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Sang Min Park just completed his Ph.D. in architecture at the Illinois Institute of Technology. Dr. Park earned his master’s degree in architecture at the same institution, and was an honored session chair at the Council on Tall Buildings and Urban Habitat’s International Conference in Seoul, Korea, last year.

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**Innovative Tall Building Form Development**

This presentation is based on a paper by the presenter, Associate Professor David C. Sharpe, and Assistant Professor Robert J. Krawczyk, all of the Illinois Institute of Technology.

During the past few years, there has been an extraordinary development of computer-aided tools intended to present or communicate the results of architectural projects. However, the use of digital tools in schematic design of tall buildings is still quite limited. Computer-aided design includes using a computer not only for visualization, analysis, and evaluation, but also for the rapid generation of design representations describing conceptual design alternatives.

This presentation will propose a series of methods to develop concepts and options of tall building form to the architect and engineer when designing geometrically complex buildings during schematic design. The proposed design process and the developed digital tools become an integral part of the design team approach for tall building design. It will establish not only the overall geometrical forms but also the specific building data for design evaluation and production of three-dimensional models.

The intention of the research on this topic is to inspire more interest in developing an innovative approach to the design of tall building forms through the integration of architecture and digital technology. The focus of this presentation is to suggest the generative forms and digital methods as applicable to architecture by means of architectural evaluations and efficient process in designing tall buildings. The suggested forms and the digital design methods presented will be of great interest in the tall building design field.
Innovative Tall Building Form Development

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ABSTRACT

This paper proposes a series of methods to develop concepts and options of tall building form to the architect and engineer when designing geometrically complex buildings during the schematic design phase. The proposed design process and the developed digital tools become an integral part of the design team approach for tall building design. It will establish not only the overall geometrical forms but also the specific building data for design evaluation and production of three-dimensional models.

To investigate how the proposed design process and tools can be executed with any combinations of geometries and any vertical transformations, four form groups, 304 building forms, are generated and demonstrated. Each combination has four variations, and each variation has four forms; morph, setback, twist, and curvilinear. Ten forms are selected from the generated variations for case studies. Explored potential tall building forms will be evaluated in more detail according to architectural and structural design criteria with the selected cases.

The intention of the paper on this topic is to inspire more interest in developing an innovative approach to the design of tall building forms through the integration of architecture and digital technology. The focus of this paper is to suggest the generative forms and digital methods as applicable to architecture by means of architectural evaluations and efficient process in designing tall buildings. The suggested forms and the digital design methods presented in this paper will be of great interest in the tall building design field.
INTRODUCTION

This paper discusses the generative concepts of a tall building form and innovative design process using digital tools that are based on a parametric design approach. In tall building design, geometry plays a critical role in the generation of building form and structure. This paper explores potential geometries and new concepts of vertical transformation to create an overall spatial form using non-conventional concepts. This investigation covers the development of a series of starting and ending floor plate shapes for a set of floors. Procedures are developed to transform that starting floor plate shape to the ending shape. Operations such as rotation, scaling, and morphing are demonstrated for a variety of basic shapes. Embedded in the generative process are architectural and structural criteria that limit the resulting form of the building.

Explored potential geometries and vertical transformations of tall building forms are evaluated by architectural and structural design criteria. A tall building form and structural system are a synthesis of the design considerations combined with user needs and requirements. Design criteria related to planning considerations are building function, lease span, floor-to-floor height and core planning. These considerations are the controlling design parameters that are interdependent on how they affect the overall building form. The evaluated geometries could contribute new concepts to tall building design.

Parametric design consists of a set of variables and a series of relations to define a form. The overall form can be manipulated by altering specific parameters that are able to automatically adjust total gross area, total building height, and aspect ratio. To develop such procedures, AutoCAD’s AutoLISP programming language can be used because of its standard format of manipulation and interfacing among CADD programs and visualizing formats. Three-dimensional generated building forms can be constructed as three-dimensional surfaces for rendering and three-dimensional meshes for structural analysis. To check building properties, a spreadsheet can be generated in the Microsoft Excel format. To physically compare alternative forms, laser-cut study models can be made. In the schematic design phase, parametric design can generate a series of designs quickly, which consider a series of architectural and structural design criteria.

