Blucher Design Proceedings

Última edição Todas as edições Expediente ISSN: 2318-6968

Junho 2024 vol. 12 num. 3 - XXVII International Conference of the Ibero-American Society of Digital Graphics

Full Article - Open Access. Idioma principal | Segundo idioma

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Full Article:

The process of planning and developing curvilinear structures remains challenging. Multiple applications with various design principles are unlikely to fade away. The interoperability employed here was not the standard kind. It was also 'live, 'real-time,' with two of the applications involved open and running at the same time. A design workflow based on the use of form-forming software associated to building information modeling, BIM, was presented. The main objective was to offer simpler ways to design and create curvilinear designs and their supporting structures utilizing two distinct types of applications simultaneously. This study offered a design process incorporating 3D modeling in a graphical interface (Rhinoceros/ArchiCAD) with visual programming-based design (Grasshopper). This clarifies the rules and permits for control over form-generating principles. The objective of this research was determining steel structures dimensions utilizing visual programming and compatibility amongst BIM systems. The outcomes are a set of algorithms for dimensioning specific structures.

Palavras-chave: Parametric programming, NURBS, Dimensioning, Structures, BIM,

DOI: 10.5151/sigradi2023-351

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Como citar:

Silva, Lilian; Buzar, Márcio; Lacroix, Igor; "Dimensioning Steel Structures with Algorithmic-Parametric-Modeling & BIM at Early Stages of Design Process.", p. 338-349 . In: . São Paulo: Blucher, 2024.
ISSN 2318-6968, DOI 10.5151/sigradi2023-351

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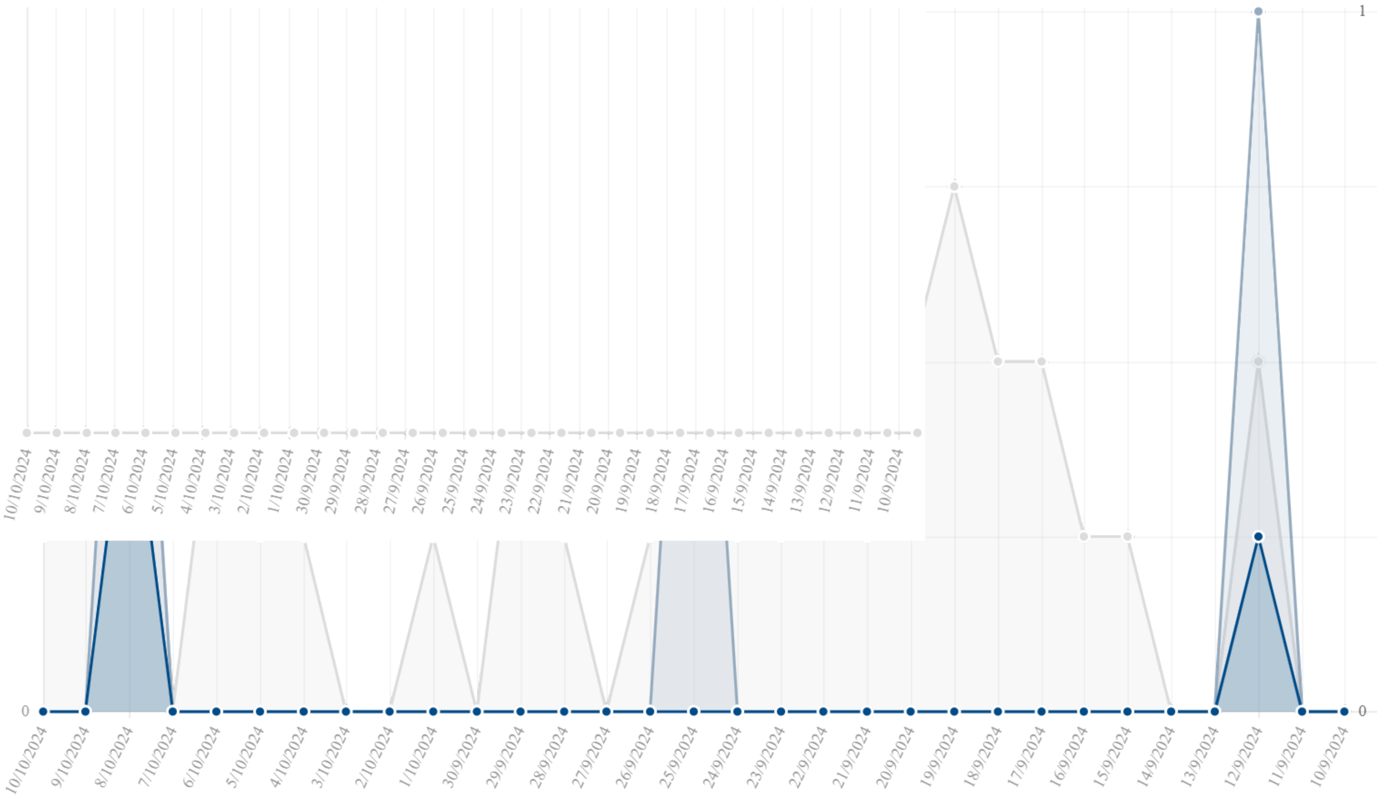
indexações



