INTEGRATING THE TECTONICS IN ARCHITECTURE DESIGN

A study on the view of structural performance design work-flow for agent-based architecture

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Abstract. This paper examines the implications of structural performance design method and techniques on agent-based architecture, through the example of a cantilevered large span cultural-complex project. The high level of form complexity of agent-based design posed a great challenge for construction and gave rise to an alternate solution: customization and optimization of the pre-rationalized supporting steel structure through a Multi-dimensional structural optimization process output a standard steel structure which allowed for accurate and relatively constructible method for agent-based structure, therefore minimizing costs, maximizing the design features, reduce construction technical difficulty and most importantly to create an articulated spatial-structural relationship. Therefore, the agent-based orientated structural performance design towards material computation was developed to optimize the overall design. This research helps support our methodology for control complexity in non-standard geometries produced by agent-based design process, which is based on adapting the design approach to customized construction methods.

Keywords. Agent-Based Design, Structural Performance, Tectonic Articulation, Digital Construction, Material Computation

1. Introduction
The traditional structural performance based design is a passive design method that focus on meeting the needs of structural laws and regulations,
architects are led by structural engineers who control the process of verify, evaluate, and approve the design to make the building comply with the established performance requirements. But over the past decade, brought by computational force and the rapid prototyping technology, structural performances of architecture could be simulated, analysed and optimized. This provided an opportunity for architects closely collaborate with engineering to push the boundary of architecture design and create articulation between spatial and structural quality of architecture (Schumacher 2012). And a new structural performance based architectural design methodology emerged.

In pre-digital era, this engineer’s contribution to architecture, structural performance based method, served as verification instrument for architects to gain better understand of structural condition and make a response to it. Although it enabled innovative architects by applying devices such as theory to make unbelievable complex spatial condition in a few centuries ago, it could not be prevented from was recognized as unimportant design tool. However, in post-digital era, it becomes crucially important and showing possibilities in addition to its analytical use and beyond its instrumentality. For example, the FEM made it possible for the architect to decode Gaudi’s mysterious geometric design and realize the construction work of Sangrada Familia (Huang and Xie 2010). Furthermore, it also provides a workable solution for emerging algorithmic design such as agent-based design practices to find potentially sophisticate and adaptive structural solution for their hyper-complex geometry. Therefore we can say, Structural performance based design method began to appear. It is intended to outline the new possibilities in creating the new form, and it perhaps articulates space, material, social need and information of architecture with a higher level of performance through this method.

In recent years, the agent-based design theory and methodology have been rapidly developed, the centre of debate constantly shifts from its design techniques to construction techniques. As agent-based architects argue, the agent-based strategies have radical implications for the generation of architectural form, structure and tectonics. Rather than consider ornament to follow or be subservient to structure, this relationship can be recast in terms of mutual influence; structure informs ornament while ornament informs structure (Snooks 2012).

However, almost all the agent-based design, at the same time it requires a single extreme intelligence material to full fill all the design requirement and work as both ornament and structure. Some designers rely the possibility of realization of agent based design on development of mechanic manufacturing techniques and building material, for example rapid
prototyping, 3D printer and GRC techniques. Yet today the progress architects have made on these areas cannot break through the boundary of small scale or unreasonable budget. It not only attributes to the slow development of materials science and engineering science, but also to unclear logic and analysis on the structural system in the result of agent based design method. In practice, it is difficult for architects to realize the design, the features of the structural performance design weights much in the actual work-flow.

In this study, a new work-flow is introduced, which is called upon to bridge the gap between agent-based architecture and the specific structural performance-oriented knowledge and also serve as the framework for design methodology development. These will help to generate more build-able agent-based architectural results and assist architects to take back the control of their free form spatial design. With the structural performance design method, the structural frame of unconventional form design can be realized with most seen building material such as shell structure and I Beam and the structural stability is reliable.

2. Research

2.1 BACKGROUND

The Current State of Agent-Based Architecture, as we observed is in a very critical situation in terms of construction. Most if not all, the agent-based architects in practices generally work as facade consultants and code technicians to cooperate with other well-established firms (Figure 1). We could observe that the agent-based architects attempt to realize the project and push this to the extreme. However, the works they have been involved in rarely fully translate their design philosophy:

- The relationship between the structural elements and their agent-based design facade is perhaps not well articulated.
- The detachment of space and structure is not efficient to achieve self-organized, composite oneness architecture (Snooks 2012).
• The current material and computational structural analysis method are sometimes difficult to assist architects to find a reliable solution for design.

Yet we would argue it is vitally important for agent-based architects to reclaim their right by applying a workflow which is more responsible for construction and structural performance of design. Many existing workflows only focus on the structural computation. As a complete solution to deal with the practical problems, it’s necessary to include Pre-Assessment, Structure assignment and post-optimization into this workflow (Figure 2).

![Figure 2. The brief Work-flow](image)

### 2.2 PRE-ASSESSMENT

Pre-Assessment acts as a rationalization process before run the agent based computation. In many cases, agent based architecture’s structure can be rationalized into a structure primitive which is the combination of several key structural features.

Pre-Assessment in early design stage are defined with basic structural ideas which could inform structural properties in the process of agent computation (Figure 3). Furthermore, this helps the agent-based architect design rational structure in the first place, which provides possibilities to maximize the freedom of design, also in later stage it shifts to structural tool which able to provide accurate analysis. This not all inclusive, duo stages method prevent architects from over complicating structural set ups in the processing as many others that attempt to do.

Pre-Assessment includes Pre-Setup, Process-Bundling and Pre-Analysis. The agent set up should include Pre-Setup at the same time, such as
supports, attach and base points before the agent generation process begins. The process- bundling is a process of agents’ simplification and there are many existing algorithms to choose from. At last, the Pre-Analysis take place by analyzing structure rebuild in Rhino Grasshopper Environment.

