Innovative Instruction of Computer Graphics

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Abstract

For over 20 years fundamental and applied research from various disciplines has been effectively integrated into Computer Graphics resulting in developments that undoubtedly have had an important impact on the way Architectural Engineering is taught. Courses on Computer Graphics that have replaced the instruction of Descriptive Geometry in most Architectural Engineering curricula, are mainly focused on methods for the communication of knowledge and information about the design of a building and its representation. This paper presents a personal effort to address Computer Graphics in the Architectural Engineering Curriculum not only as a representational and visualization tool but also as a means of extending spatial understanding and as a method of informing the design process. Towards this effort a body of knowledge mainly from Descriptive Geometry has been integrated into the instruction of Computer Graphics courses. Concepts such as parametric form development, topological surfaces, as well as advanced visualization procedures, including kinematic simulations, have also been added to the body of knowledge covered by these courses.

Introduction

One of the most important contributions of information technology to the architectural profession can be found in the 3D representations of structures. The use of digital media for architectural representation, and the introduction of Computer Graphics courses in particular, have had a significant impact on Architectural Engineering education. In most Architectural Engineering curricula courses on Mathematics and Geometry, which traditionally constituted a significant part of the architectural education, have been gradually replaced by courses on Computer Graphics. The low performance in geometric conceptualization and visualization of recent architectural engineering graduates may have been a consequence of the latter.

Geometry is not only the source of architectural form but also the principal area of knowledge that brings to stage the new digital architectural representation media. This implies that without an understanding of the geometric and mathematical base of computer graphical procedures the development of skills in any CAD software as well as the ability to cope with significant developments in the area of computer graphics and to adapt to changing technology will be limited. Indeed in most recent developments in architectural research digital media and graphics are used as a generative tool for the derivation and transformation of form and as a means for spatial logic. Such processes require an in depth understanding of the mathematical base of computer graphics and the integration of advanced geometric concepts such as topological space, motion dynamics, parametric design, genetic algorithms etc. (Kolarevic). Given the increasing use of digital media in the area of architectural representation and the geometric nature of Computer Graphics and of relevant computational procedures and techniques on one side, and the indispensable role of geometry in general in the architectural and architectural engineering education, a consolidation of geometry to the instruction of Graphics courses has been attempted. Expected contribution of this effort is that the waning interest for geometry can be readdressed and new possibilities in the domain of architectural graphics can be opened.

In an earlier publication the author has presented a personal effort to identify and selectively include a significant geometric component in the architectural engineering curriculum, which, in her opinion, can offer tools for the study and visualization of architectural and structural systems. This body of knowledge includes concepts from both Euclidean Geometry, that remains the primary source of geometric concepts that address the 3D nature of buildings, and concepts of more recent geometries, that address different configurations than the Euclidean, or focus on different non-dimensional aspects of the architectural or structural morphology such as parabolic geometry, topology, developments in fractal geometry etc. (Liapi, ASEE 2000)

This paper expands on this effort. More specifically this new effort of the author aims to provide a better background of the geometrical base of computer graphical tools and to address Computer Graphics in the Architectural Engineering Curriculum not merely as a representational and visualization tool but also as a means of extending spatial understanding and as a method of informing the design process. At the same time the integration of geometric concepts is expected to allow students to keep up with emerging trends in digital technologies and broaden geometrical thought that is independent of the methods of each time. In the following sections the way that geometry has been integrated in two courses on Computer Graphics is presented.

Introduction to Computer Graphics

The "Introduction to Computer Graphics" course is taught at the junior level and introduces students to visual communication techniques by using CADD tools and procedures that directly apply to Architectural Engineering. Since the introduction to 2D digital representations and 3D digital models of buildings, which have a purely geometric base, has been the primary objective of this course, the integration of geometric concepts has in essence expanded the knowledge content of the course.

The course is structured around a series of lectures/ assignments that have been grouped in three units: I) *Geometric Constructions*, II) *Real World Applications* and III) *3D Visualization*. Class assignments are introduced after a presentation of both the graphical tools and procedures that need to be taken into account for the assignment development, and the topics that address the geometric nature of the assignment.

