Reimagining Gego

Geometrical Reconstruction of Nubes, an undocumented and lost sculpture from 1974

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This paper describes a method to understand and digitally reconstruct two sculptures by Gertrud Goldschmidt, a German-born, Venezuelan artist also called Gego. Gego is best known for her series of works called "Reticuláres". These three-dimensional and open installations, mostly hanging freely in space, are playing with the concept and perception of space as well as challenging the definition of the traditional sculpture. The paper aims to generate information about two specific structures called "Nubes" (Clouds for Spanish) to assist in a physical reconstruction for a larger exhibition about Gego and to contribute to understanding Gego's work process. Originally, the structures were suspended from a building's ceiling as an art installation in Caracas, 1974.
There are three main challenges for this reconstruction: (1) The installations exhibit a complex three-dimensional geometry. (2) Scant drawings and photographs exist. (3) Gego might not have followed her initial drawings completely when building Nubes physically, because of the mentioned complexity and due to the light and bendable material properties of the employed material. The paper describes a computational process that recreates the object's geometry in four steps: (1) Analyse all existing media of the structure. (2) Translate found information to the digital environment of Grasshopper. (3) Use a physical simulation to derive the end state of the hanging structure. (4) Optimize and tune the simulation with an optimization algorithm for better results.
This paper demonstrates the usefulness of computational tools for reconstructing lost sculptures with little documentation. In this case, these tools allow a more accurate reconstruction and contribute to a fuller understanding of the design and realization process of Gego's Nubes.

Keywords: *Geometry Reconstruction, Lost Art, Comp. Design, Physics Simulation.*

INTRODUCTION

Gego is a German-born, Venezuelan artist whose full name is Gertrud Louise Goldschmidt (b. 1912 in Hamburg, d. 1994 in Caracas) (Groos et al. 2022). She studied engineering and architecture at the Technische Hochschule Stuttgart (Stuttgart Technical Institute) before settling in Caracas, Venezuela due to the events of World War II.

Gego is best known for her intricate and complex, partially room-filling structures as well as her geometrical drawings. She began her artistic career in the 1950s, producing more than 850 sculptures, 600 drawings and 60 engravings (Turner 2000). Gego's approach to geometric studies of lines and planes in three dimensions was largely shaped by the rationality and precision of her studies in architecture, though one also can see a playful and artistic side. Most of her works focus on the topic of the line, which usually is seen as a two-dimensional object. She managed to arrange an assemblage of lines, materialized by metal wires, aluminium sticks or thin rods as a three-dimensional structure, which always stood in dialogue with the space it was placed in.

Gego's works "Nubes l" and "Nubes ll" (Figure 1) are one example of how she used lines arranged in an almost simple grid to create a spatially complex and three-dimensional structure. The pieces were originally shown to the public in a mall in Caracas, Venezuela, in 1974 (Fundación Gego, 1974). Nubes, Spanish for "clouds", was suspended from the ceiling, hanging in an around three stories high atrium on top of an installed waterbed, which reflected the structure. The materials used were aluminium and bronze. While the sticks were planned to be "tubos de aluminio […] anodizado mate" (aluminium tubes, matt anodized) with a diameter of 3/8 inch (ca. 95 mm), the joints were custom made "anillo bronce" (rings of bronze) (Fundación Gego, 1974).

We sought to reconstruct Nubes to assist in a larger exhibition about Gego shown in the Kunstmuseum Stuttgart 2022. The aim is to create a more detailed and fuller understanding of her work process as well as of the final geometry of Nubes, for which only little documentation exists.

Figure 1
Mockup for Nube
1974
Fundación Gego
archives

METHOD

Our method of reconstruction can be separated into the following steps:

- Analysis of Nubes: Photographs of the original structure as well as the still existing documents
- Translation of the analogue plans into digital information
- Physics simulation with Kangaroo3d
- Alternative modelling approaches
- Model evaluation
- Tuning of the physics simulation with an optimization algorithm

ANALYSIS OF NUBES

When analyzing Nubes, there are three main sources one can get information from:

- Several photographs of original plans, sketches and letters (Fundación Gego, 1974)
- A video on YouTube consisting of low-resolution photographs of the original structure built in Caracas (Dunia, 2019)
- Photographs of the original models, which were built in the scale of 1:10 before building the 1:1 structure (Figure 1). Sotheby's recently auctioned these models for more than half a million dollars (Sotheby's 2022).

