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On the Application of Vector-Based Graphic Statics (VGS) for Structural Timber Optimisation – Pavilion Example

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Abstract. Over the last two decades, various contributions have shown how the use of graphic statics made it possible to design remarkable engineering structures. Vector-based Graphic Statics (VGS) has been presented elsewhere extensively as a method and plug-in for Grasshopper. This contribution shows an application to the design of a timber pavilion based on Graphic statics and its benefits for the use of materials.

Keywords: Timber Construction · Structural Design · Digital fabrication · Parametric Design · 3D Graphic statics

1 Purposes of Graphic Statics

Abstract. Graphic Statics (VGS) is already known as a designer approach for structural design leading to outstanding results. Graphic statics was originally an analysis tool, and this first section recaps its main historical purpose and uses.

Historically, graphic statics was developed for the purpose of analysing structures. Its principle is to represent the full system of internal and external forces as a set of vectors characterised by directions and magnitudes of forces. Every operation in terms of combination or calculation is managed in a geometrical and graphical environment unified with the geometric definition of the structure itself (Fig. 1).

Its graphical approach enabled the mastery of geometrically complex problems and extremely efficient calculation methods compared with algebraic approaches, which were practically the only alternative available at that time. Graphic statics allowed extremely efficient analysis of isostatic trusses and beams. Because it is necessary to close the polygons of forces that translate the translation equilibrium, the graphical approach makes it possible to check that the graphical calculation has been carried out correctly. Although it is easy in this framework to calculate deformations in trusses, the analysis was most often limited to establishing the equilibrium of forces and their respective magnitudes. For these applications, the disadvantage was that the accuracy of the calculation depended on the scale of the technical drawing used for the analysis and

H. Chai et al. (Eds.): CDRF 2024, *Symbiotic Intelligence*, pp. 164–179, 2025.
https://doi.org/10.1007/978-981-96-3433-0_15

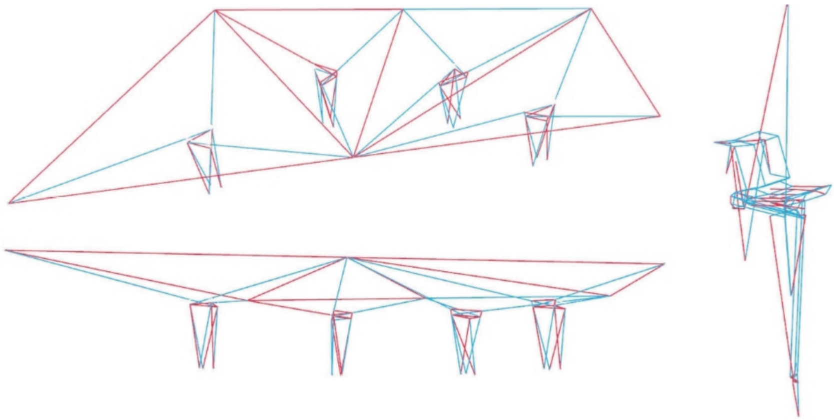

Fig. 1. 3D vector-based graphic statics: 3D form polygon F (on the left) and the magnitudes of the forces with 3D force polygon F* (on the right)

the accuracy of the drawing itself. In order to solve hyperstatic problems, it is necessary to consider the deformations of the various parts of the structure and their respective compatibilities. For these, with Graphic statics, the developments initiated by Mohr (1868) lead to a complete approach generalised by Suter (1932) and will be developed at least until the beginning of the 1940s (Han and Zastavni 2024), being progressively supplanted by the moment distributions method (Cross 1943) which proposes a more direct algebraic method. Nevertheless, the complexity of analysing statically indeterminate structures remained a challenge until the dissemination of numerical analysis tools in the 1970s, and Graphic statics was no exception. Nowadays the use of a CAD system removes the limitations due to the precision of the drawing and its scale. Combined with matrix analysis, the barrier of hyperstatic structures can be overcome for their analysis.

Combined with the lower bound theorem of the theory of plasticity (the "design theorem"), graphic statics can also be used to deal with the structural behaviour of continuous structures such as concrete walls or folded structures using materials that allow forces redistributions. The success of this approach depends on the use of strut-and-tie modelling (STM), taking advantage of the plastic redistribution capabilities of such materials. The same STM approach has been applicable, since its emergence (Mörsch 1908), to continuous type connections in concrete structures for which the method was engineered (Schlaich Jorg 1982). Recent work introduced how this same STM approach is also applicable to materials with limited redistribution capacities, such as timber, which has fragile tensile strength (Jasienski et al. 2024).

2 Graphic Statics for Structural Design

Abstract. This section presents historical and contemporary uses of graphic statics for design purposes in structural design.

