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**Abstract**

The shape of the Guggenheim Museum in Bilbao is problematized here with the didactic interest of investigating the design strategies used by Frank Gehry to reconfigure the urban fabric and landscape involved. There are few discourses about the design, accompanied by objective reasoning and supported by its formal decomposition. The convenience of this complementation is considered, given its potential as a reference in the architectural training process. We hypothesize that the shape of the building comes from a reduced repertoire of formal fragments within this fabric and landscape, configured both by classical composition rules and by fractal geometry. This interpretation, constructed by means of overlapping drawings to the photographic and technical images of the building and its immediate surroundings and by the concept of fractal dimension, facilitated the identification of strict formal control, which starts with the regulation of its representations in orthographic projection, maintaining proportions, parallelism and convergences; such as in perspective, exploring continuity achieved through anamorphic effects. Thus, we demonstrate the use of a method, of geometric approach, which facilitates the construction of hypotheses regarding design strategies. In this case, Gehry's strategies to dialog with a particular urban fabric: through recursive actions, using topologic transformations, in its mathematical meaning, in the formal vocabulary of the place itself, actions today made easy through the digital means of representation.

**Keywords:** Guggenheim Museum; Frank Gehry; Architectural form; Fractal Geometry; Teaching design.

## 1 Introduction

This paper shows a study of the design of the Guggenheim Museum in Bilbao, designed by Frank O. Gehry. He won the competition, in 1990, among three proposals presented to the Solomon R. Guggenheim Foundation. According to information available on the Museum's website (Guggenheim, 2017), Gehry's participation in this competition was invited, and the construction took place between 1993 and 1997, imposing itself on Bilbao's landscape (Figure 1).

**Fig. 1:** View of the Museum. Source: Image by Alex Ferrer Gimeno made available through Google Street View in December 2016.

Naomi Stungo, illustrating her speech with photographs of the building, considers that Frank Gehry produced "an explosion by the riverside, a riot of contours and shapes" (Stungo, 2000, p.20). The impact of this construction, also observed by Isenberg (2009), is part of the revitalization movement of Bilbao, a city that was experiencing great economic stagnation at the time. It is true that the phenomenon, known as "Bilbao Effect", should not be attributed exclusively to the construction of the Museum. It was a part of an urban requalification project that covered several areas of the city and is still being implemented, but it is recognized that Gehry's project had become the icon of this phenomenon. Stungo also comments that:

> *'[...] Gehry's architecture is not considered "difficult", as is the case with much of modern art […]. Exactly like the cubists, in the beginning of the twentieth century […]* ***Gehry's architecture, at the end of the century, presents the buildings with astonishing disharmony, an experience from all angles at the same time****' (Stungo, 2000, pp.10-11, emphasis added).*

Naomi Stungo's opinion is highlighted to question the consideration of "disharmony". In formal terms, does the building establish a dialogue with the city?

Charles Jencks, with his speech, also illustrated only by photographic images of the building, observed that:

> *'[…] it* ***reflects*** *the shifting moods of nature, the slightest change in sunlight or rain. Most importantly* ***its forms are suggestive and enigmatic*** *in ways that relate both to the natural context and the central role of the museum in a global culture. [...] This emergent strategy […] has now become a dominant convention of the new paradigm' (Jencks, 2002, pp.157-158, emphasis added).*

This discourse raises questions about what formal elements of the building the author is referring to for visualizing, for example, the relationships with the natural context. It seems it was not restricted to the sensibility of "mood" of climate variations.

Denna Jones reinforces Charles Jencks's perception, that we are facing a new paradigm in architecture's production process, stating:

'Originally a sculptural exercise, the museum's initial shape was not a result of digital methods, but of Gehry's appreciation of the landscape and the context. **As the design evolved, Gehry was increasingly impressed with the ability of digital software to generate a form**' (Jones, 2015, pp.523-524, emphasis added).

Here, Jones observes Gehry's interest in the potential of digital tools for perfecting his design process, realizing how much he could precisely control the form and its connection to the place.

Other discourses reaffirm that this form derives from a sculptural process from and for the place: "… Gehry's design creates a sculptural and spectacular structure, perfectly integrated into Bilbao's urban fabric and its surroundings" (Guggenheim, 2017, our translation) 2. Gehry reinforces these statements in an interview given, in 1995, to Zaera-Polo:

> *'Bilbao is a very contextual design, but not in the conventional sense [...]. I hope that, when people see the completed building, they realize that I'm dealing with the context. Bilbao is a very hard industrial city, with a river and amazing green landscape. The grounds of the museum are set on a wonderful bend over the river. The city lies above ground level... The problem with this building was to link the city with the river, to bring the city to the other side of the road, involve it up to the river. In fact, my first decision was to propose the site" (Zaera-Polo, 2015, p.228).*

The collection of documentation for this building, digital or printed, conveyed in scientific or non-scientific contexts, refers mainly to photographic images. It is necessary to go through the building from different visual trajectories to apprehend it. Plans, elevations, and sections are, in this case, dense and not very clear elements, even for a specialized reader.

