Protuberance Model

Topological Understanding of Toyo Ito’s architecture by Parametric Design Methods

Bhujon Kang
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The values in architecture, which architects definitely believe and which handed from the previous architects. The masterpiece buildings have taught how to keep the architectural legacies, instead of the role of architects of our former generations. No architect doubts that warm and bright top light, variety of its shadow, and the air dominating inside with holiness have no insufficiency to make the space create ultimate quality. Even though some specific architectural styles could not coexist in each period, the evaluations about the quality have been preserved underneath the appearance of buildings.

On the other hand, like the origin of the word, “architecture”, it is true that a building construction represents the current technologies as well as both the Roman domes and the concrete and steel structure of Modernist architecture do. No wonder the computer technologies have made revolutionary changes of the world, architectural industry has also adapted this radical changes. Now, I strongly believe that the computer technology is the keyword toward a new architecture. Wherever it goes, people living this era must be accustomed to deal with this magical tool.

Recently, progressive architecture, which is mainly done by young architects, makes several competitions for public buildings voluptuous showcases to introduce how much they treat the computer techniques well to public. Some brilliant architects actually have proven their proposals as a reasonable methodology in
architectural design. The tendency like this enthusiastic showmanship clearly seems to be coincident with the natural flow of the enhancement of architectural development. Despite some negative views to see these audacious trials, a series of the successful cases using parametric methodologies and its morphology has made a chance to even let the conservative architects acknowledge its necessity in their designs as well. In this sense, as far as architects cannot be the tool makers, how many tools they deal with seems guarantee how they design good buildings. With a same pace with the development of both hardware and software, the programs for architectural design are advancing as quickly as architects cannot catch up. Further information of updated tools becomes one of the decisive factors for the more advanced design and its visualization. In this sense, there is one group that this parametric methodology is the key of our future architecture. I agree with it. Also, I don’t believe that this parametric methodology interrupts the architectural quality. Instead, expressive visualizations may incommode preexisting architects, and as a chain reaction of the trials, some rookie architects turn their ways to creating more complex and weird shapes.

So, this paper looks into several aspects to see the parametric design methodologies. Far from commonly known ideas that it only focuses on form making, it unearths much potentiality of the parametric methodologies, experimenting several tests. It is not only limited in making curvy shapes, but is able to reach to many areas like enhancing design environments and construction methods even including a control of design process. In doing so, we ask where the parametric architecture can be posited.

Also, I don’t hesitate to emphasize the architecture of Toyo Ito. Not only because of my internship in the office, but because that this world famous architect has always tried to create spaces which no one ever tried. His first trials have gotten great reputations with no exceptions in terms of both spatial qualities and the beautiful shapes of the buildings with high-end technologies. So, at the first, this paper focuses on creating and understanding several geometrical constructions mainly related to ones done by Toyo Ito and Associates, Architects (henceforth TIAA.) Actually, TIAA’s works are mentioned in many books and magazines which deal with the parametric architecture for several times.

There are some reasons why TIAA buildings become the best examples to argue the position of parametric method in architectural design. In short, (1) TIAA architectures make a hierarchy of creation between forms and functions. (2) Although they control the geometries of buildings very well, the building design never begins from the digitalized tools. (3) The buildings have been designed by a specifically designated cultural base. (4) They have
realized many buildings with high-end technologies. (5) Nonetheless, the design method and the building geometries have some handicaps. In other words, since TIAA architecture may imply pros and cons of parametric architecture, they play great roles as “control groups” of the study.

A Possible Range of Parametric Design Methods

Before experiments of TIAA architecture, we set a boundary of the parametric design methods. In this part, I hope exploring the wider boundary of the parametric design methods which have been adapted in the entire design process. Through this settlement for the study, we will see how closely the parametric design methods have been engaged in the current architectural design.

Parameter

1 a : an arbitrary constant whose value characterizes a member of a system (as a family of curves); also : a quantity (as a mean or variance) that describes a statistical population b : an independent variable used to express the coordinates of a variable point and functions of them — compare parametric equation

2 : any of a set of physical properties whose values determine the characteristics or behavior of something <parameters of the atmosphere such as temperature, pressure, and density>

3 : something represented by a parameter : a characteristic element; broadly : characteristic, element, factor <political dissent as a parameter of modern life>

4 : limit, boundary —usually used in plural <the parameters of science fiction>

With its lexical meaning, in architecture, a “parameter” comprehends numeral data translated from considered variables for the design. So, purely in architectural meaning, parameter might be more or less overlapped with “contexts” or “programs” for the design, which have different directions to see the architecture. It seems to allow the meaning of “parametric” to use at least in architecture. In a narrow sense, this parametric method tends to be used when designing a complex shapes in architecture. Based on computer visualization techniques, the design methods which use “parameters” have pursued the radical sense toward the form making. It tries to visualize invisible factors which architecture had included in typical and idealized shapes because, at any case, “data” means “numbers.” As seeing in the table 1 below, some architects have tried to assess the external and environmental factors as quantified data. Through a series of assessments of the environmental performance for the building, this table shows adaptable parameters which can change the feature of the building. In this case, the external inputs like air temperature and humidity become the parameters which are decisive factors for the building entities like room dimension.
From this basic idea, several endeavors have successfully been reached to the various areas in architectural design as using the parametric design methods as well. Now, we categorize them by their objectives and by the chronological order in the design process, and do the case studies which show the relationship of the parametric methods. Simply, the process may follow the general design phases like from schematic design to construction documentation.

- **Design Aids: Automated Design Tool (Schematic Design)**
- **Control of Geometry in Buildings (Design Development)**
- **Mass Production of Complex Geometry (Construction Documentation)**
- **Construction/Fabrication Aids (Under Construction)**

**Methodologies for Design Support: Design Aids**

In Structuralists’ aspects, one of the objectives of parametric architectural methodologies is to minimize the ambiguity in design process. Ultimately, someone might think of an architectural version of AI (Artificial Intelligence) model. Based on this self-reactive system designed by a complex computer program, an architect who can be also a programmer easily reduces several tedious repetitions in the design process. It is exciting that a lot of research has been already
done in order to pursue the automation of quantitative sections in the design decision. Here is an interesting study about “planning permission ordinances in district plan in Japan. The researchers analyze the legal issues which affect the massing of buildings in an urban district. Actually, the main concern in this method is how to carve out the building mass by the oblique lines along with the streets and the direction of sunlight. Using a series of programs which is related either to GIS or JAVA based software, they control the building shapes. Generally, we can ask some questions like how to diversify design variety and how sensitive to the location optimization. As a basic level of the development, although we hardly say that this program can be going to use in practical areas, this concept of the program is enough adaptable in many areas. In this case, it seems clear that this method shows its potential range of the usage in the very early stages of the design. Since every factor is consisted of actual numbers, we expect that this type of programs could be managed by a certain control of the internal principles although it cannot be imagined how complex the program would be by the change of social and legal factors. I don’t doubt that this research would be helpful as design aids, as getting rid of the complex concerns which are however clearly fixable in design decisions because sometimes architects confront several contradictory situations that these quantitative items work as obstacles of the design development.

