

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/349611734>

# Free-Form Geometries in Contemporary Architecture : Dimensional Rules of Folded, Blob and Formlessness Architecture

Article in IOP Conference Series Materials Science and Engineering · February 2021

DOI: 10.1088/1757-899X/1058/1/012043

CITATIONS

0

READS

160

3 authors:



Anas Hameed

University of Baghdad

8 PUBLICATIONS 0 CITATIONS

SEE PROFILE



Hoda A. S. Al-Alwan

University of Baghdad

60 PUBLICATIONS 35 CITATIONS

SEE PROFILE



Nazar K Ali Oukaili

University of Baghdad

146 PUBLICATIONS 185 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Prestressed BubbleDeck Slabs [View project](#)



effect of fire flame on the behaviour of the composite deck floors [View project](#)

PAPER • OPEN ACCESS

## Free-form geometries in contemporary architecture – dimensional rules of Folded, Blob and Formlessness architecture

To cite this article: Anas Hameed Majeed *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1058** 012043

View the [article online](#) for updates and enhancements.



The Electrochemical Society  
Advancing solid state & electrochemical science & technology

**240th ECS Meeting** ORLANDO, FL

Orange County Convention Center Oct 10-14, 2021



Abstract submission due: April 9

**SUBMIT NOW**

# Free-form geometries in contemporary architecture – dimensional rules of Folded, Blob and Formlessness architecture

Anas Hameed Majeed<sup>1,\*</sup>, Huda Al-Alwan<sup>1</sup>, Nazar Oukaili<sup>2</sup>

<sup>1</sup>Department of Architectural Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.

<sup>2</sup>Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.

\*Corresponding author: anas.h.majeed@coeng.uobaghdad.edu.iq

**Abstract.** The style of Free-form Geometry (FFG) has emerged in contemporary architecture within the last three decades around the world through the progress of digital design tools and the development of constructive materials. FFG is considered as the hard efforts of several contemporary architects to release their products from familiar restrictions to discover new and unfamiliar styles under the perspective of innovation. Many contemporary architects seek to recognize their forms and facilitate dealing with according to specific dimensional rules. The main research problem is the lack of knowledge, in the field of architecture, in previous literature about the formation processes in achieving FFG in contemporary architecture as a response to the new requirements that make architecture more flexible in the final expression and breaking away from regularity. Thus, this paper aims to establish a theoretical framework to determine dimensional rules as formation techniques and utilize them as tools in designing processes, to finally benefit to attain several free-form geometries in architecture now and in the future. The research results confirm the importance of dimensional rules in the designing processes as an effective contribution to achieving FFGs in contemporary architecture.

**Keywords:** Free-form geometry FFG, dimensional rules, folded, blob, formlessness.

## 1. Introduction

Free-form geometries (FFGs) were regarded as one of the expressive appearance in modern architecture with the technical developments of reinforced concrete. FFGs have emerged strongly in contemporary architecture with the progress of digital designing tools and the technical development of steel which achieves an innovative architectural structure with excellent load-bearing solutions and an applicable aesthetic architectural style.

The eye-catching effect of the FFG can inspire new notions for contemporary architecture. FFGs were distinguished for the first time in architecture through the pioneer works of Frank Gehry via applicable and flexible surfaces. These surfaces had the abilities, by their geometries, to unfold or bend in several different directions without tearing or failing.



The lack of knowledge, in the field of architecture, in previous literature about the formation processes in achieving FFG in contemporary architecture as a response to the new requirements that make architecture more flexible in the final expression and breaking away from regularity, represents the main research problem. Therefore, This paper assumes that folded, blob, or formlessness geometries have specific dimensional rules that had an impact on FFG in architecture now and in the future.

According to this perspective, the following paragraphs tackle the main research problem through four main axes: the first axis introduces the main notions of the paper including the general relationship between form and geometry, the concepts of form versus shapes, and interactive expressions for forms and shapes. The second axis deals with the role of geometry as a starting stage in the architectural design process, including several guide methods to achieve various geometric forms. The third axes include data analysis of FFG and categorizes them into folded, blob, and formlessness geometries.

Finally, discussion and conclusions are presented as the fourth axis.