With an essentially didactic interest, we question which elements of geometry Gehry uses as support to establish this "riotous", "enigmatic" and "integrated" relationship with the city. Among so many formal elements of the surroundings, which ones were more or less determining for the building's configuration?

For Jencks (2002, p.157), several of Gehry's buildings, including this museum, incorporate elements from the fractal geometry. This geometry, systemized by Benoit Mandelbrot, uses knowledge built in the history of Mathematics associated with computer graphics, involving recursive procedures to describe the forms of nature that had not been contemplated by Euclidean Geometry.

> *'[…] It describes many of the irregular and fragmented patterns around us, and leads to full-fledged theories, by identifying a family of shapes I call fractals. The most useful fractals involve chance and both their regularities and their irregularities are statistical. Also,* ***the shapes described here tend to be scaling, implying that the degree of their irregularity and/or fragmentation is identical at all scales****' (Mandelbrot, 1983, p.1, emphasis added).*

Fractals can be defined by an initiator and a generator which go through a process of recursion and scale change, keeping, however, self-similarity or even self-affinity. Thus, the parts are reduced versions of the whole object, the difference between self-similar and self-affine being that, in the second case, the versions are formed in different scales and directions in space. Furthermore, both kinds can be exact or statistical, characterized by probability, the last one having its version in reduced scale statistically equal to the whole object.

Mathematically, fractal geometry brakes the paradigm of a whole dimension as a condition to characterize an element, constituting the concept of Fractal Dimension (D). This is used to determine the degree of space occupation, so that the bigger the irregularity of a given form, the greater its D. According to Backes and Bruno (2005, p. 51), literature provides several approaches to estimating the Fractal Dimension, with a logic that generalizes the calculation of the topological dimension in the context of Euclidian geometry (whole dimensions) to encompass also the calculation of Fractal Dimension (fractioned). The "Box-Counting" method is an approach which makes the comprehension easier by professionals used to a more visual language instead of algebraic because it adopts a procedure of counting the cells that the form of the investigated element occupies in a particular space. These cells are subdivided, recursively, until all of them acquire the condition of being completely full or empty, depending, thus, on a resolution scale. According to Ostwald and Vaughan (2013, p.242),

'Since the 1990s, fractal analysis has been used to measure the formal properties of urban designs, town plans and skylines [...]. Architectural researchers have also used a manual variation of fractal analysis to measure the visual properties of contemporary and historic buildings'.

Sedrez (2009) and Ganhão (2009), in referring to the museum's form as a fractal, reproduce Jencks (2002) and also Sala M. Martins and Henrique Librantz (2006, p. 92), in the sense that the discourses are not accompanied by graphic or numerical demonstrations.

In an interview given to Giron (2015, p.16), Gehry problematizes the use of computational means in a design process:

> *'[...] Hand drawings give it a sense of continuity (...) I love the idea of complete and ambiguous continuity. Only later do I transpose it to the computer screen. The image on the computer is lifeless, cold, horrible.* ***The computer cannot be the inventor of forms. We are the ones that must master it****' (Emphasis added).*

Even when relying on the potential of software for the development of his ideas, Gehry's design process is established initially by sketches and physical models. When questioned about the possibility of comparing his design method through the use of many models to that of Renaissance architects, Gehry replies to the architect and critic Alejandro Zaera-Polo in the following manner:

> *'Yes, it's true. [...]. If I had to say what is my greatest contribuition to the architectural practice, I would say it's managing the coordination between the hands and the eyes. This means that I have become very good at carrying out the construction of an image or a form that I am looking for. I think it's my best skill as an architect. I am able to transfer a sketch into a model and then into a building […]' (Zaera-Polo, 2015, p.221).*

For the design process of the museum, models were made after the hand sketches, which were then decoded into the CAD-CAM language using a digitalizing pen, through the software CATIA. From this model controlled in the digital space, the design team developed the documentation of the architectural design as well as the structural calculations and the details of the metal structure and coatings (Lindsey, 2001, pp. 43-44). Gehry had already experimented in previous projects, such as the fish-shaped sculpture of Barcelona's 1992 Olympic Village and the design of the Walt Disney Concert Hall, which was only finished in 2003. However, it was through the museum in Bilbao that he and his team consolidated this method and Gehry found a way of actually controlling form with the precision he desired.

The architect received the Pritzker Prize in 1989 having, thus, recognition for his work by the specialized architectural critique. His production is so expressive that it was the theme of an episode of "The Simpsons" (Fox, 2015). In the referred episode, Gehry's creative process is shown in irony, associated with the idea of being "random", devoid of a method and with no programmed connection to the city's fabric. His character draws from a crumpled sheet of paper the inspiration for the design of a concert hall. It also shows in irony the building process, showing a conventional metallic structure which is deformed by mechanic processes, appearing to be an act of destruction. This shows that his work is also appreciated and discussed by the lay public.