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Dimensioning Steel Structures with Algorithmic-Parametric-Modeling & BIM at early stages of Design process.

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Abstract. The process of planning and developing curvilinear structures remains challenging. Multiple applications with various design principles are unlikely to fade away. The interoperability employed here was not the standard kind. It was also 'live, ‘real-time,' with two of the applications involved open and running at the same time. A design workflow based on the use of form-forming software associated to building information modeling, BIM, was presented. The main objective was to offer simpler ways to design and create curvilinear designs and their supporting structures utilizing two distinct types of applications simultaneously. This study offered a design process incorporating 3D modeling in a graphical interface (Rhinoceros/ArchiCAD) with visual programming-based design (Grasshopper). This clarifies the rules and permits for control over form-generating principles. The objective of this research was determining steel structures dimensions utilizing visual programming and compatibility amongst BIM systems. The outcomes are a set of algorithms for dimensioning specific structures.

Keywords: Parametric programming, NURBS, Dimensioning, Structures, BIM.

1 Introduction

The process of designing and building double curvature architectures remains challenging (ABDELMOHSEN and HASSAB, 2020, p.1; HUANG et al, 2022). In this process, the employment of numerous applications with various design paradigms is unlikely to cease. As a result, the focus of the research described here is not merely on the architectural product, but also on the process of its conception and manufacturing. The inadequacy of the design method through drawings, as described by Alexander (Apud. Logan, 1987, p. 26) and Lawson (Lawson, 2005, p.27), is an important aspect for this research.

We present a design process that combines three-dimensional modeling in a graphic environment (Rhinoceros/ArchiCAD) with programming (visual programming in Grasshopper), allowing explicit and direct control of the principles creating shapes. The design, manufacture, and construction of curvilinear designs sometimes requires the usage of multiple computer programs. This simultaneous use of numerous applications with distinct paradigms will continue to exist within the realm of design.

The relevance of integration across independent applications is acknowledged in this research since it is assumed that software development and the diverse nature of society make a unified platform unappealing. As a result, the focus of this research is on enhancing and improving interoperability among the programs used in the design.

Interoperability is defined by Chuck Eastman and others as the necessity to move data between applications to allow diverse types of specialists and software to contribute to the design process (EASTMAN et al., 2018). We reviewed the relevant literature and identified some gaps in knowledge, which brought us to the following research questions.

- What are the main automation flaws of the method for generating the shapes of these surfaces and their support structures?
- How can you increase the degree of automation in a continuous, integrated project flow to reduce repetitive tasks and streamline the design of this kind of architecture?
- What computational resources can be developed to generate and pre-dimension a NURBS-based curved roof?
- What computational resources can be developed to generate and pre-size their support structure, as well as produce all relevant information based on parametric design and BIM system interoperability?