Class assignments are often based on historical examples of sophisticated use of geometry drown from the theory and history of building design and construction (Figure 1). Several assignments in the unit *Geometric Constructions* are dedicated to the mathematical basis of proportioning systems, which have often been considered in historical architecture as determinants of beauty and order and the basis for dimensional coordination in buildings. Proportioning systems, deriving from arithmetic or geometric sequences, or a combination of both, such as the harmonic proportion systems, are explained in class and addressed by the assignments. (Figure 3)

In addition, 2D constructions based on polygonal patterns that fill the plane (tessellations, tilings), as well as procedures that allow for 2D form or pattern generation are introduced in class lectures and explored by the students as they develop their assignments. (Figure 2):

An example of the structure of the class in lecture/discussion sessions and assignments in the unit Geometric *Constructions* follows:

Discussion	Fundamentals: File setup, view management, units and grids. 2D Basic drawing tools and manipulations. Examples of actual applications of 2D geometric constructions and transformations in historic building design and construction details
Assignment	<u>Geometric Constructions I</u> *Construction of an Ionic volute* *Construction of a spiral from quarter circles* <u>Geometric Constructions II</u> *Gothic window tracery* *Gothic mason's mark* *Tom Brune's diagrams* <u>Geometric constructions III</u> *Patterns of dihedral symmetry.*
Discussion	Advanced 2D drawing tools: Element manipulation and modifications. Examples of actual applications of complex geometry, grids, arrays and proportioning systems in building design.
Assignment	<u>Geometric constructions IV</u> *The Pantheon plan developed from the golden ratio proportioning system.*

The second unit of assignments, *Real World Applications*, is based on a rather more traditional approach to the instruction of CADD tools, that is for the production of architectural drawings. Since this is a topic that is included in the instruction of computer graphics in most curricula I will not expand on the specifics. In general this unit of assignments introduces students to typical drafting conventions and construction details , and as such is complementary to the instruction of courses on Construction Materials and Methods and Architectural Design.

An example of the structure of the this unit in lecture/discussion sessions and assignments follows:

Discussion	2D Drawing accuracy tools: Coordinate systems, precision input methods and measuring and dimensioning tools and the development of architectural plans.
Assignment	Drawing in the real world I *Japanese residence*: *Site plan, Floor plan and Elevations*
Discussion	Detailing tools: Surface and linear patterning as related to the production and effective communication of technical information.
Assignment	Drawing in the real world II *Villa Mairea by A. Aalto:* *Foundation and wall sections, Roof section detail*.
Discussion	Level organization, Cells, Multi-line and Symbol Libraries, as related to drawing conventions and the development of a design and drafting methodology.
Assignment	Drawing in the real world III *Villa Savoy (Poissy) by Le-Corbusier:* *Exterior/Interior wall line-library,* *Window/door symbol library*
Discussion	Reference files and their impact on the productivity in an architectural firm
Assignment	Drawing in the real world III: *(cont)* *Villa Savoy (Poissy) by Le-Corbusier:* *Sections and elevations*

In the third unit of lecture/assignments, *3D Visualization*, the concept of Boolean operations, that have replaced tedious graphical procedures for solid intersections, is introduced. Geometric properties of regular polyhedra, as well as the principles of combinatorial geometry, that sets the rules for the assemblage of regular shapes that fill up the space around a point, are also explained (Figure 4). Students are expected to apply these tools and principles in the development of 3D digital models of architectural projects of medium geometric complexity. Form exploration through 3D digital visualization contributes to the development of students 3D perception. The CAD software used in this class supports parametric solid modeling and dimension driven design.

An example of the structure of this unit in lecture/discussion sessions and assignments follows:

Discussion	3D working space and view organization. Introduction to solid and surface modeling: Primary solids and surfaces, surfaces and solids of projection and revolution

	Boolean operations, surface/line intersection, surface/surface intersection
Assignment	<u>3D Visualization</u> *Solar House in Kassel, Germany* *3D development: exterior walls, roofs, glass house*
Discussion	Introduction to rendering techniques, walkthroughs, fly throughs and solar studies. 3D printing options / image saving, sheet layout etc.
Assignment	<u>3D Visualization</u> (contin.) *Solar House in Kassel, Germany: Solar studies*

In general, in the *Introduction to Computer Graphics* course, students become familiar with standard professional practices and procedures, acquire skills in computer-based design tools which they use in subsequent architectural and civil engineering courses, and significantly increase their 3D perception. Furthermore, in addition to the instruction of computer graphical tools, the course provides an in depth understanding of the underlying geometric concepts encountered in historical and contemporary architecture, an appreciation for professional practices of the past, as well as a point of reference for future creative work. To some extend, the understanding of the mathematical and geometric basis of architectural forms and geometric constructions addressed by the assignments supplements the instruction of the *Introduction to Design* course, where the development of class projects requires the understanding of similar geometric concepts (Liapi, ASEE 2000).