Table 3. Parameters of usable space of building

<table>
<thead>
<tr>
<th>Parameters of the usable space of building</th>
<th>Part 1</th>
<th>Land conditions</th>
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<tbody>
<tr>
<td>S</td>
<td>Lot area Scale</td>
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<td>W</td>
<td>Width of lot frontage</td>
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<tr>
<td>A</td>
<td>Floor Area</td>
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<tr>
<td>Y</td>
<td>Zoning type</td>
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<tr>
<td>D</td>
<td>Direction of adjacent road</td>
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<tr>
<td>R</td>
<td>Front road width</td>
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<tr>
<td>C</td>
<td>Cut of corner</td>
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<tr>
<td>Part 2</td>
<td>Shape parameters</td>
<td></td>
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<tr>
<td>r</td>
<td>Rate of oblique line from front road</td>
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<td>z</td>
<td>Height limitation from front road</td>
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<tr>
<td>n</td>
<td>Rate of oblique line from adjacent road</td>
<td></td>
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<tr>
<td>H</td>
<td>Height of oblique line from adjacent road</td>
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</tbody>
</table>

Fig 2. Shape Parameters on usable space of a building (Van Leeuwen and Jos P) P.90
Cognitive Framework: Autonomous Design Tool

So, based on the idea that the quantitative parts of design process which relate legal codes and environmental data can be automated by the parametric programming, we may extend the arguments into the qualitative areas which are connected to the intuitive level of design process. We will also see that the questions—how to control or automate human intuition, are critical when dealing with TIAA architecture here in terms of understanding the design motives.

There is an interesting effort to figure out the hidden logic of design process. Predrag Sidjanin introduces a conceptual model of cognitive design tools. Since this research has shown the conceptual methodology without case studies, here we simply summarize the model instead of the concrete description. Based on “OODB—Object Oriented Data Base,” this model manage a process in a framework model which recognizes the input data. It is clear that a process between recognition and synthesis in this model is the part that the computer technology should develop more. Through this limited model, although we cannot say anything but its potentiality, this effort is apparently useful. Why don’t we keep in mind that, at any case, the superficial parts in the design process must be presented as a building shape from the architects’ ideas? This model tries to be explainable to clarify the decision making process. There is one reason why we may focus on the research beyond a simple mimicry of human brain; it derives a matter of efficiency and subjectivity as well.

![Fig 3. Relationship between meta level, synthesis and OODBS (Predrag Sidjanin) P. 90](image)

Possible Study: Church of Light, Tadao Ando—Trial to Brighten the ambiguous human intuition.

We have another interesting study of building modeling for this issue. Through analyzing the great building “Church of Light” in terms of the building elements, we see it can be decomposed with a box with a cross shaped window and a folded wall. Ando’s works usually tend to ensconce not to expose the design process. What we look for in his design process are merely several rough sketches which seem that his staffs tried hard to extract precise one-clear lines. Aside the original question how this simple box becomes a silent and sophisticated lighting box, when we enjoy this great space, a
question appears, “Is this really the best space with these elements for this building?”

Many architects may agree with the separation of emotional parts with the rationality in the design process, and also believe that the emotions can be hardly measured and analyzed by quantitative methods. This simple test for the building elements is corresponding to architects’ hidden considerations while designing pieces of buildings. With the clear factors like legal codes and programs, micro-size configurations also play roles of decision makers of the building shapes such as the size of slits for light penetrations, locations of windows frame not to be overlapped with furniture, and less one inch movement for the proportion of the entire building.

So, this Grasshopper (Henceforth GH) model and its switches which allow some parts in the building to be flexible reveal the possible variety of the transformation of this building. It means an exposure of micro decisions which architects tend to leave in an intuitive level of design. As these switches are connected to other devices which are affected by some external factors like weather conditions, it is expected that many ambiguous parts in design gets gradually decreased. A link of formulas operates a chain reaction through two-way inner communications, then, this organic system controls architecture without additional inputs.

The switches of the GH model are composed of three categories. They control proportion, height of the building, and the slit size of the front wall. Keeping a same size of building area, this model transforms as the entire mass is also flexible. If the sun angle and interior brightness analysis could be added here, architects would experiment more detailed size of the light devices. As the "parameters" become precise, architects give more considerations as numeric parameters in their design. So, it hypothesizes that, ultimately, all dimensions engaging in a building can be controlled if a computer quantifies every factor into numeric data. The whole building elements would be flexible and literally organic.

Fig 4. Variation of Grasshopper Model for the Church of Light
What can we imagine when this idea is extended? It will look like a mixture of Revit Architecture program with the flexible shapes. Once these parameters get connected with the functional or legal issues about building size, this real-time reactor will play a great rule to make architects assure their design direction. For instance, the legal restrictions for the construction can be dealt with a set of constants in the schematic design phase. Calculating the numbers related to building areas, the switches that designers control move and create a shape of building. This mathematical composition, at a glance, seems reducing a lot of ambiguities and gives a wide range of alterations of the proposals due to its flexibility.

Also, there is a potential connection between BIM and this flexible model. BIM presents every functional organization in a building including engineering issues like structures and HVAC. In case of Revit, designers layer complex organizations of building elements to easily acknowledge. So, as adapting some reactive variables—operated by the switches, and as putting an automatic calculation set to draw the efficient positioning of pipe lines or optimized size of structural elements, the created building models are composed of correlated and programmed spaces. This method is also useful in terms of reducing unnecessary repeats by the systematic discordance among the elements. The real-time activated changes show the best composition which reacts on the variables as much as possible.

