



Understanding the Role of Rhino as a Parametric Tool in Designing Architectural Built-Forms

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Abstract. In recent years, the term ‘parametric architecture’ has widened the horizons of architects and designers by creating some remarkable structures with complex geometries and optimum functionality. Parametric Architecture is a prototype that uses algorithmic design processes and parameters to create multiple design options. This type of architecture relies heavily on parametric tools for support to design responsive structures with a variety of visual, material, and structural aspects. This research aims at understanding the role of Rhino as a parametric tool in designing built forms. Rhino is part of a broader software ecosystem which includes various plug-ins with multiple uses. This research will provide an overview of use of Rhino and its plug-ins in the design process and its pros and cons as a tool will be outlined. The research method adopted is case study based. A comparative analysis of three parametric built forms will be conducted, of which two will be at the Asian level followed by one in the Indian context, to understand the differences, scopes, advantages, and challenges. At what stage and how efficiently did these buildings used Rhino and its plug-ins will be analyzed. The scope is limited to Rhino as a parametric software and architectural built forms specifically focusing on public buildings. The end goal of this research is to provide a complete guide for designing parametric built forms with the help of Rhino as a tool, to understand the significance of Rhino as a tool and analyze its future scope.

Keywords: Parametric Architecture · Parametric Tools · Parametric Design Process · Rhinoceros · Plug-ins · Digital Tools

1 Introduction

The digital aspect of architecture has evolved a lot over the years regarding its adaptation and practice. For instance, some fifteen years ago there used to be very few computers in an architect’s office, and they were primarily used for word processing and accounting [1]. However, the shift we are experiencing now has been extremely remarkable. The use of technology and thereby digital tools has taken over the architectural practice, and one cannot imagine an architect’s office without these digital tools. Right from the conceptual design stage, which is form exploration, to 3D visualization, structural analysis,

simulations, to renders and walkthroughs, technology is helping architects design and communicate their ideas effectively with their clients. In accordance with this digital revolution, Patrick Schumacher in 2008 coined the term “parametricism.” Parametricism refers to an architectural style that works on algorithms. It provides workable set of constituents i.e., parameters that can be easily manipulated to create infinite design variations [2]. By changing values of parameters, the design changes too, allowing the user to create potential structures that adapt efficiently to the environment. Expressing geometries between complex forms within parametric architecture is increasingly becoming feasible, which allows us as users to experience completely alien structures with complex forms, organic shapes, and fluid geometry.

This research aims at understanding the role of Rhino as a parametric tool in designing architectural built forms. To analyze the use of Rhino as a tool at various design stages. The scope of this research is limited to Rhino as a parametric software and architectural built forms specifically to public buildings.

1.1 Architectural Design Process

To visibly understand how parametric and conventional design processes differ, an example of the workflow for designing a structure in SHOP architects’ studio is illustrated Fig. 1. Figure 1 illustrates the “linear design thinking process” that begins with conceptual sketches and ends with presentation drawings and renders. In this kind of design process, parametric tools are frequently used as modelling or production tools to extrude 2Ds into 3Ds. These tools do not contribute to the design process. According to the arrows in the figure, this kind of design process is linear and goes from sketches to 2Ds to 3Ds and does not toggle between various stages which underestimates the potential of digital tools and their contribution at early design stage.

However, parametric design is an “iterative process” that is primarily “non-linear in nature.” It involves learning from mistakes, toggling between various stages, and introducing various tools in various stages of design process. This helps in understanding the potential of diverse design tools at different stages. Figure 2 illustrates how many

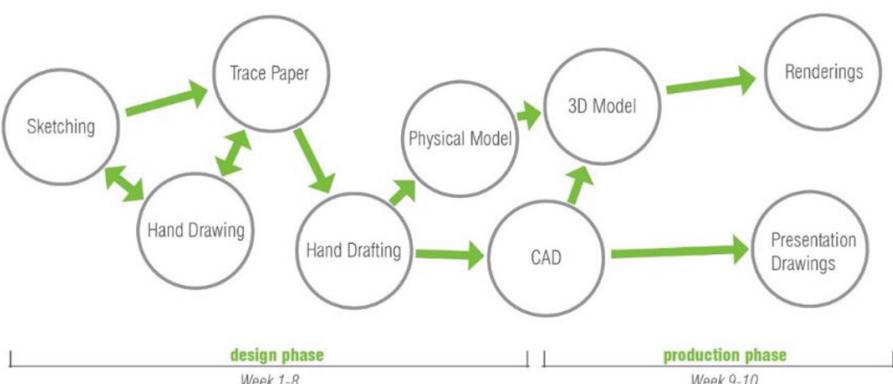


Fig. 1. Illustrates the linear design thinking process by SHOP design studio [3].

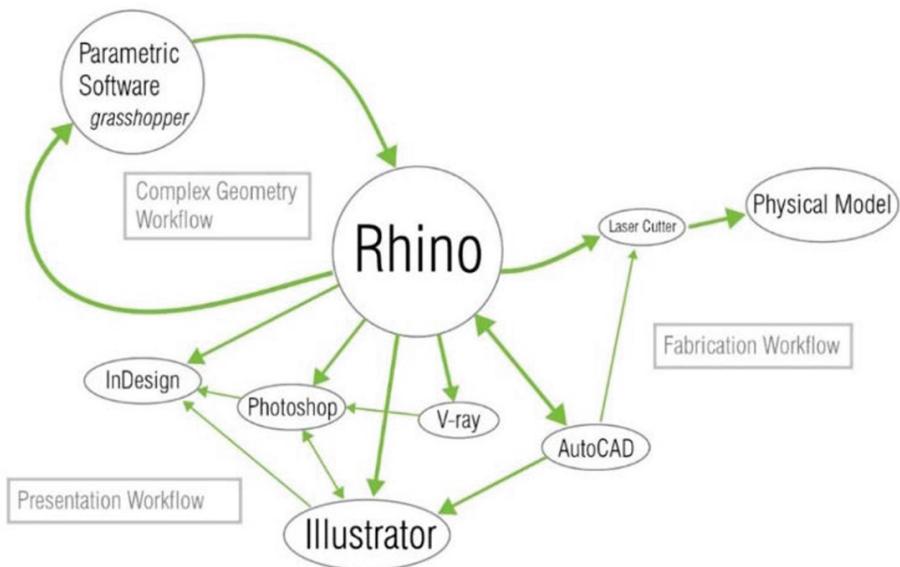


Fig. 2. Illustrates the Non- linear design thinking process by SHOP design studio [3].

times in a design process parametric tools are used. Rhino as a software is used at various stages right from form exploration to complex geometries to fabrication. Parametric design process is a cyclic process and involves repetition of steps, toggling between various stages.

