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Parametric modeling logic analysis and precision control method application of nonlinear landscape structures based on Rhino+Grasshopper platform: A case study of the 'Flying Goose' viewing platform in Beijing

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Abstract. The development of digital technology has made non-linear landscape structures mainstream and has brought new challenges to design methods. The efficiency and accuracy of applying Rhino+Grasshopper parametric modelling to such structures has gained the attention of design practitioners and scholars. However, there are still research gaps in this approach in current research. Therefore, this study uses the 'Flying Goose' viewing platform as a case study to supplement the lack of specific case studies on non-linear landscape structures; it analyses the modelling logic through three parts: morphological characteristics, structural system, appendages and decoration to supplement the lack of systematic knowledge on modelling logic; it analyses the four methods of unfolding control, isometric projection, function shaping and linear interference. The analysis and discussion of the four core precision control methods used in the Rhino+Grasshopper parametric modelling process complements the current lack of specific research on Rhino+Grasshopper parametric modelling morphological precision control methods. The aim is to provide a systematic analysis of the modelling logic of non-linear landscape structures and a detailed analysis of the precision control methods on top of the non-linear landscape structures morphological realisation, providing a theoretical basis and application examples for future research of the same type.

Keywords: BIM, digital simulation, digital architecture, parametric design, landscape architecture

1. Introduction

1.1. Challenges in the design of non-linear landscape structures

With the increasing maturity of digital architecture technology, non-linear landscape structures (NLS) have become the mainstream of modern landscape structure design [1]. Compared to traditional forms, NLS forms are more artistically intense and can create distinctive site characteristics [2]. In terms of geometry, NLS consists of shaped surfaces with a variety of basic components and complex dimensional changes [3]. In the actual construction process, it is difficult to express the dimensions of NLS using traditional construction drawings to guide the processing of components and on-site construction, so the spatial dimensional information of NLS components needs to be accurately expressed through 3D models [4]. The use of software such as SketchUp and Rhino to directly manipulate design objects based on programmed instructions ('manual modelling') is currently the dominant method of NLS design, but requires a great deal of repetition on the part of the designer [5]. When dealing with projects with short design timeframes, manual modelling can slow down the adjustment process and there is the potential for manual errors to reduce the dimensional accuracy of the model, affecting the construction schedule and the final outcome of the project [2-4].

1.2. *The Rhino+Grasshopper parametric modelling approach* gets attenti*on*

The use of the Grasshopper (Gh) parametric platform in Rhino (Rh) software to form Rhino + Grasshopper Parametric Modelling (RGPM) can improve the efficiency of NLS modelling [6-7]. During the RGPM process, the designer can invoke the 'pre-written program module' ('battery') on the Gh platform to make connections, assign appropriate adjustable parameters and modify the parameters according to the design requirements. The program automatically calculates and displays the geometry and data of the NLS in real time based on the modifications [6-13]. This replaces repetitive manual modifications by the designer, increasing efficiency while avoiding the possibility of manual errors and ensuring the accuracy of the model dimensions [14]. As a result, more and more landscape architects are becoming aware of the importance of RGPM for NLS design work and are beginning to apply it in real projects [15].

1.3. *Gaps in Rhino+Grasshopper parametric modelling for non-linear landscape structures*

A review of the literature reveals that there are still research gaps related to RGPM studies of non-linear structures as follows:

First, there is a lack of specific case studies conducted for NLS. The current research mainly takes large scale buildings such as stadiums and office buildings as case studies of RGPM [4,14,16-18], but there is a lack of research on NLS. In contrast to larger-scale buildings, NLS places more emphasis on variation in morphology and aesthetics in decorative design [1]. The geometry and dimensional information is expressed with high accuracy through RGPM, from the design to the actual construction. Therefore, RGPM research with NLS as an application case has a complementary necessity.

Secondly, there is a lack of systematic knowledge of the modelling logic. Most of the current studies directly analyse modelling methods for specific components of the modelling study object [5,14,16,18], lacking a systematic knowledge of modelling logic based on an understanding of the construction building logic of non-linear structures. Only a few studies have analysed the overall modelling logic prior to undertaking analysis of specific modelling methods [4,19]. The large number of heterogeneous components and complex dimensional changes of non-linear buildings and structures, coupled with the need for construction information to be modeled throughout the entire process from design to construction, form a multi-disciplinary collaborative workflow with BIM as the core [3]. For this complex information system, the clarity of the modelling logic directly affects the ease of model information management, which in turn affects the efficiency of the design plan generation and actual construction.

Thirdly, there is a lack of specific research into the precise control of RGPM morphology. Current research has focused on how to use RGPM to realise the morphology of specific components of non-linear buildings such as roofs and skins [4,6,16,18,20], but there is a lack of research on methods to accurately control the morphology through mathematical algorithms on top of this. In the literature review, only studies on the structural design of parametric structures have focused on how to accurately control the building dimensions based on morphological realisation [5]. For a model of a non-linear morphological structure, accurate control of the morphological dimensional data is the most essential condition for its actual construction [16], otherwise it can only remain at the stage of digital simulation of the morphology and cannot be built in practice.

In summary, this paper will use the 'Flying Goose' viewing platform as a case study, through the analysis of its modelling logic and the analysis and discussion of precise control methods in the

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RGPM process, to fill the research gap while providing a theoretical basis and application examples for future research of the same type.

Based on the research objectives, the following research questions are posed and answered in this paper: 1. What is the need to use RGPM for the design of the ‘Flying Goose’ viewing platform? 2. How to develop a systematic knowledge of the construction logic of the NLS and establish the modelling logic? 3. What are the core algorithms in the precision control methods used in the RGPM of the ‘Flying Goose’ viewing platform?

2. Case study: The ‘Flying Goose’ viewing platform in Beijing

2.1. Overview of the project

Figure 1. Viewing platform design conception.