A clear distinction must be made between structural analysis and structural design: in the first case, the geometry of the structure is given, in the second case, it must be defined. Because it offers a graphical representation of both form and forces, graphic statics prove a very powerful tool for structural design as well. Indeed, the history of structures provides us some examples where its use is encountered in the field of structural design, resulting in structure that are remarkable both for their efficiency and their aesthetic qualities. Examples by the likes of Swiss engineer Robert Maillart: Chiasso Shed (Zastavni 2008), Salginatobel Bridge (Fivet and Zastavni 2012), Vessy Bridge (Zastavni et al. 2014), but also in Maurice Koechlin's graphic design of the Eiffel iron tower (Fivet et al. 2015), Antoni Gaudi's work for the Catalan Park Güell (Gaudi-Groep Delft 1979) and Guastavino's Vaulting (Oschendorf 2010).

The last two decades have seen the emergence of significant structures designed with Graphic statics in a contemporary context and using modern tools. Some of remarkable examples are Conzett's Traversinersteg II (Mostafavi et al. 2006), SOM's Roof truss for a convention centre (Beghini et al. 2014), the Armadillo vault in Venice (Mele et al. 2016).

More recently, academic works showed how computer aided graphic statics can support structural design. Comprehensive research has been conducted to extend graphic statics to the third dimension, the two main approaches being the Polyhedron-based (Bolhassani et al. 2018; Konstantatou et al. 2018; Lee et al. 2018) and the Vector-based (D'Acunto et al. 2019; Jasienski et al. 2024).

The Vector-based 3D Graphic Statics (VGS) is a framework where the forces are represented by vectors which length corresponds to the force magnitude. It provides direct interactive feedback on forces' magnitudes and orientation and enables the design of reticular-type structures to be approached in a dynamic and interactive environment (D'Acunto et al. 2019; Jasienski et al. 2024; Rasneur et al. 2024) (Fig. 2).

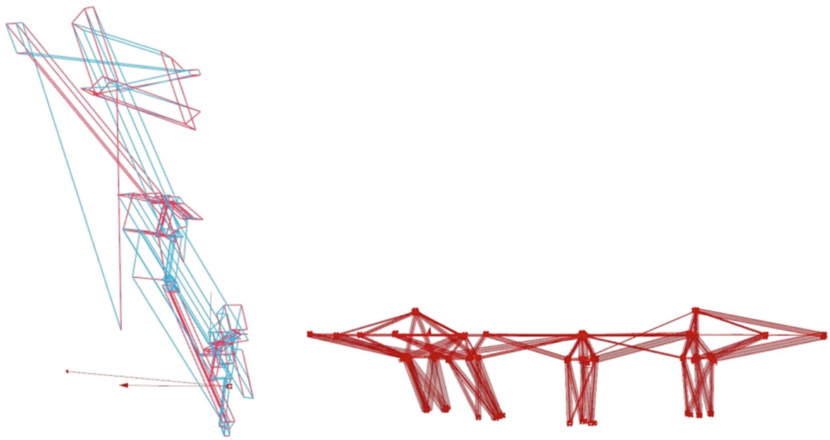

Fig. 2. 3d force diagram F* with wind and earthquake vectors (left) and the corresponding dimensioning including buckling forces (right): the consequences of longer forces segments in F* on parallel columns are particularly obvious

In most cases, architectural and structural design involves considering a vast array of requirements. These may be technical (strength, connections, available sections, constructability), spatial (useful heights, maximum overall dimensions, location of joints and interfaces) or architectural (volumetric and lighting qualities, aesthetic qualities). These are so numerous that only the designer's experience can integrate and order them properly. So, the real challenge is not the implementation of computational design protocols, but the development of environments where force-geometry interaction is efficient, visually understandable and practical for the designer. Beyond automatic structural optimization in the framework of computational design, this paper shows how the VGS plugin of Grasshopper (McNeel 2024) can be used for interactive structural design. The case study of the Guhua pavillion reveals strengths and weaknesses of this approach. It shows how this approach can support the optimization of structural behaviour and shows revision directions that architects or engineers can follow in a brain-driven optimised design process. This process showed significant structural improvements at each stage of its development.

3 The Structural Stakes of a Pavilion Design

Abstract. This section details the design objectives followed for the designs successively developed in Sect. 4 for a timber pavilion in the VGS framework.

Using the example of a 24 m × 14 m pavilion initially designed as a reciprocal-like system supported on a reduced number of 4 central supports, the article shows how VGS can be implemented to support the design of the structure and its main benefits. The case study is a pavilion submitted to our team in the framework of a National Key Research and Development Program of China (grant number:2022YFE0141400).

3.1 Efficiency Objectives for Structural Design

Structural design is a far more complex exercise than structural analysis and dimensioning. Design codes, for their part, are essentially geared towards the verification of structural elements. The verification stage alone is much simpler since it is straightforward: it avoids the phenomena of interdependence of the parameters that must be used for dimensioning. Dimensioning, even without questioning the geometry, involves these interdependencies of parameters. Structural corrections involve the geometry and reach an even higher degree of complexity. The design exercise itself combines the above with an even wider range of parameters.

Many parameters are involved in the design of structures, some of them contradictory in nature (Fig. 3).