2 Parametric Tools

An important part of the parametric design process is the use of a specific set of tools. By using parametric tools, design decisions can be made faster, and iterative changes to designs can be made quickly. Also, it facilitates problem-solving. During the design process, parametric tools are used in architecture for a varied reason. Through 3D modelling, simulation, automation, optimization, digital fabrication, and finally, digital assembly. The proper use of these tools is essential. An understanding of their strengths and the appropriate stage at which they yield optimum results should be developed.

The following list includes some parametric tools and their use in architectural design [4] (Table 1).

Table 1. List of Parametric Tools and their application

| Sr.no. | Software | Use |
|--------|----------------------------|--|
| 1. | Solid works | Solid works, a parametric modelling program owned and developed by Dassault Systems, is primarily used by engineers for creating electrical, mechanical, and automotive components. In architecture using solid works, one can generate complete, accurate designs that can be leveraged across planning, equipment design, layout, fabrication, and construction. You can also quickly create photorealistic renderings and fully-detailed fabrication drawings. |
| 2. | Catia | Developed by Dassault Systems, CATIA is widely used for product design, parametric modelling, and PLM (Product Lifecycle Management). As a result, it dominates the automotive and aerospace industries. The designers can explore more design ideas and make relevant changes in a more efficient manner. In addition to creating and animating virtual human models, CATIA can also simulate and validate the product according to user requirements and preferences. It goes beyond modelling to allow users to enter the world of virtual reality |
| 3. | Free cad | Developed to design real-life objects of any size, Free CAD is an open-source parametric 3D modelling tool. By changing the parameters of your model history, parametric modelling allows you to easily modify your design. |
| 4. | Rhino + grasshopper | This software works with NURBS (Non-uniform rational B-spline) and is widely used in a variety of fields, including architecture, engineering, and jewellery design. Grasshopper is a visual programming language that is used along with Rhino. Additionally, Rhino is used with its many plugins to analyse and fabricate performance and structural models. |
| 5. | Fusion 360 | A cloud-based 3D modelling software from Autodesk, Fusion 360 integrates CAD, CAM, and PCB (Printed Circuit Board) features. The software includes both parametric and non-parametric mesh and surface modelling tools as part of its 3D modelling functionality. Thus, the user can choose what to work on based on their needs and skills. With Fusion 360, a design team can centralise all activities and communicate effectively in real-time because it is also cloud-based. |

2.1 Why Rhino?

Rhinoceros commonly referred as Rhino is a commercial 3D graphics and computer aided design (CAD) application developed by Robert McNeil & Friends; an American,

employee-owned company founded in 1969. Originally released in 1998, Rhino has undergone several versions over time, and the most recent one was released in 2020. As a parametric design software, Rhino is preferred over other software because it works with NURBS (Non-Uniform Ration B-spline), mathematical representations of 3D geometry that can accurately describe any shape, from the simplest 2D line, circle, arc, or curve to the most complex organic freeform surfaces or solids. SketchUp, on the other hand, uses polygon (mesh) modelling, which approximates real geometry.

Listed below are the advantages or applications of Rhino that make it the most widely used parametric software [5]:

User-friendly Interface: Screen with co-ordinates, command area, pop-up recently-used commands, customizable pop-up commands, synchronize views, customizable pop-up toolbar, unlimited undo's and redo's etc. are the various user-friendly interface advantages that Rhino offers. The screen displays four viewports which gives user the visual representation of the structure from all sides in three dimensions. The interface also offers wide range of render options like artistic, pen, artic etc. to enhance the visual quality of the structure.

Wide range of Modelling and Editing tools: Rhino offers modelling of points, curves, curves from other objects, surfaces, solids mesh with the help of its wide variety of modelling tools. Commands such as SubD, BlendSrf, Revolve, MatchSrf, DupBorder, FilletSrf are the additions to its recent version making it more efficient tool to use. The Editing Tools in Rhino allows it to intersect, transform, blend points, curves, surfaces, and solids. Boolean Operations have been introduced to union, subtract, or intersect coplanar surfaces.

Multiple applications in various professions: Rhino as a software is not only used by architects but also engineers, contractors, product designers, jewellery designers and other professionals working in construction industry. This increases collaboration between various professionals and encourages teamwork. Having professionals from various fields using the same software makes collaboration easier and more convenient.

Compatibility with other software: The open NURBS libraries make Rhino's native 3DM files accessible to hundreds of other applications, including CAD, CAM, CAE, rendering, and animation programs. It allows compatibility with software like Revit, SketchUp, AutoCAD, BIM as well.

Plug-ins: A Rhino plugin or commonly known as Food4Rhino is a software module that extends the functionality of Rhino or Grasshopper by adding commands, features, or capabilities. Rhino along with its plug-ins allows an extensive range of modelling, analysis and fabrication work possible.

The following list indicates the various plug-ins of Rhino and their primary use, this will help understand the vast reach that Rhino as software have if used with its plug-ins [6, 7] (Table 2).