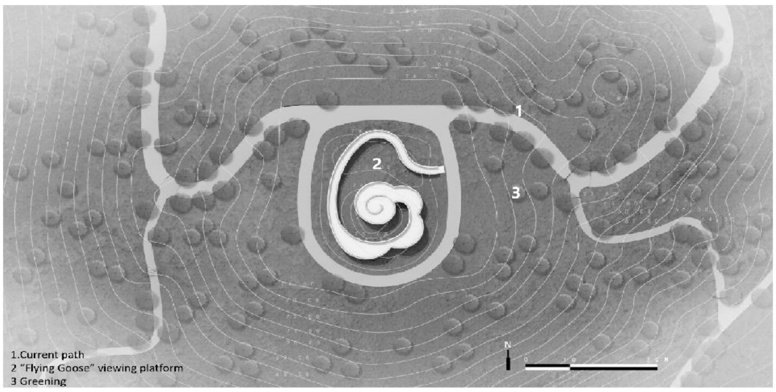

Figure 2. Plan of the viewing platform.

Figure 3. Daytime view of the viewing platform.

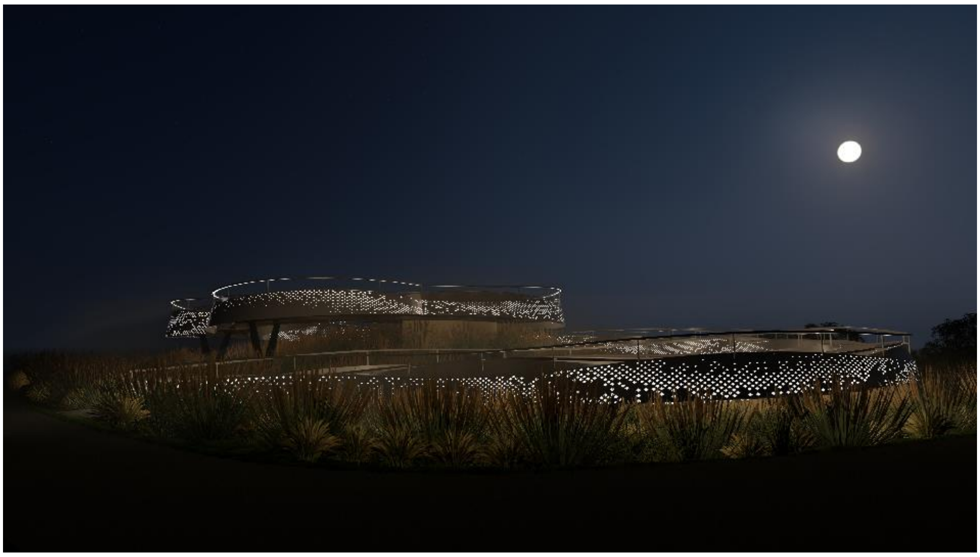

Figure 4. Night view of the viewing platform.

The 'Flying Goose' viewing platform is located on the east side of Nanyuan Forest Wetland Park in Fengtai District, Beijing. Its location offers a wide view of the park, making it suitable for visitors to climb up to the top. The design is inspired by the 'Flying Goose' and the 'auspicious clouds' (Figure 1). The plan of the viewing platform resembles the auspicious clouds (Figure 2) and incorporates a misting device to simulate clouds (Figure 3). The handrail board design uses perforated panels to simulate a 'river of stars' (Figure 4). The platform is 48m long from north to south, 36m wide from east to west, 74m above sea level, with the top of the platform raised 3m from the ground, and is mainly used as a landscape landmark in the park, with the functions of cultural display, viewing and resting.

Prior to the modelling of the viewing platform, the client wanted the overall form to mimic the auspicious cloud pattern and the design of the railings to reflect the cultural identity and aesthetics of the viewing platform. It is therefore recognised that the design of the observation deck is likely to require a number of meetings and revisions with the client. At the same time, as the viewing platform mimics the auspicious clouds in shape, the free curvature of the lines would make it difficult to realise the form of the design if traditional manual modelling is used. In addition, to meet the design commissioner's requirements for the form would require iterative refinement of the form through precise control of the data, so RGPM was chosen as the method for this study.

2.2. RGPM logical constructs for the viewing platform

Prior to the RGPM logical construct analysis of the viewing platform, a plan scheme for the viewing platform was completed in AutoCAD for this study. The plan scheme was then imported into the Rh file and imported as a geometric element reference within the Gh authoring interface. With regard to the sequencing of the setting of adjustable parameters in Gh and the actual battery connection, some studies have argued that the determination of the required parameters should be completed before the battery is connected [4]. However, this study considers that the model parameters are determined gradually during the modelling process. As Professor Weiguo Xu points out in Digital Architecture, from Virtual to Reality, *'Digital technology has also changed the design process, which is no longer a formal creation process by architects through inspiration, but has become a formal search and formal optimisation process based on design requirements and repeatedly solved by constructing parametric models [21].'* The specific design of the RGPM-based NLS is itself a process of algorithmic experimentation with the NLS, which means that the addition of parameters and the determination of specific parameter values need to be carried out progressively during the modelling process.

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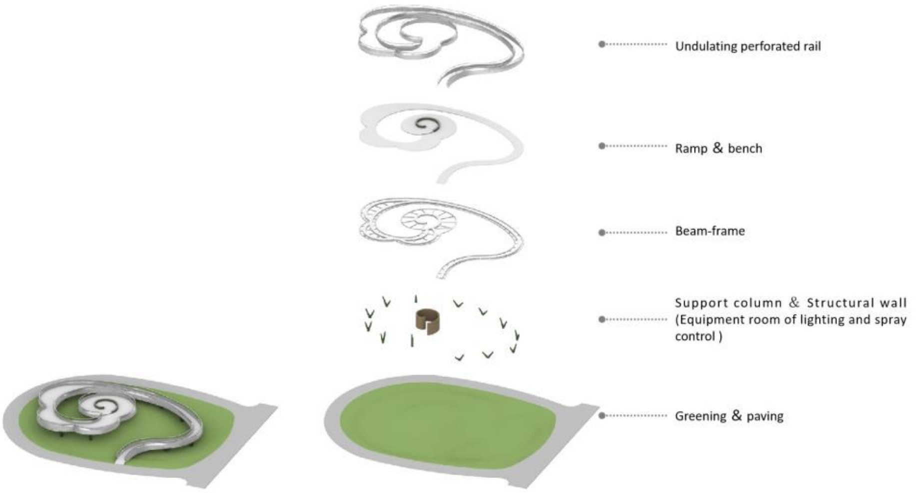

Figure 5. Vertical deconstruction of the viewing platform.

