FULLER’S FANTASTIC GEODESIC DOME
National Building Museum

About the National Building Museum

The National Building Museum is America’s leading cultural institution dedicated to advancing the quality of the built environment by educating people about its impact on their lives. Through its exhibitions and educational programs, including innovative curricula for students as well as online content and publications, the Museum tells the stories of the world people design and build.

The Museum is an independent, non-profit institution and is located in a historic landmark structure at 401 F Street NW, Washington, D.C. 20001. Connect with the Museum online at www.nbm.org, on Twitter at @BuildingMuseum, and on Facebook at www.facebook.com/NationalBuildingMuseum.

For Students and Families

The Museum’s youth programming has won the Washington, D.C., Mayor’s Arts Award for Outstanding Contributions to Arts Education and been recognized by the National Endowment for the Arts. Each year, 50,000 young people and their families participate in hands-on learning experiences at the Museum. The Museum offers school programs for grades preK–9 as well as three innovative outreach programs for secondary school students. The Museum hosts three free family festivals annually; drop-in family workshops; programs helping Cub and Girl Scouts earn activity badges; book-of-the-month readings; and more.

 Fuller’s Fantastic Geodesic Dome is funded in part by a generous grant from Bender Foundation, Inc. Additional support for The National Building Museum’s school programs is provided by the Morris and Gwendolyn Cafritz Foundation, The Clark Charitable Foundation, and The Max and Victoria Dreyfus Foundation, among others.
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To The Educator

The Fuller’s Fantastic Geodesic Dome program and is intended to help both teachers and students, grades five through nine, recognize geodesic domes and discover their importance in the world.

The information, lessons, and activities found in this packet are designed for classroom use before and after your students visit the Museum. They encourage young people to explore the complexity of structural design in buildings and help them understand the basic engineering principles of the geodesic dome.

Why Study Geodesic Domes?
Geodesic domes are unusual structures that intrigue students and offer teachers an opportunity to investigate interesting concepts in engineering, math, and environmental science. Geodesic domes are used in unique spaces—stadiums, theme parks, and playgrounds—and have a unique appearance. Through studying geodesic domes, students are exposed to an innovative solution to the ongoing challenge of creating structures—how to maximize space while creating a strong, cost effective, people friendly structure. By studying the geodesic dome and its construction, students learn about materials, structures, and forces at work in buildings.

Why Use Design as an Education Model?
The Fuller’s Fantastic Geodesic Dome school program and all other education programs at the National Building Museum inspire students to examine the people, processes, and materials that create buildings, places, and structures. All of the Museum’s youth education programs use the design process as an educational model. This model requires young people to identify problems or needs, imagine solutions, test them before building a suitable design, and evaluate the product.

Learning by doing is central to design education in general and to the Fuller’s Fantastic Geodesic Dome program in particular. After engaging in a variety of hands-on lessons that stimulate exploration of structural systems, geodesic domes, and the built environment, students gain a fresh perspective on their surroundings and begin to understand how design decisions impact the built environment.

What Are the Learning Benefits?
The Fuller’s Fantastic Geodesic Dome program and supplementary lessons in this Educator Resource Packet meet national standards of learning in math, science, social studies, technology, and visual arts. The specific standards are described on page 6. The lessons in this curriculum encourage young people to explore and recognize how, where, and why geodesic domes are used. Through hands-on, interdisciplinary lessons that address multiple learning styles, the Fuller’s Fantastic Geodesic Dome program encourages and fosters life skills such as critical thinking, problem solving, team building, and communication.

The Educator Resource Packet Includes:
- A list of national standards of learning addressed in the program.
- A matrix of optional lessons to enhance students’ learning experience.
- Introductory lessons to more fully prepare students for the Fuller’s Fantastic Geodesic Dome program.
- Reinforcement lessons for use after the Museum visit to help students continue their exploration of geodesic domes.
- Vocabulary and lists of supplementary resources.
Program Description

American inventor, engineer, and architect R. Buckminster Fuller may be best remembered for developing the structurally-innovative geodesic dome that is one of the strongest, most cost-effective structures ever devised. The geodesic dome, a system of triangular forms linked together to enclose a space, distributes stress and weight in the most economical way. A geodesic dome’s parts are interchangeable enabling it to be easily manufactured and constructed and increase in height while decreasing in width. Domes and other types of space framing are commonly used by architects and engineers and can be seen across the United States supporting signs, carports, stadium roofs, and concert halls.

Students participating in the Fuller’s Fantastic Geodesic Dome program will consider traditional architectural structures including: post and lintel, arch, dome, and truss structures, as well as the modern geodesic dome. Working as a team, the students will construct a large geodesic dome in the Great Hall of the National Building Museum and individually assemble a geo ball, or icosahedron, to take home.

This Educator Resource Packet can be used before or after your museum visit to prepare students for their trip and to build upon what they learned during the program.

Goals
After completing the Fuller’s Fantastic Geodesic Dome program and lessons in the Educator Resource Packet, students will:

- Have an increased awareness of the geometric shapes and components that make up a geodesic dome.
- Understand the basic structural engineering concepts that underlie geodesic dome construction.
- Understand the advantages and disadvantages of modern building materials in dome construction.
- Have an increased awareness of more in-depth concepts relating to the study of architecture, geometry, and structures.

