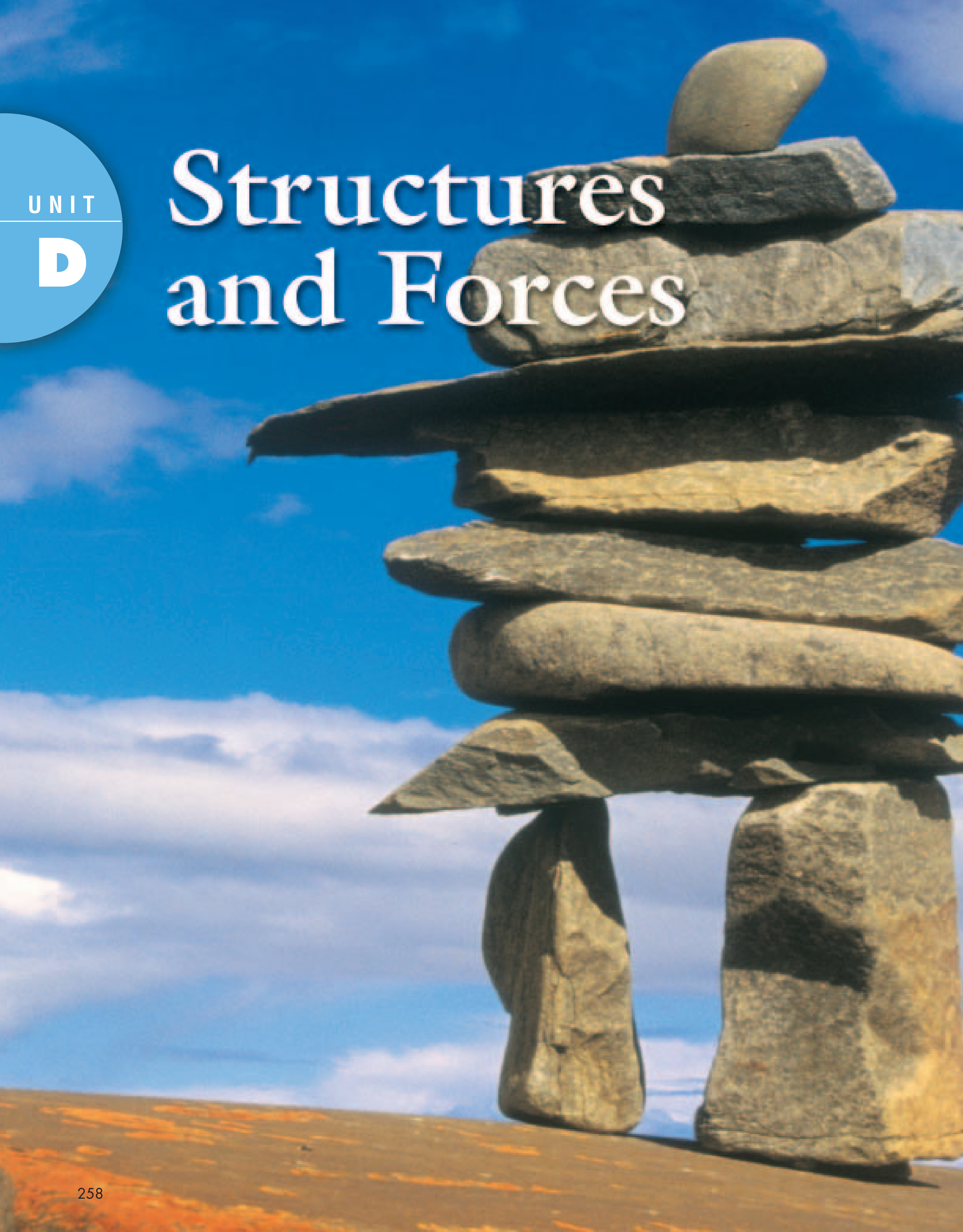
UNIT D

Structures and Forces



In this unit, you will cover the following sections:

1.0

Structures are found in natural and human-made environments.

1.1 Classifying Structural Forms

1.2 The Function of Structures

1.3 Human-Built Structures around the World

2.0

External and internal forces act on structures.

2.1 Measuring Forces

2.2 External Forces Acting on Structures

2.3 Internal Forces within Structures

2.4 Designing Structures to Resist Forces and Maintain Stability

3.0

Structural strength and stability depend on the properties of different materials and how they are joined together.

3.1 Materials and Their Properties

3.2 Joining Structural Components

3.3 Properties of Materials in Plant and Animal Structures

4.0

Structures are designed, evaluated, and improved in order to meet human needs.

4.1 Building Safe Structures in All Environments

4.2 Strengthening Materials to Improve Function and Safety

4.3 Evaluating Designs from an Overall Perspective

Exploring

Structures have a job to do. A roof must stay in place even under the weight of heavy snow, sheltering whatever it covers. A bridge must support hundreds of vehicles, as well as be able to withstand the forces of weather and, in some cases, even earthquakes. The case around a television must protect its internal parts—just as your rib cage must protect your internal parts from the wear and tear of daily life.

In this unit, you will learn about a wide variety of structures in both the natural and human-built environments, examining the many different purposes they serve and the forms they can take. Investigating and analyzing the forces that act within and on structures will help you explore how different materials, components, and ways of joining can affect structural strength and stability. As you build and test your own structures, you will also learn about the relationship between design and function. This will help you evaluate how structures built in the past, as well as those you use every day, can be developed and improved to meet human needs in a safe and efficient manner.