From a practical construction perspective, a viewing platform is a combination of various components (Figure 5), which do not exist independently, but are interlinked to form a complete system according to the construction logic. Therefore, this study will combine the construction logic with a systematic understanding of the viewing platform, forming a structural modelling logic from the whole to the detail. Depending on the actual construction process, the modelling is divided into three successive parts:

2.2.1. Morphological characteristics

Figure 6. Morphological characteristics of the viewing platform**.**

In the RGPM process of NLS, morphological characteristics are curves or surfaces that represent the overall geometry of the NLS and serve as the most basic basis for further modelling. It is important to note that, due to the flexible morphology of the NLS, the characteristic curves and surfaces are usually not limited to one, and in practice they can be constructed manually in Rh or generated directly in Gh based on algorithmic writing, depending on the requirements of the scheme.

For the 'Flying Goose' viewing platform, the curved ramp and the composition of the top platform with the auspicious cloud pattern form the overall form (Figure 6). The form of the ramp is controlled by the central axis and edge lines of the ramp, while the form of the platform is controlled by the edge lines of the platform. The above geometric elements therefore become its morphological characteristic curve.

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2.2.2. Structural system

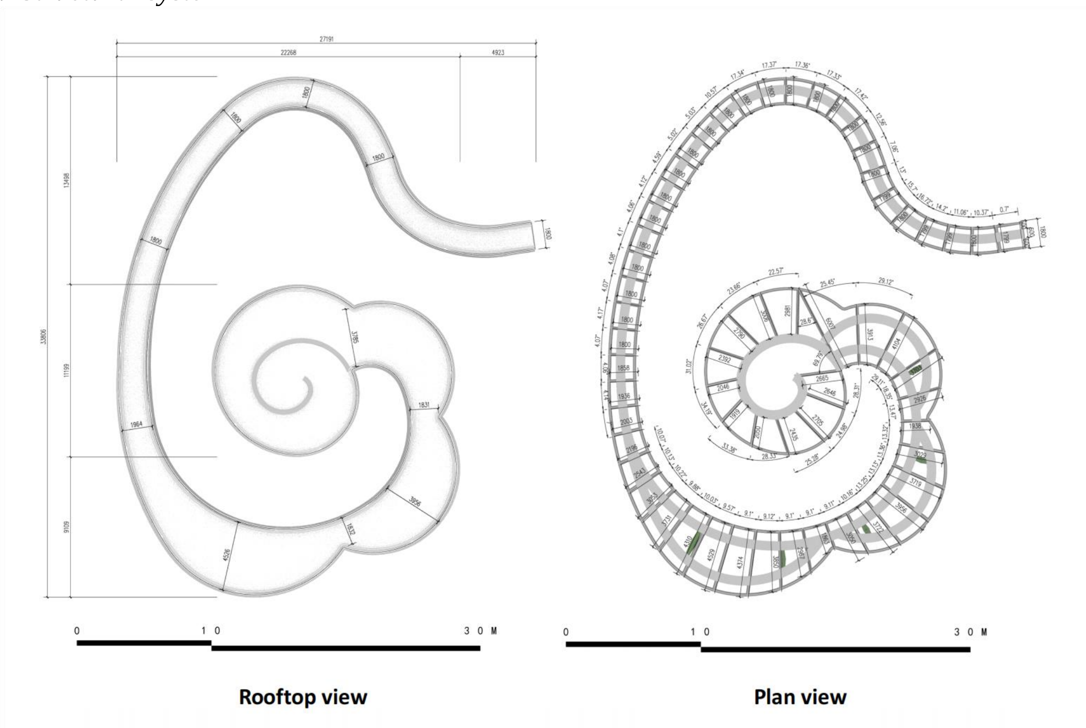

Figure 7. Dimensions of the viewing platform structure.

In the RGPM process for the NLS, the structural system refers to the spatial representation of the structure's form based on precise dimensions through modelling, thus assisting the designer in accurately grasping the actual effect of the NLS. The axes of the structural elements generated in Gh during the modelling of the structural system can be submitted to the structural disciplines for verification to ensure structural stability and further adjustments to the structural dimensions and number of structural elements.

In order to create a light and upright form, the viewing platform is constructed using steel structures. The steel structure can be divided into a beam system and a column system in terms of load-bearing elements. For the viewing platform, the beam system consists of primary beams, secondary beams and side beams; the column system consists of pairs of variable-section columns and load-bearing walls. For the ramp and platform sections of the viewing platform, the beam and column systems are designed differently (Figure 7):

The ramp at the viewing platform has both equal and unequal widths. The equal width ramp has the main beam on the central axis of the ramp, while the unequal width ramp has an arc-shaped main beam based on the main beam formed on the central axis of the ramp. On the basis of the main beam, the edge of the ramp is used as a side beam and a transverse secondary beam is used to connect the main beam to the side beam, completing the beam system of the ramp. The column system of the ramp is supported by pairs of round steel columns of variable section. For equal width ramps, the two connection nodes of each pair of columns are connected to the main beam at the same time; for non-equal width ramps, each pair of columns opens at a different angle and the two connection nodes are connected to the central axis main beam and the curved main beam respectively to complete the column system.

Below the platform of the viewing platform is the spray and lighting system control room, so the platform uses the reinforced concrete bearing wall of the equipment room as a column, with a main beam at the intersection of the bearing wall and the platform, and the edge of the platform as a side beam, and uses a secondary beam for connection to complete the beam and column system.