Form Maker: Geometry Control in Buildings + Greg Lynn

Let's move to the next role of the parametric design methods. If some architects really concentrate on the goodness of this parametric design methods only to create complex geometries, they will confront a dead-end when every architect becomes having no difficulty to deal with the geometrical complexity. This direct direction of architectural practice becomes a controversial target of conservative architects who think that that the building doesn’t have spaces but is a kind of painting. Actually in architectural design process, few architects have shown the possibility of the parametric
design method to merge with the traditional values. Like a Paradigm shift, it seemed that without a disposal of the existing values, this new methodology is hardly allowed to be adapted in design process.

Nonetheless, it is amazing that there is another type of thinking for this symptom. Ali Rahim, one of the virtuosos of parametric design methods explains a relationship between current technologies and architectural design.

“New architectural techniques are developed in one of two ways: the first is by modifying existing methods within the discipline....

The second strategy for developing new techniques is to identify promising technologies in other fields that can be adapted for architectural uses. This raises the question: how do designers evaluate which technologies offer the most promise? The answer is simple: they look for technologies likely to yield techniques with the characteristics outlined earlier. Hence, architects should be particularly interested in recent developments in other fields that facilitate the incorporation of feedback from the user of environment in real time.” (Ali Rahim) P.189

When the architect, Greg Lynn began his architectural practice, his approach to form making was very unique. It is true that, as one of the frontiers for the digital architecture, his design methods showed a way on which the next generation should go. Different from the contemporary architects who had same interests in making complex shapes such as Peter Eisenman, Coop Himmelbrau, and Zaha Hadid, he concentrated more on relationships between the computer algorithm and the meanings. As much as architects have been seriously affected by a series of his efforts, there are different judgments to evaluate them. As a result that his followers took more time to develop reasonable solutions for the cheaper fabrications and to communicate with genius engineers for the complexity in architecture, other architects now can understand and deal with the malleable shapes and their complex creations become more precise.

A tectonic absence is one weird thing that Greg Lynn still has in his design methods. Stereo-lithographic models show another limitation that this type of design methods confronts when it is realized. Even though sometimes it is acknowledged as caused by a lack of spending time, money, and human resources, a lack of interest in this also affect the issue. Actually, many architects rely on the graphical visualization and sophisticated geometries when they design architecture. It clearly increases a purchase power from their clients, however is also clear that it is not long lasting although we can hardly deny the power of graphics. There is a reason why we want to see his architecture in this paper. No matter how Greg Lynn has created extraordinary environments in the parametric design area, it has still worked as a critical limit of the range of architectural
design which is focusing on the formal morphologies. Although his
texts are so theoretical that he seems not to emphasize the form
itself, the contents of texts are created by quite private issues which
also make his followers hard to adapt his ideas. So, paradoxically, his
design method, as a role of frontier, has widened and/or restricted
one specific direction of architectural design.

Nonetheless, there is another reason why he is a VIP in the
parametric methodologies. In his books published several years ago,
he introduces some principles for the form making. For instance,
using "spline" curves instead of the composition of arcs, he shows
how a continuous line gets an actual continuity and flexibility. The
arc curves are controlled by radiuses which are also connected to
each other. The arc lines should entirely change their tangential
numbers once a size of any circle changes. Oppositely, moving
hidden "control points," the spline curves react on the instant
changes. It seems necessary that this system is very useful when we
draw curves using parametric design methodologies. Architects catch
them up with lighter amount of data and simplified control device.
This system became sophisticated as a morphing type called
"NURBS" curve.

Also, Greg Lynn adapted "animated" forms in architecture.
Now, techniques for the internal transformation are not surprised at
all since architects also became familiar with MAYA. As inserting
joints in decided locations, it makes an object move like an animal.
Regardless of the geometrical explanation, the object makes us
accept the logic of form making and gives some pleasure.
Nonetheless, even though his pioneering thoughts brought out a
shocking moment then, now every secret becomes shared to public.
Once looking inside the method with basic notions of the computer
programs like Maya and Rhinoceros, designers could understand
how his object works. Even though the typology Greg Lynn made
for architecture is unique and idiosyncratic, we soon acknowledge
that he essentially follows the extended limitation of the computer
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Fig 6. Comparison of two different types of geometry (arc VS spline) Animate form

Fig 7. Morphing Process Using Skeleton Structure Animate form
Connection to Digital Fabrication and the Construction

However, there are other directions for the parametric design method to be developed and adapted in architecture. One of them is a real-time interaction for instant adaptations of the changing “parameters” like that Microsoft Excel is reacted on an instant change which is created by newer inputs. For the possible operation of the system, architectural programs should be controlled by hidden connections of data which are interpreted from the architectural contexts. In architecture, some computer design aided programs support this function. The grasshopper (henceforth GH), a plug-in of Rhinoceros 4.0 is one of friendly programs. The “Slider” toggle in GH functions as one directional switch which gives a range of varied numbers which actually work as “parameters.” So, this parametric design tool makes available for designers to directly acknowledge the change by “parameters”, instead of its expectations in the design process.

Let’s assume one automatic system in architectural design. If the instant reaction of the parametric designs tool guarantees widening the flexibility of architects’ creativity in design development, architects may imagine a malleable skin for create a shape of the facades without any additional drafting when the data have changed. Ideally, when designing façades of a building, just by a series of controls of variables which are inputted in the program, architects assume that a building automatically compose of its elements in this system. By this assumption, all of design parameters and functional considerations engage in this systemized program. As the architectural considerations of the contextual matters are changed, the building elements are also reacted on them. In that system, what architects only do is to set the basic principles which are operated by a specific set of parameters. It sounds very reasonable as the variables are getting concrete. Specifically, the factors which are related to sustainable design methods are very adaptable to those technologies.

Unfortunately, it seems not easy for the recent works done by many frontier architects to idealize this dream. Designers can hardly deal with every factor engaging in architecture. Let’s see the quotation from what Michael Meredith mentioned in his book about an importance of many factors which are not included in the boundary of parametric design methods.

“It requires cultural/social relevance. It is not the parametric, the relentlessness malleability of form, nor is it complexity for its own sake, but rather a complex of complex relationships that produce architecture.”

Not only is it hard for architects to quantify the socio-political factors into numeric data but also hard to connect the
formal language with the changing variables. In other words, it is inevitable that quality issues have engaged in design processes at any cases. Architects don’t believe that they cannot consider the entire variables for their designs; furthermore, they don’t have to put them into the process. In addition to the issue about human intuition, the quality matter will be dealt with in the chapter for Toyo Ito’s architecture again.