We believe that programming in visual environments like Grasshopper, as well as implementing the "live" connection with Rhino-Grasshopper and ArchiCAD, is a feasible solution to the research problem. We believe this is possible by developing small new algorithms with an emphasis on pre-dimensioning the support structure of the previously described curvilinear surfaces.

2 Methodology

The following steps are part of the methodological procedures: first, the creation of the curves used to generate the NURBS surface through the operation of the type "Lofting" which is the sweeping of two-dimensional curves along a path. "Lofting" differs from extrusion by allowing to sweep along a curvilinear path. By dragging the two-dimensional shape along the curvilinear path, a curvilinear surface is obtained.

The NURBS surface information generated using the two-path sweep technique is shown in the first image. Two-path sweeping used the same sweeping logic for path, the only difference of using two curvilinear trajectories in the NURBS surface generation process.

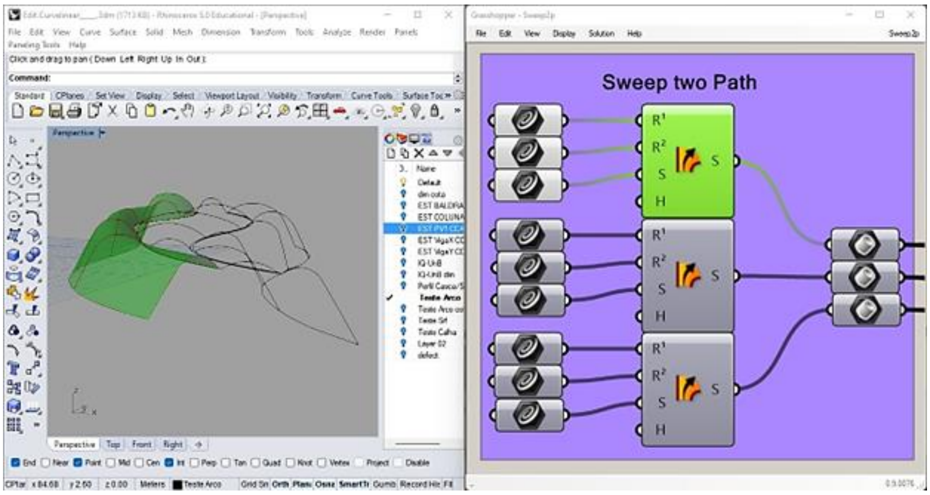


Figure 1: Selected paths, surface-generating profiles and preview of the two-path sweep result (Source: Author).

Second, the creation of structural axes or outlines by "sectioning" or "contouring" the NURBS surface. The process of "contouring" involves the regular distribution of parallel, imaginary planes utilizing a certain modulation. The intercession of each of these imaginary planes results in a two-dimensional curve to be used as the axis or outlines for the generation of the respective structural profile. The second and third images demonstrate how to create the structural axes in the "x" and "y" axis using Rhinoceros-Grasshopper's "contouring" components. The fourth figure demonstrates how the Rhinoceros-Grasshopper interface uses the structural axis established as guides to generate a mesh structure or structural grid termed "curves" for the ArchiCAD "Beam" component, beams.