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2.2.3. Appendage and decoration

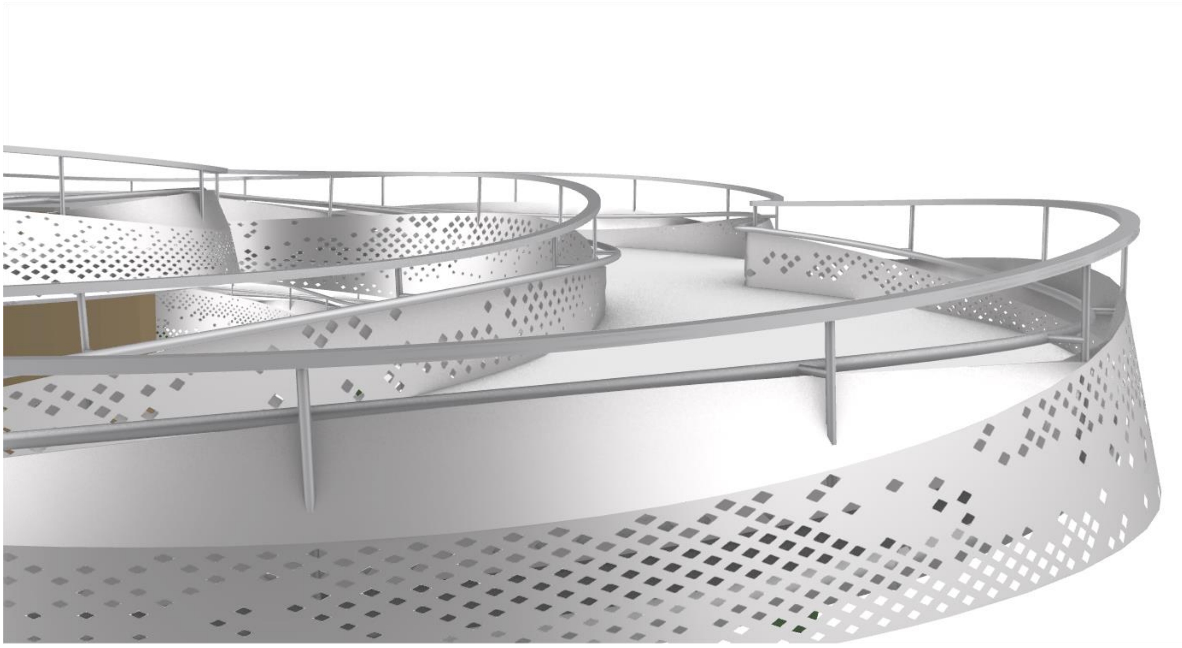

Figure 8. Viewing platform accessories and decoration.

In the RGPM process of the NLS, appendages and decoration refers to elements other than the structural system, which have a direct impact on the visual effect and the use of the NLS. Appendages elements such as benches and handrail determine the safety and practicality of the NLS. As such, they are often subject to their own dimensional specifications and need to be designed on a dimensionally appropriate basis in conjunction with aesthetics. Decorative elements, such as perforated panels, decorative grilles and handrail, are designed with a high degree of aesthetic beauty and precision to match the shaped form of the NLS and to create the character of the structure.

The ‘Flying Goose’ viewing platform has two types of ancillary elements: handrail and seating benches (Figure 8). In order to continue the ‘cloud’ character of the viewing platform in the design language, the handrail at the top of the railing and the low handrail are guaranteed to be 1.1m and 0.6m above the ground level of the ramp and platform respectively, while the handrail at the two heights of the railing are subjected to fluctuation based on a function algorithm. The seating bench is located at the top of the platform. Considering the stability of the seating bench during actual construction, this study sets the seating bench directly above the main beam of the platform, so the seating bench is modelled with the axis of the main beam of the platform as the base line shape.

For the decorative elements of the ‘Flying Goose’ viewing platform, the decorative handrail board was the focus of the design (Figure 8). The handrail board also imitates the 'cloud' form, so the same function algorithm was used to design the form. On top of this, as the inner handrail board meets the ground level of the ramp deck, the overlap needs to be removed; while the outer handrail board needs to be extended below to screen the exposed structural elements, so the lower extension also needs to be morphologically generated based on the function algorithm, thus ensuring that the overall design language is coordinated. Based on the morphological design of the handrail board, and taking into account the night-time illumination effect of the viewing platform, a perforated panel pattern was designed for the inner and outer handrail to imitate the ‘river of stars’.

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2.2.4. Summary

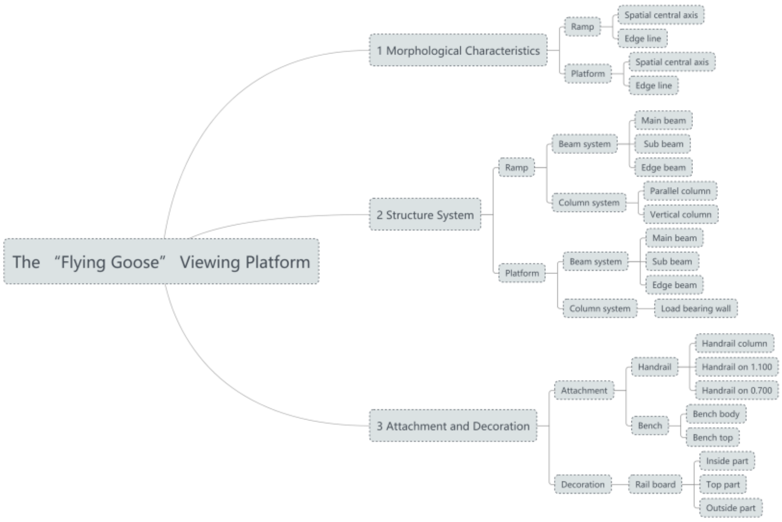

Figure 9. A logical system for modelling from the whole to the detail.