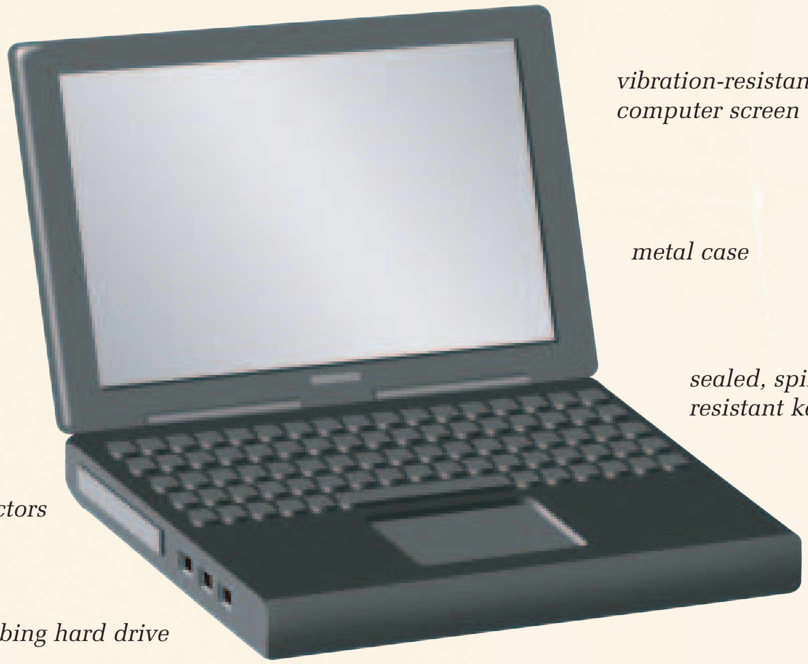
Rugged Computers for a Rugged Life

A recent survey by a leading maker of computers in the world reported that businesses in North America are spending millions of dollars each year to repair and replace damaged laptop computers. Laptops, the survey found, are most often damaged as a result of being dropped, crushed, or spilled on. This is likely to become a greater problem as people rely more and more on being able to take their laptop computers wherever they go: the office, school, the mountains, the beach—even into space.

Many laptop computers are used far from classrooms and offices. In this photograph, a satellite communicator is also being used.

A laptop computer has many delicate parts that can break. It must therefore be designed to withstand being bumped around every day. Still, it must also be light enough to carry. Early laptops were heavier than today's models because of the materials and components used to make them. As computer technology has improved, laptops have become increasingly lighter. At the same time, designers and computer technicians have come up with clever ways of making the devices more rugged. The illustration on the next page shows several of the standard features on new laptops today.

Laptops are not meant to be mistreated, but when accidents happen, today's portable computers can often survive with good results.



Give it a TRY ACTIVITY

SAVE THIS EGG!

How well could you design a structure to protect a very delicate object like a laptop computer? Rather than finding out using a real computer, you're going to test your design abilities on another delicate object—an egg.

- Brainstorm what design and materials might be used to protect an egg from cracking when it is dropped.
- Using the least amount you can of the materials listed here, design an egg protection case that will enable the egg to survive the force of impact when it is dropped from a height of 3 m.
- When everyone in the class has had a chance to test their egg protectors, discuss the results. Which means of protection worked the best? What materials provided the best protection? Was there a particular arrangement of materials that did the most effective job? Which successful protection case was the lightest (that is, used the least material)?

Materials & Equipment

Options:
- straws
- newspaper
- cardboard
- paper
- Popsicle sticks
- masking tape
- glue
- string
- paper clips
- elastic bands

Focus On Science and Technology

As you learn about structures and forces in this unit, you will be given many opportunities to solve practical problems using your knowledge of both science and technology.

Science provides an ordered way of learning and explaining the nature of things. Technology is concerned with finding solutions to practical problems that arise from human needs. As you'll discover, there are often several possible solutions to the same technological problem, each involving different designs, materials, and processes. In approaching a problem, it is helpful to

- define your need clearly
- develop an appropriate plan and design
- test and evaluate your design

To guide your reading as you learn about the nature of structures and forces, keep the following questions in mind.

1. **How do structures stand up under a load?**
2. **What forces act on structures?**
3. **What materials and design characteristics contribute to a structure's strength and stability?**

The answers to these questions will help you understand the roles that both science and technology have in the designing and building of a wide variety of structures.

1.0 Structures are found in natural and human-made environments.

Key Concepts

In this section, you will learn about the following key concepts:

- structural forms
- function and design
- structural stability

Learning Outcomes

When you have completed this section, you will be able to:

- recognize and classify structural forms and materials
- interpret and evaluate variation in the design of structures that share a common function
- compare example structures developed by different cultures and at different times
- interpret differences in structural functions, materials, and aesthetics
- describe and interpret structures found in the natural environment

Every object that provides support is a **structure**. A structure may be made up of one or more parts, and it may be large or small.

Think for a moment of all the structures that are around you in your everyday life. Some you can see in the natural environment, and some are built by people. Some are made of delicate material, and others of very rugged, hard material. Some structures have lasted a long time because they can bend without breaking. Others have lasted a long time because they are rigid.

You will probably also notice that the structures around you vary in their strength and stability. **Structural strength** refers to a structure's capacity to hold itself up, as well as any weight added to it. **Structural stability** is a structure's ability to maintain its position even when it is being acted on by a **force**.

If there are so many types of structures, how can we even begin organizing them into a meaningful classification that helps us understand them better? In this section, you will find out.

For Web links relating to 1.0, visit **www.pearsoned.ca/scienceinaction**

1.1 Classifying Structural Forms

Usually, the first thing you notice about a structure is its shape, or form. You can learn a great deal about a structure by comparing its overall form with that of other structures. How would you do this?

There are three basic structural forms. You can see these for yourself by copying the actions in Figure 1.1. First, use your hand to make a fist. This is an example of a *solid structure*. Feel what it is like. Now, open your hand and put both hands together so your fingertips are touching. This is an example of a *frame structure*. Would this form be as strong and stable as your fist if you added a mass on top of it? Next, make one hand into a cup shape, as though you wanted to carry water in it. This is an example of a *shell structure*. Suppose you added a mass on top of this form. What do you predict about its strength and stability?

Figure 1.1 Your hand in the shape of a fist is a solid structure (A). Placing your hands in a tent-like position creates a frame structure (B). Cupping your hand creates a shell structure (C).

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Portable Shelters

The earliest human-built structures were dwellings made with ice, sod, or wood. They were strong and weather-resistant, but too heavy to be easily moved. Today, synthetic building materials (materials made from chemicals) mean that many dwellings can be strong but also light and portable. Examples are nylon tents and prefabricated trailers.

Give it a **TRY** ACTIVITY

TAKE THE POP BRIDGE CHALLENGE

If someone told you it was possible for a full can of pop to be supported by a sheet of paper, would you believe it? Try this activity and find out. Your teacher has a can of pop and two stacks of books 15 cm apart at the front of the class.