This paper will propose a series of concepts and options of tall building form to the architect and engineer who design a geometrically complex building during the schematic design phase. The proposed design process and the developed digital tools should become an important part of the design team with a clear scheme of the tall building. It will establish not only the overall geometrical forms but also the specific building data with their 3D models. In addition, this paper will demonstrate a better approach to generative and innovative tall building form development based on rational idea.

PROPOSED DESIGN PROCESS

Development of tall building can be determined by design factors; these factors have several parameters of architectural and structural considerations. Items related to architectural considerations are building functions, lease span, floor-to-floor height, core planning, and vertical transportation. Structural systems, mechanical systems, cladding systems and building serviceability are considered as building systems in tall building design. These considerations are interdependent and they affect many other factors that must be considered when developing a project. Architecturally and structurally, it is a very complex task to develop an optimal tall building due to these interrelations of large number of design considerations (see Figure 1).
In schematic design phase, 3D modeling is very important tool to evaluate the characteristics of a building. From geometry modeling to system modeling and behavior modeling, these modeling have become increasingly mainstream in recent architectural practice. The geometry modeling is most commonly used in visualization purpose. As more sophisticated application for rendering emerges, architects are accustomed to looking at buildings geometry in digital perspective that is complete with the chosen materials, lighting systems and day lighting effects, surrounding building and environment. This feature is used as a study tool, as well as, a marketing and communication tool.

In the conventional practice of tall building design process, generally, schematic design starts with designer's conceptual sketches. With the conceptual sketch, many architects start to plan core, floors, and elevations, in the format of 2D and 3D drawings. However, the conventional process of tall building design requires much time and labor to develop a single alternative because of the following:

- Large number of design considerations and their complex interrelationships
- Difficult of manipulations by changing of each design consideration
- Limitations of designer’s ideal concept

When the building form is not a basic geometric form, it is much harder to plan and draw the scheme with conventional design process. The proposed design process is parametric design methods. Consequently, in the schematic design phase, the innovative design process using digital tools should satisfy the following:

- Various geometries and overall forms can be generated.
- Architectural and structural 3D models should be generated.
- These 3D models should contain sufficient architectural and structural design considerations.
- It should be easy to manipulate a scheme by the changing of any design consideration.
- Structural input files should be created for structural analysis program.
- Mass model should be made for visualization.
There are six major parts in the proposed design process. Every part plays a critical role and is executed in a sequential order to achieve a tall building form. These parts are the following:

Part 1. Zoning and Area Calculation (Using Area and Zoning Worksheet)
Preparing vertical transportation systems and appropriate core size
Preparing appropriate base and top size

Part 2. Explorations of Geometry (Using Explored Geometry Table)
Selecting base and top geometry and their combination type
Deciding number of points connecting base geometry to top geometry

Part 3. Architectural Model Generation (Using Form Generation Program)
Generating architectural 3D model
Creating building data spreadsheet
Run Form Generation Program
   Step 1: Each Function’s Necessary Number of Floor Calculation
   Step 2: All Floor Plates and Building Data Generation
   Step 3: Architectural 3D Model Generation

Part 4. Structural Model Generation
Generating Structural 3D Model
Creating Structural Input File for Structural Analysis Program
Run Form Generation Program
   Step 4: Structural 3D Model Generation and Creating Structural Input Files

Part 5. Mass Model Producing
Preparing Mass Model Making Layout
Run Form Generation Program
   Step 5: Mass Model Layout for Laser Cutting

Part 6. Evaluations (Using all output 3D models, data, and mass model)
Evaluating Generated Alternatives
The proposed design process and tools can directly benefit designers to improve the design practice, saving time, and providing the opportunity to design generative and innovative schemes for tall building. The improvement of design quality and design process using advance technology is more practical when used to specifically enhance the performance of a conceptual design.