This paper starts with the hypothesis that, far from being a random procedure, the Guggenheim in Bilbao was a project that justified the use of parametric control of form, to harmonize classical practices of form organization with the logic of fractal geometry. The connection with this kind of geometry was made to guarantee a dialogue between the building and the city in its natural and built elements. Starting from this brief literature review, we invested in formally investigating the building, in its objective elements characterized by its geometry. Thus, identifying the formal organizational logics involved, from classic to recursive.

## 2 Methodology

This paper expands on the study registered in Rocha and Borda (2016), incrementing the method, drawing on Fonatti (1988) and using the concept of Fractal Dimension. We start with the analysis of digital documentation, which includes photographs of the surroundings of the building and photographs and technical representations of the building, such as plans, sections, and elevations, made available in books, magazines, videos and on the web.

To understand the use of logics relative to the Fractal Geometry, we continued with graphic analysis, observing the incidence of self-similarity or self-affinity through a comparison process, adding the estimate of the Fractal Dimension, through the Box Counting Method. This consists in applying the grid recursively over the elevations of the building and surrounding buildings, and the analysis of proportion and number of squares occupied in relation to the total number of squares. Costa (2014, p. 80), Sala (2004, p. 41) and Backes & Bruno (2005, p.3) explain this method in more detail.

For the topologic studies, the method can be described in the same terms as Fonatti (1988):

> *'1) [...] the reflections have its origins in the didactic experience in teaching geometry; 2) the base is made up of visual communications (graphic, represented in the form of drawings, plans, formal elements, structural creation matrixes, form analysis, proportion studies and building diagrams); 3. The means is the comparative method, investigating forms and structures through a comparative analysis. And referring to the content the method has four aspects: a) the internal logic of the form… The form in its composition logic… b) The update and the effect of the form. The technical-creative aspects of the form in its origin and its didactic renewal… The form in its origin and appropriation. C) the form in its surrounding. The relation between the form and its external and exogenous constraints; … the form as a creative game in the process of communication, as a concrete result in its surroundings… D) transformation of the surroundings through the form' (Fonatti, 1988, pp.11-12).*

The results of the study show the hypotheses being presented to highlight how much the city's fabric determined and was determined by the formal logics associated with this building.

## 3 Building hypotheses

### 3.1 The origin of the form and its relation to the place

The site chosen by Gehry for the museum is on the banks of the Nervión River, close to the University, the Museum of Fine Arts and the Arriaga Theater, important cultural centers of the city of Bilbao. It has easy access through Iparraguirre Street and Salbeko Zubia Bridge, highlighted in the image on the left in Figure 2. We draw attention to the shape of the terrain, which was already outlined by the curves of the river and the bridge, and can be observed when comparing the two images on the right of Figure 2, before and after the construction of the building. This form is hypothesized as the origin of the vocabulary employed by Gehry.

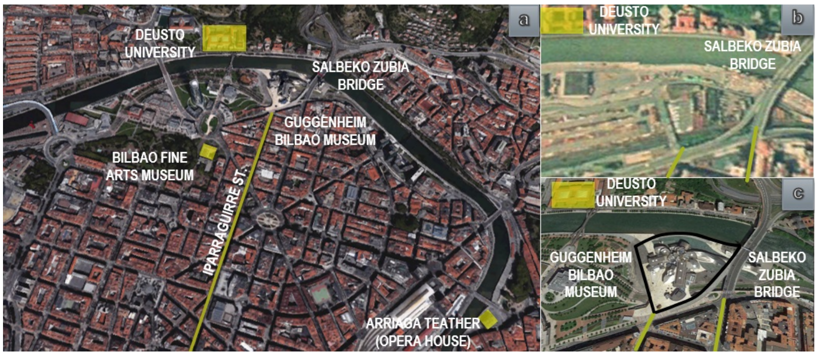


**Fig. 2:** a) The museum and its surroundings, b) site before construction (1991) and c) after construction. Source: Elaborated by the authors based on images taken from Google Earth. Accessed May 2016.

The museum stretches under the bridge, built in the 1970s, through one of its exhibition halls (Room 104), which connects to a tower on the opposite side of the bridge (Figure 3). This tower is the tallest element of all the construction and is the access to the museum for those who arrive from the bridge, being a counterpoint to the volume of the atrium, which only stands out in relation to it regarding its proportions. Gehry reports his intention in designing the tower in a video by Donada (2004):

> *'When I designed the tower, I thought of a sail. There´s a moment when you´re sailing and the boat goes about a new face into the wind. Just for a fraction of a second the sail quivers. I caught that moment. That is what I try to do with my buildings: giving them an impression of movement pleases me because that makes them part of the great move into the city. The buildings are part of life and their change. There is something transitory about them' (Donada, 2004).*

The site surroundings and its topographic conformation were decisive in Gehry's design. To the south, at a higher elevation (located at the level of the access streets), the building presents itself through orthogonal forms and traditional materials. With this, it establishes a relationship with the historical spaces of the city, both formally and by the coatings and colors adopted.