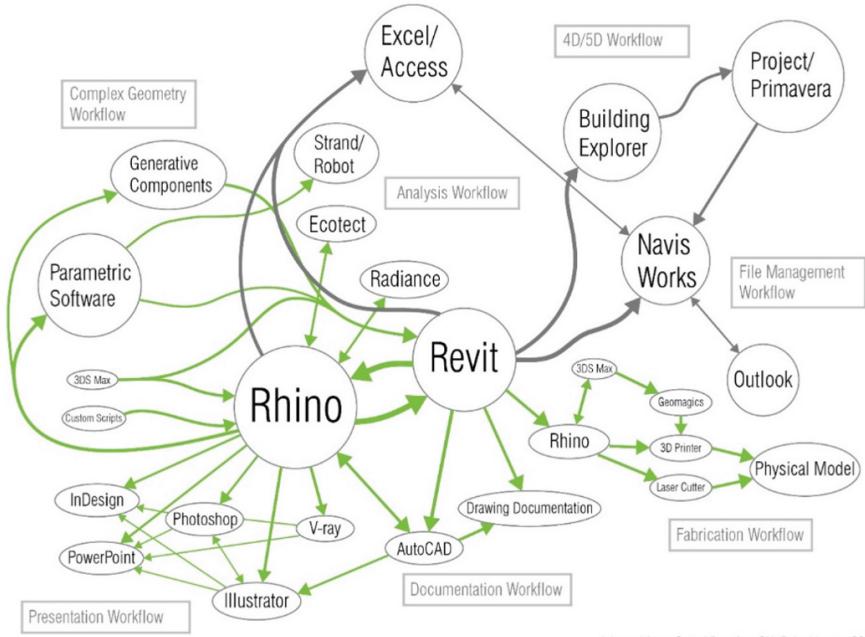
Table 2. List of Plug-ins and their application

| Sr. No. | Name of the plug-in | Use |
|---------|-------------------------|---|
| 1. | Grasshopper | 3D Form generating tool with the help of generative algorithms. |
| 2. | Ladybug | Environmental Analysis. Particularly Energy, Daylight and Radiation Analysis. |
| 3. | Honeybee | Environmental Analysis |
| 4. | Geco | Environmental and Climatic Analysis |
| 5. | Kangaroo physics | Structural Analysis |
| 6. | Karamba | Structural Analysis. Load calculations for trusses, frames etc. |
| 7. | Bullant | Structural Analysis. Allows formation of geodesic domes, curve network processing etc. |
| 8. | Humming bird | Structural Analysis. Allows bi-directional workflow between Revit and Rhino |
| 9. | Heliotrope bird | Environmental Analysis. Helps in manipulating geometry based on sun position. |
| 10. | Mantis | Structural Analysis. Links Rhino to Mathematica. |
| 11. | Lunchbox | Helps in modelling uneven surfaces. |
| 12. | Visualarq | BIM flexible. Generates all the necessary documents like plans, sections, elevation, services from 3D model within no time. |
| 13. | Fluidray | Helps in creating photorealistic renders. |
| 14. | Landsdesign | Enables landscape design in parametric form. |

2.2 Optimization of a Tool

Following Fig. 3 illustrates the complete execution of a design process along with the digital tools used at various stages. Everything in the following flowchart have a meaning right from the arrows; their graphical representation, line type, line thickness, the circles, and the ovals.

In the design process the design tasks are targeted to specific software programs, and while moving further to the one the next software is used. Professionals strategically target each task to a specific software program while defining the workflow. For instance, the use Revit or AutoCAD for drafting, software like SketchUp and Rhino for 3d modelling, Lumion, Vray for rendering, InDesign and photoshop for presentation of drawings. In the following example a variety of software are used in collaboration for a single design task. This is one type of practice adopted in a design process. But what if a single software can provide all these applications at a single interface. Optimum use of a single software is something needed to practice more often in design process. This would result in saving time, mastering one software, and using it efficiently possible. Rhino as a software along with its plug-ins allows this kind of design practice possible



Adapted from *Out of Practice*, SHoP Architects, 2012

Fig. 3. Illustrates the complete evaluation of a design process along with the various software used at various stages by SHoP design studio [3].

wherein, practicing majority of the tasks with the help of a single parametric software is possible. In this paper an attempt is made to understand this efficient use of a single tool and its optimum functions it provides while designing.

2.3 Use of Rhino and Its Plug-Ins at Various Stages in Design Process

From Table 3 it is very evident that Rhino is a vast ecosystem and as a single software can complete a design process right from concept to fabrication. Table 3 illustrates the combinations of Rhino and its plug-ins that can be used at various stages of design process that are listed down. The scope of this research is only limited to these shortlisted design stages; there can be ‘n’ number of micro level design stages and permutations and combinations of these plug-ins which are not catered in this research.

3 Case Studies

The following case studies are the part of analysis of this research paper. An attempt is made to analyze how the master architects from different countries have used Rhino as a parametric software efficiently. In how many stages have they used this tool and its pro and cons. Have it really been useful for them or does it have any drawbacks. The reason behind choosing these case studies is to understand the adaptation of the same software by people in different context. The first two case studies i.e., Morpheus Hotel,

Table 3. List of various design processes and the combinations of Rhino + Plug-ins which can be used.

| Sr.no. | Design stage | Plug-in |
|--------|---|---|
| 1. | Site Analysis | Rhino + Ladybug + Honeybee |
| 2. | Conceptual design Stage | Rhino + Grasshopper + Lunchbox |
| 3. | Volumetric Analysis & Form Exploration | Rhino + Grasshopper + Lunchbox |
| 4. | Drafting- Detailed working drawings | Rhino + Visualarq |
| 5. | Presentation Drawings- Renders | Rhino + Grasshopper + FluidRay |
| 6. | Analysis- Climatic, Environmental, Sun path, Wind and Radiation etc. | Rhino + Grasshopper + Ladybug + Geco + Honeybee |
| 7. | Structural Analysis | Rhino + Karamba + Kangaroo Physics + Bullant + Humming bird |
| 8. | Material Selection | Rhino + Grasshopper |
| 9. | Digital Fabrication. | Rhino + Grasshopper + AutoCAD |

Macau and Opera House, Harbin are at Global context specifically Asian level followed by the third case study i.e., Mumbai International Airport which is focused at Indian level context. The prime criteria behind choosing these case studies is that the structure should be designed using Rhino as a software along with its plug-ins and it should be used for maximum design stages.