Students have been shown to respond very positively to this course organization and they usually ask for further references and explore geometric concepts in depth on their own. “Introduction to Computer Graphics” course evaluation by the students has always been excellent (4.6- 4.8/5)

Advanced CAD Systems and Procedures

The Advanced *CAD Systems and Procedures* is an elective course, taught at the senior or graduate level that introduces students to advanced CAD procedures and CAD systems and their influence on building design and construction. In this course the instruction of innovative digital media is combined with the instruction of advanced geometric concepts relevant to building design.

The class is structured around three major projects, several shorter class assignments and a series of class presentations/discussions on state of the art developments in IT technologies in relation to computer graphics. Two of the major class projects address the mathematical basis of geometrically complex architectural and structural forms and require advanced modeling and visualization procedures for form generation and transformation. A significant part of this course involves the development of mathematical surfaces and solid form generation using non-traditional geometries.

The geometric topics in solid and surface geometry that are addressed by these two projects include:

Solid Modeling

- Geometric concepts, principles and constructions in relation to the geometry of polyhedra and the organization of systems of polyhedra in spatial networks: (Space packing of polyhedra in linear and grid organizations)
- Topological aspects of polyhedra
- Complex geometry related to building and detail modeling.

CAD Generated *Parametric Solids*

- Solids and Dimension driven design by a) Equation, b) Geometric constraint or c) Dimensional constraint.
- Solid transformations and form manipulation
- Applications of parametric design and modeling in Architectural Engineering

Surface Generation

- Curve Generation a) Conic Curves: ellipse, parabolas, hyperbolas
  b) B-splines and Bezier curves

Surfaces from Curves

- Hyperbolic Geometry: Pattern generation in hyperbolic geometry.
- 3-D applications of the B-Spline.
- Topological surfaces (Maebius strip)
- Ruled Surfaces: Hyperbolic Parabolas (hyper surfaces)
- Anticlastic/ Synclastic Surfaces.
- Helicoid Surfaces
- 3D Surface constructions and their applications in Architectural Engineering.

A brief description of the two major semester projects that address the above issues follows:

<u>Project 1</u>: Reverse Engineering

Students are expected to develop the 3D digital model of a structure characterized by complex geometry by using appropriate manipulations and algorithms that most CAD systems offer. Student can choose an example from the historical repertoire of architectural morphology, engineering developments of pioneer architect -engineers in the fifties, such as Nervi, Candela, Nimeyer, Otto, or of contemporary internationally recognized architects-engineers such as Calatrava, Foster, and Piano, or, to use their own design project as long as it fulfills project description requirements.

Parametric solid modeling techniques and geometric principles of regular polyhedra and space packing are used extensively in the formal exploration of space frames and geodesic domes and in the development of construction details (Figures 5 and 6). Since geometric surfaces are of critical importance for the morphological exploration and design of shell, skeletal, tensile structures, etc, most of student's projects require the application of surface generation tools and procedures. Complex, non-uniform surfaces that derive from a variety of standard graphical entities, such as curves and splines, are often generated with the application of computational geometry techniques. The parametric software that is used in the class allows for easy surface transformation, ie by changing the order of the equation of the splines that generate a surface, its curvature can be also changed. (Figure 7)

<u>Project II.</u> Kinematic Simulation and Visualization

This project addresses a specific category of geometrically complex structures, which change geometry to adapt to different uses and/or weather conditions. In this project students use advanced CAD tools for the exploration of their morphology.

More specifically students are expected to study an existing or develop a new kinematic. structure or building in which motion comprises a major component of the design and construction concepts and is directly related to its function. Among other requirements students need to develop preliminary computer simulation and animation studies of the motion of the entire building structure (Figure 8).

Students have to their disposal software packages that are appropriate for:
a) Advanced 3D geometric modeling for architectural, and mechanical applications.
b) Analysis of mechanisms and motion simulation in a 3D environment.
c) Highly accurate animations and renderings including solar studies.

Along the process students have to develop motion diagrams and mathematical expressions to determine the geometric and trigonometric expansion of the structure. Certain animation techniques such as *parametric animation* may require the development of more specialized macro-commands and animation scripts for the specification of the geometric position and orientation of a building element as a function of time.