## **2. General Relationship Between Form and Geometry**

### *2.1. Form vs. Shape*

Form and shape can be distinguished according to their two- or three-dimensional appearance. Ching [1] distinguished between them according to dimensionality, form's depth as a third dimension as well as width, and height is notable, while the shape has two dimensions. Also, shapes can be classified as either geometric or free-form. Geometries are defined by mathematical formulas, which means, mathematical formulas can be presented by the geometric graph. Circle, square, triangle is considered as standard, ordinary, and regular geometric shapes. Oval, rectangular, octagon, parallelogram, trapezoid, pentagon, and hexagon are considered as derivations from these regular forms. Otherwise, free-forms, as organic, non-standard, irregular shapes, are the deformation of these mentioned earlier by changing the amount and direction of the depths. For example, square and triangle shape; while the free-form geometrical version of these shapes can be as bent cubes or twisted cones via several ways of transformations. Architects, with the novel imagination and digital tools, use both forms and shapes with their potentialities to represent the new [1].

### *2.2. Interactive Expressions for Forms and Shapes*

The closer shape to Euclidean geometry and basic shapes, the less interaction with recipients according to activity and stability. Also, opened or closed shape may form light or heavy expression. In addition, active shapes are diagonal with orthogonal lines and they may seem more energetic, on the other hand, static shapes are often straight with horizontal lines and may appear quiet [2].

Another expression can be noticed by describing form and shape as either organic or geometric. Organic forms such as snow-covered stones with an irregular and asymmetrical outline. In other words, organic forms are the production of nature. The structural system of the building form depends on its geometry, materials, and the reaction ways of the forces that applied to them. Likewise, these can affect the dimensions, proportion, and other factors to create the geometry of the building.

## **3. Geometry**

Geometry is the starting stage in the architectural design process, it is related to mathematics as principals in classic architecture, such as Greek architecture [3]. Therefore, geometry is a branch of mathematics concerned with shape, size, positions, and properties. It arose earlier as knowledge concerning one-dimension (length, bar), two-dimensions (area, surface), and three-dimensions (volume, space), with elements of a formal science [3].

Later, geometry became more attractive in the architectural design process with great innovations from form-finding stages to the final fabrication. Advanced digital tools provide a variety of options for efficient design, analysis, and fabrication of free-form geometry, which opens new possibilities for architecture and new problems to geometry that poses the architectural context. [4]. As we know the geometry of the object has a real effect on designing via the vision attraction in order to win the eye-catching.

The digital design provides a high potentiality of new expertise in designs of free-form geometry. Helmut Pottmann confirmed that geometry is a potential effect to create a new approach of free-form design that is considered for structure [3]. Therefore, the knowledge of geometry is one of the major principles in architectural design. Much consideration has been given to this topic with the start of free-form geometry in architecture and architectural geometry is becoming unfamiliar with more complicity and complexity.

### 3.1. Geometries Guided by Basic Pieces

Before dealing with free-form or complex geometries, the first impression in dealing with the geometry of buildings is the ability to imagine if it would be supposed by linking its geometry with the basic simple forms, then it will be decided even they are simple or complicated geometry. For instance, the glass pyramid at the Louvre in Paris is considered as one of the simplest geometrical buildings, because its geometry follows a simple pyramidal form with a simple squared plan ‘figure 1’ [5]. Otherwise, designers tried to release a little from basic forms by dealing with various options of choosing pieces from simple forms to achieve the desired geometrical goals, such as Pyramid of Botanic Gardens Science in Denver ‘figure 2’ [6].