- Using only a sheet of paper (about 26 cm × 20 cm, roughly the size of a page from your notebook), design a structure that will rest between the two stacks of books and support the can of pop. You have 5 min to work on your design at your desk. You will then get a chance to put your structure to the test on the set-up at the front of the class.

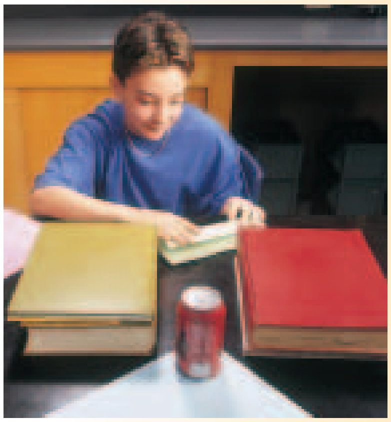

Figure 1.2 How could you create a paper bridge strong enough to support a full can of pop?

Solid Structures

A **solid structure** is formed from a solid piece (or solid combination of pieces) of some strong material. A concrete parking barrier is a solid structure. So is a brick wall and a hockey puck. A solid structure has little or no space inside, and relies on its own mass to resist the forces that act on it. (You will find out more about *mass,* meaning the amount of matter in an object, in section 2.0.) Solid structures are usually stronger than either frame or shell structures, but they are also more massive and therefore harder to move. Other examples of solid structures are shown in Figure 1.3.

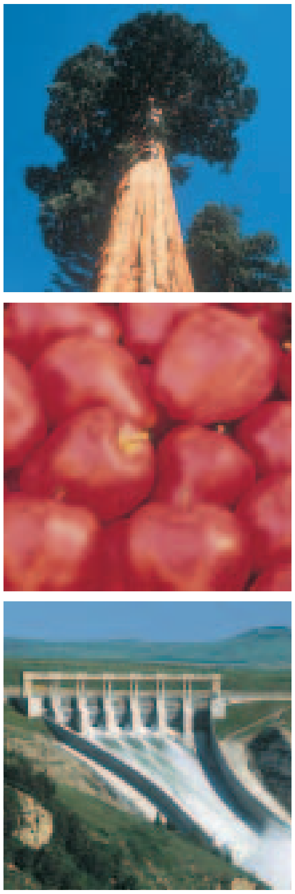

Figure 1.3 Examples of natural and human-made solid structures

Frame Structures

A **frame structure** is made up of a rigid arrangement of parts, or structural components, fastened together. An example is your skeleton, which is made up of bones, ligaments, and joints. The strength of a frame structure comes from the way the components are joined. Individually, no one component of a frame structure is as strong as the components combined.

A frame structure can be arranged in two dimensions, the way a door frame or fence is. It can also be arranged in three dimensions, as a music stand or house is. Compared to solid structures, frame structures are lighter because they use less material. Figure 1.4 shows additional examples of frame structures.

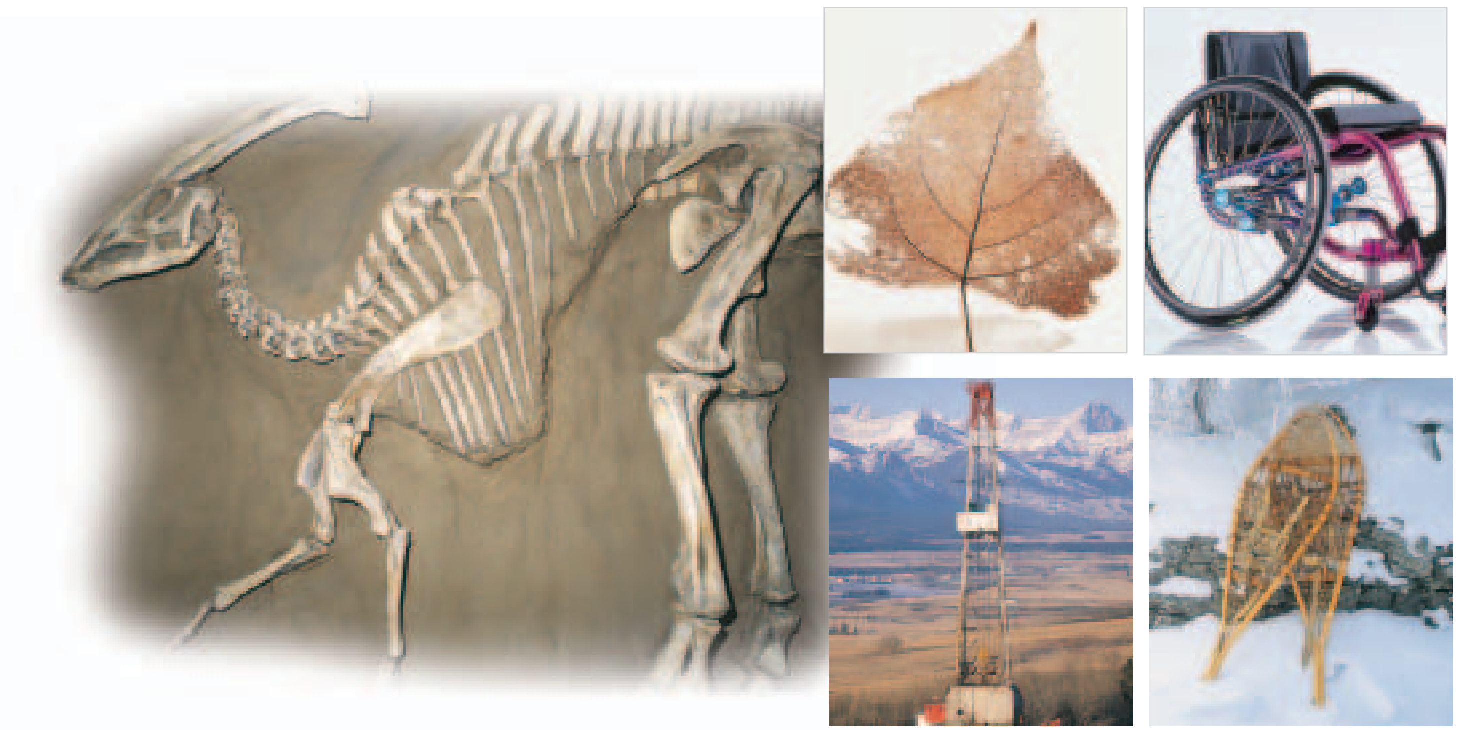

Figure 1.4 Examples of natural and human-made frame structures

Shell Structures

A **shell structure** has a solid outer surface, which may be rounded or flat in shape, and a hollow inner area. Shell structures with a rounded outer surface are usually stronger than those with a flat outer surface, because the curved areas distribute the load around the whole surface. A bean pod, a tennis ball, and a car body are all examples of shell structures. So are a flowerpot, a lunch kit, and a CD case.