In this project graphical procedures assist in developing a basic understanding of the geometric and trigonometric expansion of building structures as a result of the geometric and kinematic characteristics of the mechanism or method by which the structures transform in space and time. The computer simulation of the motion of the structure and the display of the structure as an animation of moving parts can identify problems in their initial geometric and kinematic conception. It can also assess the effect of the changing geometry of the structure on space definition, building morphology, and functionality.

In general, in the *CAD Systems and Procedures* course, students become familiar with state of the art applications of CAD software and are introduced to new emerging trends in this field. They develop an understanding of the geometric basis of CAD tools in software applications and learn how to use low level, if necessary, for form exploration and decision making. *CAD Systems and Procedures* course evaluation by the students has always been excellent (4.6- 4.8/5)

Conclusions

It has been shown that Computer Graphics in the Architectural Engineering Curriculum can be taught not only as a representational and visualization tool but also as a means of extending spatial understanding and as a method of informing the design process.

In the *Introduction to Computer Graphics* course students, by recreating sophisticated forms and patterns encountered in the history of building design and construction, are also exposed to the humanistic view of the role of geometry in their profession and are motivated to improve their understanding of geometry in the context of architectural and structural design.

The *CAD Systems and Procedures* course that consolidates concepts from Euclidean and other more recent, non- Euclidean, geometries, has offered tools for the study and visualization of complex architectural and structural systems and for the formal exploration of new innovative structures, such as kinematic structures.

It is also hoped that the instruction of these two courses on Computer Graphics has succeeded not only in developing competency in architectural and structural form description and exploration but also in inspiring Architectural Engineering students to further explore the role of geometry as an essential mental tool required for the invention and modeling of spatial structures, as well as in developing learning strategies for adapting to changing technologies.

Aknowledgments

The projects illustrated in the figures have been developed by the following students: J.Collins, S. Bell, M.Bigger, R.Badger and B.Quiroga.

References

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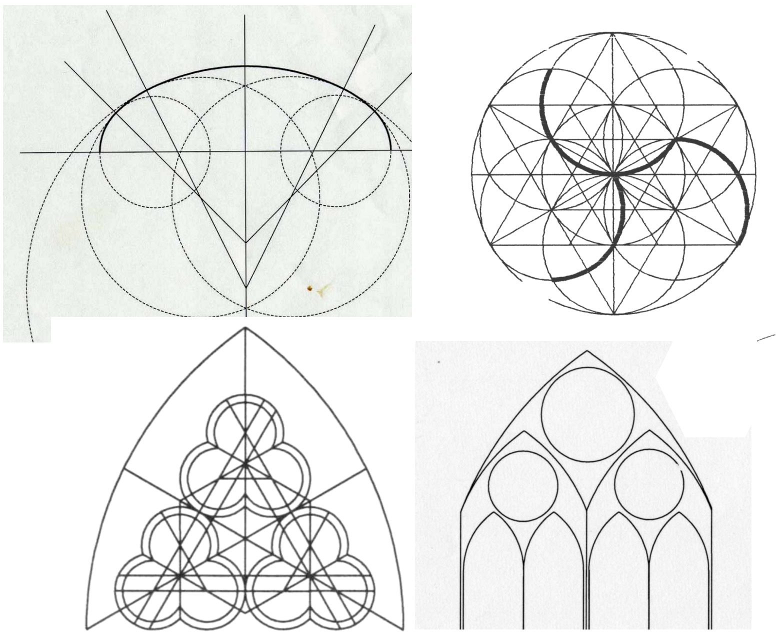
FIGURES



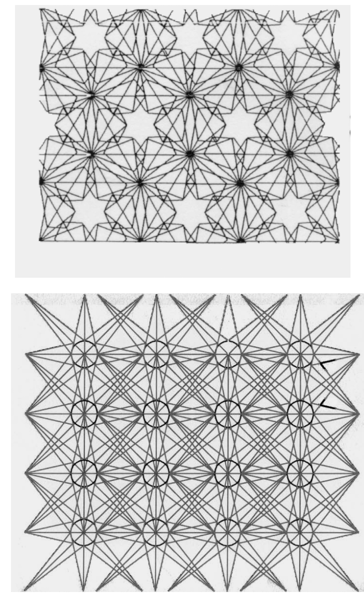


Figure 1: Geometric constructions of a) Five Centered Ogee, b) Gothic Masons' Mark , c) Gothic Tracery