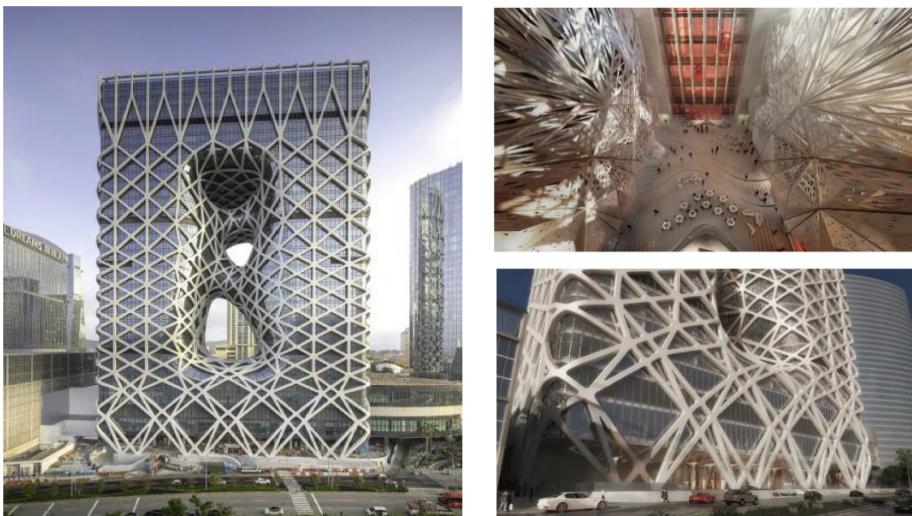
3.1 Morpheus Hotel: Macau, China

Morpheus Hotel in Macau is a 40-storey, free-form exoskeleton structure by Zaha Hadid Architects. Its unique appearance and interior spaces are created by a series of voids. Guests can experience the external voids within the building through two bridges connecting the two towers at podium and roof levels. Most of the geometrical modelling was done using Rhino3D CAD application, the Grasshopper visual programming language was used for analysis [8].

The following case study elaborates the form exploration, façade details, structural analysis, environmental analysis, and digital fabrication as design processes in the section below (Photograph 1).

Form Exploration: A notable aspect of this hotel is the jade-stone-shaped horizontal vortices that create voids throughout the building. Based on the fluid forms found in China's rich stone carving traditions a string of blanks is carved through its center to create an urban window that connects the hotel's interior spaces with the city (Figs. 4 and 5).

Façade Details: As part of Buro Happold's highly engineered façade solution, more than 30 façade systems were incorporated, including flat glazing, single-curved glazing,



Photograph 1. Illustrates the interior & exterior views of Morpheus Hotel, Macau



Fig. 4. Illustrates the subtractive massing and the formation of void in the form of the Morpheus Hotel, Macau.

unitized and stick glazing, giant free-form triangulated glazed panels and aluminum paneling for the structure's cladding. The architect provided a wire-frame model of the exoskeleton and a reference surface defining the outer boundary of the glazed envelope. These parameters were used to describe a topological mesh that describes the exterior surface of the façade. The entire facade system is composed of Rhinoceros elements and 462 GH files (Fig. 6).

Structural Analysis: The building's exoskeleton optimizes the interior with spaces that are uninterrupted by supporting walls or columns. All nodes were horizontally aligned

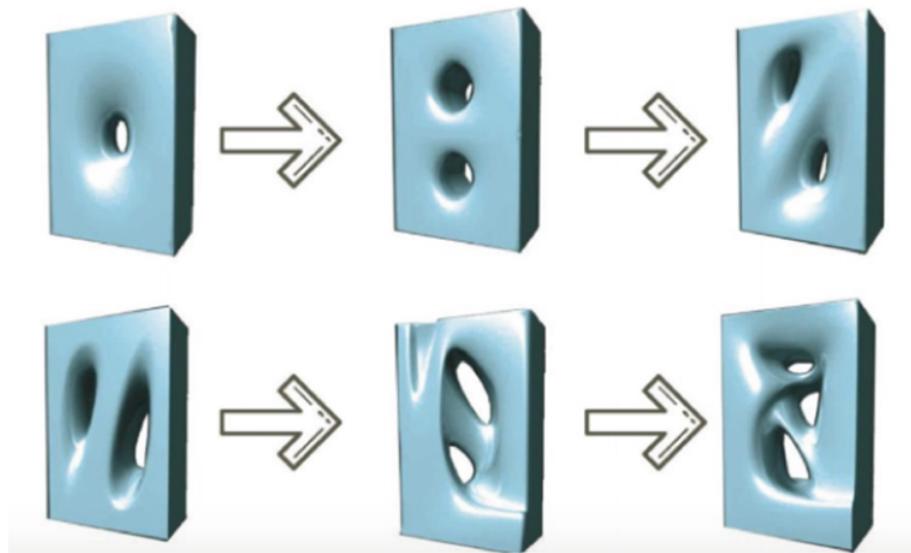


Fig. 5. Illustrates the Form Exploration Stages of Morpheus Hotel, Macau

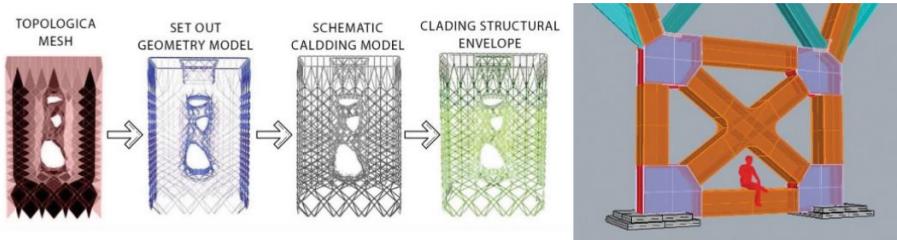


Fig. 6. Illustrates the Façade Iterations made for Morpheus Hotel, Macau



Fig. 7. Illustrates the Structural Analysis Stages of Morpheus Hotel, Macau

to the floor edge beam according to structural rules. The stubs should be horizontal and perpendicular to the glazing reference surface (Fig. 7).