Assembly

Gego and her helpers started laying out the sticks on the floor and connecting them loosely via the bronze joints (George Dunia, 2019). They then attached robes to various joints to pull the structure up in the air towards the desired height,

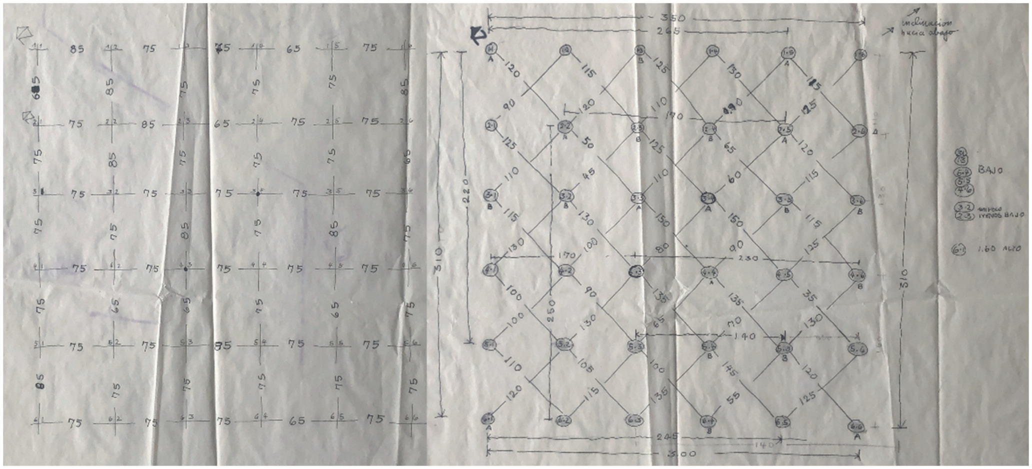

Figure 2
Left: Tube distribution sketch for Nube II
Right: Sketch for Nube II

1974
Ink on paper
Fundación Gego archives

which was around head- to overhead-high. What followed was the process of going through all of the joints and tightening the screws when the desired angle and shape of the connecting sticks were achieved.

Sticks

The original plans, sketches and letters (Figure 2) contain information about dimensions, materials and sizes. The lengths of the sticks range from 65cm to 85cm and have a diameter of around 95mm. These dimensions allowed Gego and her helpers to partially bend the sticks to achieve the desired form. From an artistic perspective, Richard Schiff is explaining: “She expanded their [the sticks’] expressive range rather than accepting their given potential and conventional patterns of use” (2003 p.119). On the other hand, from the perspective of an accurate reconstruction, the unknown variability in the sticks’ length makes the reconstruction very difficult. When we base the reconstruction process on the drawings without ever having seen the original structure, we need to assume that it is likely there are deviations between the plans and the realized structures. Gego probably adapted her plans multiple times on site. This thought will also be confirmed later when looking more closely at the plans.

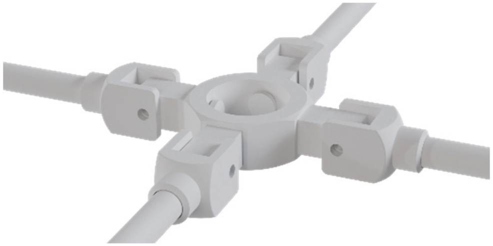

Figure 3
Visualization of the original joint design

Joints

The design of the main part, the bronze ring is closely attached to that of a conventional nut (Figure 3). Gego has designed the nut in a way that she could attach four sticks perpendicular to the nut by drilling a hole on four of the eight sides. In between the sticks and the nut are two more pieces: The stick slides into a piece, which is attached via one screw to the second, box-shaped part, which screws into the nut. This way, the sticks can rotate freely in two axes. Once Gego was happy with the position and angle of the sticks, she just needed to tighten the screws of the joints to make each part of the structure rigid.