**Cases of Parametric Design Method for Massive Production**

We are about to see a stunning hint for the issue about the application of the interactive parametric design methods from this project, the Yas hotel designed by Asymptote. At the same time with that many advanced computer programs helped architects to eliminate their tedious repetition in practice; parametric design methods have supported radical design proposals of young architects. This is a case that a virtually constructed system reacts on the occupying elements in a building—here, it is the different size of awnings by curved surfaces on the building façades. The computer technology was used when they designed the louver system on the building façade. Since each panelized unit has its own tangential value as a unique point on the curved surfaces, the building could not have even a pair of same shape of the façade unit. The over 10,000 all different units of the louver system were not possibly created without the computer calculation. Then, in order to reduce the time spending for the visualization and fabrication of design, they also used computer scripting which seems close to G.H but much more advanced programming software. Computer visualization, in that sense, played a very critical role in all the design process. It is very interesting when seeing the process that the virtual images Asymptote created on the screen are realized with digital fabrication tools. As they have already used the advanced tools to deal with complex geometries in the window frame which has multiple angles.

Fig 8. [http://www.asymptote.net/buildings/yas-hotel/](http://www.asymptote.net/buildings/yas-hotel/)
where the points of the frame elements meet, Asymptote has actively tried to adapt the technologies in their design process. Since their efforts have been successfully proved among architects and the industry, their working environment is getting wider and will be able to be challenging.

Likewise, when a program controls building elements which are composed of the parameters, it gives architects a convenient environment to produce massive similar elements. Here, I introduce another similar case of the Yas hotel. The images below are what I proposed in TIAA for the competition of Toledo Museum called "Museo de la Vega Baja." The methodology is a minimized version of the hotel. Basically, the hexagonal units composing of the plan are supported by "Y" shaped columns at the six boundary points of the units. The "Y" which seen on the plan at each point only has three constant angles 90, 120, and 150 and is repeatedly used at every intersection in the plan, which means that the planar "Y" works as a basic unit of the building space. Then, the roof is made by Catenary concrete structure which gives every single different height at the intersected points. It means that, in spite of using a common unit on plan, it gets sectional difference as changing the length of the top part of "Y" structure. For construction efficiency, it is also required to keep the same angle of the "Y" structure which has a sufficient variety of the length of the branches. So, keeping the same angle of joints—135 degree, the building should have each different shape of the columns which were created individually. Then, the GH modeling was proposed for this mass production of the column system. In the GH model, there are 6 pairs of switches which control the height of each point. And, a shared switch controls the angle of entire branches of the sectional "Y" structures. As a result, churning out the 3D columns—almost 150 units like this case, we could save much time as not doing the repeated work of 3D modeling with the GH model—we finished making this colonnade in a day which was expected to take a whole week.

However, the method used for in this museum competition still has some defections that the GH model is verbose. We should reduce the entire amount of the commands in the model as being merged by the repeated operation. Also, the computer technologies for mass production still have some questions—how much can this type of building method maintain architectural quality? Can architects reduce the time for the verification of the entire design as much as the speed of their construction is getting increased? We actually acknowledge that this method creates a few unexpected malfunctions in the automatic process, and human emotion also dominates a critical part of designs motivations, it is not always true that a progressive architecture means a more complex geometrical manipulation. Rather, sometimes we say that temperate and refined
Methodologies guarantee controlled and sophisticated forms in architecture.

Fig 9. Grasshopper Model for the competition project

Fig 10. Screenshot of the grasshopper model
Experience in Toyo Ito and Associates, Architects

A building as a “masterpiece” inspires many architects to follow its legacies. Likewise, since Toyo Ito has achieved noticeable projects which once seemed impossible to come true, I expect that they can develop more advanced geometrical solutions and realize in architecture with the great manifesto. Passing through several changes of the architectural styles, Toyo Ito architecture has been evolved in terms of both use of technologies and geometrical issues. As one of old staffs, Mr. Kobayashi mentions, Ito’s architecture is mainly classified with three decades—Sendai Mediatheque, and before/after the Sendai. It is crystal clear that the building announced a new era for the contemporary architecture at the beginning of the 21st century as enlightening us. The transparent and blurred tube structures made the building achieve architects’ long-cherished desire, gravity deviation and a victory of Japanese engineering.

After the Sendai, Toyo Ito changes his ideology into finding more complex and difficult systems. They manifest so called “Liquidity”, which has a characteristic of continuity like a cell division. After Sendai, his design has been pursuing toward creating a unique system composing of unitized building elements. Admittedly, this great change was affected by a series of innovations of computer technologies. As his preference to elliptical geometry had made of his earlier buildings with curved shapes, a freedom that architects became easily deal with 3D curves in computers strongly motivated his desire toward the advanced morphologies.

It is a very unique point that this office which merges Japanese architectures shows a characteristic that the creativity comes from the architects’ hands. Although the actual technologies they adapt are located on the peak of the current level, in the schematic process, sketches and models which seem close to emotional expressions play critical roles for the next steps. It is worth understanding once we follow Japanese traditions of the craftsmanship. The tradition won’t be deeply dealt with in this paper, however it is true that intuitive and experiential expressions are not only the great resources but also justified through the cultural bases. So, even if their productions have no rationalities or no precisions at the first stage of design, it doesn’t really matter at that time because they really know well how to refine the rough stones. Someone might think beauty can beat any reasonability here.

Then, it is amazing to see the process that high-tech engineering supports these designs “Made in Japan” and come true their imaginations. Different from admitted expectations, TIAA architects are not familiar with further knowledge about advanced engineering and/or construction technologies. Instead, they have the
greatest supporters for the designs—like Sasaki Structural Engineers and Inoue Furniture Company. They have worked with TIAA during several decades with the whole responsibility and totally understand the way of the design direction. They also actively participate in the design discussions, and have made many good solutions.

As TIAA have changed their design direction into making unitized systems, the design process became much tougher than before although their architectural qualities could get richer. Some insufficiencies of these ideas reveal confictions between the functional organization and the spatial quality. Theoretically, we pretend that an ideal space clearly has a reactive consistency which automatically allows the functional variety. However, since every architect cannot react on all expected changes in design process, it is no wonder that this unit making process always confronts a series of difficulties. Architecture of unit extension should guarantee keeping a spatial consistency. It should absorb a functional variety—different heights, sizes, façade transparency, and etc. Geometrical solutions created by functional requirements tend to break the original intention for the building shapes. It is exactly same as the previous contradiction that we confirmed as “reverse engineering.” So, at least in these present conditions, TIAA’s architecture seems to have more additional hidden processes to optimize them.