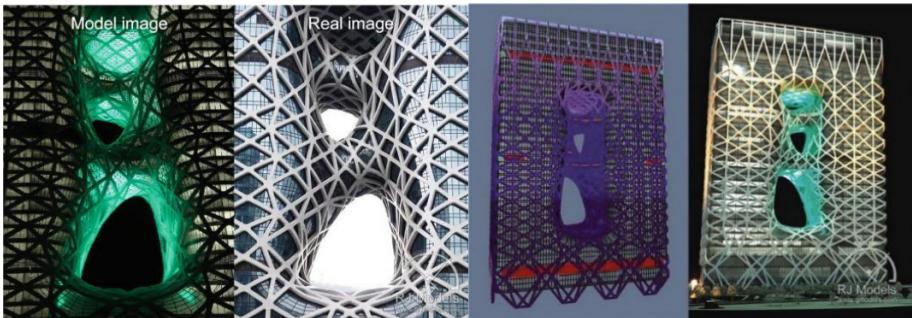


Fig. 8. Illustrates the Digital Fabrication & Model making Stages of Morpheus Hotel, Macau

Environmental Analysis: The exoskeleton of the building provides additional shading from the sun. High-performance glazing minimizes solar gain.

Fabrication: Fabrication took place primarily as part of RJ Models' model-making process for the structure. By utilizing 3D printing and CNC technology, it was possible to manufacture the components that made up the hotel model more efficiently. In order to accurately depict the details of the original 3D building, RJ Models re-mapped the hotel model in 1:80 scale (Fig. 8).

3.2 Opera House: Harbin, China

The Harbin opera house is situated in the wetlands of the northern regions of China and designed by MAD architects. The construction reaches a height of 56 m at its peak. Designed to respond to the climate in the region, the curvaceous exterior, topography, and luxurious interiors of the structure are used to blend into and feel closer to nature. The smooth white aluminum panels used in exterior helps the building to camouflage during the snowy winters. Some functions of Rhino- Grasshopper like Kangaroo, weave bird etc. are used for designing and modelling of this structure [9].

The following case study elaborates the context analysis, structural analysis, environmental analysis stages of design process followed by some additional stages in the sections below (Photograph 2).

Context Analysis: The opera house emerged as part of a larger master plan and wetland landscape along the Songhua River. The project has 3 main parts: main building, annex building and outdoor plaza. Nurbcurve method was used to control the relationship between these three parts (Fig. 9).



Photograph 2. Illustrates the view of Harbin Opera House.

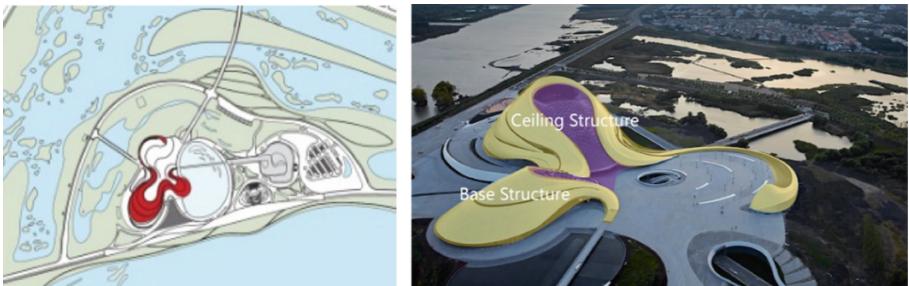


Fig. 9. Illustrates the Site & Context Analysis Stage of Harbin Opera House, China

The baseline is generated on the nurbs curve method using the 13 given points. The functions of “loft” and “scale” help to create the curved surface that wraps all the three main parts of the structure between and finish the building mass.

Kangaroo to create curved ceiling: In the line of top layer, several specific points are selected for dome ceiling area by function icon of “cull index” then, using spline “function” to convert points to surface and using weaverbird function to convert surface to meshes the curved ceiling was designed (Fig. 10).

Curvature Analyses in Rhino & Grasshopper

See Fig. 11.

Environment Map Analysis in Rhino

See Fig. 12.

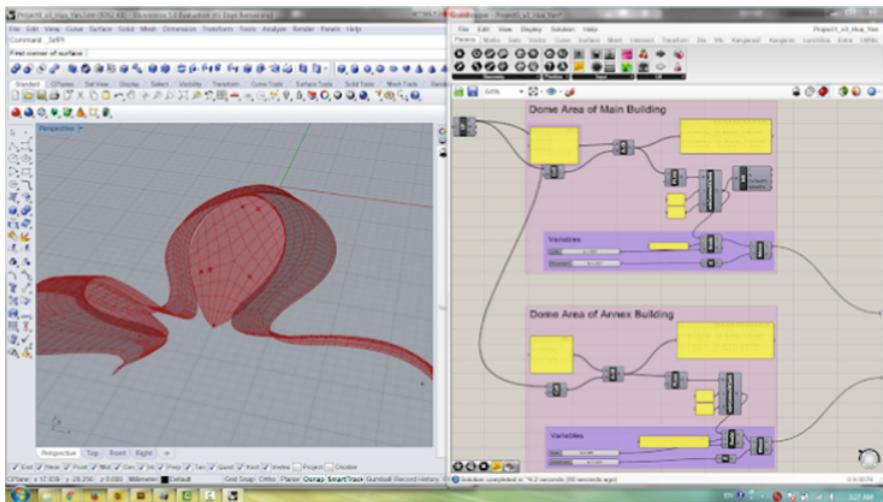


Fig. 10. Illustrates the Curved Ceiling Formation of Harbin Opera House in Kangaroo

Draft angle Analysis in Rhino

The draft angle analysis visually evaluates surface draft-angle using false-color analysis. Draft angle is often used to design injection molded parts that must eject from molds (Fig. 13).