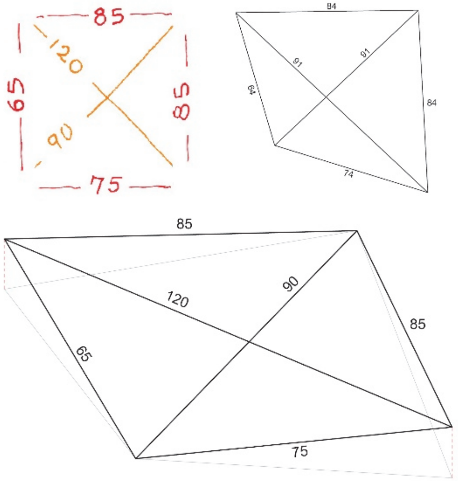

Figure 4
Interpretation of Gego's method to create foldings

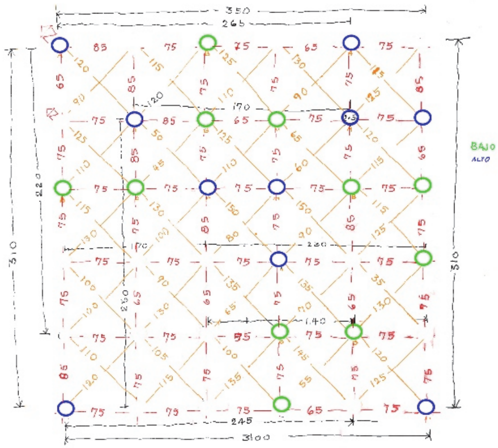

Figure 5
Combined and categorized plans in colour

TRANSLATION OF THE ANALOGUE PLANS INTO DIGITAL INFORMATION

The two most important documents to reconstruct Nubes are two original plan drawings (Figure 2). The left plan shows the principal layout of the aluminium sticks including their individual lengths, as well as the orientation of the structure in space. The joints that connect the sticks are numbered in both plans, which assures coordination between the plans. The right plan contains additional information and measurements about Nubes. This second drawing is open to interpretation since the drawn diagonal lines are not physically represented in the built structure, nor discussed in any other existing document. We interpret these diagonals as follows: as shown in Figure 4, the diagonal lines measure the distance between the nodes. If one divides each rectangle into two triangles, one gets an imaginary folding line between two nodes of the rectangle. Along this line, the triangles can be folded until they reach the right distance given in the plan. The shorter the distance, the smaller the angle and the closer the opposite nodes move to each other. Without folding the two triangles, an equilibrium of all six measures mostly cannot be reached as shown in the upper right picture of Figure 4.

In addition to the diagonal measures, there are seemingly random chains of dimensions, which measure between either horizontally or vertically aligned nodes.

The legend on the right side of the original plan drawing (Figure 5) contains information about the high and low points of the structure. "Bajo" is Spanish for "under" or "low" and "Alto" means "upper" or "high". In the plan, one can find little letters under some of the nodes, which are either "A" or "B", so they can be assumed to be a short version of presented words in the legend, representing if a particular node in the structure should move up or down.

Contradictions in plans

If we divide the initial structure of Nubes into individual rectangles as we do in Figure 4, we discover multiple contradicting measurements for the folding of the rectangle. For multiple cases, a geometrical solution that fulfils all six measurements conditions cannot be found, even when folded three-dimensionally. This again raises the question of how much deviation there is between the original structure and the plan Gego has drawn.

Technological pipeline

The .csv data format is used to translate all information described in the previous section into Grasshopper geometry. As can be seen in Figure 5, for each different kind of measurement a matrix is created with the corresponding information in numbers. In this matrix, the location of e.g. the sticks (coloured red in Fig. 5) aligns with the location of the number representing the specific length in the matrix. In total, six different matrices are used to translate all information:

- Lengths of the sticks in X-direction (red in Fig. 5)
- Lengths of the sticks in Y-direction (red in Fig. 5)
- Diagonal lengths between the nodes in XY-direction (orange in Fig. 5)
- Diagonal lengths between the nodes in negative XY-direction (orange in Fig. 5)
- Location of high and low points (blue/green in Fig. 5)
- Extra chains of dimension between multiple nodes (black in Fig. 5)

For the measurements of the sticks as well as the diagonal measures between the nodes, two matrices are needed respectively to translate all information: one for the direction in X (sticks) or positive XY (diagonals) and one for the direction in Y (sticks) or negative XY (diagonals). For the low and high points, we create a matrix with values ranging from 0 to 2 representing the state for each node: either neutral, high or low. The special chains of dimensions, which do not connect neighbored nodes but measure between nodes further apart from each other, the matrix format is adapted in a way that each row contains information about the start and end node as well as the desired distance.

PHYSICS SIMULATION WITH KANGAROO

For physically simulating the arrangement of the sticks in space while trying to follow the rules set by Gego's plan drawings, we use Kangaroo3d.