Figure 2: Variations of Dihedral Symmetry

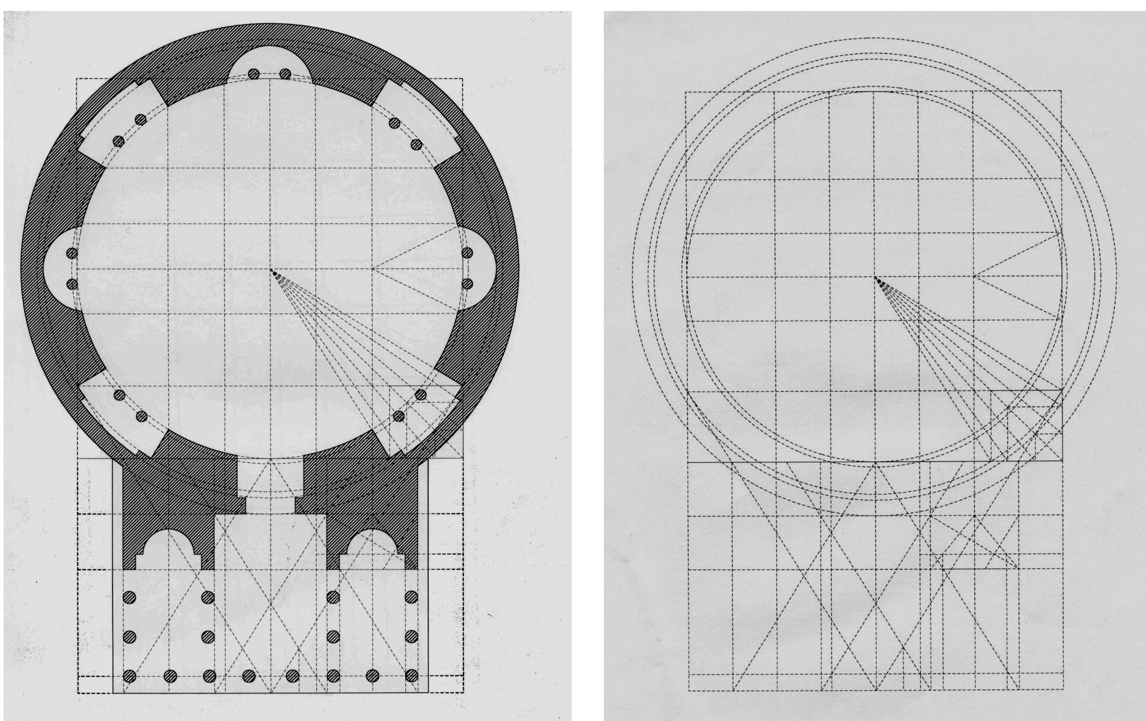


Figure 3: The geometric basis of the plan of the Pantheon in Rome (after Mathila Ghyka)