The elements facing North, by the river, show organic forms and reflective materials, such as glass and titanium, which value the relationship between the building and the water and nature, which is reinforced by the presence of a water surface mirror. The titanium gives the building its copper-like color and changes shade according to the time of the day and climate conditions, as observed by Charles Jencks. The fact that this part of the terrain is on lower ground than its surroundings allows the building, even on a monumental scale, to respect the heights of the surrounding buildings, integrating itself to them and still representing an unprecedented element in the landscape.

The atrium, as well as being an internal organizing element, giving access to the galleries through walkways, is also an organizing element in terms of volume, contrasting with what surrounds it. It constitutes a hybrid space, between the exterior and interior, communicating the building to the city and the river thanks to the three storey high glass panes. This space is covered by "a large skylight in the shape of a metal flower" (Guggenheim, 2017), it also seems to be related to the form of the original lot (Figure 2b), which is similar to a leaf or petal (self-affinity).

### 3.2 The form and its external constraints

Figure 3 shows the regulatory strokes and axes with the starting point on the Salbeko Zubia bridge's path. We observe that there is a convergence of such strokes where the atrium is, reflecting its importance in organizing the internal spaces, connecting the axes of the prismatic volumes: the one with greatest extension (which also converges with the axis from the bridge), the one with the smallest extension (to the left) and the one from exhibition room 104, already mentioned before for extending beneath the bridge and connecting to the tower.

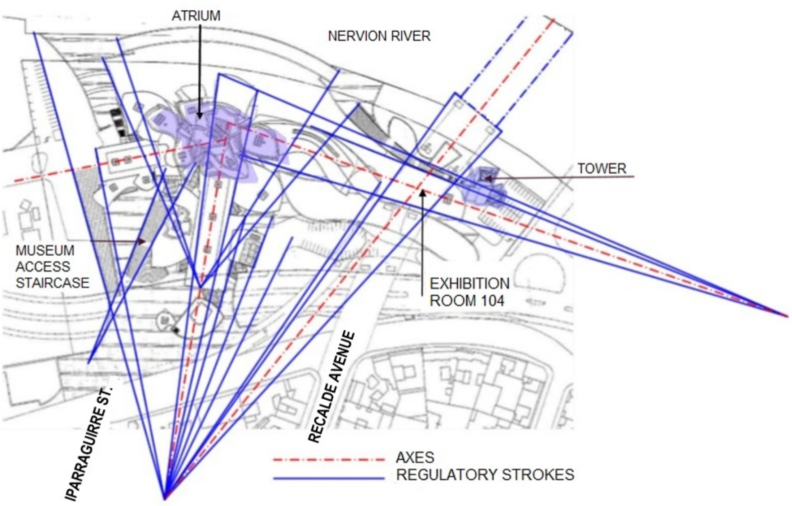


**Fig. 3:** Regulatory strokes. Source: elaborated by the authors based on images available on the internet. Available at: www.jaumeprat.com/el-lugar-de-la-ensenanza/ [Accessed 2 March 2016].

### 3.3 The formal repertoire

The building transits between polyhedral and curved surfaces, between developable ruled surfaces, reverse surfaces and surfaces with a greater degree of freedom. Understanding the organizational scheme of the museum gives us clues to understand some purposes of formal associations, as shown in Figure 4: a) the atrium (in yellow) is a space of central distribution, in hybrid conformation, integrating the formal types of spaces which characterize the building; b) the volumes of the administrative, commercial and exhibition spaces on the ground floor are organized around the atrium, and walkways promote the circulation above it (in yellow); c) "usable areas" are distributed in three floors, and glass panes make the vertical closure between the volumes; d) overall volume, observing prisms, cylinders, these with curved guidelines and orthogonal generatrix (in beige and blue), and cylindroids or free forms (in gray); e) the demonstration of the "working height" of the building, which is less than half of its total height.

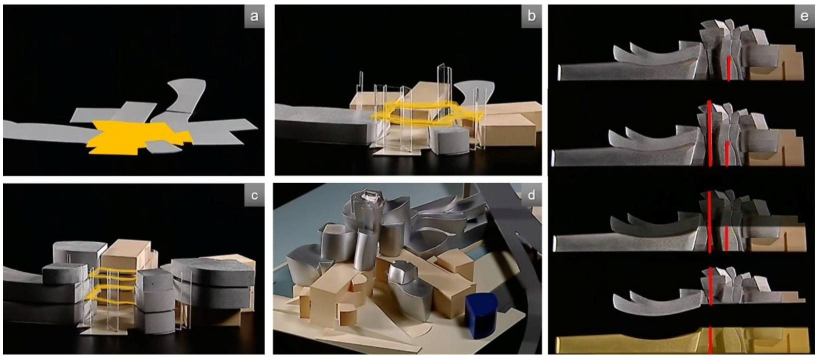

**Fig. 4:** Organizational structure of the museum. Source: Elaborated by the authors based on images from the video by Donada (2004).