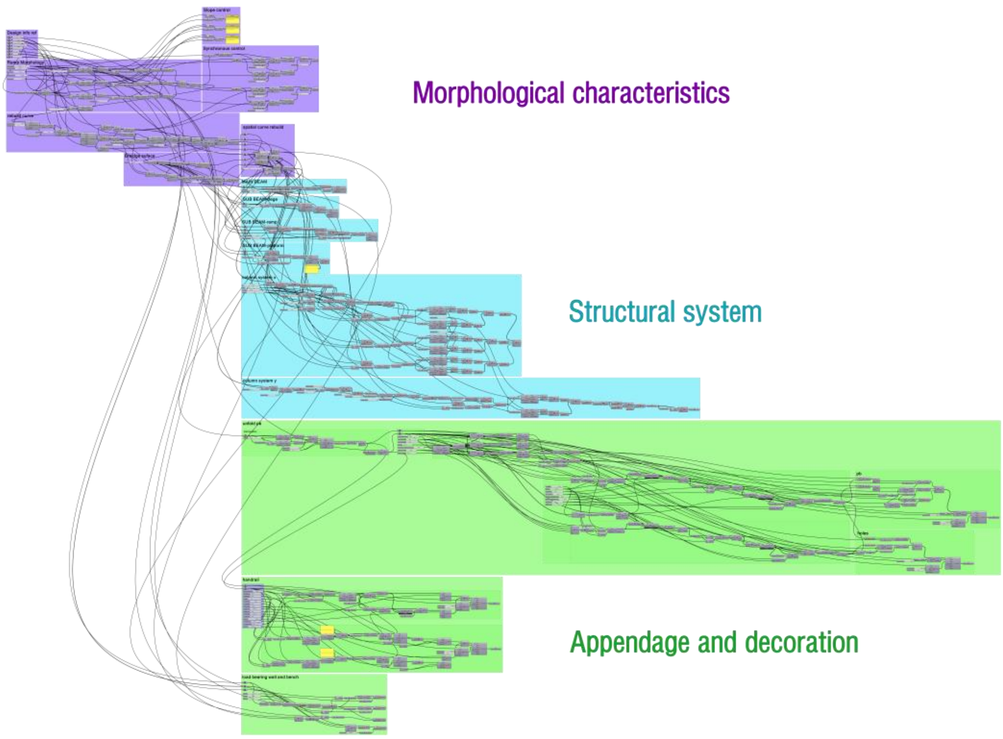

Figure 10. Full view of the Gh file based on the modelling logic written.

In summary, the modelling logic of the 'Flying Goose' viewing platform is based on an overall understanding of the logic of the construction of the building itself, and on the basis of this understanding, a distinction is made between the sequence of the modelling elements, and then the specific geometric component types required for each part of the work. For both the structural and decorative components, it is necessary to clarify the component types and then the specific forms of combined components that each component type contains. This results in a systematic modelling logic from the whole to the local (Figure 9). The Gh file was then prepared based on the above modelling logic to complete the construction of the viewing platform model (Figure 10).

2.3. Application of RGPM precision control method for the viewing platform

Above and beyond the morphological realisation carried out, this study further focuses on the core methods for the accurate control of the RGPM of the 'Flying Goose' viewing platform. It is important to note that these methods need to be combined with other basic methods for the complete construction of the individual components of the viewing platform in the actual modelling process based on the modelling logic described above. This section will therefore continue the three parts of the modelling logic described above, analysing the precision control methods for each part separately.

2.3.1. Precise control of the morphological characteristics of the 'Flying Goose' viewing platform

Name of method: *Unfolding control method* - precise control of dimensions and simultaneous control of spatial forms based on equal length unfolding lines

Reference geometric element: central axis of the ramp plane

Modelling object: ramp space median

Necessity of application: In order to create an upright overall form, the design scheme divides the ramp into three sections, with the third section having the lowest elevation and a moderate slope, the second section being relatively flat, and the first section having the highest slope, thus creating a visual contrast in the building and setting off the overall upright form. At the same time, there is a requirement for a maximum slope limit in the ramp design code, and the form needs to meet both the design code and the aesthetic requirements. A method is therefore needed to show the form of the ramp while controlling its slope precisely.

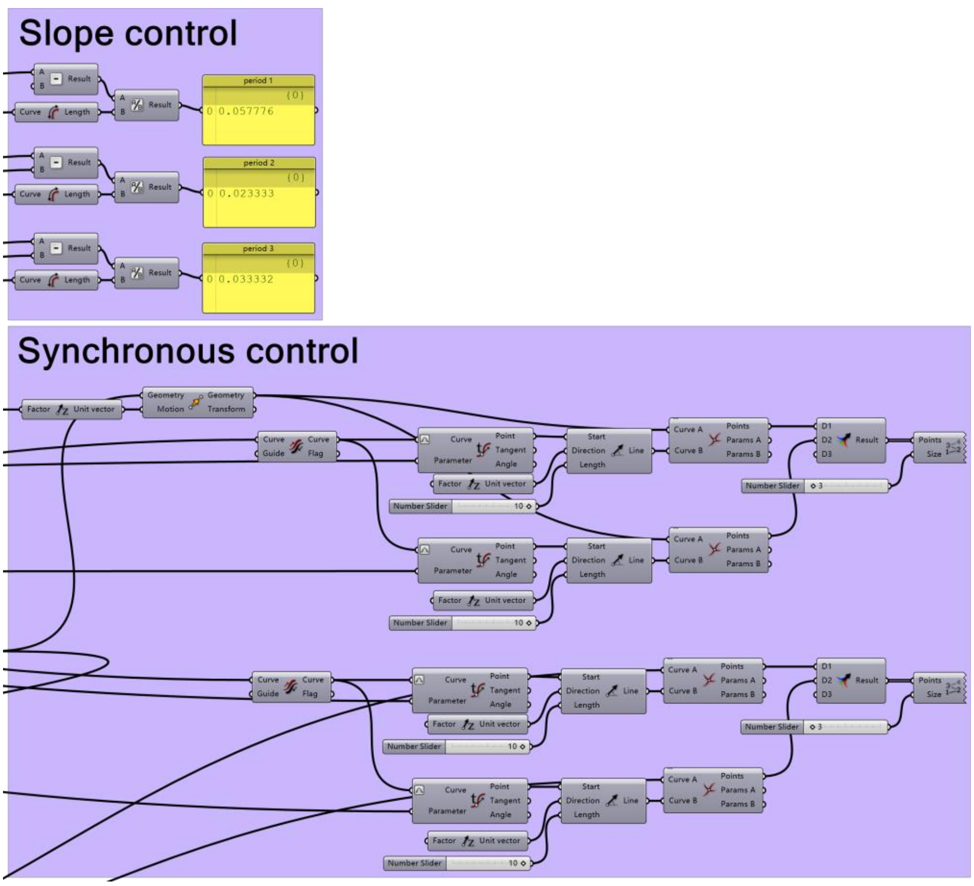

Figure 11. Gh core algorithm for the *'unfolding control method'*.

