adjustments (Figure 11 left). In the envelope *system model*, all parametric operations were directly related so that any design modifications were acceptable as long as it were before production. Regarding panel design develop-
ment, a *system standard* product allows a product designer (in this case it was facade engineer) to customise units within a systematic variety, meaning the component’s overall geometry can be different but whose sub-components such as corner braces and metal screws had to be identical. This was also for decreasing the newness of developing a new product so that the manufacturer is protected from potential financial risks. Eventually, all panels were separately annotated in drawings (although not necessary), CNC fabricated, and installed with *super standard* sub-components to ensure a production efficiency (Figure 11 right).

**DISCUSSION**

Through comparing two non-standard projects of their design-to-materialisation process, we present how an architect’s parametric modelling strategy may interact with a project’s development criteria and eventually impact its implementing result. We argue that the tolerance which an architect created, between his design exploration and collaborators’ capacities, relies on how he uses the precision of parametric modelling to accommodate uncertainties of multi-disciplinary collaboration. In the realisation of Dichi Tourist Center, a gap appeared between formal requirements proposed by the architects and materiality constraints of selected materials. The unsatisfied implementation was a result of an unplanned solution given by the on-site contractors. The expansion of the implementor’s solution space has overtaken the architect’s authority in process control, and related uncertainties might jeopardise the feasibility of an architect’s design exploration. In the second case, Tianshui Tourist Center, the architect has intentionally expanded his solution space to cater to the collaborator’s fabrication capacity. The architect has created the tolerance, regarding form details of a ready-to-come building comparing to its original design intent, to stay in control of the building product developments via digital means. Parametric modelling, in this case, was not only representing the structure of a design’s internal problems but also providing solutions to potential external constraints. In architectural practice, design freedom decreases along a project progresses (Davis, 2013). Creating a tolerance between each party’s solution space helps an architect to exclude irrational flexibility in the early stage and ensures his ability to control in the later phase. We see design tolerance as the negotiation between a design’s ambition, description, and solution.

**CONCLUSION**

This study relies on the hypothesis that an architect’s authorial role may shift in current digital paradigm. It presents a design ideology that, using parametric modelling as a medium, an architect may structure design problems the way that desired solution spaces interact. This attributes to the parametric capacity that allows an architect to make changes during project development when his knowledge gained. The interaction between the modelling and product development presents criteria that define each participant’s solution space, and which can be taken as the basis where an architect plans his design strategy.
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