Objectives
After completing the Fuller’s Fantastic Geodesic Dome program and Educator Resource Packet lessons, students will be able to:

- Identify and understand the forces of compression and tension and how these forces affect structures.
- Identify how triangles and tetrahedrons support and distribute weight.
- Identify five roofing systems and understand the advantages and disadvantages of each.
- Work cooperatively as a team to assemble a geodesic dome.
- Assemble a geo ball, or icosahedron (a 20-sided geometric shape), individually.

Skills

- Analysis
- Application of knowledge
- Cooperative learning
- Experimentation
- Evaluation
- Problem solving
The *Fuller’s Fantastic Geodesic Dome* program and Educator Resource Packet lessons meet local and national standards of learning in several disciplines. The national standards are outlined below.

### Standards for the English Language Arts, National Council of Teachers of English & the International Reading Association

<table>
<thead>
<tr>
<th>Students will...</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate and synthesize data from a variety of sources to communicate their discoveries in ways that suit their purpose and audience</td>
<td>7</td>
</tr>
</tbody>
</table>

### Principles and Standards for School Mathematics, National Council of Teachers of Mathematics

<table>
<thead>
<tr>
<th>Students will...</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships</td>
<td>Geometry</td>
</tr>
<tr>
<td>use visualization, spatial reasoning, and geometric modeling to solve problems</td>
<td>Geometry</td>
</tr>
<tr>
<td>build new mathematical knowledge through problem solving</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>recognize and apply mathematics in contexts outside of mathematics</td>
<td>Connections</td>
</tr>
</tbody>
</table>

### National Science Education Standards, National Research Council

<table>
<thead>
<tr>
<th>Students will...</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>properties of objects and materials</td>
<td>B</td>
</tr>
<tr>
<td>form and function</td>
<td>B, E</td>
</tr>
<tr>
<td>abilities of technological design</td>
<td>E</td>
</tr>
<tr>
<td>science and technology in society</td>
<td>F</td>
</tr>
</tbody>
</table>
### Curriculum Standards for Social Studies, National Council for the Social Studies

<table>
<thead>
<tr>
<th>Students will...</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>describe how people create places that reflect ideas, personality, culture, and wants and needs as they design homes, playgrounds, classrooms, and the like</td>
<td>3</td>
</tr>
<tr>
<td>work independently and cooperatively to accomplish goals</td>
<td>4</td>
</tr>
</tbody>
</table>

### Standards for Technological Literacy, International Technology Education Association

<table>
<thead>
<tr>
<th>Students will...</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>technology and society, including the effects of technology on the environment</td>
<td>4, 5</td>
</tr>
<tr>
<td>design, including the attributes of design and engineering design</td>
<td>8, 9</td>
</tr>
<tr>
<td>the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving</td>
<td>10</td>
</tr>
<tr>
<td>the designed world, including the use of transportation and construction technologies</td>
<td>19, 20</td>
</tr>
</tbody>
</table>

### National Standards for Arts Education, Visual Arts Category, Consortium of National Arts Education Associations

<table>
<thead>
<tr>
<th>Students will...</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>intentionally take advantage of the qualities and characteristics of art media, techniques, and processes to enhance communication of their experiences and ideas</td>
<td>1</td>
</tr>
<tr>
<td>generalize about the effects of visual structures and functions and reflect upon these effects in their own work</td>
<td>2</td>
</tr>
<tr>
<td>employ organizational structures and analyze what makes them effective or not effective in the communication of ideas</td>
<td>2</td>
</tr>
<tr>
<td>describe and place a variety of art objects in historical and cultural contexts</td>
<td>4</td>
</tr>
<tr>
<td>analyze, describe, and demonstrate how factors of time and place (such as climate, resources, ideas, and technology) influence visual characteristics that give meaning and value to a work of art</td>
<td>4</td>
</tr>
<tr>
<td>describe ways in which the principles and subject matter of other disciplines taught in the school are interrelated with the visual arts</td>
<td>6</td>
</tr>
</tbody>
</table>
**Lessons Matrix**

Use the following Lessons Matrix to prepare students for their visit to the National Building Museum and to build upon what they have learned during the *Fuller's Fantastic Geodesic Dome* program.

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Purpose</th>
<th>Standards of Learning</th>
<th>Duration</th>
<th>Materials Needed</th>
</tr>
</thead>
</table>
| Understanding Forces at Work: Compression and Tension p. 26 | Introduce students to the forces of compression and tension and geodesic domes. | Mathematics Problem Solving, Connections Social Studies 4 Science B, E | 2 class periods, 45 - 60 minutes each | For each student:  
• A chair  
• Magic markers  
• Ruler  
• Hardcover books  
For every two students:  
• One soft kitchen sponge |
| Shapes and Solids: Investigating Triangles, Squares, Pyramids, and Cubes p. 30 | Experiment with two and three-dimensional shapes and forms to determine the strength of certain shapes. | Mathematics Geometry, Problem Solving Science B, E Social Studies 4 Technology 10 Visual Arts | 2 class periods, 45 - 60 minutes each | For each student:  
• One pair of scissors  
• Three index cards (4x6”)  
• 11 small brass paper fasteners  
• Photocopy of *Triangles vs. Squares, Tetrahedrons vs. Cubes* Worksheet p. 34  
For every two students:  
• several single hole punches |
<p>| Architecture Investigation: Traditional and Geodesic Structures p. 38 | Examine traditional structures used in buildings and identify these structures in their surroundings. | Mathematics Connections Science F Social Studies 3, 4 Technology 4, 5, 19, 20 Visual Arts 4 | 1 class period, 45 - 60 minutes, homework assignment | Structures Investigation Worksheet p. 40 |</p>
<table>
<thead>
<tr>
<th>Geodesic Domes: Take a Closer Look p. 44</th>
<th>Connect geodesic domes to the larger society and other areas of the curriculum using these project ideas or homework assignments.</th>
<th>Language Arts 7</th>
<th>Teacher’s Choice</th>
<th>• None</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mathematics Geometry, Connections</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Science B, E, F</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social Studies 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Visual Arts 2, 4, 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fun Field Trips: Exploring Your Community p. 42</td>
<td>Connect the school work and Museum field trip to students’ larger life and involve their families using these fieldtrip ideas or homework assignments.</td>
<td>Mathematics Geometry, Connections</td>
<td>Teacher/Family’s Choice</td>
<td>Teacher/Family determine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Science B, E, F</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social Studies 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Visual Arts 2, 4, 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The following section is designed to introduce you, the teacher, to geodesic domes and basic engineering principles. These readings can also be used to introduce students to some of the terminology. For additional information refer to the Resources section beginning on page 34.