Kangaroo is a plugin for the CAD software Rhino with its visual programming plugin Grasshopper. It is widely used to simulate behaviours in real-world materials and objects (Piker 2013). Chéraud (2020) defines a Kangaroo simulation (Particle Spring System) as follows: "it [the form-finding process] is the search for a state of equilibrium of forces under given conditions and according to a given stress". We start like Gego by laying out a grid of sticks and nodes digitally in two dimensions. Then the structure gets deformed while trying to reach the following geometrical goals set from the information we find in Gego's plan drawings:

- Kangaroo's "Length(Line)" goal is used for all measurements described by Gego.
- The "Load" goal was used in the earlier stages of the project for creating a movement of the notes categorized in high and low points in Z-direction. This was later replaced by just moving the nodes slightly up or down according to their purpose before starting the simulation. This has the same effect but makes the simulation lighter thus faster. And it does not have the effect of the load goal trying to push a node e.g. higher even if it already can be considered a high point.
- Another "Load" goal for all nodes simulating gravity was also tried, but we quickly could see the structure is stiff enough to be approximated the same with and without gravity. Thus the specific location of where the structure is hung from the ceiling has no influence.

There is no need to set a condition for the behaviour of the nodes. Gego designed the joints as discussed in a way that the sticks can rotate freely on every axis. This behaviour is already the default one for a Kangaroo simulation.

Model evaluation

To evaluate the model, one main method is used. Since we already digitalized all the measures from Gego's plans drawings, we can compare this data to the measurements we receive from the simulation. The measures from the simulation are divided into the sum of the deviation for (Table 1):

- The sticks' lengths (coloured red in Fig. 5)
- The measures of the diagonals between the nodes (coloured orange in Fig. 5)
- The chains of dimensions between multiple nodes (coloured black in Fig. 5)

This way we can not only see the total deviation of the whole model but can also see what method performs better for what sort of sub-result.

We also use a second method of evaluation by comparing rendered images of the final model to pictures of the original structure and pictures of the 1:10 model. With this method, an objective comparison gets way harder than with the first method. Therefore it was mainly used to orient our final model within the visual design space of the given pictures. Thus it becomes an important additional step to verify the result from the simulation and optimization, which is only informed by the deviation of measures and not by the geometrical result.

TUNING THE PHYSICS SIMULATION

Since this initial Kangaroo simulation did yield an imperfect result, it was finetuned by optimizing the Kangaroo goals for better performance. The Grasshopper plugin Opossum was used and the optimization was performed with the single-objective CMAES and RBFOpt algorithms (Wortmann 2017).

Optimizing the "strength" value

The first step is optimizing the value of the "strength" input that every Kangaroo goal has. According to Piker (2017), the Kangaroo solver tries to find the equilibrium by calculating a weighted sum of all goals. In this formula, the strength input stands for the weight of each goal. Therefore a numeric value is connected to each strength input of all three main goals (Length(Line) goals: stick lengths, diagonal measures between nodes, extra dimension chains). Multiple tests for the range of the value concluded the most effective optimization is done with strength values between 0.1 to 100.0. In a range between 0.1 to 1.0 or 0.1 to 10.0, we can see the optimization process is limited and has only little effect on the performance (Table 1). One can notice a change in the geometry of the simulation result (Figure 6), and the deviation is lowered by a maximum of around 106 cm. Both optimization algorithms were run 300 iterations for both ranges of the three strength values. Due to the higher number of possible combinations between the three variables with the second range (0.1 -10.0), it can be that number of iterations for the optimization is too low. Interestingly, this changes when the possible range of values is set to 0.1 to 100.0. The optimization uses the full range to explore and eventually settles inside 300 iterations. Better results are scored thanks to a larger possible difference between the individual strength values. But the range has a limit. When using values from 0.1 up to 500.0, the optimization is not settling and scoring less good results than before.

For the range of 0.1 – 100.0, a difference between RBFOpt and CMAES is noticeable, when both are run 300 iterations. RBFOpt performs better and is lowering the deviation of the simulation by a total of around 92 cm in comparison to the range of 0.1 to 1.0, while CMAES does only improves the deviation by around 56 cm.

Optimizing for low and high points

The second step of optimization deals with the initial setup of low and high points in the structure. Since in Gego's plans, the information about high and low points is the most unclear one, it is a good variable to optimize for. For each of the 36 nodes, a number between 0 and 2 is set to determine whether this node should be either a high, a low point or a neutral point.