**Protuberance Model**

Now, it is the time to mention the title, “Protuberance.” This metaphorical term is used to explain the characteristics of TIAA architecture especially in terms of the topological relationship. Of course, all TIAA buildings do not belong to this type of morphology. As seeing several connections among TIAA architecture related to this protuberance model through the table below, the protuberance models share some formal characteristics. The table shows several representing TIAA buildings after Sendai Mediatheque. They are separated by three types—façade-based, roof-based, and internal units-based.

The façade based model, the earliest type literally focuses on the way of surface manipulations. Controlling the building surfaces, they developed very interesting variations in a sense that the surface system works as the only structural system, and a continuous patterned plane encloses the internal spaces as keeping its lightness which minimizes the boundary. In spite of the beauty and awesomeness, the reason we stop mentioning this type is because these buildings only have two dimensional geometries. It is like a flat sheet of paper once unfolded. This pictorial method is somewhat far from the interests of this paper. Rather, I see a transition from the roof-based type to the internal unitization as an
enhancement of the TIAA architecture.

The most important characteristic for a definition of the protuberance model is that a model should have at least twice geometrical transitions. It becomes clearer as imagining an icicle. By gravity and cold weather, water drops which were pooled underneath horizontal objects such as roofs change their flowing direction toward the ground. That vertical movement creates a different type of water activity and the shape of the icicle. But, as we know, icicles have their horizontal trajectories as well. This gestural connectivity is very good for understanding the dimensional transition of the TIAA's buildings, especially when they need to define the perpendicular plane on the gravity since architecture somehow should support live load when they design seamless surfaces of a building.

From the Sendai Mediatheque which tried to erase the visual resistance against gravity, this “protuberance” concept seems more developed as merging the broken edges of the building elements. As a matter of fact, this notion so called “architecture of fluidity” is not uncustomed idea to architects. There are a lot of discussions among architects and Deuleuzian theorists—directly we can quote the story of Eisenman and Deuleuze. Many architects have come true the ideas in architecture.

However, the most idiosyncratic characteristic of TIAA architecture is on the other side, which can be hardly classified in the same types mentioned above. The important point is on a separation of the structure with others. It seems like an enthusiastic pursuit of architectural purity. They focus on making continuous structural system which synthesizes the building elements. It is perfectly different from other architects group like UN Studio. Without any manipulation of the basic units, Toyo Ito architecture uses primarily created pure units. So, it experiences a series of attachments of slabs, interior walls, and furniture. So, this pure systematic and flexible system shows lots of potential to be adapted in parametric methods. The purity is able to stand alone without external considerations. In other words, they get an absolutely controllable model in their design process.

As a result of keeping spatial purity and separation of furniture from structural elements, TIAA became have an absolute freedom to manipulate their spatial system. It is well-connected with the notion “unlimited extension of the system.” It is not much different from an idea that a thin and homogeneous layer defines characteristics of spaces which we have watched in the contemporary Japanese architects. The systems are allowed to posit in any dimensions with any shapes. Following the rule of self-reference, architects put a series of decisive functional considerations into the system, which also decide the actual size of a construction which acts like an organic object. The boundaries defined by the programs
look like “cutting edges” which are literally sectional façades of the system. That’s when we become pleased with a chance discovery.

So, the following table shows a series of Toyo Ito Architecture after Sendai Mediatheque. Like mentioned above, we see a transition of interests in the unitized model from 2D to 3D. Passing through the “façade” period like Serpentine Gallery, Brugge Pavilion, and TOD’s, a new advent of protuberance model in KaKamigahara had changed many things in TIAA architecture. Following their typical way of architectural practice—self-referential, they have developed better solutions without losing the original values like Taichung Opera House exactly has same shape as Ghent Music Hall although someone criticizes it.

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<th>2002</th>
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<th>2006</th>
<th>2007</th>
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<td>Curved Wall</td>
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Fig 11. Periodic table of Toyo Ito’s architecture after Sendai Mediatheque
<table>
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<tr>
<th>Project Name</th>
<th>Year</th>
<th>Character</th>
<th>Homogeneity</th>
<th>Protuberance</th>
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Table 1. List of TIAA architecture related to Protuberance Model

**Topographical Understanding of Protuberance Model**

Based on the idea that a pipe and a donut have the same topological level, the Klein bottle is one of the good cases to explain a basic logic of the protuberance model. In order for this model to get continuity in a Cartesian space, it is inevitable to have one breaking point where two surfaces overlap. Protuberance model begins admitting this crack. Instead, it pretends to be potentially connected toward an unlimited space. This idea is very important to mitigate a topological discontinuity in reality and the concept of the TIAA architecture. In other words, it means they don’t need to represent continuity in the buildings which only can be justified when they are proved that the spatial system may be unlimitedly extended in concept. How mathematical! They merge the functional limitation of the spatial size with the potentiality of the unitized spaces in reality.

![Fig 12. Difference between the models based on the morphing process](image)
splines with many precise isoparms or isocurves in NURBS models. Although two models below have similar shapes, the logic of form making is apparently different. The right model is composed of three parts—a base patch, a part of a cone and the filleting surface connecting the patch and the cone. Therefore, the patched bottom surface and the part of cone have no geometrical relationship. Instead, only the region of the center filleting part plays a role of a connector. So, architects can hardly create this surface in without the computer calculation although they could manually make the “guide lines” of surfaces. The isoparms presented on the surface in the image below which shows the complex geometries of this model. The first reason of the difficulty of the control for the manual manipulations is due to the dimensional transition of the geometry. Admittedly, the “sweeping” techniques in 3D modeling programs guarantee a creation of this kind of complex form making.

Fig 13. 3D Structural Model of Taichung Opera House, Courtesy of TIAA

Fig 14. Screenshot of a representative model of Taichung Opera House
I believe the first step for creating a new trend in architecture begins with architects' curiosity. An extension of available skills makes them challenge doing unfamiliar trials. In this sense, the central park “Grin-Grin” in Hokuoka was suddenly brought out. In other words, by a pure curiosity toward morphological exploration, we might say that an architectural trend of an architect can be changed. So, this building is the first case that TIAA broke the rule of folding edges. It only has two parts as a pure structure—a concrete surface like pizza dough and glass windows. Instead this building has no internal columns; the external windows play roles of vertical boundary as a building. In an aspect, it can be said as an imperfect or irrational shape. Even though the engineering supports the design very well, the logic of form still has a lack of justification in the morphing process.
This well-made building, however, stands on the front line of the next generation of TIAA architecture. This building which even seems like a morphing test which clearly has a connection to the building, the crematorium in Kakamigahara. It shows well of their desire toward free-from architecture. Plus, from this building, we see a potential of the protuberance model in reality. Keeping a same topological level on the roof which means a seamless one surface, it looks forward an anchoring on the ground. Being pulled down from the specific bottom points of the roof, the extended parts become a set of vertical structures—columns.