Zebra Analysis in Rhino

See Fig. 14 and Photograph 3.

3.3 Chhatrapati Shivaji Maharaj International Airport, Mumbai India

The Mumbai international airport can accommodate 40 million annual travelers, with an area of 105 hectares. A four-storey structure with height up to 45m. The complex combines international and domestic passenger services beneath one encompassing roof canopy, reducing customer walking distance. India's national bird, the peacock, has a teardrop-shaped eye that inspires the design of the molded coffered panels. In the center of each coffered panel is a round aperture for natural and electric light. A laminated lens is in each gap, which produces two colors based on the angle at which light strikes it [10, 11] (Photograph 4).

The following case study elaborates the structural analysis stage in the section below (Figs. 15 and 16).

Designed to achieve optimal thermal performance and mitigate glare, terminal 2 employs a high-performance glazing system with the custom frit pattern. With perforated metal panels within the building's curtain wall, low sun angles are filtered, creating a comfortable environment for passengers waiting. Lighting controls that balance external and internal light levels for optimal energy savings. Strategic placement of skylights throughout the check-in hall reduces the terminal's energy consumption by 23% (Figs. 17 and 18).

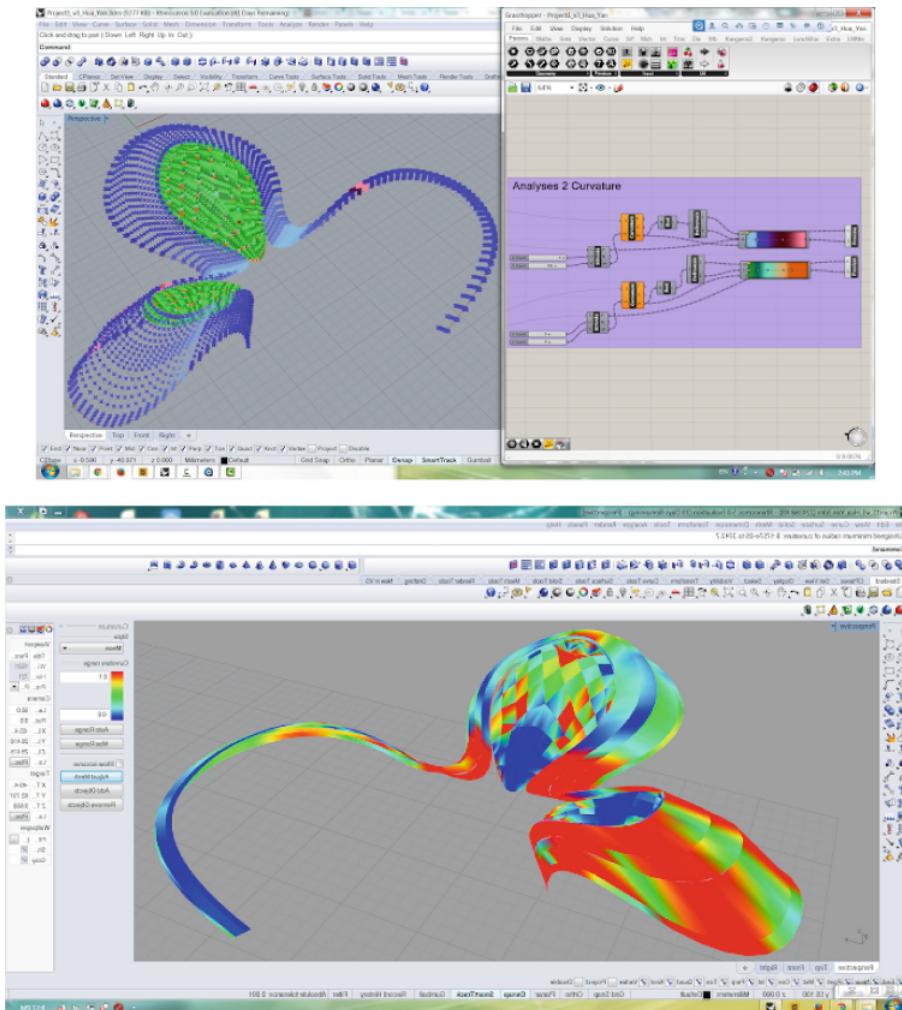


Fig. 11. Illustrates the Curvature Analysis of Harbin Opera House in Rhino, and Grasshopper interface simultaneously.

Note: All the case-studies chosen are designed with the help of Rhino. The screen pictures displayed are the Rhino and Grasshopper Screens.