As can be seen on the set of images in Figure 5, the types of galleries are associated with the geometry of the spaces. The prismatic volumes comprise mainly the "traditional" galleries, its plans being of rectangular or square shapes, which receive the "classic" exhibitions. The galleries for contemporary art exhibitions have curved floor plans and much higher ceilings.

**Fig. 5:** Exhibition rooms. Source: Elaborated by the authors based on images from the video by Donada (2004).

### 3.4 Form and its composition logic: between proportion and symmetry

As shown in the images in Figure 6, we found correspondence with certain proportions: (b) shows the square root of 2 rectangles on the bounding rectangles of the prismatic volume of the elevation, the grouped windows and each individual window; (c) and (d) show the golden ratio on the prismatic volumes of the "traditional" exhibition rooms, square proportion on secondary volumes and in the "traditional" exhibition rooms, and square root of 2 proportion on the bounding boxes of the curved surfaces. (a) shows the wooden models which, resulting from the plan analysis, we hypothesize as being made from bounding boxes controlled by the square root of 2 proportion which is most frequent in the design. The fact that these forms were produced individually in wood indicates that great care was taken in modeling these surfaces. Lyndsey (2001, p.45) reports that after the design's development in CATIA, a verification model was produced to guarantee the precision of the forms.

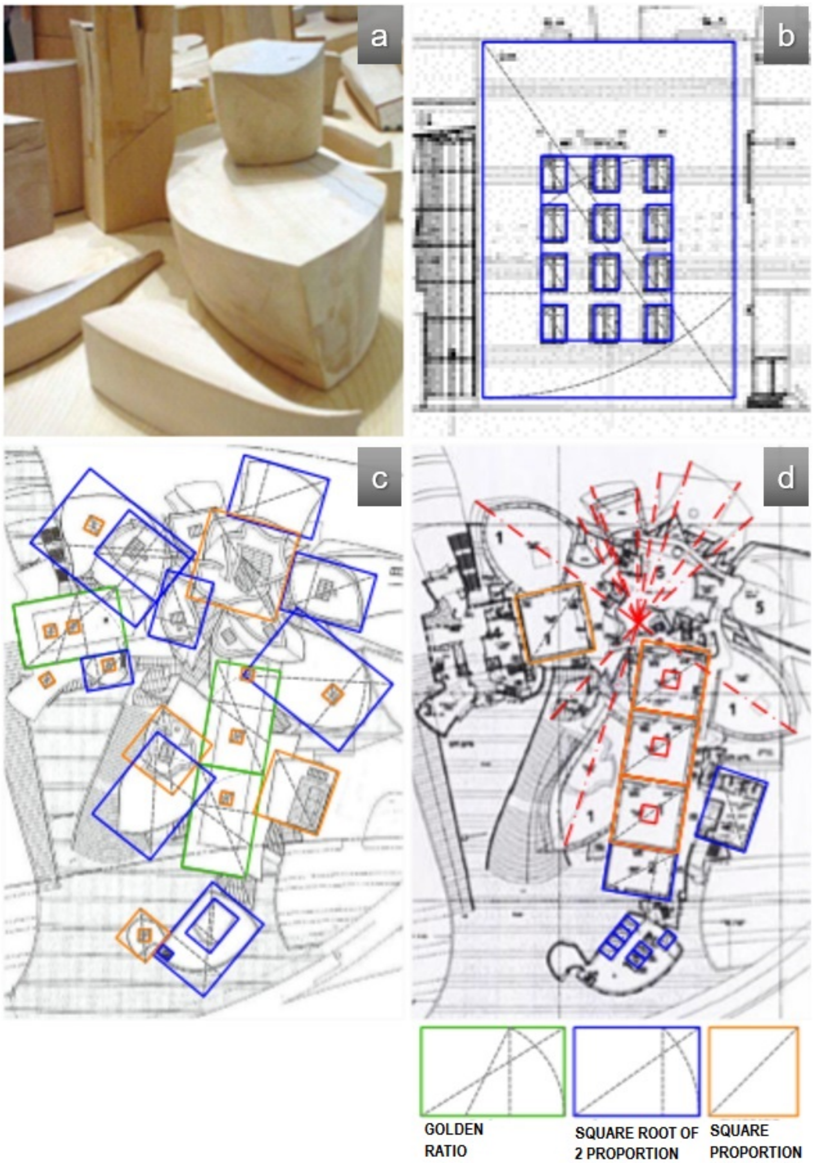


**Fig. 6:** Proportions and symmetries. Source: elaborated by the authors from images available on the internet in Guggenheim, 2017; Pagnotta, 2016 and Slessor, 2010.