Having a hollow interior means that shell structures are lighter than solid structures. They are also often stronger than frame structures and are therefore commonly used to provide protection. (Think of helmets, for instance.) Other examples of shell structures are shown in Figure 1.5.

math Link

The spider's web at the beginning of this section can hold up to 4000 times the weight of the spider that made it. If you were a spider, how much weight would your web hold?

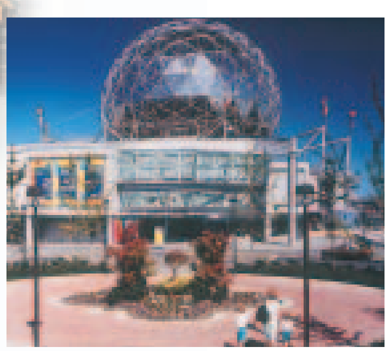

Figure 1.5 Examples of natural and human-made shell structures

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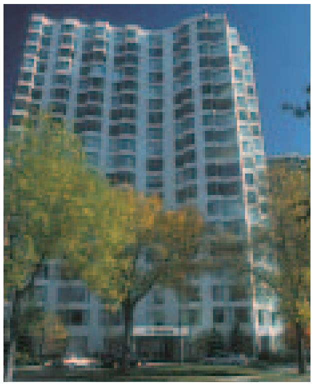
Combination Structures

You may have noticed that most structures in the built environment are actually a combination of structural forms. Combination structures use the best of the three basic forms to advantage. Study the structures to the right and decide which structural forms they combine.



Calgary's Saddledome shows how innovative architects can be when it comes to designing buildings.

Examples of combination structures

Check and Reflect

1. Name the three main structural forms. In your notebook, make a simple sketch of the basic design of each.
2. Copy the chart below into your notebook. Write the names of the three structural forms in the left-hand column. Then, for each structural form, write in two examples from the natural environment and two from the human-made environment. Try to make all your examples for (b) ones that have not been shown or mentioned in the text.

Structural form	Examples from the natural environment	Examples from the human-made environment
1.	a) b)	a) b)
2.	a) b)	a) b)

Figure 1.6 Make a chart like this for Question 2.

3. Large human-built solid structures are often made from brick, concrete, mud, or stone. Why do you think these materials are used to construct solid structures?
4. Consider these facts: a) a bird's wing bones are hollow, not solid; and b) the supporting skeleton of some invertebrates (such as sea stars and lobsters) is outside, not inside, their bodies. What advantages do these structural designs have?

1.2 The Function of Structures

Imagine the following situation:

You are a landscape designer who has been hired by the local parks commission to design a style of park bench that will last a long time and can't be easily moved. Knowing what you do about structural forms, you decide that a solid bench is the best choice. From your design, 10 block-like concrete benches are built. Several months after they are installed, a member of the parks commission calls you with a concern. Few people ever use the benches because they are so unappealing and uncomfortable.

What important point was overlooked in the design task? It was that the main **function** of the benches (that is, their use or purpose) was not properly considered. Too much attention was given to designing a bench that would be durable and secure. Not enough attention was given to designing a bench whose function was to provide comfortable, inviting seating.

Figure 1.7 The Muttart Conservatory in Edmonton is noted for its five glass pyramids. Housed within these pyramids are indoor gardens that include tropical and desert plants.

Multiple Functions

Many structures are designed to serve more than one function. An airplane, for example, provides both movement and shelter. So does a train. Sometimes these two types of structures are built to move and shelter cargo. Other times they are built to move and shelter people.

When a designer knows what all the functions of a planned structure are to be, he or she will be better able to design a structure that will be used.

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Inukshuit

What human need does an *inukshuk* (pronounced "in-OOK-shook") meet? This structure, found across the Canadian North, is a unique symbol of Inuit culture. It expresses "joy and much happiness" to anyone who encounters it. More than a greeting, however, many types of *inukshuit* also serve as signs, providing valuable information for travellers. For this reason, they must be clearly visible, stable, and strong.

Some *inukshuit* point in the direction where, traditionally, caribou herds have been hunted.

FUNCTION AND EFFECTIVE DESIGN

Technological problems can often be solved in a variety of ways, using many different structural designs, materials, and processes. What all successful solutions have in common, however, is that they pay close attention to function. For example, consider Canadian inventor Norman Breakey. In 1940, he grappled with the following technological problem: how do you paint a large wall quickly and inexpensively? People had been using paint brushes, but it was a slow process and sometimes wasted a lot of paint.

Breakey thought of designing a device that would allow the paint to be rolled on quickly and smoothly. Wisely, he also remembered to think about how the device would be used. It had to be light enough for people to handle, easy to use in large or small spaces, and inexpensive to make. After making many modifications to his prototype, he developed the hand-held paint roller. Today, the roller is used by professional and do-it-yourself painters all over the world.

Figure 1.8 Predict what might have happened if Norman Breakey had thought only about the science of how his new device applied paint, and not about the practical problems of using the device.

To get ideas for structures that will meet particular functions, many designers, architects, and inventors look at the natural world. For example, Prairie rancher Michael Kelly invented barbed wire in 1868 when he realized he needed something that would function the same as a thorny bush to keep his livestock in one place. Over time, Kelly's invention has been refined, but the basic design has stayed the same.