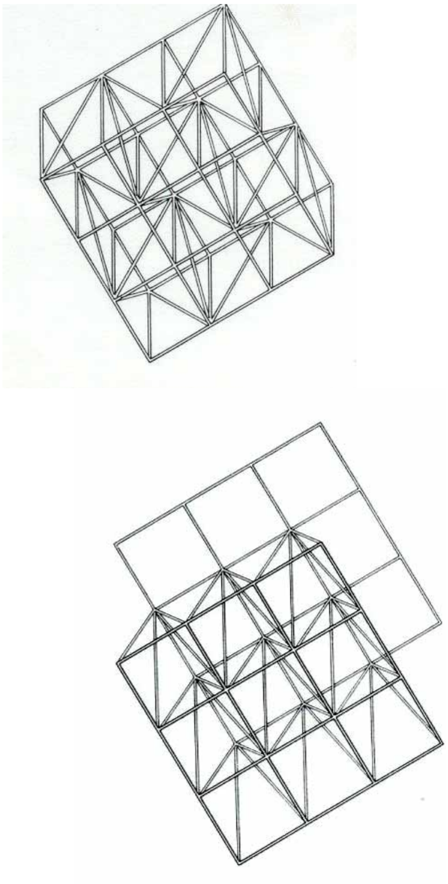


Figure 4: Space packing of regular polyedra and 3D frames

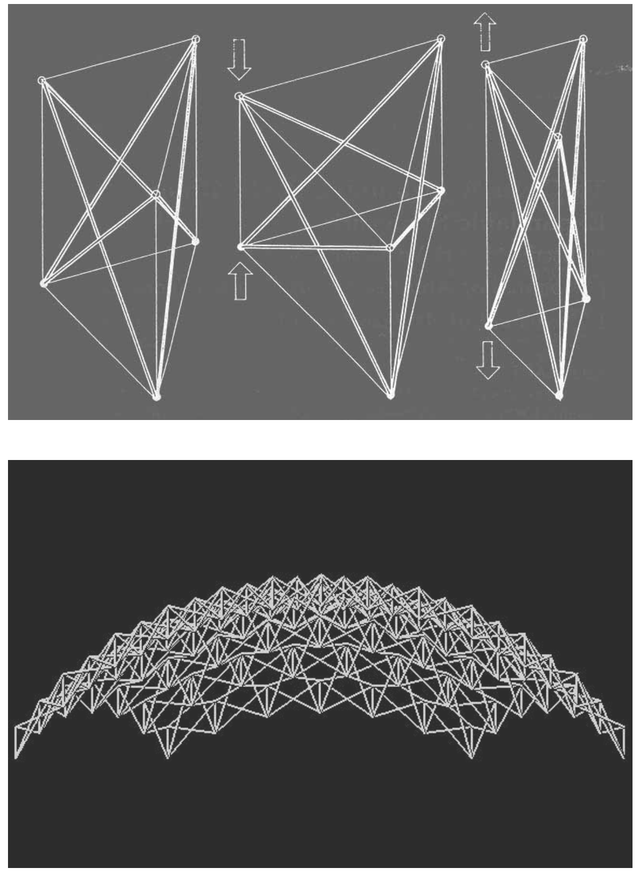


Figure 5: Geodesic dome composed of deployable prismatic units

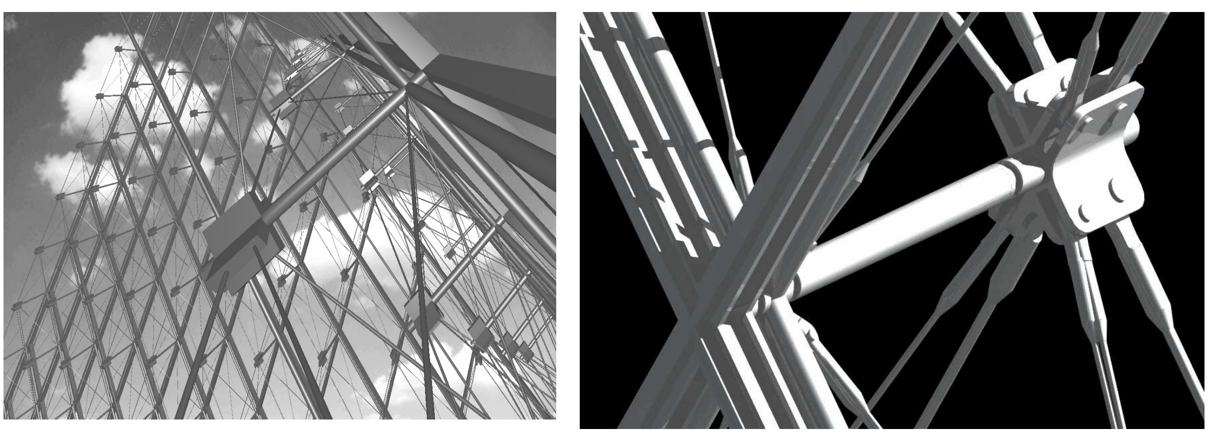


Figure 6: Entry to the Louvre by I.M. Pei. Development of construction details using parametric modeling