For trusses, the following criteria could be considered for an optimization works on the geometry (typology) of trussed beams: the total amount of material used; the number of nodes; the number of bars per assembly node; the length of compressed bars (in relation with buckling issues); the magnitude of forces (which is influenced by the geometry); aim for constant force geometries (for rationalization); to rationalize topology, e.g., for constant and minimal sections; having same angles everywhere between bars to rationalize connections; meaning of combining several materials according to their intrinsic

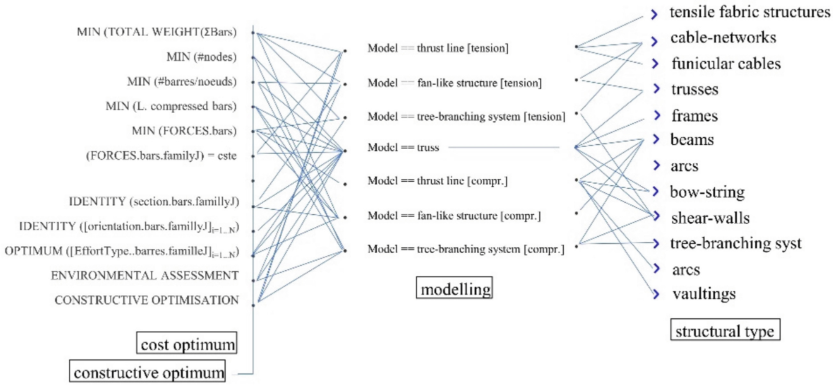

Fig. 3. A selection of design optimisation goals for bars or STM structural models

properties; rigid VS hinged connections; embedded or hinged supports; hyperstatic or isostatic systems; aim to foster specific structural working, etc. The designer is required to order and weight each of these parameters to obtain a "best" solution, that is always relative. Pareto Optimality is mentioned in this context as a criterion for the best option.

3.2 Pareto Optimality and the Design Parameters

The essence of the Pareto optimum is to aim for a state of "best" solution for multiple parameters. The term Pareto-optimality originates from his work on the distribution of resources with limited availability and conflicting goals (Pareto 1906; Pareto 1978). In the context of optimization, it can be formulated that a Pareto optimal solution cannot be improved for one goal without degrading another. Therefore, there is not one best solution, but many trade-offs between the extremes (Vierlinger 2022).

Pareto is today primarily attributed with the so-called 80–20-rule, after which 80% of the results can be achieved with 20% of the effort. This is the philosophy that had prevailed for this design exercise. Since the detailed geometry of the structure is the final goal, the forces acting on it are essential parameters along with geometrical parameters. Forces are at the heart of the challenge of the complete dimensioning of the structure. In this respect, the Graphic statics environment is perfectly suited to the task for revealing respective forces' magnitudes.

In the following structural implementation, the cross-sections will be considered square since the structural working in tension/compression only will be targeted and fostered for its efficiency. The main parameters are defined as follows: The material is glued laminated timber TCT28. Horizontal loading on the roof is 3 kN/m^2 including deadload and live load; wind force is 0,5 kN/m^2, earthquake forces are between 0.09 and 0.14 g: snow load will be considered as negligible with 0.3kN/m2 in Shanghai compared to vertical loading on the roof. This is an open structure composed of between 51 and 89 bars depending on the version of the design. A minimal dimension of structural members will be kept at 150 mm width, and their section will be considered constant along bars. For the most complex example, LVL and CLT will be considered as alternative to GLT.

4 The Assessment of the Guhua Pavilion in the VGS Framework

Abstract. This section details the elaboration of revised designs for a timber pavilion and presents the designs successively developed in the VGS framework with their main benefits for material saving on constructability.

4.1 Model 01 = Start Structure: "Full Reciprocal" Design

Assessment starts on a preliminary project defining the structure of the roof as such: 4 supports, each consisting of three bars, each carrying two bars which form the primary part of the roof structure itself (Fig. 4). These bars form the bisectors of slightly inclined triangular surfaces that are encountered four times, i.e. a triangle centered on each of the supports. Since the columns each carry two intersecting bars, the principle is like reciprocal structures, although not entirely so. To ensure that the structure behaves correctly overall, the bars must be rigidly connected to the supporting columns. The bars of the main structure are subjected to significant bending forces at the point where they are connected to the heads of the columns. If the triangles they support do not form closed frames capable of withstanding significant tensile forces, the main beams operate exclusively in bending. This also means that the connections must resist bending moments and must be designed accordingly.

In addition, due to the geometric complexity of the structure and its asymmetry, several joints and bars are warped (torsion, vertical and horizontal bending) and their behaviour leads to complex arrangements of joints between elements, and oversizing columns and bars.