Problem Solving
Activity

Design the Perfect Desk

Materials & Equipment

- ruler
- metre-stick
- graph paper (optional)

Functions (*Ways I want to use my desk*)	**Design** (*What special features my desk will have so I can use it that way*)
Writing	A flat surface large enough to hold a workbook and textbook

Recognize a Need

Right now you're probably sitting at a desk. Think about what your desk has to do. What are its main functions? How does its design help the desk perform those functions? Is there something you would add to make your desk more useful? Here's your chance to improve on an old design.

The Problem

Design the "perfect" desk, one that serves all the functions you need it to do during the school day.

Criteria for Success

For your design to be considered successful, it must

- represent a completed desk that would fit an area no larger than 60 cm $\times$ 90 cm on the floor and 120 cm high
- show at least six unique features not used in current desks

Brainstorm Ideas

1 Working on your own, make a list of (a) your desk's essential functions and (b) the extra functions you think it could serve. For example, do you need more work space? Do you want a place to keep your lunch cold?

2 Beside each function you've listed, write down possible design solutions. Maybe you need a built-in pencil sharpener, or a hook for hanging your backpack off the floor? Be creative, but practical!

Make a Drawing

TOOLBOX

3 Decide what scale you will use in making a diagram of your design. For example, 6 cm in actual size could be represented by 1 cm in your drawing (see Toolbox 8).

4 Draw your design ideas on paper, using the scale you have set. If you need to, make two or three drawings to show your desk from various views, such as side, front, and back.

5 Label the design features shown in your drawings. Also, label the measurements of the overall desk as they would be in actual size.

Test and Evaluate

6 Post your completed drawings on the wall.

7 As a class, assess whether the various designs look as though they would be strong and stable enough to serve their intended functions.

Communicate

8 Share with the class any additional design ideas you had but were unable to use because of the size limitations or another reason. Invite your classmates to make suggestions for possible design solutions you hadn't thought of.

Common Function, Different Design

Some structures, although they look very different from one another in their design, actually share a common function.

For instance, look at the roofed structures pictured in Figure 1.9. In simple terms, all roofs serve the same purpose. They provide a top covering for a building and protect the contents inside. Yet, as the pictures show, there is great variation in the way roofs are designed and built. All of the roofs shown here are effective in their own way because they suit the local climatic conditions and they meet the needs of the people using them.

Over time, people have discovered through trial and error what works and what doesn't work in roof design. How effective do you think a flat roof on a house would be if the house were located high in the mountains? After one season of heavy snow, how would you modify the roof design?

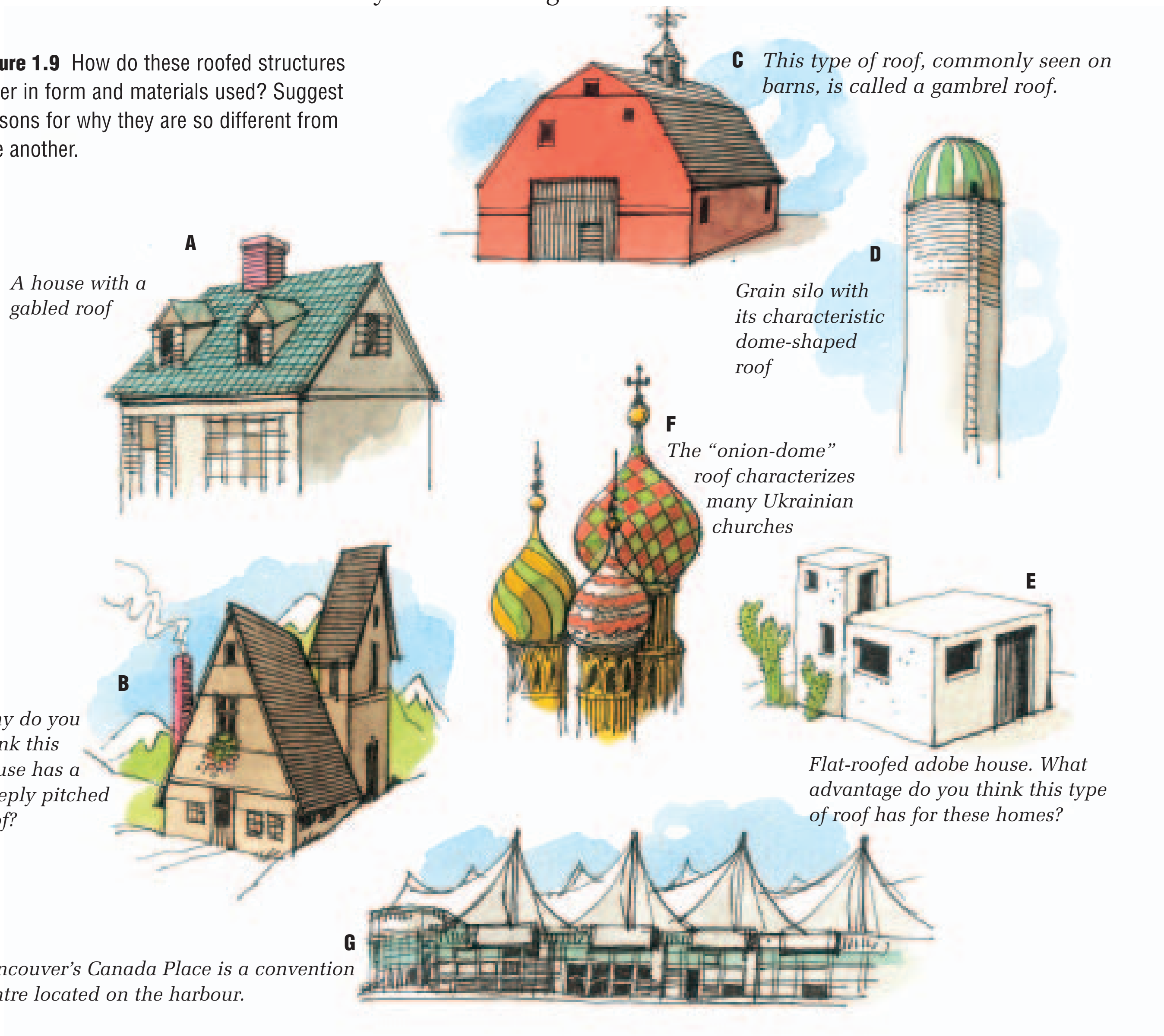

Figure 1.9 How do these roofed structures differ in form and materials used? Suggest reasons for why they are so different from one another.