EXPLORATION OF GEOMETRY

Geometry plays a critical roll in the generation of building form and structure. Geometry in the schematic design helps to explore design ideas. This paper explores potential geometries and new concepts of vertical transformation to create an overall spatial form using non-conventional concepts. Each geometric shape has its own architectural and structural characteristics. Tall building forms can be designed based on a variety of geometric shapes. The geometries for tall buildings in this paper are focused on symmetry: simple polygons and generated polygons. One simple polygon’s corner can be another simple polygon’s center. These combinations generate many symmetrical forms usable for tall building form. Same edge distances and same bay corner columns characterize these symmetry geometries. This research presents the development of a series of starting and ending floor plate shapes for a set of floors using simple polygons and generated polygons. Figure 3 shows the combinations of generated polygon geometries.

EXECUTION AND EVALUATION

To investigate how the proposed design process and tools can be executed with any combinations of geometries and any vertical transformations of four form groups, 304 building forms are generated and demonstrated. Twenty combinations of geometries were selected from the geometry tables. Each combination has four types and each type has four forms; morph, setback, twist, and curvilinear. All forms were generated with same functional, gross area, and floor-to-floor height by function summarized as follows:

- Functions
  
  Office (2 million sq ft); Office Zone1 (1 million sq ft), Office Zone2 (1 million sq ft)
• Hotel (450,000 sq ft)
  Residential (600,000 sq ft)
Without any lobbies and mechanical floors

• Floor-to-Floor Heights
  Office: 12.5 ft
  Hotel and Residential: 9.5 ft

• Set Geometries by Area
  By zoning and area calculation worksheet
  Base Floor: 40,000 sq ft
  Top Floor: 12,100 sq ft

With the same architectural parameters, different combinations of base and top geometries and transformation, such as, morph, setback, twist, and curvilinear forms are generated through Step 1 to Step 3 of form generation process. The outcomes of this process are 3D surface models and summarized building data. An example of results is demonstrated in Figure 4. The objectives of generating 304 forms of selected geometries are as follows:

1. To verify that proposed process can be executed with any combinations of geometries and any defined transformations such as morph, setback, twist, and curvilinear.

2. To suggest various possible concepts of tall building development.
   By showing various forms with 3D surface models, it can help architects and engineers exploring innovative concepts of tall building development.

3. To find the general characters of each form group.
   With 3D models and summarized building data, architectural and structural general evaluations can be established. These evaluations can give architects and engineer design general based on form.
Fig. 4 03-34 & 34-03 Forms
CASE STUDIES AND EVALUATIONS

Explored potential tall building forms can be evaluated in more detail according to architectural and structural design criteria with selected cases. A three-dimensional model is one of the manifestations of the computer model. The forms are developed completely with digital models from the very beginning. As an outcome of this research, three-dimensional generated building forms can be constructed as three-dimensional surfaces for rendering and a three-dimensional model for structural analysis. To check architectural building properties automatically a spreadsheet can be generated in the Microsoft Excel format, and input data file can be created for direct analysis by structural analysis program. Finally, to physically compare alternative forms, study models can be made by a laser cutter.

In the schematic design phase, parametric design can generate a series of designs quickly, which consider a series of architectural and structural design criteria. The proposed design process has the advantage that procedures perform set of inter-related all necessary tasks in the schematic design phase such as planning and design, visualization, analysis, and model making.

Four forms are demonstrated from selected forms for case studies. The selected forms all have same functional types, gross areas, and floor-to-floor heights by function; summarized as follows:

- **Functions**
  - Office (2 million sq ft): Office Zone1 (1 million sq ft)  
    Office Zone2 (1 million sq ft)
  - Hotel (450,000 sq ft): Hotel Back of the House (150,000 sq ft)  
    Hotel Guest Room (300,000 sq ft)
  - Residential (600,000 sq ft)
  - Sky Restaurant: One floor above top of the residential floor
  - Observatory: One floor above sky restaurant
  - Lobbies: Main lobby and 3 sky lobbies (office zone2, hotel, residential)
  - Mechanical Floors: 4 Mechanical floors

- **Floor-to-Floor Heights**
  - Office: 12.5 ft
  - Hotel and Residential: 9.5 ft
  - Sky Restaurant and Observatory: 9.5 ft
  - Lobby: Main lobby (37.5 ft), the other lobbies (25 ft)
  - Mechanical Floor: Top mech. floor (28.5 ft), the other mech. Floors (25 ft)