**Introduction to Domes**

- Basic Engineering Principles
- Space Framing
- Geodesic Domes

**Who was Buckminster Fuller?**
Introduction to Domes

Basic Engineering Principles

A dome is defined as a large hemispherical roof or ceiling. Although many different types of domes exist, all domes share certain advantages, whether or not they are geodesic. Their compound-curved shape is inherently strong, giving a self-supporting clear span with no columns as supports. Domes are resource and energy-efficient because they are hemispheres. A sphere is the 3-dimensional form that contains the most volume with the least amount of surface area. Thus, as a hemisphere, for a given amount of material, a dome encloses more floor area and interior volume than any other form.

A dome’s design is dependent upon many factors, including:

- Needed area and span, or distance between supports.
- Budget and building schedule.
- Forces, such as compression and tension, acting on the structure.
- Building materials.

Area and Span

The architect must consider the area to be covered by the dome and the needs of the structure in terms of space and uses. Span is the length of a structural element between supports. The shape of the structure, materials, and budget all impact the total length of the span.

Forces of Compression and Tension

A force is a push or a pull on an object that is the result of its interaction with another object. In every structure, there are invisible forces at work. In this program we will focus on two: compression and tension. Compression is a force that pushes or squeezes an object; objects in compression tend to get shorter. Tension is a force that stretches or pulls an object; objects in tension tend to get longer.

Materials

Engineers must consider the properties of building materials when making choices for any structure. When considering building materials, engineers take into account the cost, proposed use of the structure, location, aesthetics, and durability.

Space-Framing

Space-framing (a network of triangular supports) is often used in dome construction. The most important element of a space frame is the triangle, which is also the strongest form used in architecture. Different types of geometric forms (or polyhedra) are used in space framing. One common form is the tetrahedron—a four faced triangular polyhedron, or a kind of pyramid with four faces and six edges. The connecting of triangles in this way provides a structural system that is strong and uses minimal amount of materials, all of which are interchangeable.
Geodesic Domes

R. Buckminster Fuller spent much of the 20th Century investigating ways to improve housing. In 1944, the United States suffered a serious housing shortage with the many millions of veterans returning after the war. At this time Fuller began focusing on the problem of how to build a shelter that would be more comfortable, more efficient, and more affordable for a larger proportion of the population.

Fuller would exploit the strengths of triangles to create a stronger and more cost efficient housing structure. Fuller investigated the properties of triangles, and platonic solids including the icosahedron (a 20 sided polyhedron made of equilateral triangles). He discovered that by subdividing the triangular faces of the icosahedron into smaller triangles he could approach a form that was essentially a spherical structure created from triangles. This new type of dome consisting of triangles, would be both very strong and very economical.

**Positive Features of Geodesic Domes**

Geodesic domes are:

- The strongest structures per pound of material employed.
- Inherently strong and light; their curved form creates a span with no need for additional support (such as columns) and equally distributes stress throughout the structure.
- Resource- and energy-efficient because of all possible shapes, a sphere contains the most volume with the least surface area.
- Streamlined spherical forms let wind slide smoothly over their surface, thus helping to maintain a constant interior temperature with less need for heating and cooling systems.
- Structures that allow air to easily circulate, reducing heating and cooling costs.
- Easy to manufacture and construct due to interchangeable parts.

**Negative Features of Geodesic Domes**

Geodesic domes:

- Do not fit certain lot shapes, particularly traditional rectangular city blocks.
- Do not gracefully accept additions.
- Difficult to enlarge by adding a second story.
- Often look identical to each other.
- Quickly distribute sound, smells, heat, cold, smoke, and fire because of their efficient circulation.
- Difficult to divide into separate spaces (such as rooms of a house or office).
- As its exterior becomes warm or cold with changes in weather, a dome’s materials expand and shrink causing gaps where water can leak into the structure.
Who Was Buckminster Fuller?

Architect, mathematician, engineer, inventor, visionary humanist, educator, and best-selling author, R. Buckminster Fuller, also known as Bucky, has been called “the 20th century Leonardo da Vinci.” Born in 1895, he grew up in the northeast United States without automobiles, aircraft, radio, television, or computers.