A *A house with a gabled roof*

B *Why do you think this house has a steeply pitched roof?*

C *This type of roof, commonly seen on barns, is called a gambrel roof.*

D *Grain silo with its characteristic dome-shaped roof*

E *Flat-roofed adobe house. What advantage do you think this type of roof has for these homes?*

F *The "onion-dome" roof characterizes many Ukrainian churches*

G *Vancouver's Canada Place is a convention centre located on the harbour.*

Other Characteristics of Structures

In addition to form and function, structures can be interpreted and classified according to the materials and components they are made of. You will learn more about these in section 3.0, but for now, look at the structures in Figure 1.10 and analyze their characteristics.

Match one of the natural structures with one of the human-built structures that is similar in shape. Compare the two structures. How else are they similar besides the design? How are they different? For example, a bat's wing and an airplane wing are similar in shape. They are also similar in function since both provide a means to fly. However, they are different in the materials they are made of, and they are different in how they work.

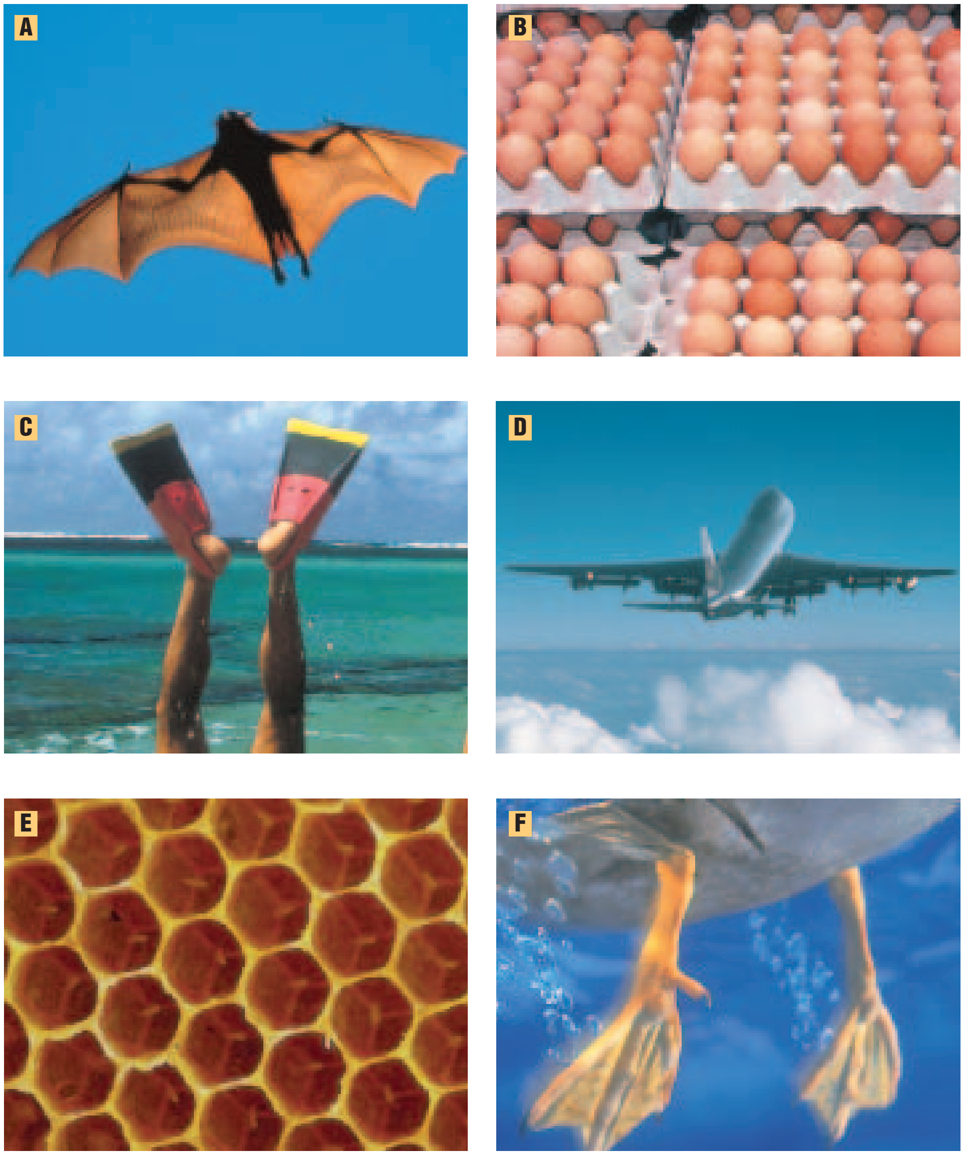

Figure 1.10 In terms of structural characteristics, which objects from the natural environment and which from the human-built environment can be paired up?

Aesthetics

One other way that structures can be interpreted and classified is in terms of their aesthetic quality. **Aesthetics** refers to the pleasing appearance or effect that an object has because of its design. Not all structures need to be aesthetically pleasing. For example, the framework supporting a train trestle does not have to be beautiful in design, colour, or finish, but it does have to be strong and stable. A park band shell, on the other hand, should be pleasing to look at and use.

Figure 1.11 Honouring its Ukrainian heritage, the town of Vegreville built this monument to the *pysanka* (Ukrainian Easter egg). The aluminum egg, weighing 2270 kg and measuring 7 m by 6 m, stands on a steel and concrete base. Why might a concrete block with a plaque have been a less aesthetically pleasing structure?

Humans throughout time and across cultures have shared a need for beauty in their surroundings. Indigenous peoples around the world have traditionally decorated their dwellings on both the outside and the inside with painted designs and other artistic features. Today, people still make a conscious effort to design and embellish their dwellings and other buildings so that they are attractive.