### 3.5 Technical-creative aspects and the didactic renewal: the estimation of the Fractal dimension of the building

The calculation of the Fractal Dimension was done based on two confronting images, with the purpose of comparing them: the south elevation of the museum and the group of buildings outlined by vegetation in the background. This was done due to the similarity between the two images (Figure 7), a possible strategy for reflecting the city not only by the light effect on the titanium but also as a result of a geometric transformation, repeating the form itself.

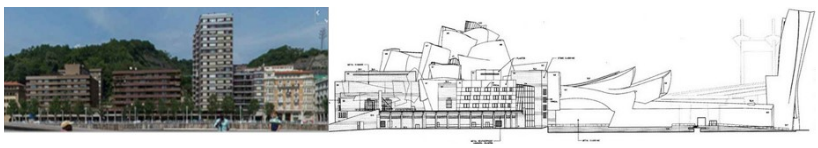

**Fig. 7:** On the left, the image of the surroundings that confront the building, and on the right, the south elevation (facing the city). Source: Elaborated by the authors from images available on Google Earth Application and in Pagnotta, 2016.

We applied the “Box Counting” Method considering three iterations of the recursive procedure of subdividing the reference grid, as shown in the examples of the south elevation in the sequence of images in Figure 8.

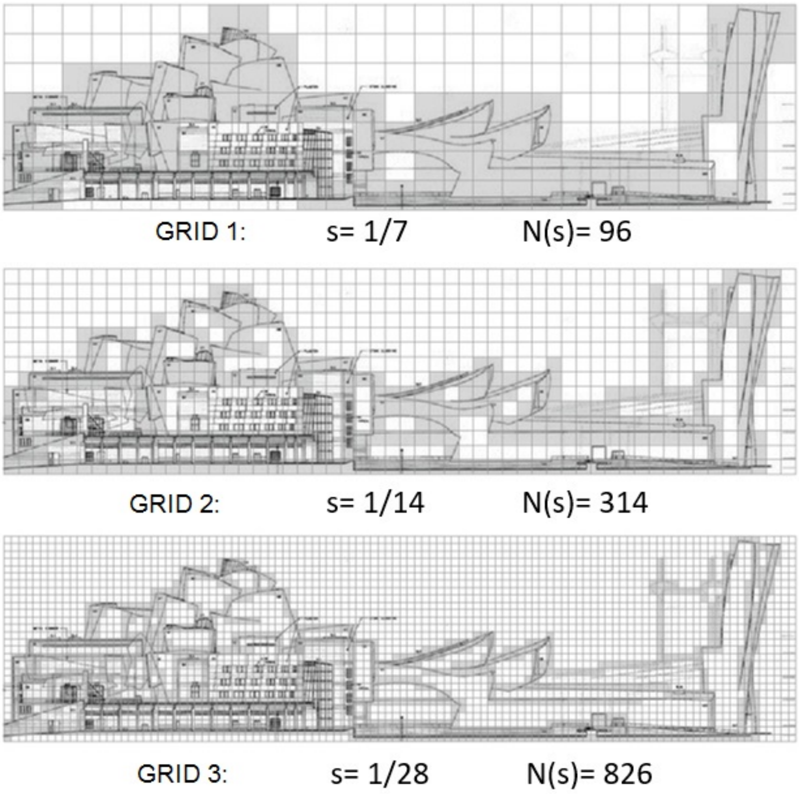


**Fig. 8:** Box Counting method applied to the south elevation (facing the city). Source: Elaborated by the authors from images available in Pagnotta, 2016.

Table 1 shows the calculations in applying the method. The values are very close, demonstrating that although it seems like a group of “riotous forms”, the degree of space occupation, in visual terms, seems to correspond to that of the pre-existing landscape. Thus, permanence is observed through this approach. Rhythmic orthogonal elements in the foreground and later curved contours with similar roughness to the background.

**a) SURROUNDINGS**

| | ITERATION | GRID | VALUE OF "N"(OCCUPIED SQUARES) | S | $D = \frac{\log N(2^{-(k+1)}) - \log N(2^{-k})}{\log 2^{k+1} - \log 2^{k}}$ |
|---|---|---|---|---|---|
| GRID 1 | 0 | 4X12 | 27 | 0,14 | 1,35 [3] |
| GRID 2 | 1 | 8X24 | 69 | 0,07 | 1,21 [4] |
| GRID 3 | 2 | 16X48 | 160 | 0,04 | |

**b) SOUTH ELEVATION (FACING THE CITY)**

| | ITERATION | GRID | VALUE OF "N"(OCCUPIED SQUARES) | S | $D = \frac{\log N(2^{-(k+1)}) - \log N(2^{-k})}{\log 2^{k+1} - \log 2^{k}}$ |
|---|---|---|---|---|---|
| GRID 1 | 0 | 27X7 | 96 | 0,14 | 1,71 [3] |
| GRID 2 | 1 | 54X14 | 314 | 0,07 | 1,40 [4] |
| GRID 3 | 2 | 108X28 | 826 | 0,04 | |

**Table 1:** Calculation of D for a) the surroundings and b) the south elevation. Source: elaborated by the authors.

Note [3] Value calculated based on interactions 0 and 1.