- **Set Geometries by Area and Dimension Adjustment**
  - By zoning and area calculation worksheet
  - Base Geometry: Approximately 40,000 sq ft
  - Top Geometry: Approximately 12,100 sq ft
  - Dimension adjustments are needed for rational development
Morph Form (03-34-b-m)

The building is 1,485.5 ft high, 123 stories with the 77.3% total space efficiency and 979,000 sq ft total façade area. The building is a triangle at the base; 300 ft each side that evolves to a Y-shape geometry 34 at the top (see Figure 5). The building has nine sides. Six sides are parabolic as the ascent and middle three sides are flat (see Figure 6). Parabolic side is 115 ft at the bottom and 66 ft 5 in at the top and flat side is 70 ft at the bottom and top. By virtue of its tapering façade the tower offers a variety of floor plates, ranging from 38,900 sq ft on the building’s lowest floor to 16,000 sq ft on the top. The building data spreadsheet is summarized as follows:

- Total Height: 1,485.5 ft
- Total Number Floors: 123
  (office1: 28, office2: 35, hotel function: 6, hotel guest: 13, apartment: 32)
- Total Gross Area: 3,304,000 sq ft
  (office1: 991,000 sq ft, office2: 999,000 sq ft, hotel function: 146,000 sq ft, hotel guest: 294,000 sq ft, apartment: 610,000 sq ft)
- Total Space Efficiency: 77.3%
  (office1: 77.3%, office2: 71.5%, hotel function: 83.6%, hotel guest: 82.3%, apartment: 84.2%)

In this building, framed tube with strong shear wall is the principle structural system. Adding outriggers and belt trusses at the mechanical floors reinforces this system. The exterior columns of this building are spaced at 28 ft 9 in the base plan and gradually taper off to 16 ft 7 in at the top plan. For the flat sides, the column bay is 35 ft at bottom and top. If it is necessary, diagonal bracing can be applied at the flat sides.

![Fig. 5 Geometries and Dimensions (03-34-b-m)](image)

![Fig. 6 Architectural and Structural Renderings (03-34-b-m)](image)
Setback Form (34-03-a-s)

The building is 1,485.5 ft high, 123 stories with the 77.4% total space efficiency and 1,137,000 sq ft total façade area. The building is a Y-shape, explored geometry 34 at the base; 100 ft each side that evolves to a triangle; 200 ft each side at the top (see Figure 7). The building has six setbacks with their step rates; 8: 5: 3: 3: 4: 4. Six different floor plates are ranging from 34,300 sq ft on the building’s lowest floor to 17,300 sq ft on the top. The building data spreadsheet is summarized as follows:

- Total Height: 1,485.5 ft
- Total Number Floors: 123
  (office1: 30, office2: 33, hotel function: 6, hotel guest: 13, apartment: 32)
- Total Gross Area: 3,345,000 sq ft
  (office1: 1,029,000 sq ft, office2: 987,000 sq ft, hotel function: 156,000 sq ft, hotel guest: 283,000 sq ft, apartment: 606,000 sq ft)
- Total Space Efficiency: 77.4%
  (office1: 71.4%, office2: 72.8%, hotel function: 84.6%, hotel guest: 83.2%, apartment: 84%)

In this building, framed tube and mega columns with sub-columns are a possible structural system with strong shear wall. Adding outriggers and belt trusses at the mechanical floors intensifies this system. The exterior columns of this building are spaced at 25 ft and 50 ft in the base plan and gradually setback to 25 ft the top plan. Setback distances of five different columns are perpendicular for column A, 6.2 ft for column B, 12.4 ft for column C, 7.4 ft for column D, and 2.6 ft for column E (see Figure 7). These distances of setback distances and the locations of column transferring should be carefully considered with structural limitations and functional allocations.