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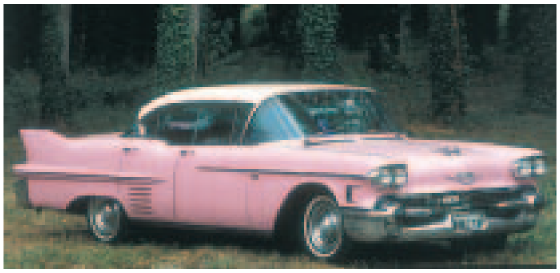
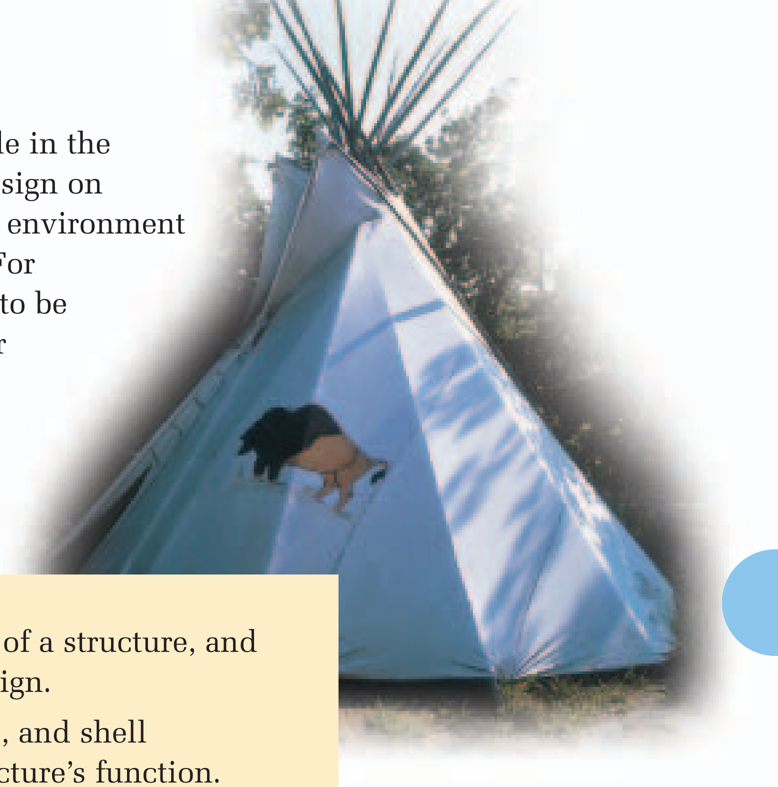
Nice Fins ...

Just as with clothing, trends and styles in structural design come and go. What was considered aesthetically pleasing at one time may not be many years later. Cars built with large "fins" were popular in the 1950s and early 1960s, but that feature gave way to more rounded vehicle forms. Choose another type of structure that interests you and research how changing tastes in aesthetics have affected the structural design of that object over the years.



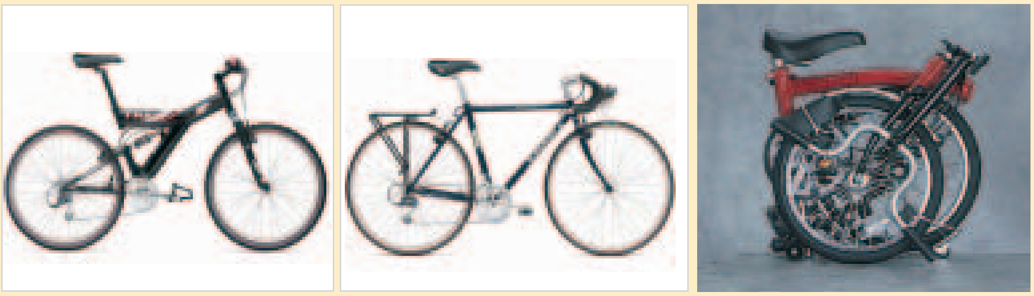
Aesthetics plays a big part in structural design. Aesthetics, of course, is "in the eye of the beholder."

Aesthetics has always played an important role in the structural designs of First Nations people. The design on teepees used by Plains First Nations reflected the environment as well as the owner's personal spiritual beliefs. For example, the animals portrayed were considered to be sacred and were thought to provide protection for the family living within.



Check and Reflect

1. Briefly explain what is meant by the function of a structure, and why function is such an important part of design.
2. Think about the characteristics of solid, frame, and shell structures, and about the importance of a structure's function. With these points in mind, decide which structural forms you would use to make each of the following and explain why:
   a) a bridge to carry trains over a deep valley
   b) a rain shelter in a public garden
   c) a stand to hold a guitar
   d) a stand to hold a large plant
   e) a child's playhouse
3. Study the three bicycles in Figure 1.12.
   a) Even though they all share a common function, what does the variation in their design show?
   b) Evaluate the effectiveness of each design. Does each bicycle serve the function it was designed to? Explain your answers.



A B C

Figure 1.12 (A) a mountain bike, (B) a racing bike, and (C) a folding bike

4. What is aesthetics? List three structures that you consider beautiful. Explain why this beauty is important to their function.

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Stonehenge

Stonehenge is an ancient monument on the Salisbury Plain in England. Built more than 3000 years ago, the structure consists of more than 36 megaliths (large stones) arranged in a circle and surrounded by a ditch 91 m in diameter. Although there are many theories about how Stonehenge came to be, what its function was when it was built is not completely understood.

1.3 Human-Built Structures around the World

Figure 1.13 Taj Mahal, Agra, India

Throughout this unit, you've already seen or thought about many different types of structures. Some of these are modern and some are from ancient times; some are from Canada and some are from elsewhere in the world. As the examples of various roof structures in Figure 1.9 showed, even those structures with a common purpose can have very different designs. Climate, culture, tradition, technology, and economics are among the main reasons that structures are so varied.

The Human Home

Homes developed by different cultures and at different times are just one example of how widely humans have adapted a basic form.

Many people around the world built homes that, while providing protection, were also portable. Similar to the North American teepee, for example, were the yurts used in Siberia and the tents used in the deserts of the Middle East.

Houses built of sod (clumps of earth) were long used by early peoples in Europe. This was also a common structure built by pioneers in the Prairies. The material was easy to get and didn't cost anything. It also created a relatively protected enclosure that could be heated by a fire.