Bucky attended Harvard University—the fifth generation of his family to do so—only to be expelled twice and never earn a college degree. His jobs included work in a cotton mill and meat packing plant. During World War I, he served as a naval officer, all the while learning about complex mechanical systems.

Bucky dedicated himself to a “lifelong experiment” to discover what he could do to help make humanity a success on Earth. He documented nearly everything he did and amassed an archive weighing 45 tons! It includes sketches, statistics, trends, models, even traffic tickets and dry cleaning bills.

Bucky’s first inventions and discoveries were numerous. During the 1930s and 40s he created an aluminum car and house. They were radically different from structures known then or now. At the time, aluminum processing was expensive, so mass production of these inventions was impossible.

Following the mixed success of a home constructed as a dome, Bucky began researching how to strengthen and enlarge such a shelter. He soon discovered that a sphere constructed of geometric shapes was the most efficient way to enclose a space. The first such structure to become known as a geodesic dome was built in 1922 by Walter Bauersfeld for a planetarium in Germany. However, Bauersfeld never patented his structure or developed the principles of building this way. Bucky likely knew of this earlier dome. His first large-scale outdoor model was attempted in 1949.

Geodesic structures can now be found everywhere. They are present in the structure of viruses and the eyeballs of some vertebrae. The soccer ball is the same geodesic form as the 60-atom carbon molecule C60, named buckminsterfullerene in 1985 by scientists who had seen Bucky’s 250-foot diameter geodesic dome at the 1967 Montreal Expo. This dome was the largest of its time and still stands today.

Though he secured many patents for his designs, Bucky put his profits towards his research and never became wealthy. He was often disappointed that he did not receive more credit for his work. The geodesic dome at Disney’s EPCOT center is familiar to much of the world, but its inventor is not.

Of all his contributions and creations, Bucky considered his World Game Institute, founded in 1972, to be one of his most important. This organization collects and shares comprehensive world resource data. Bucky hoped that it would show that international cooperation was such an obvious advantage that war would become unthinkable. Thousands participate in World Game workshops, and the Institute is one of the largest of its kind.

Fuller was seen by his peers as both a genius and a failure because his ideas were so new and little understood by the time of his death. Over the course of his life, Fuller received 47 honorary degrees for his contributions in design science. Since his death in 1983, appreciation for Fuller has continued to grow. The Fuller Institute in Santa Barbara, California, which opened in 1995, now educates the world about his life and work.
Before visiting the Museum, these lessons may be used to introduce students to the basic engineering and geometry within building design and construction. These lessons are optional.

**Understanding Forces at Work: Compression and Tension**

**Shapes and Solids: Investigating Triangles, Squares, Pyramids, and Cubes**

*Shapes and Solids* Student Worksheet

Patterns for Creating Cubes and Tetrahedrons
Understanding Forces at Work: Compression and Tension

National Standards of Learning: Mathematics – Connections, Problem Solving; Social Studies – 4; Science – B, E

Duration: Two class periods; 45 – 60 minutes each

Overview

In any structure, there are always two forces at work—compression and tension. Architects and engineers must consider these forces when they design or construct buildings.

Domes, like all built structures, rely on unseen forces that hold them together and enable them to support additional weight, or loads. It can be difficult to visualize forces acting on an object or structure that appears to be at rest. This activity is designed to help students imagine these unseen forces and, thereby, better understand the mechanics of domes.

Objectives

Students will:

- Examine how forces act upon an everyday object, a chair.
- Define compression and tension and find elements under these forces in their classroom or school building.

Materials

- Chair
- Magic markers
- Soft kitchen sponges, at least 1” thick (one per two students)
- Rulers
- Hardcover books

Teacher Prep

- Scope out several places in your classroom and school building that have elements under compression and tension.

Vocabulary

- Compression
- Force
- Structure
- Tension
Lesson Plan

PART I. Define and Demonstrate Forces, Compression and Tension (30 minutes)

1. Discuss the Forces of Tension and Compression
   • Explain that a force is a push or pull on an object. When an object is at rest (not moving), the forces acting on it are balanced.
   • Explain to students that compression is the act of being pushed or pressed together. Have students place their hands with their palms together and elbows bent. Tell them to press their palms together. This pushing force is called compression.

2. Search for Forces in the Classroom
   • Divide the class into two teams. Ask each team to search for building elements under compression and/or tension in the classroom or school.
   • Give the class a time limit of 15 minutes to find:
     5 elements under tension
     • 5 elements under compression
   • Appoint one group member from each team to write down the information. When the time is up, compare the lists.

Examples of elements under compression: walls; vertical sides of doors or window frame; columns; piers

Examples of elements under tension: cables or strings hanging from the ceiling with an object attached to it, such as a map, poster, or screen; arches and triangular structures are in both tension and compression
PART II. Investigate How the Forces of Compression and Tension Act on a Surface (30 minutes)

- Arrange students in pairs and give each pair a large soft kitchen sponge. (New sponges work best for this activity because they are flexible.) Have the students draw a series of lines approximately 1/2 inch apart crosswise around the sponge.

- Next, have the students take turns bending the sponge into a U-shape and observe what happens to the lines. Let them describe what they observe. The lines inside the U-shape get closer together, while the lines outside the U-shape spread farther apart.