In the case of “Grin-Grin,” the roof surface should be merged with the actual ground surfaces because the green roof is perceived a continuous ground which makes the boundary of external/internal space blur. In doing so, it helps the botanical garden, the actual function of this building to be able to actively occupy the place. Oppositely, the function as a crematorium needs a separated and identical interior space. Also, this structure gives a feeling of being under Heaven. The white wavy roof is floating above the boxy rooms and is sculpting softly weaving clouds. I think it is a very appropriate formal reaction of the building since this is for farewells of the families. This building plays a role of a very special place for them. To do so, as the columns minimizing the touching area on the ground, the roof structure maximizes the independency of the building.
Voronoi Curves for Planar Organization: Taiwan Univ. Library

One protuberance model created by Voronoi diagrams is structurally robust. As researching several precedents using this diagram, TIAA has adapted it in the recent projects. The Library for Taiwan University is one of the representing projects. Although any architects might imagine Johnson Wax building of FLR with a similarity of both structures, here the focus is on the morphology of the roof organization.

These patternized curves are linked with a series of points which play roles of actual center points for the Voronoi lines and they are repeatedly making the enclose area. The advantages of this system are on the spatial flexibility and the structural connectivity. Following the location of the points, the lines recreate each barrier which encloses the outside of the point. This occupation defines an occupied area for each enclosed space. When a Voronoi diagram is created, it is believed that they can be used as a structural frame as well. However, in the Taiwan Univ. Library project, TIAA tried to transform the framework into a link of curvatures for the pattern of the roof. Using the end and mid points of the enclosed edges, a series of curves can be drawn. The cell-like curves in the library are used on the roof and give an organic sense. In doing so, the roof structure needs in-between additional structural connections for each unit.
**Principle of Form Making for Taichung Opera House**

I don’t hesitate to pick up Taichung Opera House as one of the most extraordinary and stunning architectures in these days. Overcoming the failure in the competition for the Ghent Music Hall, TIAA redeveloped the systemic morphology and tried to adapt in another competition, Taichung Opera House. At a glance, this building has extremely complex geometries with a structural ambiguity. However, with understanding the fundamental logic of the morphing method, we are surprised at the simplicity and the sophistication.

I introduce a paragraph for the explanation of the formal logic where is in the recently published by A+U magazine.

"Two types of circular zones, A and B, are arranged in checker board fashion on a Cartesian grid. The two curbed zones are displaced from each other and built up in parallel, and the stack of circles of one type is connected along the shortest lines. This causes two spaces A and B to appear, separated by a single shell curve but continuous in both plan and section. Further, we introduce the concept of “emerging grid”, allowing the grid itself to be flexibly deformed to enable richer and more complex cave-like spaces.

The free curve shells that separate spaces A and B becomes the structure. They are defined as “catenoids” (three-dimensional shapes made by rotating catenary curves around the x axis.) We performed an enormous number of simulations to arrive at reasonable shapes were the structural and
acoustic requirements. As these two requirements tended to be contradictory, the design team iterated through repeated adjustments of the emerging grid using 3D models on shared computers, accompanied by aesthetic judgments.”

So, as we understood in the previous chapter about the description of the protuberance model, the building is composed of the bunch of the catenoid surfaces, “internal part of a donut.” Like the image of the exhibition model of the building which is made by wire meshes, the half donuts are connected with other ones at both top and bottom edges. Seeing the below image, the basic unit which looks like “)” shape, is stitched to each other. There are the adapted parameters as well. Basically, the donuts are morphed by a defined area of the Voronoi diagram which is made by the functional requirements. From the stacked planar diagrams, the segmented and offset boundary is created for the vertical connections which form a three dimensional shapes in the net structure which plays roles of scaffold works. Yes, it is perfectly same as a scaffold. Imagine a continuous tensile fabric which is tightly pulled by the intersected points of scaffolds. Then, we exactly acknowledge how these lines morph the smooth and continuous surface. So, as far as the lines are connected, the surface extends the area unlimitedly. Continuing to morph them, the entire network becomes a building structure. Also, the height of the vertical connection and the tangential value of the curvatures are also controllable by a set of parameters. So, despite the most advanced technique of the “protuberance” model, Taichung opera house has a very simple geometry.

As a matter of fact, TIAA is in trouble with some construction issues for this building. They already completed the construction documentation including the structural calculation with Ove Arup, the structural engineering office. However, the initiation of the construction is delayed at the process for finding capable contractors which can afford to actually build the building. Recently they could get a contact with a Taiwan domestic construction company in a reasonable range of the budget. The company is slowly beginning the construction with a mock-up model which is going to verify the way they build. This is not a first case that TIAA's staffs confront practical difficulties. In the case of Sendai mediatheque, they experienced similar situations. The entire budget became come over the annual operating money of the city of Sendai, and TIAA, contractors and engineers should have create a first precedent for the building that no one had ever executed before. The citizens doubted if the building would be really necessary. Then, some of them actually demonstrated to deny the construction. It is amazing that the TIAA’s staffs have kept energetic even though they have been challenged by a series of hardships. Admittedly, it is
explained through a Japanese national character. I, however, also believe that their own precedents work as their great motivations. And, it is clear that the working conditions which require a kind of internal competition affect as synergies.

Two Dimensional Protuberance Model
Experiencing a series of difficulties about realization of their architectures, TIAA looked for a simplified model for another type of the unitization. Not only does the model keep the previous concept with the typological continuity, but it also has clear simplicity and sophistication in terms of both the architectural geometry and its construction issues. Since they have some troubles for the Taichung Opera House in the construction period in the Tama University Library project, they anticipate that the simplified building geometries would help the construction. The Tama University Library is the first successful architecture of this two dimensional protuberance model. In this building space, the dramatic interior that the simple units create reminds of classical sublime and shows a direction of the contemporary architecture. The arches which are only exist as structural and architectural elements, are reproduced and keep a consistent density in the building.