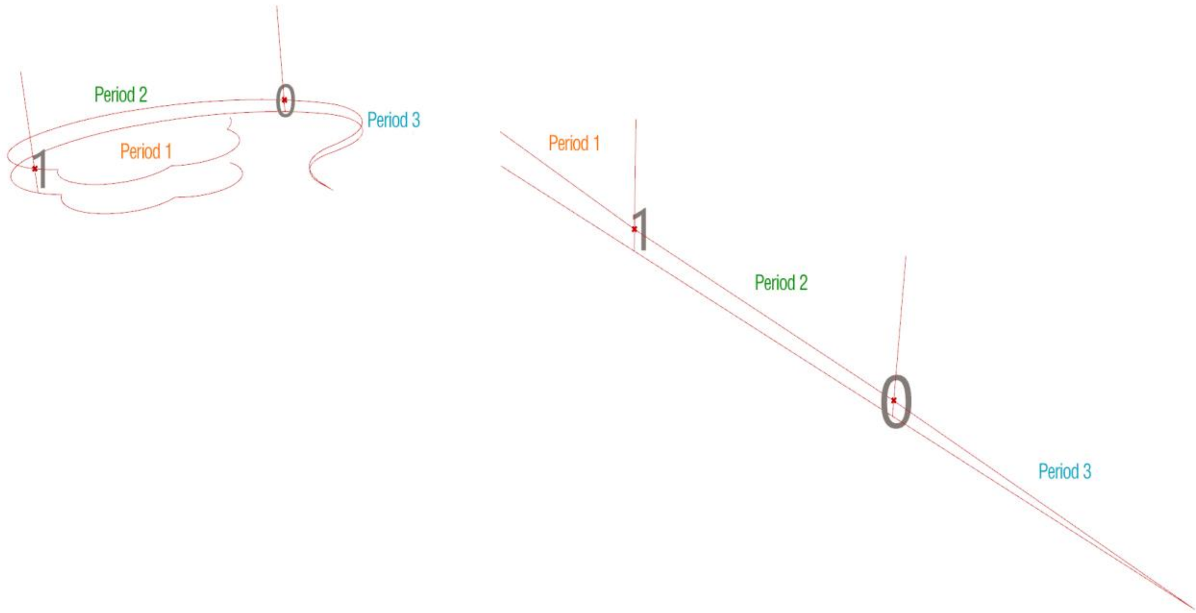

Figure 12. Illustration of the geometry of the *'unfolding control method'*.

Application logic: When using the unfolding control method, the length of the ramp plane curve needs to be extracted first to create a straight line of equal length. The horizontal length of the slope and the end elevation of each section are controlled parametrically to monitor each section of the ramp in real time (Figure 11), thus completing the precise dimensioning of the unfolded ramp form line, and then using the 'flow' battery to produce a spatial curve that conforms to the shape of the plan curve in the scheme, using the equal length straight line as the basis and the plan curve as the target (Figure 12). The spatial curves are then shaped using the 'flow' cell, which is based on a straight line of equal length and a flat curve as the target, thus completing the precise shaping of the ramp form (Figure 12).

2.3.2. Precise control of the structural system of the 'Flying Goose' viewing platform

Name of method: *Equipartition projection method* - Accurate control of structural dimensions based on curve equipartition and control point projection

Reference geometric element: ramp plane axis

Modelling object: beam and column structures for ramps and platforms

Necessity of application: There is an artificially shaped terrain below the 'Flying Goose' viewing platform and the starting point of the branches of the paired variable section support columns must be located on the surface of the terrain according to the design and the opening angle must be adjusted according to the structural calculations and aesthetic requirements. The direction of the secondary beams must be perpendicular to the main beam and the side beams, and the spacing of the secondary beams must be adjusted in accordance with the structural calculations. In addition, the width of the boundary of the viewing platform is variable, each element of the structure has a dimensional difference and the slope is constantly changing, with the ramp not being parallel to the ground. Accurate control methods therefore need to be applied to accurately represent the dimensions of the construction through the model.

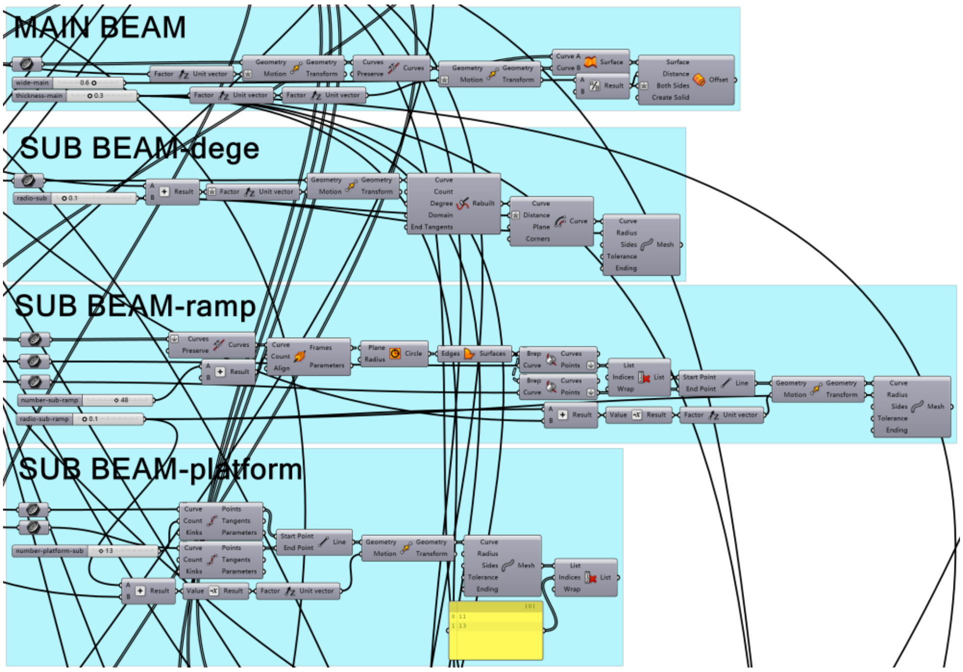

Figure 13. Gh core algorithm for the beam system.