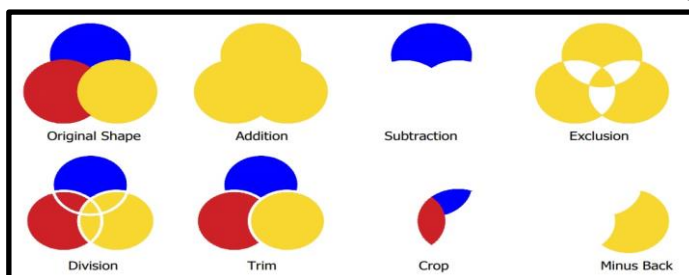


**Figure 1.** The glass pyramid at the Louvre in Paris [5].



**Figure 2.** Pyramid of Botanic Gardens Science in Denver [6].

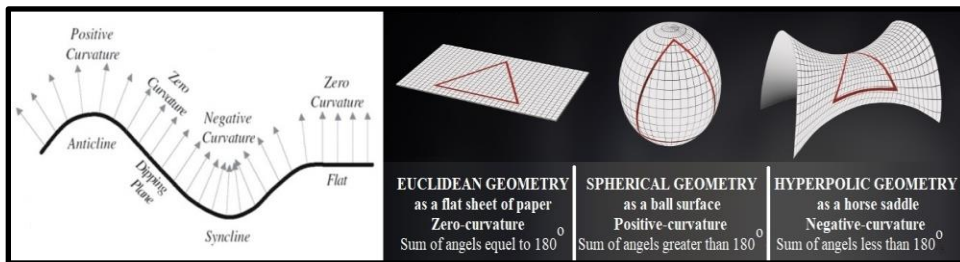
Besides, the various pieces of simple form or shape can produce complicated and complex geometries by the effects of joints. Explanations of the procedure in each category will be followed to create an analytical framework for the geometry. It can be clarified the idea by using circles, for example, with different properties and the final results will be different according to the applied effects on the three colored circles which are shown in ‘figure 3’ [7].



**Figure 3.** Different results on a simple shapes according to various possible effects [7].

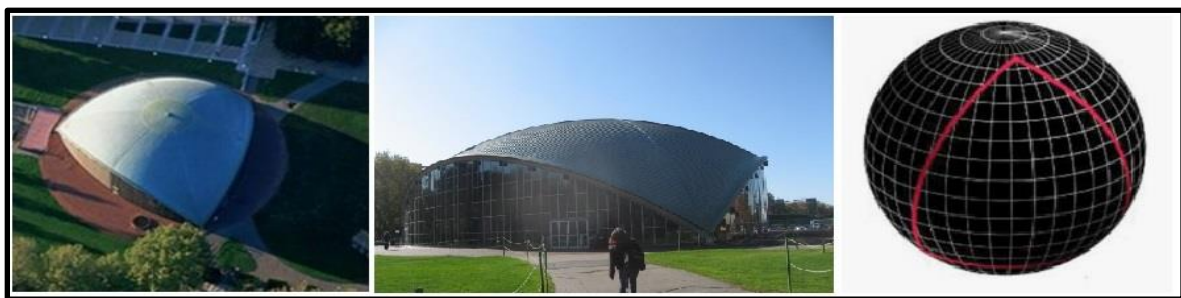
### 3.2. Geometries Guided by Curved Lines

As it is known, the basic elements of standard shapes are line and plane. The behavior of the line, as the first tool of design, is represented according to its common directions on the three-dimensional space to create the geometries. This means that geometries can be guided by lines’ behaviors according to their directions whether *Positive-curved lines* or *Negative-curved lines* [8]. Therefore, it can be noticed that a positive-curved line guides the spherical geometry, while a negative-curved line guides hyperbolic geometry, ‘figure 4’.



**Figure 4.** Lines' behaviour: Positive-curved lines and Negative-curved lines [8].

*Positive-Curved Lines* respond to repulsive forces, like a spherical surface, that does not have any boundaries [9]. Kresge Auditorium in Cambridge is an obvious example of such geometries that are guided by positive-curved lines 'figure 5' [10].



**Figure 5.** Positive-curved lines guide the geometry of Kresge Auditorium in Cambridge [10].

*Negative-Curved Lines*, which like a saddle, mean that negative curvature which is parallel to attractive forces creates hyperbolic geometry. Chapel of Nôtre Dame du Haut is a clear example of such type 'figure 6' [11] which has a huge shell of the concrete roof with curved walls that gave the building a sculptural form [12].



**Figure 6.** Negative-curved lines guide the geometry of Chapel of Notre Dame du Haut in Ronchamp [11].

Mixing by simple ways in the joining areas of the two previous types of curved-lines, or curvatures clarifies and simplifies the design processes of complex buildings. Besides, It helps the designers to a wide domain with rhythm and diversity in designing processes in order to produce a different composition. Mixing with positive and negative curvature can be noticed with the project of The NeuroSpin Building 'figure 7' which was constructed with a wave-shaped roof [13].