![Fig. 7 Geometries and Dimensions (34-03-a-s)](image)

![Fig. 8 Architectural and Structural Renderings (34-03-a-s)](image)
Twist Forms (53-05-b-t)

This pure twisted building is 1,444.5 ft high, 119 stories with the 78% total space efficiency and 1,006,000 sq ft total façade area. The building is an explored geometry 53 at the base; 100 ft each side that evolves and twist 72 degree to a pentagon at the top; 100 ft each side (see Figure 9). The building has ten sides. All sides and edges are curved (see Figure 10). Each twisted side is 100 ft at the bottom and 50 ft at the top. Variety of floor plates is ranging from 39,500 sq ft on the building’s lowest floor to 17,600 sq ft on the top. The building data spreadsheet is summarized as follows:

- Total Height: 1,444.5 ft
- Total Number Floors: 119
  (office1: 28, office2: 34, hotel function: 6, hotel guest: 13, apartment: 29)
- Total Gross Area: 3,336,000 sq ft
  (office1: 1,010,000 sq ft, office2: 1,000,000 sq ft, hotel function: 152,000 sq ft, hotel guest: 308,000 sq ft, apartment: 591,000 sq ft)
- Total Space Efficiency: 78%
  (office1: 72.8%, office2: 72.4%, hotel function: 84.2%, hotel guest: 83.1%, apartment: 85.2%)

In this building, dia-grid tube with strong shear wall is the principle structural system due to all curved sides and curved edge lines of the form. The dia-grids are spaced at 20 ft on center in the base plan and 10 ft on center in the top plan, and diagonally connect every two stories for this scheme. A careful consideration of dia-grid spacing is necessary with given geometries.

Fig. 9 Geometries and Dimensions (53-05-b-t)

Fig. 10 Architectural and Structural Renderings (53-05-b-t)
Curvilinear Form (37-03-a-c)

The building is 1,433 ft high, 120 stories with the 78.5% total space efficiency and 982,000 sq ft total façade area. The building is a much dynamic curvilinear form with explored geometry. The building is an explored geometry 37 at the base; 70 ft each side that evolves to a triangle at the top; 160 ft each side. Six edge lines are curvilinear with given amount of curvature and number of cycle, and six edge lines are straight. The building has one curvature type; 0.15 curve factor, 2.0 cycles (see Figure 11). The maximum cantilever distance is 18 ft. The building data is summarized as follows:

- **Total Height:** 1,433 ft
- **Total Number Floors:** 120
  (office1: 23, office2: 32, hotel function: 6, hotel guest: 13, apartment: 37)
- **Total Gross Area:** 3,347,000 sq ft
  (office1: 1,017,000 sq ft, office2: 1,009,000 sq ft, hotel function: 142,000 sq ft, hotel guest: 299,000 sq ft, apartment: 608,000 sq ft)
- **Total Space Efficiency:** 78.5%
  (office1: 77.7%, office2: 74%, hotel function: 83.1%, hotel guest: 82.6%, apartment: 81.5%)

In this building, framed tube or mega columns with strong shear wall is a possible structural system with straight column lines inside of curvilinear envelope. Adding outriggers and belt trusses at the mechanical floors intensifies this system. Column spacing of this building; 35 ft at the base plan and gradually taper off to 20 ft at top (see Figure 11). The amount of curvature is limited by the cantilever distance from columns for curvilinear forms.

![Fig. 11 Geometries and Dimensions (37-03-a-c)](image)

![Fig. 12 Renderings (37-03-a-c)](image)
CONCLUSIONS

Creative building form has become one of the most important design requirements in tall building development due to its symbolic value. The approach to designing evolutionary tall buildings is an open subject of professional debate, and the role of the architect in designing them is very important, particularly from the point of view of form generation. In the future, in architectural design practice, advanced computer aided design technology can be used as an architectural tool to produce, not only the better performance design, but also creative and innovative concepts in tall building development.

In the conceptual design process, architects not only can sketch their design concept, but also establish the real space problem and objective using digital tools. By integrating digital tools based on design criteria and requirements with new concept of tall building form, rational potential forms can be generated. Development of such a method enables the designer to uniquely apply his design concepts easily and evaluate a variety of alternatives. The improvement of design quality and design process, using advance technology, is more practical and challenging for professional development.

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