Nota [4] Value calculated based on interactions 1 and 2.

### 3.6 Self-affinity: from urban to the building scale

Depending on the level on which sections are made to obtain the floor plans, the forms of the Museum assume different curvatures. However, in the analysis of the building's site plan, it is possible to identify a counter-clockwise recursive procedure of variation in scale of the different forms, the position of the atrium being the central axis. Figures 9 (a) and 9 (c) show the leaf shaped (same shape as the terrain) patterns and the overlap between these patterns, showing a topological correspondence among them. Figure 9 (b) shows the same patterns on the site plan.

**Fig. 9:** Sickle leaf patterns. a) the patterns identified; b) site plan with the sickle leaf patterns; c) overlap of the patterns. Source: elaborated by the authors from images available on the internet. Available at:www.http://jaumeprat.com/el-lugar-de-la-ensenanza/ [Accessed 2 Mar. 2016].

### 3.8 Transformation of the surroundings from the form: tangency continuity, parallelism and convergence relations in the views

Using physical models, or with precision, through digital means, Gehry controls the form at eye level. He seems to take advantage of anamorphic effects (optical illusions from certain points of view) to achieve continuity and parallelisms. As observed on the images in Figure 10, the photographs chosen to be shown on the Museum's official web site make the intention of continuity and convergence explicit.

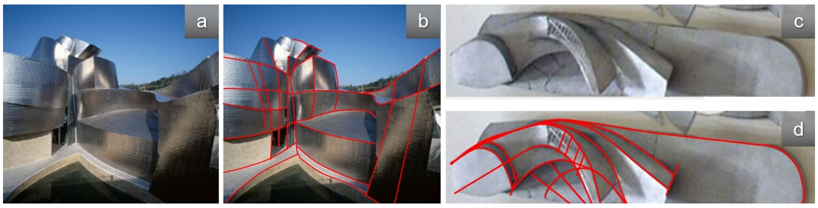

**Fig. 10:** Continuity. Source: elaborated by the authors based on images available on Museum's web site (Guggenheim, 2017).

These images also show the reinforcement of the idea of recursion, of the fractal characteristics of the building, in which the views always refer to the form of a leaf, from which the reference comes from the terrain itself (Figures 2 and 10).

## 4 Results and discussion

We observed that there is considerable distance between the caricature of Gehry's design process, the supposed randomness, shown by the episode of "The Simpsons", and the effective complexity and control of such process. The architect extracted from the site itself the formal vocabulary to be used, as a strategy for establishing a harmonic relationship with the city's fabric. He transited between classic procedures, such as symmetry and proportion reflecting the surrounding landscape, and the use of recursive logics from the fractal geometry, from the urban scale to the detail, the concrete to the perceptive, through anamorphic effects. To decipher this process, we used graphical analysis tools, including the concept of fractal dimension.

Gehry relied on technological advances to ensure the precise control of form, using parametrization techniques, associating the geometric parameters that control each formal type used, re-approximating Mathematics to the action of architectural design. The parameters applied determine convergence, parallelism, perpendicularity, proportions derived from these relations, continuity between each one of the building's elements and the fragments of the urban surroundings. Such relations seek to establish harmony with the place it is in. The parameterization did not determine permanence on the shape of the city, but on the contrary, it generated counterpoints that made its landscape dynamic. On the floor plan, there is the precise circular movement transition between polyhedral and curved surfaces, associated with the purpose of integrating the formal repertoire of the place itself. The riots mentioned by Naomi Stungo were not random but fully controlled, in its visual effects from different points of view. The published photographs of the building, taken from strategic points of its immediate surrounding, declare this purpose. The rhythm is given by the subtle repetition of the formal element extracted from the terrain's contour, perceived by a spectator more attentive to the transformation of the city's landscapes.

## 5 Concluding remarks

We consider that the hypotheses constructed and graphically evidenced explicit the strategies used by Gehry to establish the dialogue between the building and the city's urban fabric.

The use of fractal logic to set the relationship with the place was the strategy to guarantee that the building would maintain its formal unity, at least in geometric terms. The architect uses recursion to establish a harmonic and rhythmic relationship with the place. Proportions and repetitions build a dialog with the existing architecture of the immediate surroundings.

We conclude with the didactic convenience of building architectural criticism associated with objective elements. We understand that this investigative posture activates concepts and procedures, requiring the knowledge structures involved in the designing action to be made explicit.