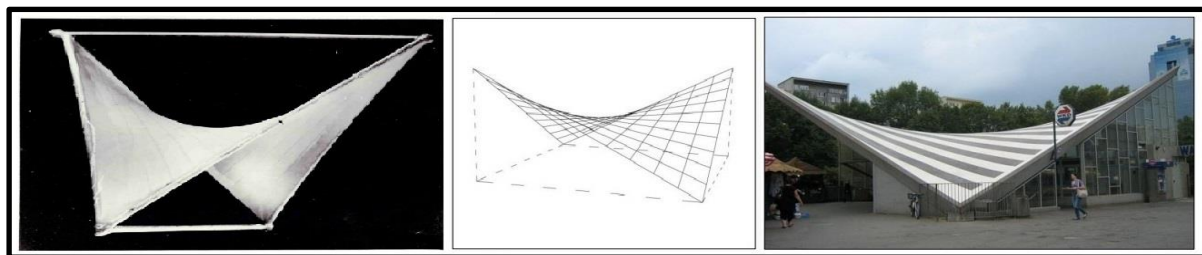




**Figure 7.** Mixing the positive and negative curvatures in The NeuroSpin Building in Paris [13].

### 3.3. Geometries Guided by Basic Pieces with Curved Lines

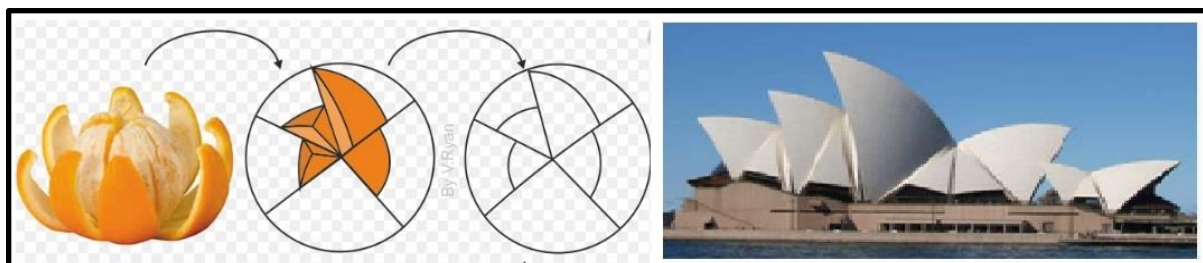
Hyperbolic paraboloid shape can be transformed into geometry by double curvature with twisted straight lines. The doubly curved-surfaces, of this geometry, have horizontal cross-sections with a hyperbola shape and vertical cross-section with a parabola one. This shape can be constructed as a saddle roof from diagonal straight beams [14] producing a strong effect with the properties and possibilities of structural necessity especially the principle of self-supporting. This is because of the warped-shape which helps to control buckling effects in the compression state with some stressed members to involve the capability to tension. Warszawa Ochota railway station in Warsaw ‘figure 8’ is considered as a clear structural example of such geometries [15].



**Figure 8.** Hyperbolic paraboloid structures of Warszawa Ochota railway station in Warsaw [15].

#### 3.3.1 Complicated Geometries from Cut-Pieces Guided by Curved-Lines

Various curvatures as positive, negative, and mix of them have been showing and analyzed. Furthermore, there are many other methods to combine directions of these curvatures in order to create more complicated geometries such as cut-pieces guided by curved lines. Sydney Opera House ‘figure 9’ is the clearest example to explain the method of combination between directional curvatures and cut-pieces from the basic form, the sphere [16].