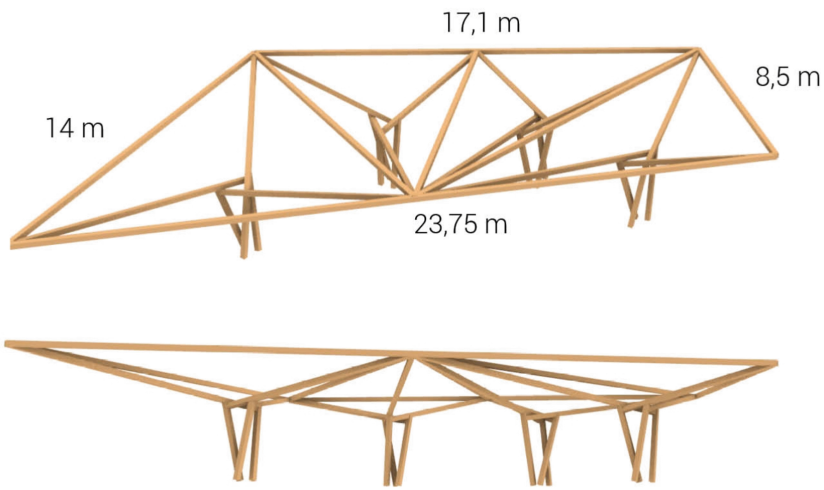

Fig. 4. Perspective view from top with general dimensions and perspective view from below of the pavilion (model 01)

Because of the importance of the bending forces, the width of the members including buckling and composed 2-axis bending, will be between 320 mm and 710 mm; the total volume of glulam timber is 18.2 m^3. The assessment was made using FEM analysis and custom dimensioning according to EC5 (Cen 2014), as summarised below:

Max.bending My/Mz/Mt (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
746,1/238/73,58	672,38	-713,11	0,15	0,63	14,73	103756,89	17,8

4.2 Model 02 = "Full Reciprocal" Design Including Upper Tension Ring

With the aim of favouring traction or compression forces for the structural working (so that the entire cross-section works at maximum stress, unlike bending), a peripherical tension ring is considered by connecting firmly the ends of all the upper beams. Enhancing the structural behaviour in that way, main roof elements develop compression forces alongside with bending forces although these are reduced. Maximum sections drop to between 150 and 370 mm and timber volume reduces by 9%. *Load path* magnitude (defined as adding the product of bar lengths and their forces magnitude) raises considerably since bending is not included in its calculation.

Max.bending My/Mz/Mt (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
103,3/113,9/39,2	359,49	-569,63	0,16	0,48	14,73	161671	16,43

Doubling the three bars making up each of the four support devices to give them a V-shaped design helps cancelling any negative effects linked to the asymmetry of the system. This strategy enables to cancel bending forces, which simplifies connections and enable contact joints. This has significant consequences in terms of magnitude of force, despite a limited impact on sections, working from now at 100% of their thickness. Next model will also go a step further in cancelling forces at the upper zone of support devices.

4.3 Model 03 = "Reciprocal System" with Stabilised Supports: Including Upper Tension Ring

Model 3 defines connexions as hinges to have traction and compression forces only while cancelling bending forces. Without additional modification, this destabilises the system. Therefore, additional members were added to the system (Fig. 5).

- two layers of structural rings at the head of tripod systems, respectively in compression and tension going downwards,
- maintaining a V-shape design of the element constituting the tripod systems of support
- bracing free nodes of bars and rings converging at the head of support systems.

At this stage of development, the analysis can be transferred to the Vector-based Graphic Statics [VGS] tool, which allows forces to be visualised in the form of 3D force polygons, enabling the absolute and relative magnitude of forces in the structural members to be assessed. For this, several points must be addressed. First, VGS is composed of a series of modules with various purposes. The "Evaluate Equilibrium" module relies on an algebraic calculation (equilibrium matrix) and so requires the structure to be stable to deliver results. In the process of hinging all connections, a careful attention must

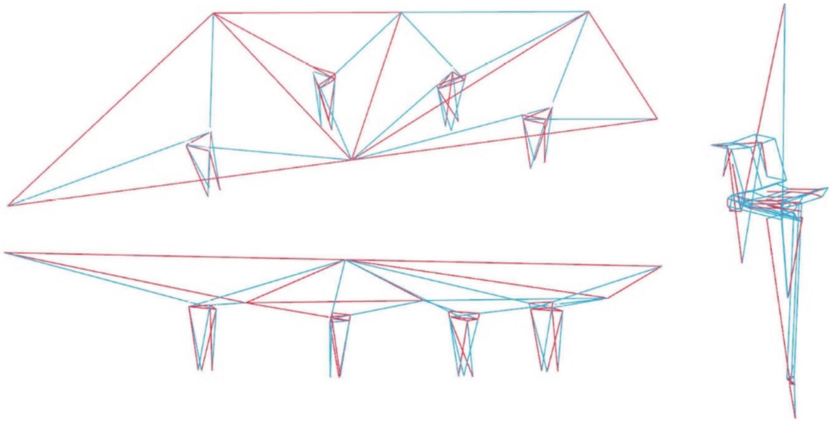

Fig. 5. Form diagram (left above and below) and forces diagram (right) of the pavilion (model 03) with members in compression (blue) and in tension (red)

be given to implement supplementary bars to guarantee equilibrium and the “Evaluate Equilibrium” module helps for this by providing direct feedback.