In the case of the above project, the original design is preset in the processing, the supports and attach placed according to the existing context. In run agent process, the design agents’ lines bundled and a preferable design has been chosen. In the later stage the extracted lines has been use as reference to rebuild a spatial surface to accommodate the agent design result. In the analysis, the mesh has been rebuild as overall structure in Karamba, a FEM based structure plug-in for Grasshopper. The Pre-analysis result shows that few cantilevered parts of space have structure problems. And the maximum cantilevered part is 30 meters. Through calculation the maximum displacement of this design is 0.24m.

2.3 STRUCTURE ASSIGNMENT

Derive from the previous step, the result of agent based on process and structure information could be used as starting point of structure assignment. Structure assignment ensures a precise simulation of one or multiple structure types, materials, and elements. Thus improving the feasibility and even provide cost control of the final result. The characteristics of a defined structure type and material give rise to various constraints in the construction process. These constraints are often neglected in the agent-based design process which may cause unreliable results. In the work-flow, the structural, material properties and even construction methods (such as optimize, control and reduce variation of elements and standardize elements) are taken into simulation via ways of converting them into geometric constraints, so called line and shell models in the structural analysis engine as Karamba.

In this case, the main structure type has been choose as 3d spatial steel frame structure and the main material has been choose as steel. The structure has been build based on the agent based line model. The extent of beams types such as hollow beams, I beams and circular beams, is surveyed through experiments in the computer model (Figure 4). After selection, the specified material type, profile type and structure type has been carefully input into the structural performance model and start to regenerate different structure models.
After choose desirable settings, the next step is control and the number of structure members. The range of sizes has been narrow down to achieve optimum construct-able result and the variations of elements has been optimized to find a balance between better structural performances and minimize construction cost.

As we can see from the Figure 5, the different sizes of beams are applied to the model. The first one create highly differentiated model which kept the most properties of agent based model, but the 30 different sizes might need more spends and joint types. The last one is most economic efficient one but the model is relatively too standard. Thus, the good solution is the one in the middle which allows for limited number sizes of beams and balancing between cost and performance.

The process of structural assignment takes the form of transforming structural behaviors of the actual structure, material and construction features into its corresponding behaviors in the computational structural engine.

2.4 POST-OPTIMIZATION

After previous processes, the well-established structural performance based model has been set up. The advanced tool-Karamba developed by Clemens Preisinger in cooperation with Bollinger-Grohmann-Schneider ZT GmbH Vienna, enable architects to step further and make more detailed optimization of the structural frame.
Post-Optimization includes visualization and data management of the preceding result. It’s helpful for the agent based architects to evaluate the quality of the space and structural result as seeking for the solution of resolving construction issue. As a complete set of solutions, visual feedbacks of the structure properties of design are reflected in the present process (Figure 6) as well as some engineering related to structure drawing such as numbering and dimension (Figure 7). It’s also possible to export the statistics contents of the structure model to many different formats of structural analysis software and it will be very advantageous for the structural engineers to design according to agent-based architects requirements.

We could analysis and optimize and solve more specific structural and spatial design issue. In the example, the large cantilever parts has been optimized and the structure has been enhanced to keep the original large span no column space, this create necessarily space for specific programmatic requirements such as auditorium and theatre space (Figure 8). And more importantly the structural informed space articulate structure
ornament and function together, finally achieve the quality that agent based architects desired.

3. Debate

We use two structure system to support an agent based space - the traditional beam and column system, and structural performance design system. The two sections above present two entirely different space effects. (Figure 9)

Traditional structural system limits space division, encroaches design’s initiative with elements which can stretch vertically and horizontally only. Structure also becomes a passive appendage to the building shape. The most typical disadvantage is in large –span space.

Figure 9. Section Compare

Here in this left section, the large open space above the ground is divided into several small areas by traditional beam and column system divides with columns.

The agent based structural performance design system, does not only release large span space, but also provides reliable support with a structure system generating in the shape generation development, which can fit the nearest part of building shape in any direction. It means in this system, structure is congruent with building shape in every meaning.

Figure 10. Final Design Result
4. Conclusion and Further Studies

To conclude: At first, Structural Performance design for agent-based design method develops and employs computational techniques and digital fabrication technologies to unfold innate structural characteristics and specific latent performance capacities. Extending the concept of structural systems and agent-based system by embedding their material characteristics, geometric behaviour, manufacturing constraints and assembly logic within a computational model, systems manipulations can be recurrently evaluated in relation to structural performance. (Kolarevic 2005)

Secondly, structural performance design for agent-based design is neither simply using form-active structure primitives as driver of design, nor using structural behaviour properties as traditional form-finding tool. It establishes a new form of collaboration between agent-based architects and engineers and it made it possible for architects to develop a new agent-based multi-objective design process. It also makes the design more responsive and adaptable (Figure 10).

Finally, structural performance based methods is the method that enables agent-based architects to involve and play a more important and engaging role in rationalization and realization of complex geometry’s structural design, yet it also helps architects to improve completeness of projects. More importantly, architects could be used as a vehicle to create a new form to articulate architecture space and structure members.

For the future developments, there are few things on the schedule of the improvement. At first, improvement of computational technology and algorithmic research to make it better copes with all sorts of construction problems. Secondly, it is still hard for us to evaluate the construction efficiency of design, we would like to suggest the control of material and element types has positive effect on cost control, but it is difficult for us to find a well-established value judgment system for this. At last, tools such as flexible joints to help contractor locate and construct spatial frame need to be improved. These future developments will allow a more efficient and accurate structural performance design for agent-based architecture.

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