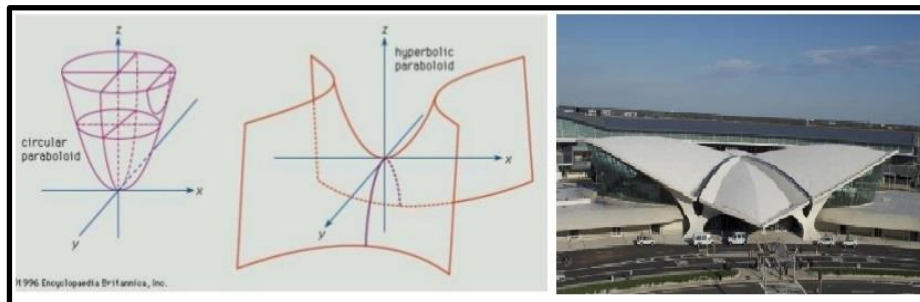


**Figure 9.** Complicated geometries guided by cut-pieces with curved-lines of Opera Sydney House in Australia [16].

#### 3.3.2 Complicated Geometries from Join-Pieces Guided by Curved-Lines

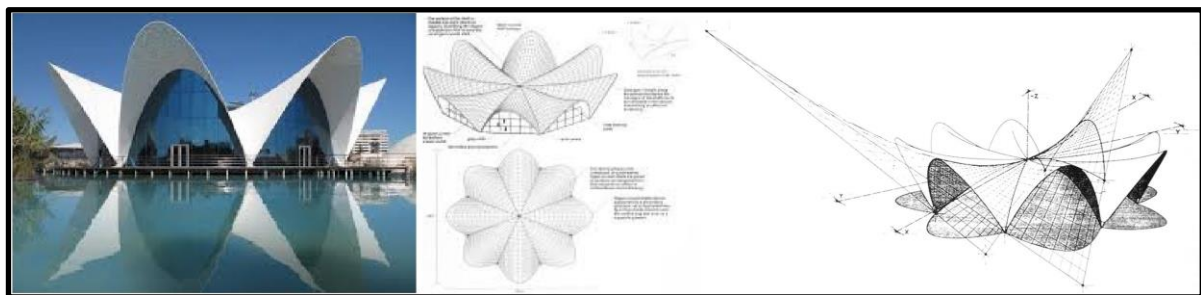
Hyperbolic paraboloid, a single whole form, can be separated into several curved pieces. In other words, the whole form can be divided into basic elements of this form as curved pieces, then they are

joined together to create possibly new complicated and complex forms. TWA Terminal roof, in New York City ‘figure 10’ [17], has a major central curvature which can be defined, according to the previous explanation, as a cut piece of hyperbolic paraboloid form lied between another two curvatures. The joint expression of these pieces reflects the flying inspiration. This example is considered as one of the modern geometric buildings [18].



**Figure 10.** Complicated geometries by joining pieces with curvature lines of TWA Terminal roof in New York [17].

The curvatures’ joints have adequate flexibilities that reflected the architectural desires to create free-form geometry. Candela’s first idea of releasing from traditional geometries was a Lotus Flower Building 1958 ‘figure 11’ [19]. The geometric form was produced by an eight-segments space (as joining pieces) assembled from four hyperbolic paraboloid form [20].



**Figure 11.** Curvatures’ joints of Candela’s Lotus Flower Building in Mexico City [19].

#### 4. Free-Form Geometries

Free-form geometries are noticeable notions of contemporary architecture since the late 20<sup>th</sup> century till now. The geometrical form of these structures can be created with graphical software programs that can produce new, irregular, non-standard forms under the principles of digital design. CAD, as one of the digital design tools, enables architects and designers to produce non-limited free-form geometries for innovative contemporary architecture [21]. To realize the geometries of these free-forms, it can be categorized into three types, as will be clarified, according to their various visual expressions among them.

##### 4.1 Folded Geometries:

Folded geometries emerged and became popular in the contemporary era, they had inspired by several architects to create three-dimensional models (geometry) from two-dimensional sheets (surfaces). This transformation from two- to three-dimensional geometry provides simpler and more intuitive solutions in architecture [22].



The 'Origami' term, in Japanese 折 comes from the word (Ori-) which means folding, and (kami-) which means paper, is the art of folding papers that have been closely related to Japanese culture. Contemporary applications of "Origami" that are related to the comprehensive term for all folding practices, in spite of their cultural origin, aim to transform a flat plane shape to a final geometry by folding techniques without any usage of cutting nor pasting in order to produce a self-supported system. Which means, this type of structure depends on the strength properties that are produced from the folding techniques on the form [22].