Second, the stable version of our hinged structure when symmetry is maintained in support tripods has an indeterminacy level of 3. This information is delivered again by the “Evaluate Equilibrium” module. For the indeterminacy to be solved, without deformation assessment as in classical FEM approaches, the user needs to implement *self-stresses*. A *self-stress* is tensioning (or compression) a bar, the effects of which will propagate throughout a structural (sub) system, like tensioning a tensegrity module for example. By extension, since the VGS environment is resolutely design-oriented, with connexions to the framework of plastic design, the approach is to impose the magnitude of several member forces which after allows to dimension the structure accordingly and overpass an indeterminacy for instance. To optimise the structural dimensioning, the minimal solution must be targeted. For this, an optimisation process has been carried out to define the magnitude of respective *self-stresses*. The volume of timber, with or without minimal dimension or buckling consideration, or using *load path*, or minimising the largest forces can be used as the main goal for the optimisation. *Load Path* is of interest as an indicator in the rest of the study and is frequently used in the framework of graphic statics. Another goal is particularly meaningful for the optimisation process: the compactness of the Force Polygon, provided as visual feedback of VGS. The force polygon quickly shows which forces are dominant and to which bars they correspond, which will guide the rest of the design process. In our case, the major forces are found in the support system.

Applied to model 3, some forces raise locally in the structure, but maximum sections drop to between 150 and 470 mm and timber volume reduces by 32%. *Load path* magnitude drops of 36%.

Max.bending (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
	2461,85	-2581,55	0,15	0,44	14,73	102630,88	11,11

Furthermore, the deployment of one *self-stress* as the only force in the model highlights the level of propagation of a force in the structure. This turns out that propagation is particularly important in the case of a principle of structural reciprocity, that does not go in the direction of structural safety and robustness. Also, the weak point of that model is high forces to transmit between bars forming steep angles so that joints become problematic, what drive us to review the design.

4.4 Model 04 = Folded Model with V-Shape Folded Columns (Basic)

Model 4 implement larger supports arrangements and folding plate for designing structural elements. Support devices are braced and are supposed to represent two CLT plate connected as a V in plan. Currently, their orientation and inclination are random and could be analysed by an optimisation process. This stage also allows the use of CLT panels for the rest of the structure as an alternative to glued laminated timber. For the sake of consistency, each element will however continue to be modelled as a STM system consisting of bars. This mainly reduces max. forces (Fig. 6):

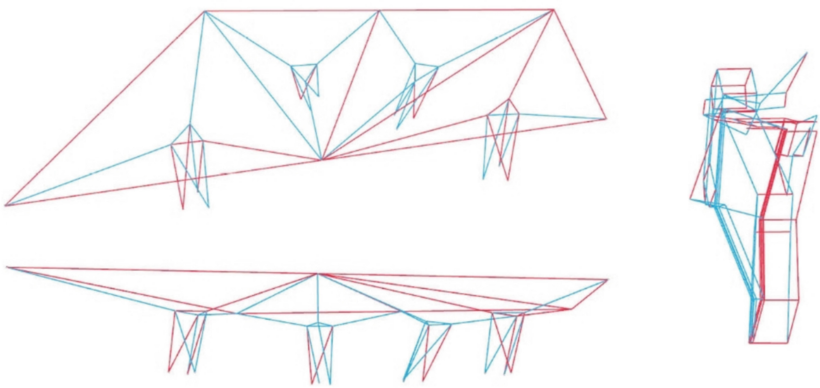

Fig. 6. Form diagram (left above and below) and forces diagram (right) of the pavilion (model 04) with members in compression (blue) and in tension (red)

Max.bending (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
	1481,83	-1292,48	0,15	0,34	14,73	100385,49	10,42

By examining the polygon of force, it is possible to try out a simple operation consisting of doubling the thickness of the roof, from 1 m to 2 m. This corrects the current weak point in the structure with a very low volume of material (−25.6%):

Max.bending My/ Mz/Mt (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
	876,92	-794,53	0,15	0,27	14,73	52997	7,75

4.5 Model 05 = Stared Folded Model with V-Shape Folded Columns (Basic + Flat Upper Side)

The thickening the roof system investigated above as a variant on model 4 radically changes the appearance of the structure and will not be retained for this reason, despite its effectiveness. However, a more secure approach involving tessellation of the areas with the greatest cantilevers has been devised in model 5. In this case, the main features of the structure are the following (Fig. 7):