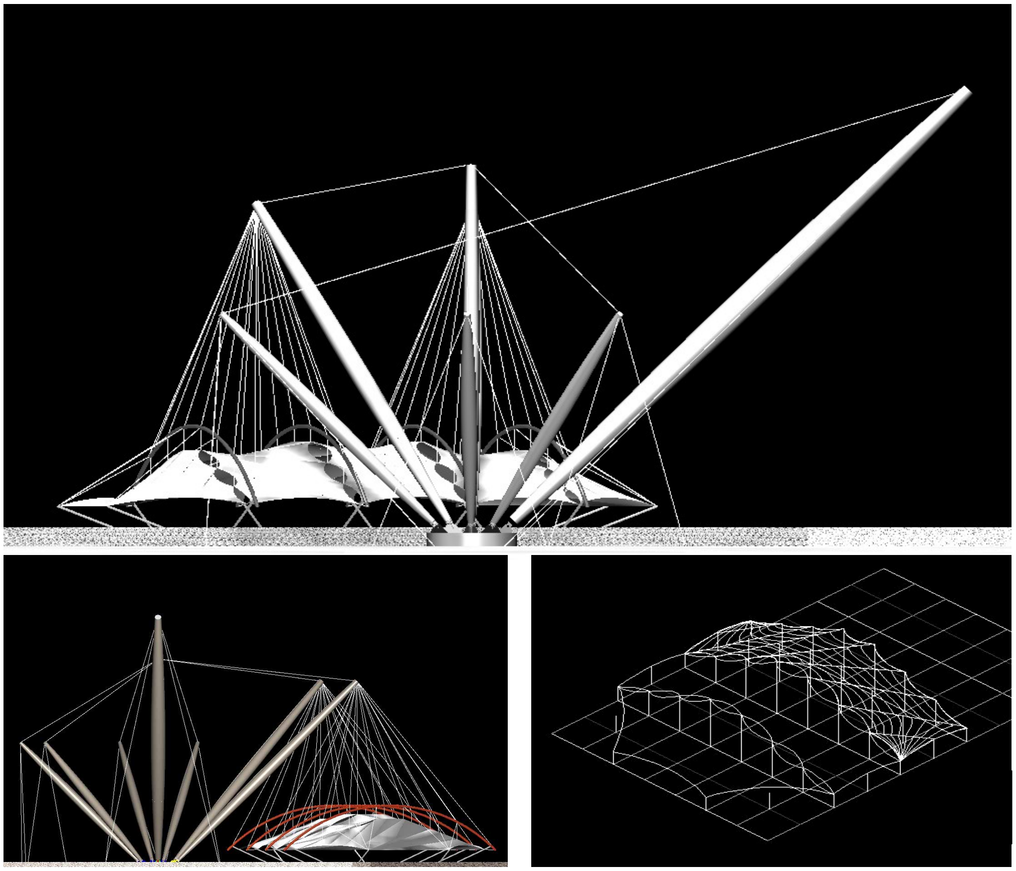


Figure 7: The Grande Bigo by R. Piano. Study of surfaces with B-Splines

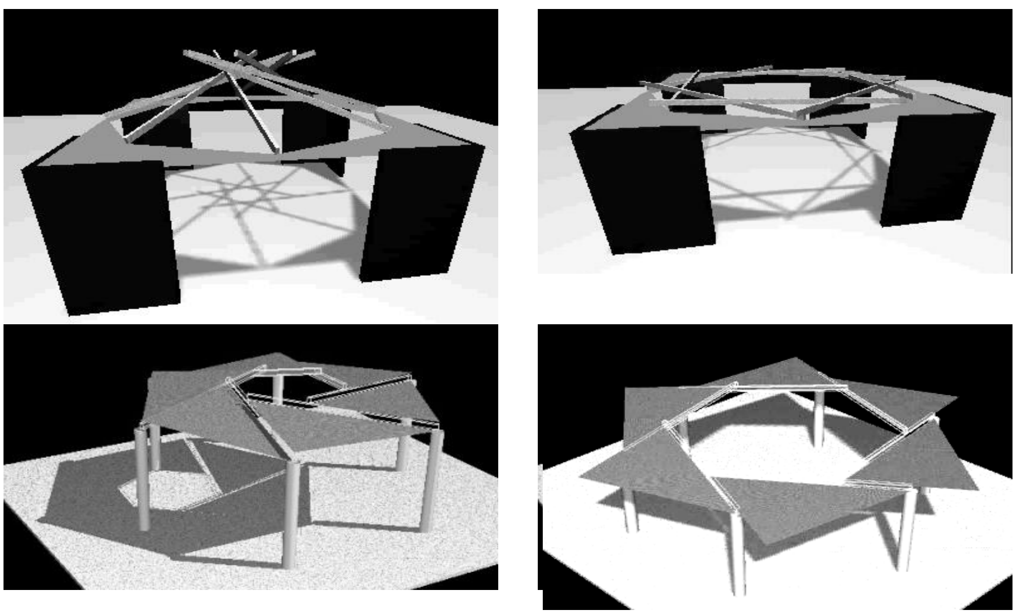


Figure 8: Computer Simulation and visualization of an innovative kinematic structure