3.4 Inference from the Case Studies

Table 4 illustrates the comparative analysis of the three case studies elaborated in Sect. 3.3. From this analysis it is evident that generally Rhino is used at structural analysis stage with the help of plug-ins like Karamba, Kangaroo etc. The first two case studies also illustrate use of this software at conceptual design and volumetric analysis

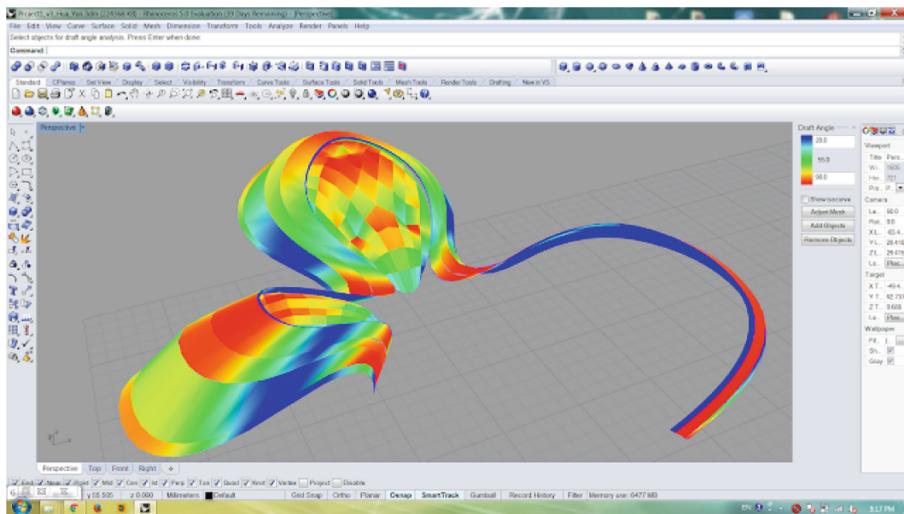


Fig. 12. Illustrates the Curvature Analysis of Harbin Opera House in Rhino, and Grasshopper interface simultaneously

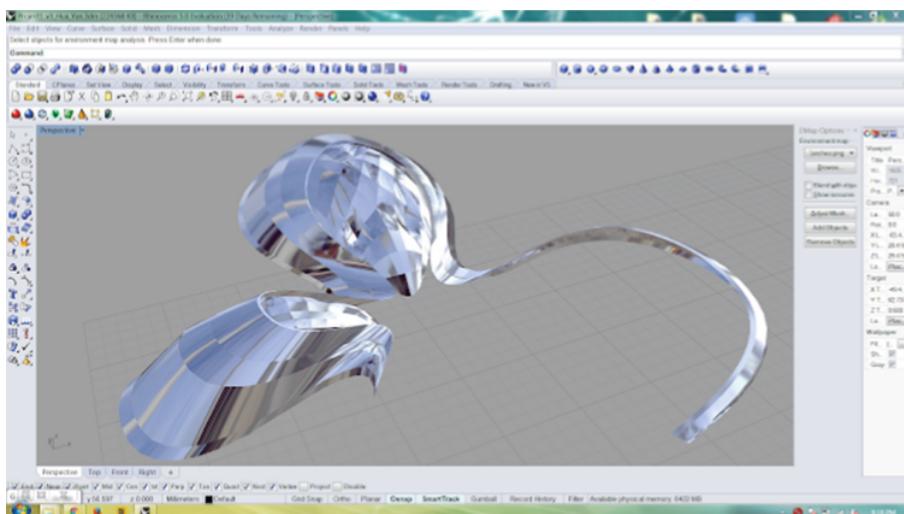


Fig. 13. Illustrates the Draft Angle Analysis of Harbin Opera House, China in Rhino

stage. Additional stages carried out using Rhino are also listed down in the Table 4. This demonstrates the wide applications of rhino possible.

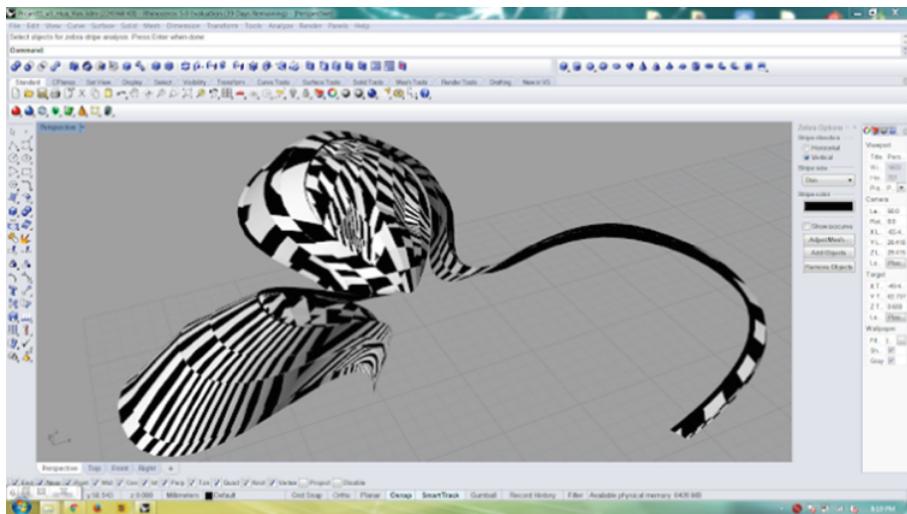


Fig. 14. Illustrates Zebra Analysis of Harbin Opera House in Rhino



Photograph 3. Illustrates the views of Harbin Opera House, China

4 Discussions

Throughout the initial phases of research, it is been explored the parametric design process, and digital tools and parametric tools, specifically identifying Rhino as a tool and its wide range of applications, followed by plug-ins and their efficient use in various design stages to illustrate the variety of tasks a single tool can accomplish in design. It is evident from the case studies that a similar tool is adapted differently in the global and Indian contexts.

4.1 Global Level Scenario

The reason behind choosing the Rhino as the parametric tool for this research was that it is a tool used by architects globally. Based on the global case studies, it was evident that Rhino was used in the initial stages of design such as conceptual design and form exploration. Here the use Rhino is as a designing tool and not just a presentation tool.