- Ask where the sponge is in compression. **Answer:** The inside of the U-shape. Where is the sponge in tension? **Answer:** the outside of the U-shape. How could students balance out the forces of compression and tension acting on the sponge to make it stronger? **Answer:** Some ideas include using a stiffer material for the beam, or adding supports, such as knitting needles or pencils, to the sponge.

- Show students the image of the dome below. Based upon the exercise with the sponge, ask them where the compression and tension might be in the dome.
Shapes and Solids: Investigating Triangles, Squares, Pyramids, & Cubes

National Standards of Learning: Mathematics – Geometry, Problem Solving; Science – B, E; Social Studies – 4; Technology – 10; Visual Arts – 1

Duration: Two class periods; 45 – 60 minutes each

Overview
In this lesson students will examine different shapes and materials to determine their strength and suitability when building structures. Students will come to understand that the strength of a structure does not depend only on the material its made of but also its shape or form. Some shapes and forms are stronger than others.

Objectives
Students will:
- Create and examine three two-dimensional shapes—a square, a triangle, and a rectangle—and determine which is the sturdiest.
- Discover how changing a structure’s three-dimensional shape can increase its strength.
- Identify points of compression and tension within geometric shapes.

Materials
- One pair of scissors per student
- Materials to create struts: three index cards (4 x 6") per student*
- Materials to create connectors: 11 small brass fasteners per student*
- Shapes and Solids Student Worksheet, page 34 (one per student)
- Photocopy of Patterns for Cubes and Tetrahedrons onto heavy paper, page 26 (one per student)
- Several single-hole punches (they can be shared among student

Vocabulary
- Compression  
- Cube  
- Engineer  
- Form  
- Pyramid  
- Structure  
- Square  
- Tension  
- Tetrahedron  
- Triangle

* For additional suggestions of materials to use to make struts and connectors refer to lesson plan.
Lesson Plan

PART I. Create Three Two-Dimensional Shapes (30 minutes)

1. Introduction
   - Explain to students the actual shapes or forms from which a structure is made contribute to its overall strength or weakness. Some shapes and solids are stronger or weaker than others.
   - Tell students that in this activity, they are going to examine three shapes—a square, a triangle, and a rectangle—and determine which is the strongest.
   - Explain to students that they will be making each shape out of two parts—struts and connectors. In this lesson we’ll be using index cards to make the struts and paper fastners as the connectors. Other materials that can be used are:

<table>
<thead>
<tr>
<th>Struts:</th>
<th>Connectors:</th>
</tr>
</thead>
<tbody>
<tr>
<td>toothpicks</td>
<td>gum drops</td>
</tr>
<tr>
<td>plastic straws</td>
<td>pipe cleaners or bent paper clips</td>
</tr>
<tr>
<td>wooden dowels</td>
<td>tennis balls or balls of clay</td>
</tr>
</tbody>
</table>

2. Build and Test Shapes
   - Provide each student with a Shape Construction Worksheet. Give students 10 minutes to construct their 2-dimensional shapes.
   - After students have built their shapes, ask students to test their strength. Take the triangle, square, and rectangle and push down on the corners and sides of each shape.
     - What happens? Answer: The square and rectangle should collapse; the triangle will keep its shape.
     - Why? Answer: The triangle is made up of the least number of sides possible for a geometric shape, locking its three sides into place.
   - Can students identify which parts of the triangle are in tension and which are in compression? Answer: If pressure is applied to any of the corners, the two sides radiating from that point will be in compression, while the side opposite that point will be in tension. If pressure is applied to any of the sides, that side will be in tension, while the other two sides will be in compression.

3. Discuss the Results of the Experiment
   - Based on the results of this experiment, which shape provides the most structural strength? Answer: Triangle
   - Explain to students that geodesic domes get their strength from triangles. Triangles can be arranged into many patterns, which can create different and unique structures.
PART II. Create Two Three-Dimensional Solids. (30 minutes)

Just as some two-dimensional shapes are stronger than others, certain three-dimensional solids or forms are stronger than others. For example, a triangular pyramid, or tetrahedron, is more rigid than a square-based pyramid or cube. Using the patterns (page 26) for creating cubes and tetrahedrons, ask students to construct both a cube and a tetrahedron.

PART III. Evaluate Three-Dimensional Solids (15 minutes)

After the students have constructed their solids, ask them to test the cubes and tetrahedrons. Have students complete the Which One Will Win? Student worksheet (page 26).

Answers to the worksheet:

1. Edges per structure:

<table>
<thead>
<tr>
<th></th>
<th>Tetrahedron</th>
<th>Cube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edges</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

2. Number of faces per solid, including the bases:

<table>
<thead>
<tr>
<th></th>
<th>Tetrahedron</th>
<th>Cube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faces</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

3. What is the surface area of each solid? (These answers are based on using the Patterns For Cubes and Tetrahedrons worksheet in which one edge of each form measures 2").

<table>
<thead>
<tr>
<th></th>
<th>Tetrahedron</th>
<th>Cube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>10.38 in²</td>
<td>24 in²</td>
</tr>
</tbody>
</table>

4. If you had to pay for your construction materials (ie the paper the patterns were cut from), which form would cost the least?
   - The tetrahedron has the least amount of surface area and therefore required the least amount of materials. The tetrahedron would be less expensive to construct.

PART IV. Discuss Geometric Forms Conclusion (10 minutes)

- Discuss the students findings from the worksheet.
- Ask which structures they would select to build with and why?