So, folded geometries are formed by repeating some of the approximate prototypes of polygonal geometric forms. These prototypes are created with considering the properties of geometry, proportion, and order as means of inspiration for several different architects of the world because of the unique characteristics of origami thought such as [22]:

- Dynamic behavior that ranges between two- and three-dimensional space.
- Continuity by using one surface.
- A variety of expressions result from the various process of surface folding.

Folded geometries can be classified into two sub-categories according to their formations and the final expression using descriptive analysis,:

**4.1.1 Rigid (segmented) folding geometries.** This type focuses on the joints of sectors of free-directional lines to achieve the form transformations for these geometries [23]. These joints are essential elements of this stylistic folded system with the existence of surface plates between the folds that remain flat which gives the advantage of modifications and developments of such forms. Origami Pavilion in Shinto reflects this type of folding geometries 'figure 12' [24].

**4.1.2 Flexible (curved) folding geometries.** This type focuses on achieving a curved bending line, which is characterized by complexity compared with the previous type, because the making-process of a curved bending changes both the bending lines and the faces between them simultaneously, which makes it difficult to describe the bending processes [25]. Duncan, in his book *Mechanics of Sheet Metal Forming*, provided a new description of the surface relationships between the curves of each side of the bend as well as the curvature of the bend line itself. Al-Wakrah Stadium reflects this type of folding geometries 'figure 13' [26].



**Figure 12.** Rigid (segmented) folding geometries and its application on Origami Pavilion in Shinto [24].



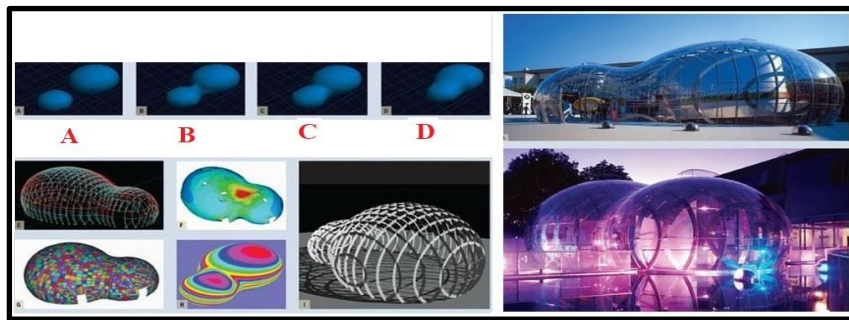
**Figure 13.** Flexible (curved) folding geometries of Al-Wakrah Stadium in Qatar [26].

#### 4.2 Blob Geometries

Blob geometries, as a new type of free-form architecture, became noticeable landmarks with the progress and the developments of spatial structures, especially grid-shells, that served wide spans and covered open-courtyards. These irregular forms need innovative design processes, advanced technological and structural systems that vary from traditional and familiar systems. Blobs, which are distinguished as irregular geometry, are not instituted on Euclidean principles of plane surfaces.

Various analytical researches concluded that the designs of blob geometry, which are based on several parameters according to external forces, for example, have new products with informal and unfamiliar compositions that produce eye-catching-influences especially in the urban context and skylines [7].

BMW Bubble Pavilion in Germany, 'figure 14', is generated by an unfamiliar design process depending on a virtual prototype. Its generative three-dimensional model is powered by 3DStudioMax started by two various water drops laid on a horizontal plane, then they are getting touched, merged, and finally frozen [7].



**Figure 14.** Blob form of BMW Bubble Pavilion in Germany [7].

The available solutions for the structures of blob architecture are numerous and various, but the grid-shell structures with metal, glass, or plastic claddings are the most sufficient and applicable techniques for such a form of geometries.

Another example of blob form is the grid-shell roof of the Złote Tarasy complex building 'figure 15' [27], it consists of a rippled geometrically complex surface, the steel elements of its grid-shell were assembled with triangular panels of glass which cover the internal spaces with transparency for lighting and shading that are required for the main courtyard. The formal potentiality of the blob-surface makes the roof touches the ground at the front side, forming the main entrance to the complex.