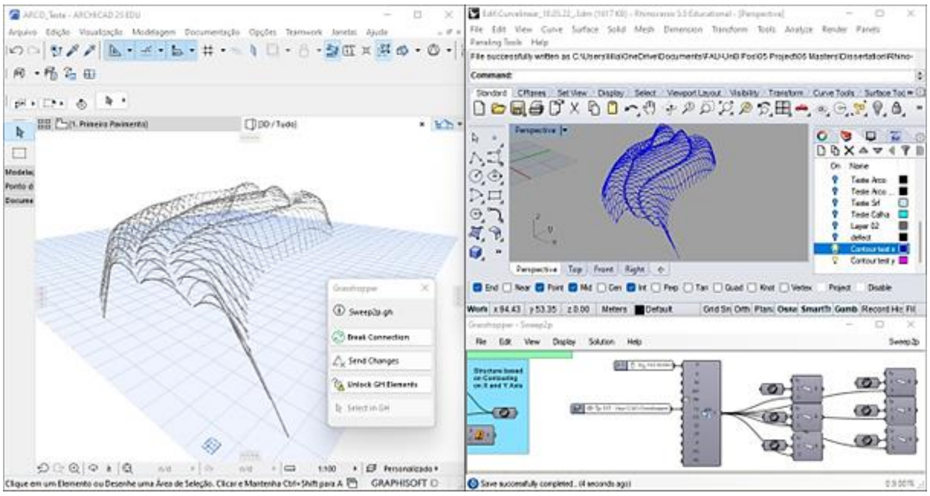


Figure 2: Extraction of structural axis on the “x” and “y” axes From Rhino-Grasshopper to ArchiCAD (Source: Author).

Third, once the sum of loads is made, whether linear or cantilever beams, soon after the resistance of steel to such load is calculated. For arc-like beams, the section area is determined by the force or load on section area. After this process, a search for steel beams or tubes that best fit the criteria of resistance to loads and maximum displacement for roof beams is carried out (L/250 and standard Brazilian Norm for Laminated Glass – NBR 14697:2001).

	Formulas	Standard/Source
Maximum Displacement Roof Beams	$\frac{L}{250}$	Araújo, 2016, p.273
Maximum Displacement Laminated Glass	Dimensions B,H > 4000mm => 6mm	NBR 1469:2001

Figure 3: Maximum displacement of laminated glass (a) and maximum displacement of roof beams (b) (source: NBR14697:2001; Araújo, 2016).

Fourth, generation and modeling of the structural profiles defined in step 3 using Rhinoceros-Grasshopper programming is carried out. Fifth, creation of triangular panels of the NURBS surface through panelization, i.e., subdivision of the surface into smaller planar surfaces is performed. Sixth, automatic generation of structural profiles in ArchiCAD, defined in step 3 and 4 in Rhinoceros-Grasshopper is executed. Seventh, automatic generation of NURBS surface triangular panels in ArchiCAD, defined in step 5 by panelling in Rhinoceros-Grasshopper is carried out. This involves the activation of the link between Rhinoceros-Grasshopper and ArchiCAD. This simultaneous connection offers the possibility of defining the geometry created in the

Rhinoceros-Grasshopper interface as elements and constructive components in ArchiCAD. This allows you to create elements in ArchiCAD that are as native BIM components.

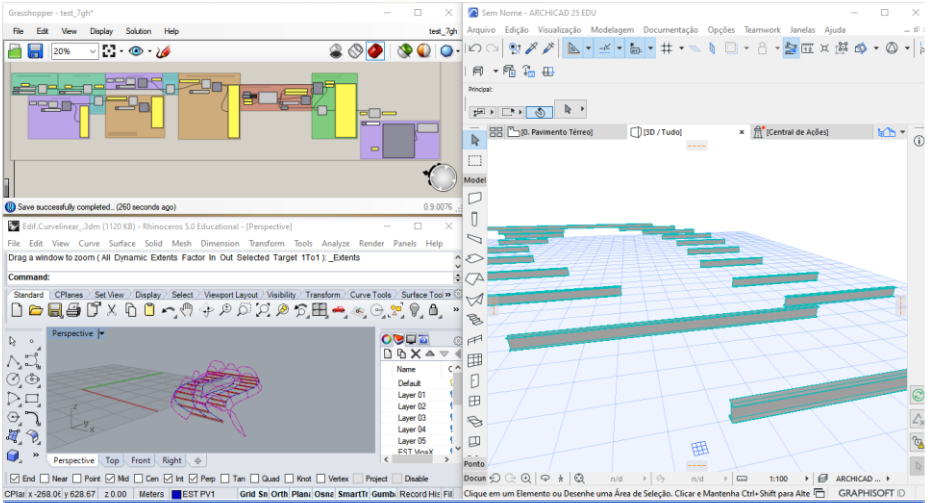
3 Results

Determining profile size, width and thickness of steel linear and cantilever beam using the steel resistance formula was presented by Junior (2014). First, the distributed load was calculated in Kgf/m² using load estimates from the Brazilian Construction Norm, NBR 6120, yielding 3198 Kgf/m over a six-meter region of influence.