To build structures as strong as possible, it makes sense to use triangular forms. However, because squares can provide additional area and blend with human surroundings, like city blocks and furniture, a mixture of both squares and triangles is often incorporated in buildings.
Student Worksheet

Constructing Shapes

1. Cut each index card into four one-inch strips, lengthwise. You should have 12 strips total.

2. Punch a hole in each end of the ten strips.

3. To make a triangle, connect three strips together with the brass fasteners.

4. To make a square, connect 4 equal strips together with the brass fasteners.

5. To make a rectangle, cut one strip in half, so you have two 3" long strips. Punch a hole in the un-punch-ed ends. Connect these two shorter strips with two longer strips to make a rectangle.
Which One Will Win?

Which one will win? Compare the area, surface strength, and cost of the tetrahedron and cube.

1. How many edges does each solid have?
   ______ tetrahedron ______ cube

2. How many faces does each solid have? (Hint: Don't forget to count the base)
   ______ tetrahedron ______ cube

3. What is the surface area of each solid?
   ______ tetrahedron
   ______ cube

4. If you had to pay for your construction materials (ie the paper the patterns were cut from), which form would cost the least?
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
Student Worksheet

Patterns for Creating Cubes and Tetrahedrons

1. Cut along solid black lines.
2. Fold along dashed lines.
3. Tape edges to create solids.
After visiting the National Building Museum, use these optional Reinforcement Lessons to strengthen the students’ understanding of geodesic domes and build on the students’ museum experience.

**Architecture Investigation: Traditional and Geodesic Structures**

*Structures Investigation* Student Worksheet Part I

*Structures Investigation* Student Worksheet Part II

**Geodesic Domes: Take a Closer Look**

**Fun Field Trips: Exploring Your Community**
Architecture Investigation:
Traditional and Geodesic Structures

National Standards of Learning: Math – Connections; Science – F; Social Studies – 3, 4; Technology – 4, 5, 19, 20; Visual Arts – 1, 3

Duration: One class period; 45 – 60 minutes each

Overview
Now that students understand that different shapes and forms have varying strengths, they can further investigate traditional architectural structures. This lesson also encourages students to investigate their neighborhoods and communities and examine why architects might have chosen certain forms.

Objectives
Students will:

- Understand that buildings today share many of the same structures as buildings built thousands of years ago.
- Learn several different types of traditional building structures.
- Identify traditional building structures in their own neighborhood or in Washington, D.C.

Materials
- Structures Investigation Worksheet, page 40

Vocabulary
- Arch
- Dome
- Geodesic Dome
- Post and Lintel
- Pyramid
- Space-Framing
- Structure
- Triangle
- Tetrahedron
Lesson Plan

1. Introduce Different Types of Structures Used in Buildings (20 minutes)
   - Explain to students that there are some architectural elements or structures that have been used for thousands of years as parts of buildings. Architects and engineers continue to figure out new ways to build stronger and more efficient buildings. Let them know they will be learning about and investigating some of these structures today.
   - Using the Architecture Investigation student worksheet introduce students to the architectural structures. The worksheet shows different types of structures and how they were used in historic buildings.
   - As a group discuss each structure then create a list of buildings in the Washington, D.C metro area that use these structures. Optional: Encourage students to “act” out the structures using their bodies so they understand how the forces of tension and compression work in each structure.
   - The table below lists buildings in the Washington, D.C. metro area that use the architectural structures discussed in this lesson.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Example in Washington, D.C. area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post and Lintel</td>
<td>• Lincoln Memorial</td>
</tr>
<tr>
<td></td>
<td>• National Archives</td>
</tr>
<tr>
<td>Pyramid</td>
<td>• Top of Washington Monument</td>
</tr>
<tr>
<td></td>
<td>• George Washington Masonic Temple in Alexandria, VA</td>
</tr>
<tr>
<td>Arch</td>
<td>• National Building Museum</td>
</tr>
<tr>
<td></td>
<td>• National Cathedral</td>
</tr>
<tr>
<td></td>
<td>• Franc Scott Key Bridge</td>
</tr>
<tr>
<td></td>
<td>• Arlington Memorial Bridge</td>
</tr>
<tr>
<td>Dome</td>
<td>• Library of Congress</td>
</tr>
<tr>
<td></td>
<td>• Capitol Building</td>
</tr>
<tr>
<td></td>
<td>• National Gallery of Art, West Building</td>
</tr>
<tr>
<td>Space-Framing</td>
<td>• Roof of Verizon Center</td>
</tr>
<tr>
<td></td>
<td>• Interior Roof of Pentagon City Mall</td>
</tr>
<tr>
<td></td>
<td>• Fedex Field</td>
</tr>
<tr>
<td>Geodesic Dome</td>
<td>• Jungle Gym on Playground</td>
</tr>
</tbody>
</table>

2. Investigate the Structure of a Building in the Neighborhood or Washington, D.C. (25 minutes in class or assign for homework)
   - Using the Structures Investigation Worksheets, pp. 40–43, as a guide, have students consider why one building was built to look the way it does. Have students investigate their school building, a structure in their neighborhood, or a building in Washington, D.C. Students can visit the physical building or view mages of the building on the computer or in books.
# Structures Investigation: Part I