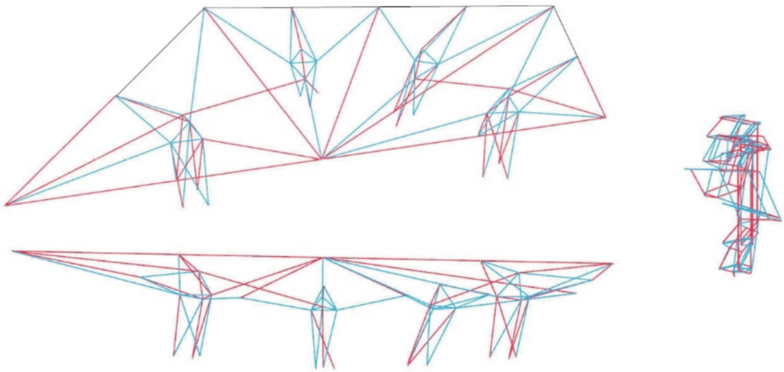

Fig. 7. Form diagram (left above and below) and forces diagram (right) of the pavilion (model 05) with members in compression (blue) and in tension (red)

Max.bending (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
	1333,32	-1778,16	0,15	0,33	14,73	102687,31	11,94

4.6 Stared Foldel Model with V-Shape Folded Columns (Basic+ Raised Top Support)

Finally, to address the problem of steep angles in joints, a last improvement is implemented by raising the converging connection points above columns. With this, a new improvement is reached with the following magnitudes (Fig. 8):

Max.bending My/ Mz/Mt (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
	1290,77	-1601,77	0,15	0,32	14,73	83739	10,77

Another optimisation goal can be used to minimise compression force involving buckling. This has a cost of +8% volume, but lowers this Min.force by two:

Max.bending My/ Mz/Mt (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
	816,08	-772,79	0,15	0,32	14,73	101175	11,71

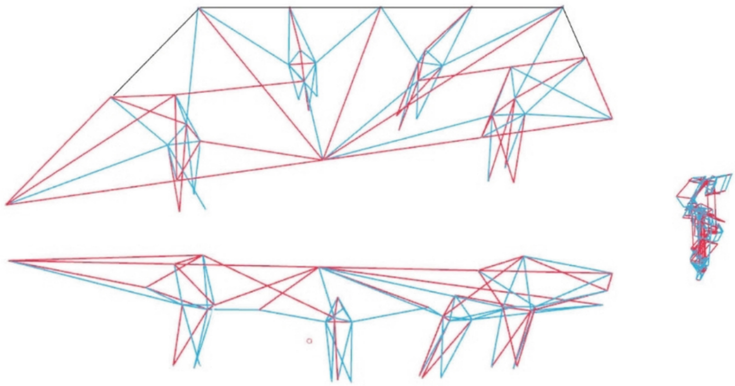

Fig. 8. Form diagram (left above and below) and forces diagram (right) of the pavilion (stared folded model) with members in compression (blue) and in tension (red)

The same structure opens to another way to redistribute forces on the roof, involving loading more intensively directly above the support tripods. Therefore, we see the magnitude of forces reduce again, as *Load path* and volume of timber. With this modelling, volume is lower of 23% and *Load path* divide by 3:

Max.bending (kN.m)	Max.traction (kN)	Min.compression (kN)	Min.sec. width (m)	Max.sec. width (m)	Max.sec. length (m)	Load Path (kN.m)	Volume (m3)
	369,74	-438,10	0,15	0,23	14,73	28812,02	8,23

With this model, we have reached the limit of what can be achieved in terms of dimensioning gains. We are also faced with the limit of the minimum cross-sectional dimension for a proper joinery. Would we consider a minimum width reduced from 150 mm to 125 mm, that a saving on timber volume of 23% is again possible.

4.7 Wind Force, Earthquake, Snow Loads and Final Comparison

The analysis is based on a set of 7 models assessed through 20 simulations. The full analysis included several loading cases presented under §3.2. Since earthquake and wind forces are directionally applied, analyses showed that worse case is the occurrence of their simultaneous horizontal orientation. Nevertheless, wind force and earthquake are acting in opposite vertical directions. In the numbers, wind forces partially cancel the effects of gravity and the worst case for the structure remained vertical loads only, despite horizontal loading (Fig. 9).

Fig. 9. Axonometric front view of the pavilion (stared folded model) with faces

When comparing the versions of design model 6 (without redistributing forces), a consequent saving of 40.2% of timber volume is reached in comparison to model 1 (34.4% compared to model 2 having a ring effect around the roof and that should serve as a reference), even if the number of bars is practically doubled. The maximum section width can be divided by 3 with the great advantage of normalising sections for the benefits of joinery.

The evolution of the structural design under the guidance of VGS from first to latest models without bending showed that forces magnitudes can be reduced from enhancing the geometry of the structure. Final improvements on the structural efficiency could still include considering repositioning device supports, optimising their width, number, inclination and orientations. But these were not considered for this study.