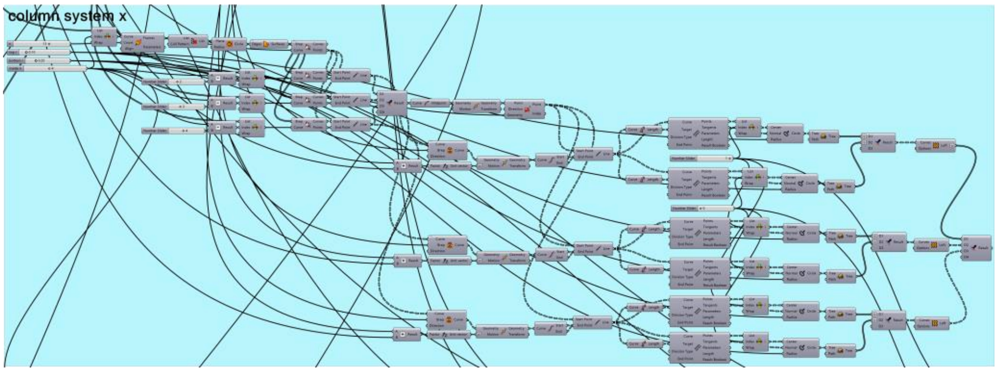

Figure 14. Gh core algorithm for column system.

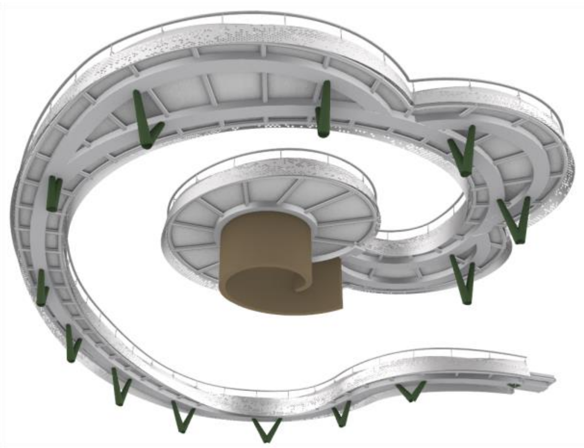

Figure 15. Illustration of the geometry of the *'equipartite projection method'*.

Application logic: The so-called equidistant projection method, for the beam system of the viewing platform, is to carry out a parametrically controlled equidistant division of the central axis of the ramp, on the basis of which a plane perpendicular to the tangential direction of the curve is used to cut the edge line where the side beams are located on both sides, so as to ensure that the secondary beams formed after the corresponding points of the main beam and the side beams are connected are completely perpendicular to the main beam, thus achieving the best force effect (Figure 13). For the column system of the viewing platform, the biggest problem is not only the angle of separation of each pair of columns, but also the precise connection with the natural topography of the undulating ground. Therefore, the 'project' battery was used to connect the two intersections of each pair of columns with the main beam, extract the midpoint and project it onto the surface of the terrain to find out the position of the column points in space on the terrain, and then use this projected point of each group of columns to connect with the two intersections on the beam to complete the construction of the column system (Figure 14). Using the Equipartition projection method, the dimensions of the elements can be controlled on the basis of the freedom to adjust the positions of the structural elements of the beams and columns, resulting in a precise and aesthetically pleasing beam-column structural system (Figure 15).

2.3.3. *Precise control of the appendage and decoration of the 'Flying Goose' viewing platform*

Name of method: *Function shaping and linear interference method* - Accurate control method for subsidiary and decorative forms based on function shaping forms and linear interference algorithms

Reference geometric elements: ramp plane and merging edge of ramp

Modelling objects: handrail and decorative handrail board

Necessity of application: In accordance with the design requirements described in the modelling logic above, the balustrade and decorative balustrade panels of the 'Flying Goose' viewing platform need to mimic the form of the 'clouds' and, above this, the decorative pattern of the balustrade panels needs to mimic the 'river of stars'. This process requires not only a constant adjustment of the form at an aesthetic level, but also precise control of the balustrade and decorative panels in order to provide accurate dimensional data for the actual construction.

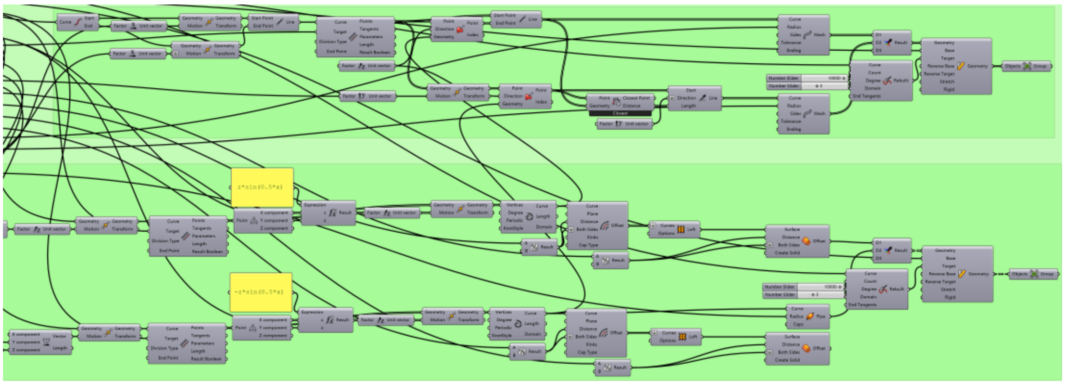

Figure 16. Gh core algorithm for the 'function shaping method' for handrail.

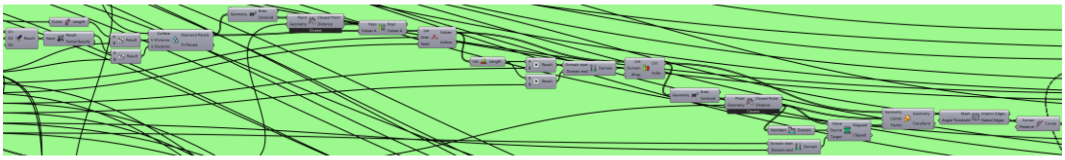

Figure 17. Gh core algorithm for the *'linear interference method'* for perforated handrail board.