Take a look at these architectural structures. They will help you identify structures in other buildings.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Historical or Natural Model</th>
<th>Examples in Washington D.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post &amp; Lintel</td>
<td>Greek Parthenon, Greece</td>
<td></td>
</tr>
<tr>
<td>Pyramid</td>
<td>Pyramids of Giza, Egypt</td>
<td></td>
</tr>
<tr>
<td>Arch</td>
<td>Roman Coliseum, Italy</td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>Historical or Natural Model</td>
<td>Examples in Washington D.C.</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Dome</td>
<td>Hagia Sophia, Turkey</td>
<td></td>
</tr>
<tr>
<td>Space-Framing</td>
<td>Spider web</td>
<td></td>
</tr>
<tr>
<td>Geodesic Dome</td>
<td>Disney’s EPCOT Center, USA</td>
<td></td>
</tr>
</tbody>
</table>
Student Worksheet
Structures Investigation: Part II

Now that you’ve learned about types of architectural structures it’s time to investigate a building in your neighborhood or Washington, DC. Visit the building or view pictures of it to answer the questions below:

1. Name and address of building: __________________________________________________________

2. Building’s use: ______________________________________________________________________

3. In the table below, describe three types of structural systems used in the building. Explain the purpose of each structure.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Location</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>example post and Lintel</td>
<td>entryway</td>
<td>provides a simple short space for doorway</td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Document your findings. Draw or paste a picture of your building here:
5. How do you think these structures affect the building? Circle your choices and explain why below.

- it saves money
- it makes the building appear grand or stately
- it helps the building blend with its surroundings
- it mimics a structure from the past
- it makes the building appear modern and innovative
- other ________________________________

________________________________________________________________________________________
________________________________________________________________________________________
________________________________________________________________________________________

6. How would you describe the appearance of these structures?

- inexpensive
- expensive
- beautiful
- functional
- traditional
- modern
- historical
- funky
- utilitarian
- other
- other ________________________________

7. What materials is this building made from? Do you think these materials are a good choice for the building? Why or why not?

________________________________________________________________________________________
________________________________________________________________________________________
________________________________________________________________________________________
________________________________________________________________________________________

8. If you could change this building by adding a different type of structure, which one would it be? Why?

________________________________________________________________________________________
________________________________________________________________________________________
________________________________________________________________________________________
________________________________________________________________________________________
Geodesic Domes: Take a Closer Look

Go to the Designer
Interview an architect or engineer about his or her work. Ask questions like the following:

- How did you become interested in building structures?
- What do you build?
- What education did you need to get your job?
- What is one skill that you didn’t know you would need to be an architect or engineer?

Innovative Architecture
Research an example of visionary design—a structure or object that uses geometry, physics, or materials in an innovative way. Consider what you like or dislike about this structure or object; how well it has stood the test of time; and the designer’s methods of invention. Think about looking at one of these awe-inspiring designers or buildings:

- Designers:
  - Leonardo da Vinci (An artist, engineer, and inventor who created artwork and designed innovative machines)
  - I. M. Pei (An architect that designed modern buildings using large abstract and geometric shapes)
  - Frank Lloyd Wright (An architect and furniture designer who designs were inspired by their site or nature)
  - Frank Gehry (A contemporary architect who used materials in innovative ways)

- Buildings:
  - Eiffel Tower (Constructed of iron trusses which were previously used only in bridges)
  - Parthenon and other Greek temples (Uses geometric proportion for refinement and optical effect)
  - Aqua Building in Chicago (Uses uniquely shaped balconies to reduce the amount of forces acting upon the building from the Chicago wind)

Creative Framing
Think of other ways space-framing can be used in buildings. Write an essay, draw a picture, or create a model of your new use for space-framing.

Redesign the World
Redesign a building of your choice using the architectural structures you just learned about. This could include creating a model or drawing of the building as it is now and how it will look with your new structural changes. Be sure to explain how your design is stronger or more effective than the previous one.
Parents/guardians, your children are learning about the geodesic dome and architectural structures in school and at the National Building Museum. Encourage them to explore homes and buildings in their community and have them teach you about the basics of structures.

1. Walk or drive around your community, notice the buildings and homes that you pass. What roof structures do they have? Which designs work best with the weather patterns in your area? Which roof designs require the greatest structural support?

2. Take a close look at the local school playgrounds and parks for jungle gym structures. Ask your child why triangles are so strong.

3. Learn more about engineering at the National Building Museum’s annual day-long family festivals, which allow young people to explore hands-on engineering and other building activities. Check the Museum’s website or call for more information.

4. Take a tour of the U.S. Capitol, which includes an impressive dome.

5. Visit www.pbskids.org to learn how your family can use newspaper and masking tape to create a geodesic dome at home.

Visit the National Building Museum,
Where families can discover the world we build for ourselves!

401 F Street NW Washington, DC 20001 202.272.2448
Red Line Metro, Judiciary Square
www.NBM.org

Programs for Schools, Families, Scouts, Outreach Programs, Discovery Carts, Exhibitions, Birthday Parties, Festivals, and Summer Camp.
Information in this section comprises the following:

Geodesic Dome Vocabulary
Books
Websites
Videos
Activity Kits
Organizations
Geodesic Dome Vocabulary

Arch
A curved structure which spans an opening; usually consists of wedge-shaped blocks.

Architect
A professional who designs, plans, and coordinates the building of structures.

Architecture
The art and science of designing and building structures.

Barrel Vault
A roof constructed as a continuous semi-circular arch.

Built Environment
Human-made surroundings, such as buildings, structures, parks, streets, bridges, etc.