5 Conclusion and Discussion

The initial analysis of the pavilion under study revealed the impact of asymmetry and bending mechanisms on its structural efficiency. Subsequently, we employed VGS as a suitable tool to revamp the pavilion as a sophisticated reticular system. This resulted in significant material savings ranging from 34 to 40%. Additionally, VGS has the advantage to reveal the structural parts that are most impacted by loadings and to guide the designer for his fundamental conceptual revisions. With the help of VGS, structural adjustments and load redistributions led to final reductions of up to 54,2% in volume and 72% in *load path*. A synthetic overview of these adjustment is proposed in a table in Appendix.

Throughout this design process, the VGS add-on for grasshopper demonstrated its full potential to drive structural improvements by providing outputs that highlight structural weak points in a user-controlled design process. Graphic statics' force polygon makes it possible to quickly identify and locate the highest force magnitudes, while also characterizing them from a geometrical point of view. Following the Pareto principle, VGS visual feedback based on the compactness of the forces diagram enables their distribution in a hyperstatic system to be optimized to within 15%. With feedback on volume, this brain-driven approach enables the optimal solution to be found to within 5% in a few minutes, as opposed to several hours with genetic optimizations.

VGS is user-oriented, fostering an interactive design process. Conversely algorithm-driven or computer-driven procedure carried at their conclusion present optimized structures such as very high Mitchell trusses, which are of very limited use in real-life situations.

For the pavilion, LVL (Laminated Veneer Lumber) and folded plate system (such as CLT, Cross-Laminated Timber) were considered. Alongside the environmental cost of LVL, this material did not lead to significant saving due to limitations linked to a minimal thickness of members for proper joinery. CLT addressed bucking issues (enabling a significant reduction of utile structural volume depending of the initial structural working) but necessitated fundamental revisions to connections. Nevertheless, the efficient timber structural core without buckling saw an additional 48% reduction compared to buckled members, even if volume comparisons become meaningless without considering the entire material volume, including the whole roof composition.

Moreover, beyond providing results of structural analysis and feedback, VGS also informed the designer of the state where an equilibrium stage was reached, in case of reviewing structural principles with systematic hinging. Implementing structural robustness through structural redundancy also impacts the number of *self-stresses* and too many of them really complexify the design with VGS.

Indeed, in the case of *self-stresses*, the first challenge is to be able to identify a number of independent *self-stresses* equal to the number of unknowns in the hyperstatic structural system. The task becomes more complex as the number of *self-stresses* increases. Then comes the question of evaluating their respective magnitudes, including in this the difficulty caused by their reciprocal interaction on the overall structural system represented by the polygon of forces. If the process is computer-driven, the optimisation times required can become hard to manage. At each stage, therefore, the designer's experience and common sense will be called upon and will guarantee the success of their definition.

In the design as presented above, computer-driven optimization could have been implemented also with the VGS-Transformation module, an interactive optimization process with several goals possible.

As a final conclusion, it should be noted that the final design has yet to reach its completion. Minimal dimensions (here 150 × 150 mm) and connection angles between bars were necessary to ensure proper force transmission, though these were considered in the designer's choices. The approach we followed eventually provided an interactively dimensioned structure, with different conclusions depending on whether the structure is thought of as a system of assembled bars, or as a folded system made up of CLT elements. Nevertheless, this contribution demonstrates the strong capabilities of the VGS-tool for designing, understanding and managing a structural system while the designer remains in control of the design process, and hence is able to develop enlightened design solutions.

Appendix

See Fig. 10.