Photograph 4. Illustrates the view of Mumbai International Airport

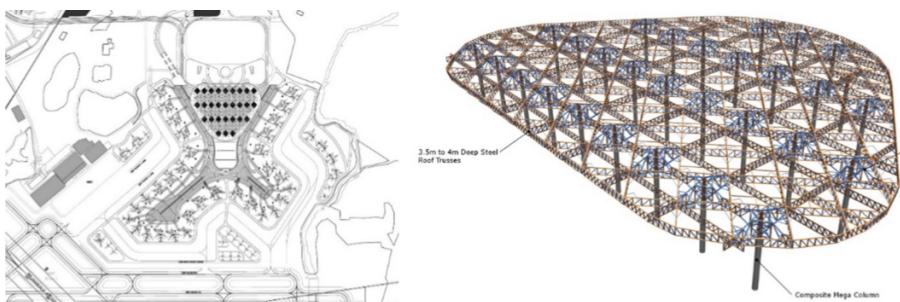


Fig. 15. Illustrates the context and the Structural Isometric of the Airport

Another observation was that the software-to-reality ratio of these parametric structures is quite high globally in countries like China, Japan, UAE, etc.

4.2 Indian Level Scenario

The research and the search for case studies of parametric buildings in Indian context illustrates that there are no actually constructed parametric forms in India. The constructed parametricism in India is confined only to canopies, facades, false ceilings, and furniture. It however does not imply that we are not proficient in the software or do

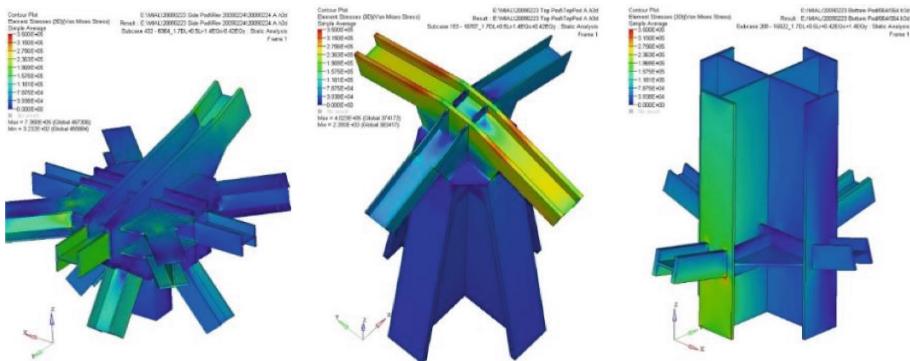


Fig. 16. Illustrates the Analysis of Stresses developed in members of the canopy

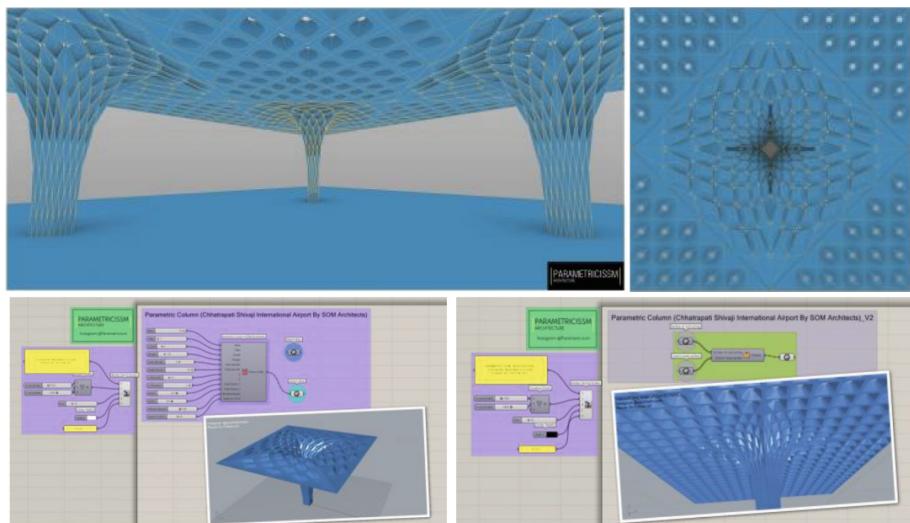


Fig. 17. Illustrates the Analysis of Mushroom Columns in Grasshopper

not know how to use it. Numerous firms in India practice parametric design, and have designed remarkable parametric buildings. Nonetheless, they are limited to competition entries, renderings, and virtual designs. Indian professionals are proficient with the technology and are making its optimum use virtually. Identifying the reason behind this gap between the use of parametric software and the reality of parametric structures in India is beyond the scope of this paper.



Fig. 18. Illustrates the On-Site Modular Fabrication

Table 4. Illustrates the Comparative Analysis of all the 3 case studies

| Sr. No. | Case-study | Morpheus Hotel | Opera House | Chhatrapati Shivaji Maharaj International Airport |
|---------|--|----------------|-------------------------|---|
| D | Site analysis | | | |
| E | Conceptual design stage | | | |
| S | Volumetric analysis & form exploration | | | |
| G | Drafting – detailed working drawings | | | |
| N | Presentation drawings | | | |
| P | Environmental analysis | | | |
| R | Structural analysis | | | |
| O | Material selection | | | |
| C | Digital fabrication | | | |
| E | Additional | Façade details | 1. Curvature analysis | |
| S | | | 2. Draft angle analysis | |
| S | | | 3. Zebra analysis | |

Note: the shaded cells indicate the use of Rhino as a parametric tool in that specific design stage.

5 Conclusion

This research focused on understanding the optimal use of a single software. Every software has its advantages, and that is the reason to switch between different applications for different tasks. However, if a single software has the ability to perform numerous tasks, and it should be used to the fullest extent possible. Although this may not be the case with other parametric software, Rhino is an ecosystem that along with its plugins makes the term “one for all.” possible. There have been notable developments in the use of parametric software for designing structures in recent years. But these are only the initial stages of its use. The wide range of applications and the scope of the kind of wonders these tools can create are hardly known to professionals. Or if even

known bringing them to reality is still a task. Once the importance of these tools is fully grasped, experts in computation can make several modifications and advancements to this software which will help modern architecture in diverse behaviors. The emergence of these new technologies is going to reshape the future of architecture. Architects and engineers are no longer going to be the only professionals working in the field of architecture. Computational experts, coding experts, data analysts, and other professionals will together take the field of architecture to new heights in the future [12, 13].

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