**Figure 15.** Blob grid-shell form of Złote Tarasy Complex Building in Warsaw [27].

Guggenheim Museum 'figure 16' [28], is considered according to analysts and specialists, is a mixture form that is created from folded geometries (Foldism) and blob geometries (Blobism). Its exception came from the absence of straight lines and flat surfaces on its structure, which is covered by polished titanium panels according to the architect's concept, Frank Gehry [7].



**Figure 16.** Mixing between Folded and blob in Guggenheim Museum in Bilbao [28].

#### 4.3 Formlessness Geometries

Formlessness geometries can be distinguished after reviewing the definition of ‘form’. Form relates to shape, has a visual appearance with the configuration of an object. It has framed, systematic and geometric regulations that are potentiated by mathematics. The architectural form is applied to organized rules which drive this form in an ordered or in a systematic frame. For an obvious example, designing houses was dependent on a very simple cube, or other basic geometric forms, which was represented by six sides included with its plan side. While dealing with formlessness geometries drives this form release from the ordered or systematic familiar frame but the expressive appearance and a foggy system. In other words, straight lines or corners will be absent.

Therefore, formlessness geometries can be considered as an advanced and developed geometry of the de-construction movement which has been changed the forms, spaces, and the overall definition of geometry. So, de-constructive geometries were a starting point for formlessness and the special example of this movement is the Notre Dame du Haut in Ronchamp ‘Figure 6’. Nature, with its great formless and disordered sources, is inspired by several recent architects, it is interpreted as being free-guided, just like splitting a fluid over the ground with no order or guide to pouring [29].

Frank Gehry’s example of The Experience Music in Seattle, Washington 1996 ‘figure 17’ [30] contains a cluster of six bulging units which are cladged and assembled with different materials and various colors. The surfaces with curvatures and folds have quite finished metal skin with the impression of flexibility and plasticity [31].



**Figure 17.** Project of the Experience Music in Seattle [30].

## 5. Conclusion

This paper addresses a topic of free-form geometries in contemporary architecture, which tries to release from the Euclidean principles, by distinguishing remarkable global examples. Analyzing the geometrical implementation of these examples can be considered as principal clarification for this contemporary style. Thus, dimensional rules, as a result of the geometrical analysis, will help to suggest few extensions with new applications to obtain an infinite number of potentialities according to their assemblage of geometrical components.

After revealing the main concepts of free-form geometry and highlighting them with elected remarkable global examples, the following conclusions were drawn:



- Dealing with the geometry of buildings starts with the ability to imagine the links between the geometry of existing buildings with the basic simple shapes. Then, it can choose pieces from these basic shapes to create complicated geometries.
- Dimensional rules had a great role in the complicated geometries through their guidance of basic pieces, curved lines, or both, taking into consideration the cutting and joining techniques.
- Dimensional rules of folded geometries represented by enabling a flat two-dimensional surface to transform into a three-dimensional geometry through folding techniques to produce a self-supported system with repeating approximate prototypes of polygonal forms. The final folded geometries are highly inspired due to the dynamic behavior that ranges between two- and three-dimensionality, the surface continuity, and the variety of expressions.
- Blobs geometries have free-form, irregular, and unfamiliar compositions that consist of plane surfaces. Dimensional rules enable surfaces to transform into blob geometry, according to several parameters such as external forces, with the assistance of grid-shell potentialities.
- Formlessness geometries, which have been changed the total definition of geometry, are inspired by the nature as a great source because of unfamiliar order or free-guided flow.