The geometrical idea has been developed after the difficulty of Taichung Opera House. Although we can hardly say the directional interconnection between two buildings owing to the different staffs for each project, it seems clear that the fundamental ideas in two buildings are shared. The geometries in this building is a two dimensional representation of the crematorium. As a new type of arches, the geometry of the columns is drawn by evenly subdivided
points. Like the Candela’s mushroom structure, the intersected lines are connected by “interpolate” curves in 3D modeling program. In doing so, the curves are flexibly putted into the curvy grid lines in the building. So to speak, since the subdivided distance in the rectangle is proportionally changing,

Unfortunately, TIAA’s efforts are not successful to adapt this concept in buildings. Excluding Tama University Library, they have failed either to win competitions or to get commissions of their proposals. Recently, there was a competition for the Ghent library as alternating the previous competition of Ghent Music Hall which TIAA also participated in. They used another type of spatial concept for similar unitization with Tama Library. In spite of several failures, I feel that they have well constructed their conceptual ideas for this simplified version of the protuberance model. As a realizable and economic model, this two dimensional manipulation of geometries seem much potential to be developed. I also anticipate the next step of the current effort of the office.
Applied Studies

Through the researches about Toyo Ito’s architecture, we could formularize the geometrical rules related to the protuberance model. From now on, we try to create a series of the reactive transformed models. These four models will show the expansive possibility in their interconnected relationship. In doing so, we concentrate on how the protuberance models will be applied by several changes of complex parameters. As reinterpreting the morphing processes, we insert a set of variables which might be operated as building materials in architectural design. Based on the studies related to topological relocation of the geometries of the models, we experiment the wider boundaries of the protuberance model. As each model has different connections, openings, angles, and so on, the shape of the surfaces becomes have complex relationships. After seeing the section diagram of the models, we will look into the specific cases which are categorized by different geometrical relationships.

The diagrams at the right side show the sectional changes of each model. By the topological change of the models, they become have very interesting variations in section.

Fig 25. Sectional Diagram for Applied Studies
Voronoi Catenoid Surface

Fig 26. Plan for a catenoid surface

This experiment is exactly corresponding to the method for Taichung Opera House. As we already saw the basic principle, the nets of Voronoi curves hold the neighbor lines tightly. Once the scaffolding net structures are completed as they confine spline paths, it morphs a continuous surface.

From this morphological method, it is able to make a connection with parametric design for the modeling. Designers have controllable switches as the center points of Voronoi curves, height of offset curves, and curvature values which decide tangential of the surfaces. The center points are controllable by a programming. The Voronoi polylines, which are automatically drawn from the relationships of the central points, create own area.

Then, some parametric variables define the shape of net structure like the inner area of each enclosed polyline, its height, and choice to be extruded up/downside. So, finally, the net structure becomes one continuous surface by the control of parameters.

Fig 27. A process of catenoid surface making
This method focuses on making dimensional continuities on the vertical plane which actually plays a role of a hole of the surface. Leonardo Glass-Cube building shows the advanced geometry with the connected net structure. The following model shows how much the joint could be subdivided to be connected with the linear elements. The partial soccer ball shape is actually ready to be connected at the extruded parts. With hexagons and pentagons, potentially it may be enclosed as a sphere shape. Each piece of the sphere is selectively either blanked or extruded. We easily imagine that the angles and depths of the sphere determine the entire shape and the number of extrusions. Also, this surface is continuous.
Subdivided Transplantation

This model is created in order to see the dimensional transition from the bigger one unit to the smaller and four times many extrusions. A connection is subdivided as branching from the bottom to the top plates. Geometrically, we expect that, at the middle of the connection, there is another operation as the protuberance model again. In spite of the dimensional diminution, we see that the model keeps a topological directionality through the branches. We can also say that this model shows a selection of joint conditions in linearity.

One interesting thing in this model is that the branches can be worked as a set of switches. As a controllable parameter, the extruded edges flexibly work. In a notion of supplier/receptor, as assuming a set of the edges, we widen the range of the combinations of the assembly. By the possible manipulation, we imagine some variations like an overlapped surface and a twisted branch.
Intersectional Connectivity


This model is an applied Klein bottle model. In order for the surface not to be overlapped but keeping one surface, a surface continuity exists inside a hole of the flat part of the model. This model has no broken edges different from other models. Although this self-circulating structure seems to closely pursue a geometrical perfection, it is not appropriate for a building structure. Building structure doesn't support the loads by itself, but it should transfer the gravity to the ground. That's why a protuberance model has a broken edge as a building structure. Similarly, Greg Lynn has thought something related to this geometric entanglement. Slavin house, one of his house projects shows a potential how that type of topography is used as structural frames. The house has a set of twisted curve lines as the columns. Both two models show an unlimited process of the geometrical repetition along with the guide lines.

Let's go back to the first part of this paper. We remember a relationship of the geometrical morphology with the design methods. As one characteristic of TIAA's architecture, the integrated notion of the consistent unitized expansion in interior space gives the structural identity which plays a role of a space maker. In this sense, the space programs work as subsequent matters. Since the spatial unit of the building which is assumed to be flexible by the change of the program has a set of parameters, it is able to contain the complex function in the idea of integrated unitization. Nonetheless, this model still has several weaknesses as a synthesized tool. Here we summarize them from the ambiguous operation which requires the “reverse engineering process.” These three issues arguably represent them.

1) Restrictive use of the referential geometries
2) Uncertainty from automatically created variety
3) Subjective choices of positioned elements

So, the focus of these issues is mainly on a difficulty for operating the form making systems by complex geometries. Parametric design methods sometimes have internal conflicts as a perfect geometrical solver. In other words, once designing a series of operating geometries which are reacted on the parameters, an architect expects a kind of automatically calculated shapes from the internal operations. However, sometimes geometrical limitations deter the flexible and expansive operations of the parameters. Because of that, there should be a process so called “Reverse Engineering.” Here is a case to show the geometrical limitation of form makings. A TIAA's recent building, “Za-Koenji Public Theater (座,高円寺)” has a very unique roof shape. It is formed by seven curved surfaces which were morphed by parts of cones and cylinders. With the beauty of the shape, the method made possible that they could use the steel plates on the roof without any three dimensional transformations. It was designed in order to realize so called a “developable surfaces.”

One more interesting fact of this method is that they create non-geometrical edges among the surfaces. As a matter of fact, the roof shape of the theater was drawn by several experiential drawings not by a precise computation which is more or less far from enough rational considerations even though the beautiful roof shape reciprocates a lack of rationality. With a clear rule of form making, the geometry of this building is designed as a result of the hundreds possible cases. So, it is clear that TIAA designers cannot expect the exact geometrical conditions on the roof. Instead, sculpting (or scooping) the top side by required height for functional aptness,
they got an approximate shape of the roof.