**References**


Backes, A. and Bruno, O. M., 2005. Técnicas de Estimativa da Dimensão Fractal: um Estudo Comparativo. INFOCOMP (UFLA), v. 4, n. 3, pp. 50-58.

Bilbao Ría 2000, S.A., 2015. *Bilbao Ría 2000.* Bilbao. Available at: <http://www.bilbaoria2000.org/ria2000/cas/bilbaoRia/bilbaoRia.aspx?primeraVez=0>. [Accessed 21 May 2017].

Costa, P. C., 2014. *Metodologia aplicada ao cálculo da dimensão fractal de formações urbanas utilizando o índice de desenvolvimento humano municipal (IDHM) como critério de seleção.* Revista Mackenzie de Engenharia e Computação, v. 14, pp. 71-90.

Donada, J. (Director), 2004. *Le Musee Guggenheim de Bilbao* [Movie Film]. Available at: https://www.youtube.com/watch?v=hhJ62_IJKWw&t=307s.

Fonatti, F., 1988. *Principios elementales de la forma en arquitectura.* [s.I.]: Gustavo Gilli.

Ganhão, S. M. G. R., 2009. *Fractais na arquitectura.* Artitextos, 8, pp. 261-271.

Giron, L. A., 2015. O Arquiteto Espetacular. *Revista Florense*, 45, pp. 12-19.

Guggenheim, 2017. *The Solomon R. Guggenheim Foundation.* Available at: <https://www.guggenheim-bilbao.eus/el-edificio/> [Accessed 18 May 2017].

Isenberg, B., 2009. *Conversations with Frank Gehry.* New York: Alfred A. Knopf. E-book.

Jencks, C., 2002. The New Paradigm in Architecture. In: C. Jencks, ed. 2002. *The New Paradigm in Architecture: The Language of Post-Modern Architecture.* London: Yale University Press. pp.155-163.

Jones, D., 2015. *Tudo sobre Arquitetura*. Rio de Janeiro: Sextante.

Lindsey, B., 2001. *Digital Gehry: material resistance / digital construction.* Basel; Boston; Berlin: Birkhäuser.

Mandelbrot, B. B., 1983. *The fractal geometry of nature.* New York: W. H. Freeman and Company.

Fox television, 2005. *The Simpsons.* Episode 349: The Seven-Beer Snitch. Available at: <www.youtube.com/watch?v=S4S0Qk813fg&list=PLkRnEV5E-n9xSysZ4HmfEokbEuol09yfi&index=6> [Accessed 21 May 2017].

Ostwald, M. J.; Vaughan, J., 2013. Representing architecture for fractal analysis: a framework for identifying significant lines. *Architecture Science Review*, 56, pp. 242-251.

Oxman, R., 2006. Theory and design in the first digital age. *DESIGN STUDIES*, 27. London: Elsevier, p. 229-265. Available at: <http://www.technion.ac.il/> [Accessed September 2015].

Pagnotta, B., 2016. *Clássicos da Arquitetura: Museu Guggenheim de Bilbao / Gehry Partners.* Tradução: Eduardo Souza. 2016. Available at: <www.archdaily.com.br/br/786175/classicos-da-arquitetura-museu-guggenheim-de-bilbao-gehry-partners> [Accessed 02 June 2017].

Rocha, L. S. and Borda A. S. A., 2016. Entre o discurso e os elementos objetivos que descrevem a forma do museu Guggenheim de Gehry. In: *4th Enanparq: Encontro da Associação Nacional de Pesquisa e Pós-Graduação em Arquitetura e Urbanismo,* Porto Alegre: PROPAR / UFRGS.

Sala M. and Librantz, H., 2006. A geometria fractal e suas aplicações em arquitetura e urbanismo. *Exacta*, pp. 91-93. [on line] Available at: <http://www.redalyc.org/articulo.oa?id=81009916> [Accessed 18 May 2017].

Sala, N., 2004. *Complexity in architecture: a small scale analysis.* In: M. W. Collins and C. A. Brebbia ed. 2004. *Design and Nature*. v. 2. Sowthampton, Boston: WIT Press.

Sedrez, M., 2009. *Forma fractal no ensino de projeto arquitetônico assistido por computador.* Master. Universidade Federal de Santa Catarina.

Slessor, C., 2010. *1997 December: Guggenheim Museum By Frank O. Gehry & Associates (Bilbao, Spain).* Available at: <www.architectural-review.com/buildings/1997-december-guggenheim-museum-by-frank-o-gehry-and-associates-bilbao-spain/8603272.article> [Accessed 04 June 2017].

Stungo, N., 2000. *Frank Gehry.* São Paulo: Cosac & Naify.

Zaera-Polo, A., 2015. *Arquitetura em Diálogo.* São Paulo: Cosac-Naify, pp.203-237.