Column
A free-standing vertical support in architecture.

Connector
Something that joins or connects at least two other elements.

Compression
The stress resulting from a pushing force on a structure; the opposite of tension.

Cube
A regular solid of six equal square sides or a cube.

Dome
An evenly curved structure of intersecting arches on a circular, elliptical or polygonal base.

Engineer
A professional who applies mathematical and scientific principles to the design of structures, equipment, and systems.

Equilateral Triangle
A triangle with sides of equal length and angles of equal degree.

Face
A planar surface of a geometric solid; a side.

Force
A push or a pull on an object; when an object is at rest (not moving) the forces acting on it are in balance.

Form
A three-dimensional object.

Geodesic
The shortest line between two points that lies on a curved or plane surface.

Geodesic Dome
A lightweight dome supported by a grid of rigid members dividing the surface into regular facets.

Perimeter
The boundary of a closed plane figure.

Polyhedron
A solid formed by flat faces which are all polygons.

Post and Lintel
A structure with two upright members and a horizontal member spanning it. Usually supports the load above an opening.

Pyramid
A polyhedron consisting of a polygon base and triangular sides with a common vertex.

Space-Frame
A three-dimensional framework of struts evenly distributes forces in all directions.

Span
The distance between two supports.
**Structure**
An object constructed of a number of parts that are put together in a particular way.

**Strut**
A structural piece designed to resist pressure in the direction of its length.

**Tension**
The stress resulting from a pulling force; the opposite of compression.

**Tetrahedron**
A solid with four faces. A regular tetrahedron is one where all four faces are equilateral triangles.

**Triangle**
A polygon having three sides.

**Truss**
A rigid support structure that is made up of interlocking triangles.

**Vertex**
A point at which two or more lines end.

**Volume**
The amount of space contained by a three-dimensional object as measured in cubic units.
Books


A thorough biography of Fuller's ideas and their relevancy today.


Activities for grades 3-5. Download or order from www.aimsedu.org


Provides basic insights into geodesic design of higher frequency structures from the fundamental icosahedral blocks. Cut out patterns provide some hands-on building.


Originally published in 1987. The author worked with Fuller during the last few years of his life. She clearly explains Fuller’s synergetic geometry in easy to understand language.

Videos

*Buckminster Fuller: Thinking Out Loud* 

Biography of Fuller's life and work. Filmmakers were given wide access to the Buckminster Fuller Institute archives for footage and information.

*Building Big With David Macaulay: Dome* 
Produced by Tom Levenson

Macaulay visits the world’s greatest domes to tell their stories and the stories of the people who built them. Includes a mini dome building exercise. (2000).

*Around the Universe in 90 Minutes* 
A taped chat with Fuller introducing his most famous concepts and discoveries. Available from the Buckminster Fuller Institute, Santa Barbara, CA.
Websites

Buckminster Fuller Institute
www.bfi.org/domes

Contains information on R.B. Fuller, photos of domes, articles on design science, a geodesic dome slide show, and information and pictures of the 10 largest domes in the world.

Buckminster Fuller Resources
www.worldtrans.org/whole/bucky.html

List of books by Buckminster Fuller as well as a bibliography of additional books and materials.

Building Big
www.pbs.org/wgbh/buildingbig/

A five part video series and interactive website exploring what it takes to build large structures. Includes a forces lab.

Constructing a Geodesic Dome
www.insite.com.br/rodrigo/bucky/geodome.html

Middle School age friendly text describing the construction of a geodesic dome.

Geodesic Dome Photography
www.insite.com.br/rodrigo/bucky/house.html

Photos of geodesic dome houses.

Historic American Building Survey (HABS)
http://www.loc.gov/pictures/collection/hh/

Documents historic architecture—primarily houses and public buildings—of national or regional significance.

Historic American Engineering Record (HAER)
http://www.loc.gov/pictures/collection/hh/

Documents nationally and regionally significant engineering and industrial sites in the United States.

National Engineering Week
www.eweek.org

Includes information on engineering, libraries, science centers, and other resources. In addition, find information about annual National Engineers Week events for teachers and students.

Materials & Activity Kits

Roger's Connection

Black magnetic rods and balls that connect to create geometric structures (as used during Museum program). Available for purchase online www.rogersconnection.com.

Geomags

Small colorful magnetic rods and balls that connect to create geometric structures (as used during Museum program). Available for purchase on multiple websites.

Bridge Basics Program Kit

National Building Museum curriculum and hands-on materials to teach about bridge engineering. go.nbm.org/bridgekit
Other School Programs at the National Building Museum:

• Be a Green Builder
• City by Design
• Fuller’s Fantastic Geodesic Dome
• Patterns: Here, There, and Everywhere
• My House, My Home
• Washington: Symbol and City

Other Youth Programs at the National Building Museum:

• After-School and Community Groups
• Birthday Parties
• Family Programs
• Festivals
• Outreach
• Scout Programs
• Summer Camp

For more information on these programs visit go.nbm.org/schoolvisit.

Visit go.nbm.org/educators for free lesson plans and information about the Museum’s curricula kits.

Teaching resources are available in the Museum Shop. Visit go.nbm.org/shop.
The National Building Museum tells the stories of architecture, engineering, and design. The Museum offers something for everyone, from children to design buffs to building professionals. The engaging exhibitions and all-ages programming showcase the world people design and build.