There is a weakness of this geometry. We know that a cone is composed of one peak and the bottom circle. It means that architects only can use those two sets of the parameters when manipulating the cones in Cartesian grid. Nonetheless, in this forming method, we investigate other lines which are occasionally created by the intersection of two cones. So, despite the beauty of the lines, we cannot draw the lines before intersecting the two cones.

In this sense, I also exemplify an exhibition material which I participate in the first part of the internship in TIAA. The exhibition materials were planned as imitating the structural frame which was used for the proposal of Oslo Library Competition although it failed to win, but they still see more chances to realize. In the frame of the exhibition, seven selected surfaces which composed of fabric and wooden panels become canvases for extended systems representing six projects—Tama Library, Oslo Library, Taichung Opera House, Berkeley Museum, Taiwan University Library, and Za-Koenji Public Theater.

Meanwhile, I could have a good chance to design the model for Za-Koenji Theater. The fundamental idea of this exhibition is to show the conceptual expansion of the spatial system of TIAA’s architecture which keeps consistency as unitized cells. Then, different from other buildings, Za-Koenji Theater has a kind of directionality in geometry. Due to the unique conical manipulation, the center point of the roof should be the highest, and the slope of the entire surface is also proportional to the size of each unit. In other words, the original nature of this geometry is not consistent but centralized. So, I named it “Mt. Fuji” for fun. Anyway, as allowing the slope of the entire surface, I tried to extend the basic logic of this geometry.

In doing so, I confronted a challenging issue related to its subjectivity. The collective pieces extracted from the cones are chosen from the top parts of the crumbly mixed cones which reveal the intersections above the mass. The idiosyncratically intersected curves are hardly drawn with geometrical calculation because multiple cones merge with each different center point, center ax, and
radius. Ironically, it makes this morphology beautiful, from the geometrical and developable surfaces to unexplainable curves. At last, I could finish creating the entire surface with 120 cones which have no rule of the composition. So, we see a defective point of the geometrical manipulation. Even though I didn’t use any of automatic tools in design process, we can imagine its interpretation in the parametric tools. The parameters and the operations are decided by the designers. So to speak, it is close to a set of systemized intention in form making.

Fig 33. The screenshot for the Za.Koenji exhibition material

Fig 34. The process of installation

Fig 35. The exhibition at the opening ceremony
Let’s see more of the proposal for the competition, “Museo de la Vega Baja” Toledo Archeological Museum. One of my early proposals for the roof systems was considered being created by a part of a cone like the Za-Koenji Theater. Since a shape of a right cone is defined by the bottom circle and the end point which has a same distance from the boundary of the circle, the geometrical reference to manipulate the shape is very restrictive—two points and its vector(start/end), and the radius. TIAA decided to redevelop this conical manipulation from Za-Koenji in the competition proposal.

Like two diagrams at the right side, I proposed several variations for the roof design. Through several experiments, I got to know that a shape of roof can be controllable with at least three intersected cones due to the points of the columns. Nonetheless, since Mr. Toyo Ito wanted to see just one cone for one planar unit; we threw away all of those proposals. Anyway, here we can also see another weakness of the parametric design tools in geometrical manipulation. When the design confronts an aesthetic issue, it tends to easily break down. In other words, this method has a characteristic that we cannot imagine the finalized shape of the models. It is also connected to a danger that, once the set of geometries is getting complex, it becomes have much potentiality of the geometrical uncertainty, and might work as an obstacle of the entire harmony of the design.
Where parametric tools go?

As much as we now cannot imagine a design practice without computers, the contemporary technologies have evolved in an area of architectural designs. Like the reason why the Apple designed products have attracted their consumers, the contemporary technologies have come true the imaginations which people had dreamt. I think that the parametric design methods should be seen as same as the computer technologies have worked in the society like that. Young architects and the students have been fascinated by the new wave of architectural design. Their curiosity seems to clearly work enough to catalyze the enhancements with the technologies.

I believe that those radical changes in the architectural tendency are reflected on the active adaptation of many architects. As dealing with a huge amount of data, the computations which are interpreted by the operations of a set of parameters have helped create the spatial forms as building elements. The real-time interaction has many architects more easily understand the complex geometries in shapes. When they produce the unitized shapes in buildings, the parametric design methods reduce the time amount for morphing the geometries. Some researchers, furthermore, in order to minimize the subjectivity in architectural design, have tried to develop the more advanced programs to control the process of design decisions. Nonetheless, we have reached to a certain conclusion that a designed entity is created by a process which necessarily requires a series of relative choices. In other words, at any case, designs strongly include the creators’ subjectivity.

Also, Toyo Ito's architecture includes all these meaningful values as showing pros and cons of the parametric design methods. Although there are some proofs which are doubted if his architecture can be categorized in the parametric methods, some of his buildings which are read as a series of protuberance model have presented a structural integrity and geometrical potential with the computer technologies. And, we still see much potential as flexible composition of spatial units in his architecture. About the ideal thought of the parametric design methods which are eager to be close to an automatic design tool, Toyo Ito's architecture gives several interesting approaches to understand the internal characteristics of the parametric design methods. He uses the computer technologies as one of productive tools. It is still excited how the dreamful drawings and rough models become very precise and realistically presented by the digital devices.

While working in his office, I anticipated, as adapting the more advanced methods in the projects, I could transplant more radical design methods in his architecture. As programming a Grasshopper model for a flexible operation, to some extents, we
confirmed possibly acceptable directions. Nonetheless, in addition to the learning that his architecture is basically created by the cultural foundations and that a building project should contain a set of strong design intentions at any case, it became a good lesson to see some handicaps which the parametric models have.

In spite of a series of efforts to reduce the ambiguity in architectural design, we still see a limitation which the methods have. The approval of subjectivity in creative processes also means that the intuitive area of human thought is still ambiguous and is distant to be proved by rational verifications. Nonetheless, we don’t believe that the ambiguity negatively affect the design process. Rather, two ideas are extracted through the relationship—an apparent distinction between human intuition and the design tools reinforces the justification of subjective creativity, and the parametric design tools guarantee an expanded range of the design potential as eliminating the external clichés which are necessary but constant.

- All of the images which do not show any references were created and/or taken by the author.
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