This optimization by itself turns out to be more of a control process than an optimization process. The optimization works to a certain degree, but visually it is very clear to say that the high and low points set by Gego appear to be the right ones if the simulation is compared to the photographs of the models and the original structure. A greater effect is achieved when combining the optimization for the low and high points with the optimization for the strength value. In this process, the model with the least deviation is found. A downside of this model is the complexity of optimizing 39 parameters simultaneously, which takes up more time than the other models. Both optimization algorithms are run for 1500 iterations. RBFOpt again performs better finding the overall best result of a deviation of 236.14 cm, while CMAES performs worse than the best optimization run where we only optimize for the strength parameter taking Gego's low and high points as starting positions. This could be due to the relatively low iteration count set for a lot of variables.

Table 1
Model evaluation based on dimensions in plans

Model	Deviation				Fig. 6
Description	Total	Sticks	Diagonals	Large dim's	Image
Simulation only	435.43	258.26	159.17	18.0	1
Optimized strength values (0.1 – 1.0) RBFOpt, 300 iterations	357.25	28.92	317.33	11.0	2
Optimized strength values (0.1 – 10.0) RBFOpt, 300 iterations	351.78	37.37	311.42	3.0	3
Optimized strength values (0.1 – 100.0) RBFOpt, 300 iterations	265.25	2161	223.64	20.0	4
Optimized strength values (0.1 – 1.0) CMAES, 300 iterations, 3 runs	357.25	28.92	317.33	11.0	
Optimized strength values (0.1 – 10.0) CMAES, 300 iterations	329.52	36.68	289.85	3.0	5
Optimized strength values (0.1 – 100.0) CMAES, 300 iterations	301.23	34.61	256.63	10.0	6
Optimized strength values & low/high point positions RBFOpt, 300 iterations	278.29	57.69	217.6	3.0	7
Optimized strength values & low/high point positions RBFOpt, 1500 iterations	236.14	23.42	195.72	17.0	8
Optimized strength values & low/high point positions CMAES, 1500 iterations	292.22	56.58	225.64	10.0	9

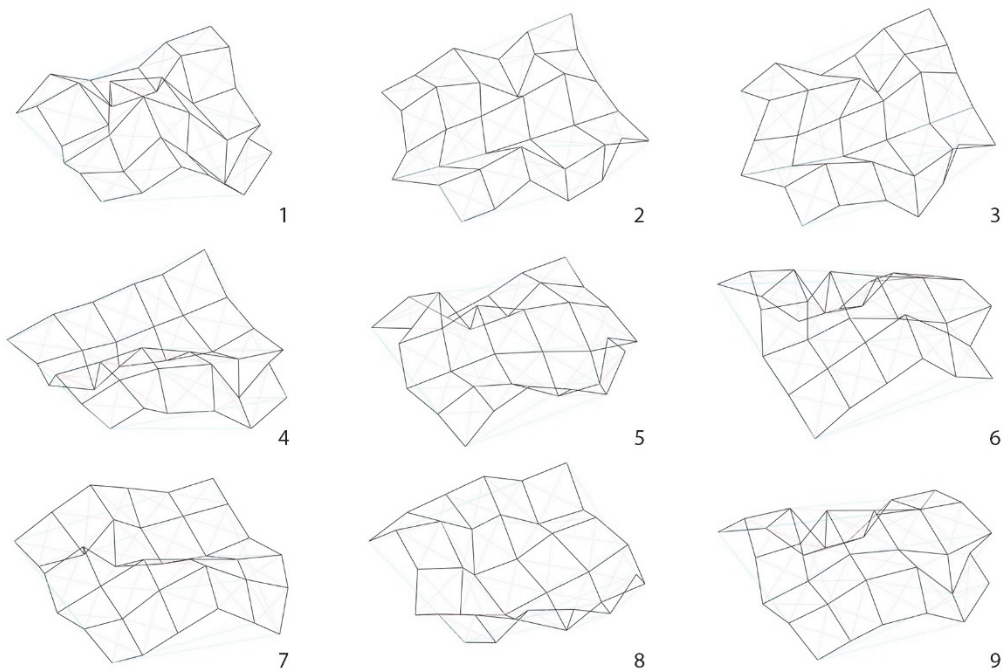

Figure 6
Variation in geometry of different optimization methods

RESULTS

As seen in Table 1, using an optimization process for tuning the simulation produces geometry with less deviation from Gego's original plans. After only the simulation performed in Kangaroo with Gego's original high and low points and all strength values for the goals set to 1, the deviation from original measures is 435 cm or about 3.39%. The best performing simulation after optimization with RBFOpt is 236 cm (1.84%) of the original measurements from Gego's plan drawings. This equals around a 36 mm difference in the length of each stick. By taking into account the likeliness of bending the aluminium sticks, as well as artistic deviations from the plan drawings, the model's performance can be considered as good. The optimization helped to reduce the deviation to almost half the size it had been after the simulation. One can also see a more balanced result of the individual deviations (right columns in Table 1, Deviations) when the overall deviation of the model in comparison to the original structure is smaller.