	Formulas	
Momentum Linear Beams	$M = \frac{(x * L^2)}{2}$	
Momentum Cantinary Beams	$M = \frac{(x * L^2)}{8}$	
Resistance of Steel	$W_x = \frac{M\max}{(0{,}6 * F_y)}$	
Coeficient of Steel	$F_y = 2500 Kgf/cm^2$	
Loads		**Weights**
Dead Load	Painel Wall floor	32
	Steel Structure	50
	Internal Partitions	45
	Finishing	100
Live Load	Multi-pourpose/Exposition Room	306
Total Load	in Kgf/m²	533
Range Influence	in meters	6
Distributed Load	Total load * Range Influence (Kgf/m)	3198

Figure 4: Resistance of steel straight beams and distributed load formulas (Source: Author).

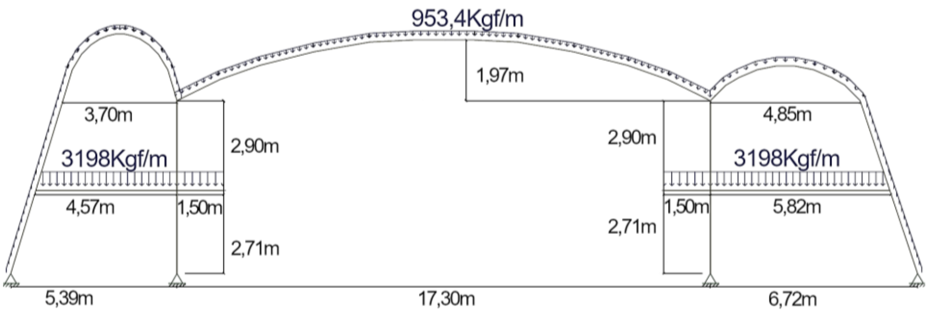
Second, within the Rhinoceros-Grasshopper programming interface, the steel's momentum and resistance were calculated and the resulting output was used to locate a profile that fulfills the resistance requirement in the Gerdau profile steel library in an Excel spreadsheet. Furthermore, because Gerdau did not supply an Excel file format, the spreadsheet containing the steel profile library was made manually beforehand.



Linear Beam Selection Algoritm tasks in Rhino-Grasshopper	
Step 1	Calculate Momentum of Linear and Cantinary beam
Step 2	Use obtained momentum values in resistance of steel formula
Step 3	Search closest resistance value in profile Beam excel spreadsheet

Figure 5: The selection of appropriate beams within excel spreadsheet and corresponding steel profiles database of ArchiCAD. (Source: Author).

The beams were dimensioned by calculating distributed load on the area section of the metallic tube on the NURBS surface roof, using what was learnt from linear and cantilever beams and the case study of the Institute of Chemistry's roof of the University of Brasilia. First, it was calculated the distributed load and obtained 953.4kgf/m.



Loads		Weights
Dead Load	Steel Structure	77,4
	Glass Panels	26,0
Live Load	Instalations	10,0
	Uplift	50,0
	Wind	60,0
Range Influence	in meters	6,0
Distributed Load	Total load * Range Influence (Kgf/m)	953,4
Normal	in Ftool	18950
Section Area (cm2)	A = N*(0,4*2500)	18,95
Closet section area (cm2)	Algorithm via Rhino-Grasshopper	18,90

Figure 6: Structure dimensions and dimensioning data for tubular arch structure (Source: Author).

First, the axial force and displacement diagrams were obtained consulting FTOOL software. This structure has a Moment of 1.49tfm and a Normal of 18.95tf. This information yields a normal of N = 18950 f and a maximum displacement of 287.13 mm. Second, the normal value = 18950 f was used to calculate the tube section area with the formula: A = N(0.4*2500), with a steel elasticity coefficient of 2500, obtaining 18.95 cm2. Third, it was searched in an Excel Spreadsheet for a tubular profile with this section area.