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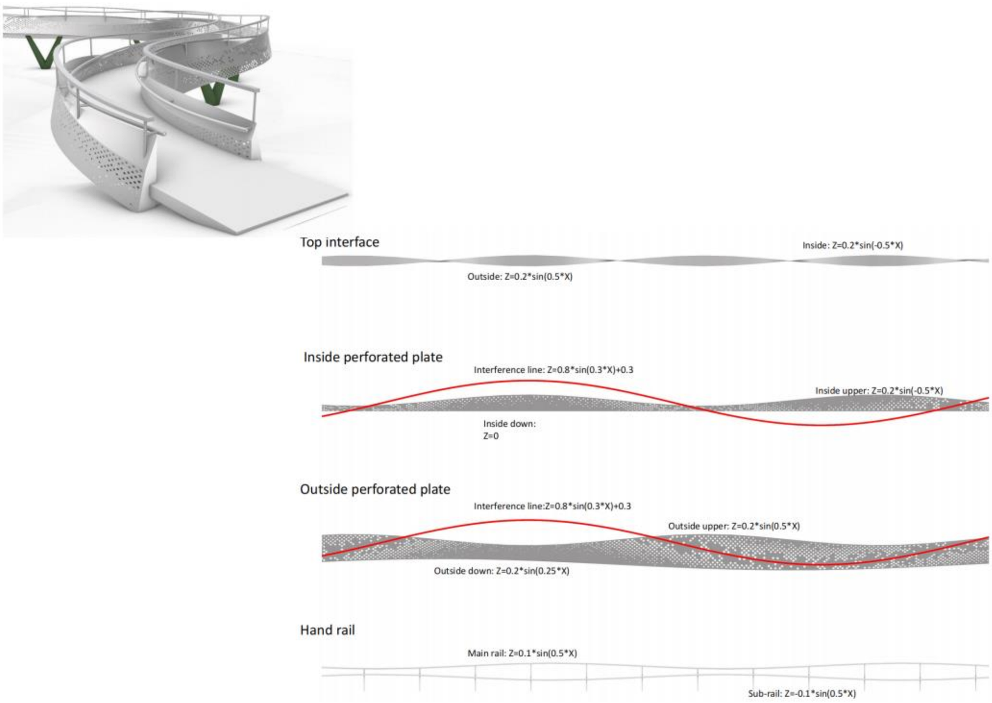

Figure 18. Illustration of the geometry of the *'function shaping and linear interference method'*.

Application logic: The function shaping and linear interference method needs to be carried out on top of the application of the unfolding control method. Firstly, the edges of the ramp as well as the platform are combined to form a spatial curve followed by the production of a straight line of equal length. In the design of the balustrade handrail, the top and bottom of the balustrade are controlled using the trigonometric formula based on the overall height requirements of the design specification, forming a wavy tie, thus echoing the cultural symbol of the 'cloud' in form (Figure 16). In the design of the balustrade stop, the linear interference method was used to precisely control the size and sparsity of the perforation points. The key to the application of the linear interference method is the establishment of a mathematical relationship in terms of the distance from the centre point of each small hole in the perforated panel to the interference line. After extracting the distance from each point to the interference line, the first step is to make a 'close and far' variation. The key to this variation is the ranking of the points according to their distance from the interference line from the largest to the smallest, and then the parameters are adjusted to determine the number of central shops to be retained in this order, thus creating a tight fit. The remaining points after the 'close and far' variation are then subjected to another line of interference and the distances are transformed into a range of values from 0 to 1 and connected to the 'scaling' battery, creating a 'close and far'. As a result, the railings of the flying geese platform form a decorative pattern of 'near dense and far sparse, near large and far small' (Figure 17). In addition, the inner and outer handrail board are shaped using the same function as the handrail, giving the handrail board an artistic aesthetic that is both rhythmic and varied, with precise and feasible component dimensions (Figure 18). This is the finishing touch to the entire 'Flying Goose' viewing platform.

3. Conclusion and perspective

This study uses the 'Flying Goose' viewing platform as a case study to answer and explain the necessity of using RGPM for the design of it, filling the gap of the lack of specific case studies on NLS; The modeling logic is systematically analyzed through the three parts of morphological characteristics, structural system, appendages and decoration, answering and explaining how to systematically perceive the construction logic of NLS and establish the modeling logic, fills the gap in the current lack of systematic understanding of modeling logic; The analysis and discussion of the four core precision control methods used in the RGPM process, namely the unfolding control method, the equipartition projection method, the function shaping method and the linear interference method, answers and explains the core algorithms of the precision control methods used in the RGPM of the viewing platform, and fills the gap in the lack of specific research on RGPM morphological precision control methods. In general, it achieves the objectives of analysing the modelling logic of the NLS in a systematic manner and analysing in detail the precision control methods on top of the NLS morphological realisation, providing a theoretical basis and application examples for future research of the same type.

Based on the results of this research, looking forward to future research on RGPM of NLS: Firstly, more specific case studies can be added to future research on RGPM of NLS, and on this basis, the types of NLS can be further classified, the logic of RGPM of each type of NLS can be compared and analysed, and the inner logic can be summarised to form the basic logic of future modelling. Secondly, for the precise control methods of RGPM, it is not only limited to the four methods listed in this study, but needs to be further summarised in conjunction with more types of NLS cases, and these methods can be comparatively analysed to summarise the inner logic of the precise control methods. Thirdly, for the RGPM of NLS itself, in addition to the analysis of modelling logic, morphological realisation and precision control in conjunction with specific cases, it needs to be perceived from the perspective of BIM workflow. In multi-disciplinary cooperation, RGPM generates a large amount of geometric information, and the management of this information and the optimisation of information in the delivery process become the key to the operational efficiency of BIM workflows, and are worthy of in-depth study.

Note: All Figures in this study are created by the author.

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