Designer Input

For the geometrical reconstruction, it is also important to compare the numeric results and the visual ones. As seen in Figure 6, after the simulation and the optimization process there is a variety of outputted geometries. Since we are reconstructing an artwork, human input should not be underestimated. The models range from a deviation from the original measures of 3.4% to 1.8%. This result does not mean we have to choose the best performing model. As already explained there are multiple reasons why the digital structure can vary

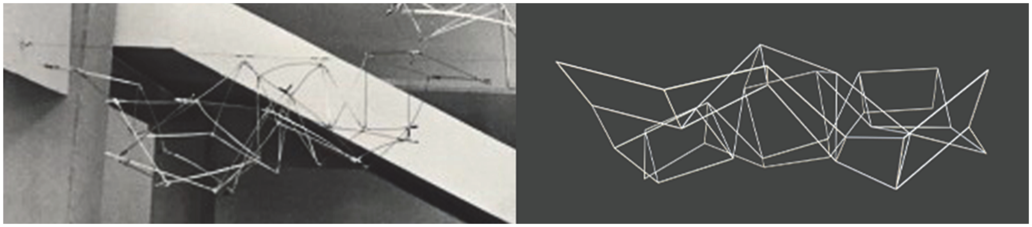

Figure 7
Visual comparison between original and digital model

from the original one. Thus we as designers are choosing the right model in the end for a mainly visual reason. Even if the quality of the photographs of the physical structure are low-resolution, we can still make out characteristics in the design (Figure 7). These characteristics range from the overall height-to-width ratio over the distribution of higher and lower areas to the shape of certain areas containing only a few sticks. For example, in the left front of the original photograph, we can recognize a very similar shape to the chosen simulated model. The same is true for the global high point around the centre of the structure. Even if the simulation and optimization found a very high performing geometry, we as a designer are overruling the results by choosing the geometry which visually looks right to us and "makes the most sense".

Other than being visually distinct from the photographs of the original structure, the best performing model seems to be rather boring in comparison to what Gego created in 1974 (Figure 6.8).

DISCUSSION

Gego's work makes very clear what we have to consider when digitally reconstructing structure with little documentation:

- Analysis of existing plans and pictures
- Choosing the right method of reconstruction
- Constant comparison between original and reconstruction
- Comparison of different results

This process is not linear and can be better described as a circle. The analysis gets completed by the simulation and vice versa.

This digital reconstruction shows the usefulness of computational tools, without which this full and accurate understanding of Nubes would not have been possible. But it also gives a better understanding of what digital tool or approach makes sense in which situation.

Gego's approach to creating such a structure obviously must have been different to the approach elaborated here. She created the whole, very complex structure in times without digital tools as we have them today. Instead of having access to the suite of 3D programs as we have, she only used two main drawings to create Nubes. In addition to these drawings, she used her skills as an artist on site to perfection the geometry.

This of course raises the question of what she would have been able to do when having access to computational tools. Even if Gego's plans show the power of two-dimensional drawings representing a well thought through system, analogue drawing and modelmaking only allow a few design iterations due to the time consuming and labour-intensive process. In contrast, modern tools offer a seemingly unlimited design space in no time (Chéraud 2020). Nubes is in the end still reliant on two-dimensional plans. Today, Gego might have been able to extend her spatial studies to an even more complex structure than already present. Therefore, computational tools become an attractive alternative. We have proved the simulation with Kangaroo produced reliable and accurate results.
The second important question is the role of the artist. Knowing that we cannot reach the same

geometrical result as Gego did in 1974, we can assume that Gego as an artist played a deciding role in creating her sculptures. The drawn plans were only tools for her to reach her goals, as Grasshopper might be the tool for artists nowadays to reach theirs. The artist or designer remains an important factor in a successful design.

Future work and research might include taking the method outside the field of reconstructing lost sculptures. It can work as a basis to create new art and architecture inspired and based on similar processes challenging current standards of designs and their methods.

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