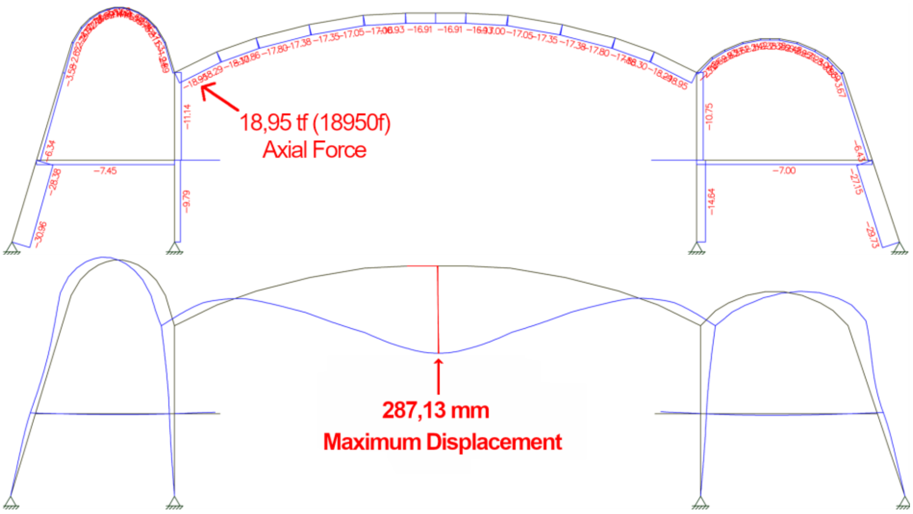


Figure 7: axial force and maximum displacement diagrams of NURBS surface structure in Ftool. (Source: Author).

Fourth, it was verified that it complied with the L/250 criteria for roof beams. A tube with little or no inertia produces a large amount of displacement. According to the maximum displacement criterion of the structure "f = L/250", Table 2.3 of Maximum displacement, page 273, in the book Construction Structures Design with Tubular Steel Profiles by Araujo and others, you need to have a vertical displacement of 6.92 cm with this roof structure.

	Normal (N)	Required Section Area (cm^2)	Closest Section Area (cm^2)	Kg/m (weight)	Displacement (mm)	Displacement (cm)	<= 6,92m (L/250)	<= 6mm (NBR 14697:2001)
T127x5,6	18950	18,95	21,40	16,80	235,77	23,58	!	!
T101,6x6,3			18,90	14,80	287,13	28,71	!	!
T273x10			82,60	64,90	53,60	5,36	OK!	!
T273x20			159,00	125,00	34,82	3,48	OK!	!
T323,8x10			98,60	77,40	36,78	3,68	OK!	!
T323,8x20			191,00	150,00	23,67	2,37	OK!	!
T419x60			677,00	531,00	7,76	0,78	OK!	!
T508x20			307,00	241,00	9,00	0,90	OK!	!
T508x30			451,00	354,00	7,12	0,71	OK!	!
T508x60			844,00	663,00	5,05	0,51	OK!	OK!
T559x12,5			215,00	168,00	9,93	0,99	OK!	!
T559x20			339,00	266,00	7,40	0,74	OK!	!
T559x30			499,00	391,00	5,83	0,58	OK!	OK!
T559x60			941,00	738,00	4,07	0,41	OK!	OK!
T610x12,5			235,00	184,00	8,31	0,83	OK!	!
T610x20			371,00	291,00	6,18	0,62	OK!	!
T610x30			547,00	429,00	4,86	0,49	OK!	OK!
T610x50			1040,00	814,00	3,34	0,33	OK!	OK!

Figure 8: Sample Structure Dimensioning Data and Maximum displacement tubular arches (Source: Author).

The displacements of the T273x10, T323,8x60, T419x60, and T508x60 profiles were evaluated at Ftool, and they satisfied the L/250 criteria. The maximum permissible displacement in NBR 14697:2001's laminated glass standard is 6 mm. The T508x60 tubular profile meets the two requirements of L/250 and NBR14697:2001. If the structure was a 17.30m linear beam it would have a height of 86cm, h=L/20. As it is an arch, what matters is compression, not deflection. The ratio of span to beam height in arched structures will decrease significantly. The structure that supports the glass is made of tubes with a circular section, T508x60. The T273x10 profile is used in the roof's Alucobond panel and sheet metal structure.