## 6. References

- [1] Ching F 1996 *Architecture: Form, space, and order* second ed. New Jersey John Wiley and Sons
- [2] Allen D Mar 2003 The Surface of Fuller and Sadao US Pavilion at Montreal Expo 67 *Architectural Design* **162** 51-55
- [3] Pottmann H 2007 *Architectural Geometry* Bentley Institute Press 1<sup>st</sup> edition
- [4] Mungan I 1988 Domes From Antiquity To The Present *proceeding of the IASS-MSU international symposium* 251-252
- [5] Jiang Y 2019 Globalization National Identity and the Transformation and Renovation of Museums in France and Mainland China *KnE Social Sciences* 14-25
- [6] Article 85985 2020 denver botanic gardens science pyramid [online] Available at: <<https://www.buildingenclosureonline.com/>> [Accessed July 2020]
- [7] Biondi E 2006 When The Architecture Comes From a Water Drop The Blob Structures *Politecnico Di Torino* 10-15
- [8] Callens S J and Zadpoor A A 2018 From flat sheets to curved geometries: Origami and kirigami approaches *Materials Today* **21** 241-264
- [9] Taffur S 2010 *propuestas in\_consultas Retrieved from Entrevista W James (Jimmy) Alcock Premio Nacional de Arquitectura 1993 Venezuela Arquitecto venezolano Karina Lyn Entre Rayas*
- [10] Plunkett J W, Mueller C T 2015 Thin Concrete Shells at MIT Kresge Auditorium and the 1954 Conference *In Proceedings of the 5th International Congress on Construction History. Chicago.*
- [11] Kaimakliotis D and Lau B 2011 *The poetics of contemplative light in the church of Notre-Dame-du-Haut designed by Le Corbusier* PLEA
- [12] Outmoune N and Arrouf A 2019 July The design process at Le Corbusier, case of the Ronchamp chapel *In Proceedings of the Design Society: International Conference on Engineering Design* Cambridge University Press **1** 1275-1282
- [13] Kiser C 2004 *Arcspace Corporation Retrieved May 29 2012 from Arcspace web site* <http://www.arcspace.com/architects/calatrava>
- [14] Sprague T 2012 *Hyperbolic Paraboloid and Northwest Modernism arch* [be]log
- [15] Mościcka A, Pokonieczny K, Wilbik A, Jakub W J 2019 Transport accessibility of warsaw: A case study *Sustainability* **11** 5536
- [16] Rey J R 2013 *The disappearance of the structural analysis barrier the Sydney Opera House from a contemporary perspective Structures and Architecture Concepts Applications and Challenges* Taylor and Francis Group

- [17] Whitehead R 2014 Saarinen's shells: The evolution of engineering influence. *In Proceedings of IASS Annual Symposia International Association for Shell and Spatial Structures (IASS)* **2014** 1-8
- [18] Stoller E 1999 *The TWA Terminal The Building Block Series* Princeton Architectural Press 1<sup>st</sup> edition
- [19] Mendoza M, Chilton J C 2008 *Learning from the shell builder: Felix Candela International Symposium IASS-SLTE 2008 New Materials and Technologies New Designs and Innovations - a Sustainable Approach to Architectural and Structural Design*
- [20] Burger N 2006 *An Examination of The Xochimilco Shell* Department of Civil and Environmental Engineering Princeton University Princeton NJ USA
- [21] Elizah N 2011 *Amazing Architecture Retrieved from 15 (More!) World's Weirdest Buildings*
- [22] Azzam M 2020 Twenty-two Architectural magazine no. 85th March 2020 A monthly Arabic-language architectural magazine published on the twenty-second of every month that contains translated projects and a number of articles research papers and interviews
- [23] Tachi T 2010 Freeform rigid-foldable structure using bidirectionally flat-foldable planar quadrilateral mesh *Advances in architectural geometry* **14** 203-215
- [24] BANGHAY S 2000 From Virtual to Physical Reality with Paper Folding *Computational Geometry Theory and Applications* **15** 161-74
- [25] Bacinoğlu Z, Piskorec L, Kotnik T 2019 CURVED IT A design tool to integrate making with curved folding into digital design process *ITUAZ* **16**
- [26] Abdullah A, Said I, Ossen D 2013 Zaha Hadid's techniques of architectural form-making *Open Journal of Architectural Design* **1** 1-9
- [27] Berezko O 2013 Walkways Analysis of Złote Tarasy Mall in Warsaw *Geodesy Architecture & Construction (GAC-2013)* 21-23
- [28] Plaza B 2006 The Return on Investment of the Guggenheim Museum Bilbao *International Journal of Urban and Regional Research* **30** 452-467
- [29] Mostafavi D L 2002 *Surface Architecture* United State MIT press
- [30] Crowley W 2003 *Experience Music Project opens at Seattle Centre* 2000 <http://www.historylink.org/file/5424>
- [31] Johnson J 2007 *Frank Gehry in Pop-Up* (2nd ed. 10-24) UK: Baker and Taylor Pub