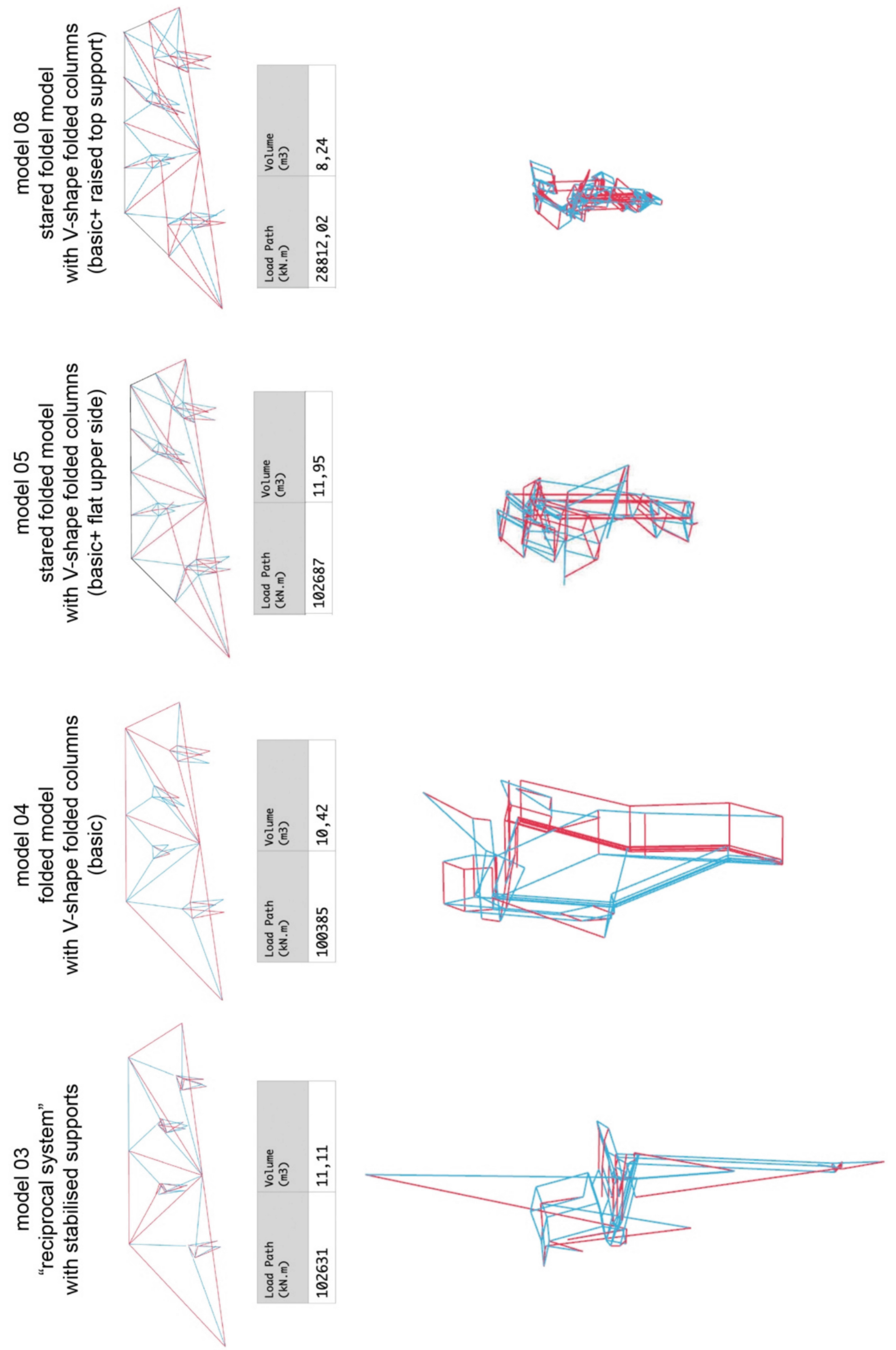

Fig. 10. Step by step view of the evolution of the Guhua Pavilion in the VGS framework.) Each model is identified by its structure, followed from top to bottom by the form diagram, the cumulative values of load path and volume and the force diagram.

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Computational Design and Robotic Fabrication

Hua Chai
Ding Wen Nic Bao
Zhe Guo
Philip F. Yuan *Editors*

Symbiotic Intelligence

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Hua Chai · Ding Wen Nic Bao · Zhe Guo ·
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ISSN 2731-9040 ISSN 2731-9059 (electronic)
Computational Design and Robotic Fabrication
ISBN 978-981-96-3432-3 ISBN 978-981-96-3433-0 (eBook)
https://doi.org/10.1007/978-981-96-3433-0

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

In 1960, American psychologist and computer scientist Joseph C. R. Licklider proposed the concept of "Man-Computer Symbiosis," creatively likening the mutual benefit seen in ecological systems between different species to the emerging relationship between humans and computers. Today, with advancements in technology reaching unprecedented levels of intelligence and autonomy, there is a renewed emphasis on establishing a positive and harmonious symbiotic relationship between humans and technology.

Dutch philosopher Peter-Paul Verbeek argues that the relationship between humans and technology can no longer be simply summarized by traditional mediated intentionality, where technology serves as a tool between humans and the world. The relationship between humans and machines is gradually manifesting diverse and complex attributes, notably hybrid intentionality and composite intentionality. In the field of architecture, the "hybrid" and "composite" of the designer and technological intentionality are reshaping the production paradigm and knowledge landscape of the discipline. The development of technologies such as machine learning, collaborative robots, and brain–computer interfaces is significantly enhancing the role of human–machine interaction in architectural design and production decision-making. At the same time, the unprecedented creativity demonstrated by artificial intelligence continually challenges and impacts the unique position and creative abilities of architects. Against the backdrop of increasingly prominent global challenges, the relationship between architects and technologies needs to evolve into a more intricate and mutually interdependent symbiotic state, collectively providing innovative solutions to issues including climate change, pandemic propagation, and resource and environmental crises.

As the architectural domain transitions into a new epoch characterized by the flourishing development of intelligent and autonomous technologies, architectural studies need to rethink and redefine the symbiotic patterns between human and technology. As the theme of CDRF 2024, "Symbiotic Intelligence" aims to promote global exchange and reflection on the transformation of architectural paradigms under the influence of intelligent technologies. This conference encourages the actively exploration of the rich possibilities of symbiotic intelligence in the field of architecture, collectively driving innovation and development in the architectural discipline.

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H. Chai et al. (Eds.): CDRF 2024, *Symbiotic Intelligence*, pp. 549–551, 2025.
https://doi.org/10.1007/978-981-96-3433-0