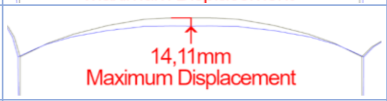
Profile	Ftool Displacement Diagram	Below or equal 6,95cm	Below or equal 6,00mm
T273x10		OK!	NO!
T323,8x60		OK!	OK!
T419x60		OK!	OK!
T508x60		OK!	OK!

Figure 9: NURBS surface structure global displacement diagrams on Ftool with profile (a) T273x10, (b) T323,8x60, (c) T419x60 and (d) T508x60 (Source: Author).

The first set of results obtained is the creation and application of four algorithms to generate automated NURBS surface panelization individually producing triangular panels. The NURBS surface panelization algorithm can be observed in the upper right image. Paneling in Rhinoceros-Grasshopper is shown in the image in the lower right corner. The panels that ArchiCAD generated produced the image on the left.

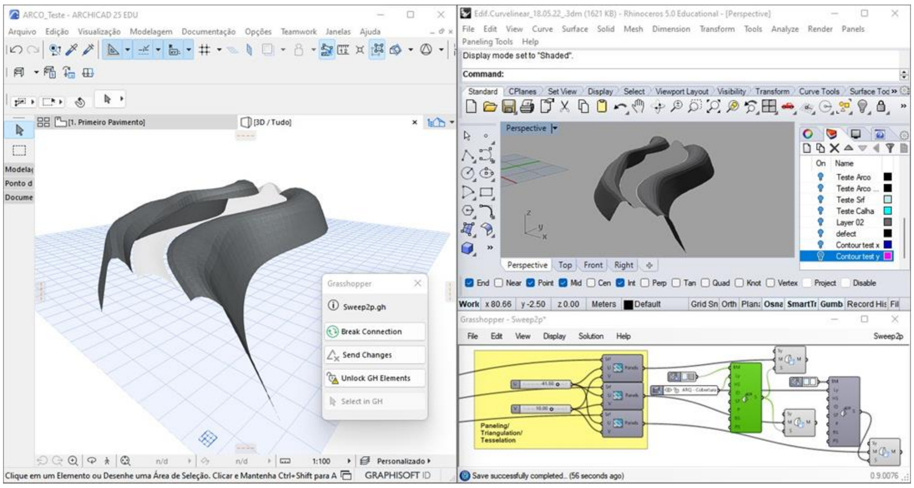


Figure 10: NURBS paneled surfaces (Source: Author).

The development and use of four algorithms to construct structures with an I-profile and tubular section that support these metallic and glass triangular panels makes up the second set of results. Pre-dimensioning algorithms for beams and arches are displayed in the image in the upper left corner. The Excel tables for Vallourec tubes and Gerdau I-profiles may be seen in the lower left corner of the picture. A sample of Rhinoceros and ArchiCAD's structure generation may be seen in the upper and bottom right photos.

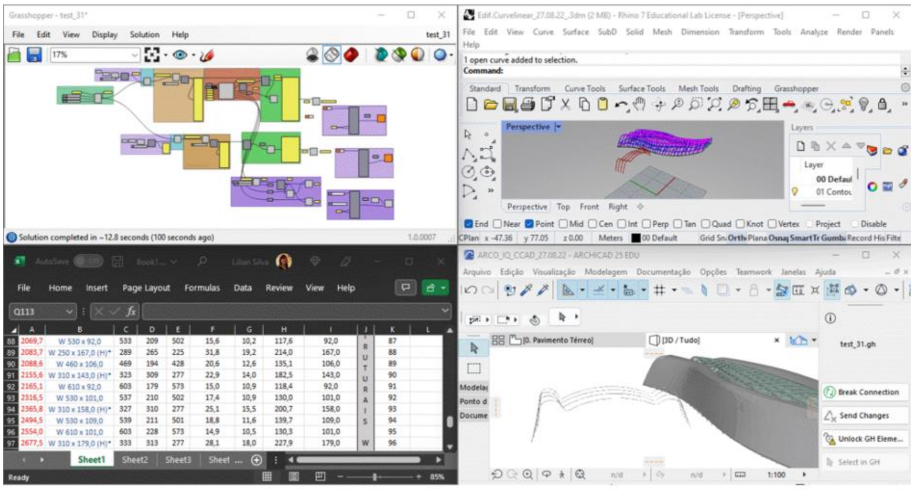


Figure 11: Algorithms for dimensioning arches beams and structure generated in Rhinoceros and ArchiCAD (Source: Author).

The development and use of four algorithms to generate I-profile and tubular supports for these metallic and glass triangle panels is the third set of outcomes. The beam generating algorithm for arch structures is displayed in the upper right image of Grasshopper-Rhinoceros. The structural axis of Grasshopper-Rhinoceros are displayed in the lower right image. In the figure on the left, beams were chosen in ArchiCAD using Grasshopper and Rhinoceros. The beam generating algorithm for arch structures is displayed in the image in the upper right corner of the screen. The Rhinoceros structural axis has been chosen and adjusted in the lower right image using Grasshopper. Rhinoceros-Grasshopper was used in ArchiCAD to adjust one of the chosen beams, as seen on the image on the left.

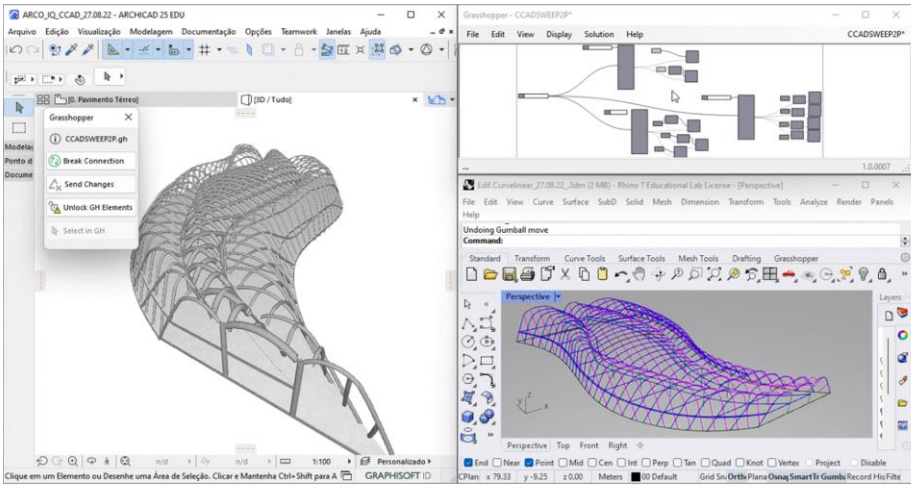


Figure 12: Modeled Structure in ArchiCAD as Beam BIM element (Source: Author).

The generation of the building resulting from these algorithms using algorithmic parametric modeling in Rhinoceros-Grasshopper and ArchiCAD is also an expected by-product. When the link between Rhino, Grasshopper, and ArchiCAD is disconnected. Even if the connection is disconnected, the generated data is still there in the ArchiCAD system.

4 Discussion

The desired amount of automation was initially achieved with Grasshopper programming and the "live" Rhino-Grasshopper-ArchiCAD connection. In fact, the creation of these novel algorithms provides for the pre-dimensioning of the support structure of curved surfaces. The data collected indicates this research proposal is promising.

The objectives of this research have mostly been met through the development of these algorithms for the roof, the main roof structure, which have contributed significantly to this research. As a result, to the best of our knowledge, we have produced a novel contribution to an area of considerable relevance for innovation in contemporary architecture.

Future research should focus on developing a more exact mathematical formula for NBR 14697:2001 that defines the thickness of the glass in proportion to the displacement of the arc structure without requiring another external tool within the BIM system or on Grasshopper. They should also include the development of NURBS elements for usage like building elements in ArchiCAD and other BIM systems.

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