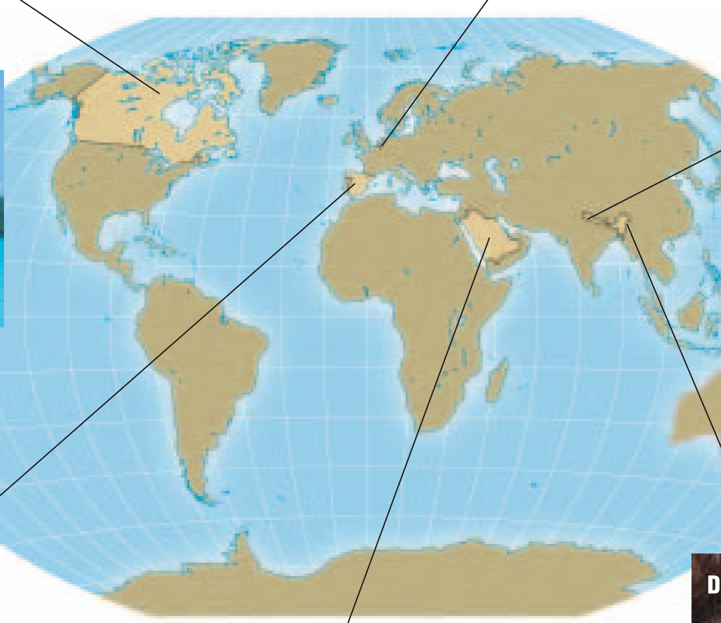
In countries with hot climates, houses have traditionally been constructed of sun-baked brick (adobe), clay, or mud. These materials, combined with a shell form having few windows or door openings, create interiors that can be kept cool even under intense sun. Dwellings made of grasses and bamboo have been built for hundreds of years in many warm, wet countries. In some locations, these homes are constructed high on stilts to raise the dwelling above wet ground.

Look at Figure 1.14 to see examples of these and other types of homes. As different as they are from one another, they still share two essential characteristics of effective structures: 1) they are all basically stable; and 2) they all provide shelter for the people who live in them.

Igloos have been used by the Inuit for thousands of years.

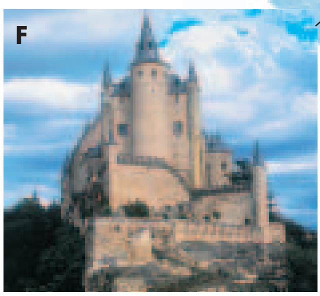
In European cities, apartment living is common.

Figure 1.14 Dwellings such as those pictured here show the tremendous variety there is in human-built structures around the world.

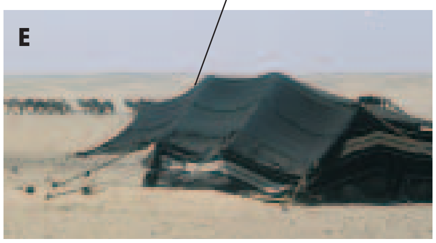


Many homes in the world are floating homes, such as this one in French Polynesia.

Stone mountain huts, such as this one in the Himalayan mountains of Nepal, are warm once heated inside.



Buildings, such as this medieval fortress in Spain, provided a home and protection against invasion.



Tents offer desert dwellers protection from sun, wind, and cool night temperatures. This photograph was taken in Saudi Arabia.

In a tropical climate, houses must keep people cool and dry. This bamboo house is in Assam state, India.

Give it a **TRY** ACTIVITY

CURRENT OR CLASSICAL? ANALYZE A STRUCTURAL DESIGN

You work for a company called "Build It Yourself: Current or Classical Boats." It's an unusual business that specializes in selling kits to people who want to build their own life-size sailing vessel. All the kit designs are of authentic sailing vessels, from all cultures and eras. You have been hired for your skills in interpreting different types of boat structures. This week's assignment? The sales staff want you to assess three vessels and write notes that they can use to help their customers in choosing a kit.

- Study the three sailing vessels shown in Figure 1.15. Analyze each vessel's general design and the materials from which it appears to be made.
- In a small group, brainstorm as many advantages and disadvantages as you can think of for each vessel. Record these on a large sheet of paper. Share your ideas with the class.

Figure 1.15 Human-built structures vary widely, even those that share a basic function and design.

CHECK AND REFLECT

1. What are some of the main reasons for the great variation in even the same type of human-built structure?
2. Look at the two modern suburban houses in Figure 1.16. In what kind of climate do you think each of these houses is located? In what ways do you think the designs of these houses would differ because of the climates?

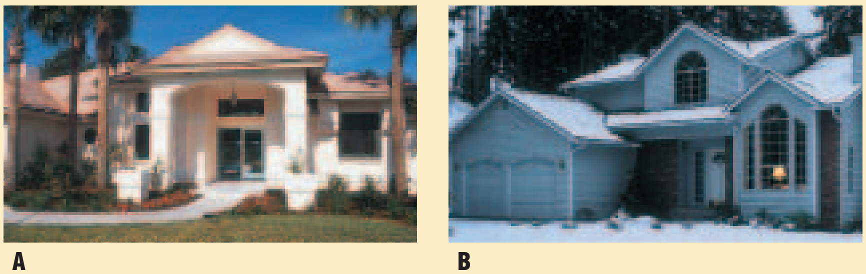
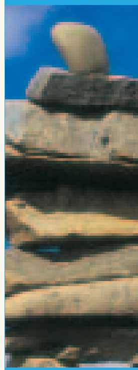


Figure 1.16 Question 2.



Assess Your Learning

1. Choose a structure in your classroom.
   a) Identify its basic structural form, and then describe its function.
   b) What special features of the structure allow it to be used the way it is? Are there any features you would change if you were redesigning this structure?
   c) Given the materials and design characteristics of the structure, briefly describe how long you think the structure will last.

2. Name three examples of human-made structures that are copies of natural structures in design and function.

3. In design terms, is it fair to say that an umbrella is stronger than a mushroom, or that a jet is more efficient at movement than a hummingbird? Why or why not? Express your views in a class discussion.

4. Think of examples in your own neighbourhood where aesthetically pleasing features are part of various structures. Compare your examples with those of your classmates. Do you all have the same opinions about what is aesthetically pleasing and what isn't? Discuss why defining an object in terms of aesthetics can vary from individual to individual.

Focus On — Science and Technology

When a technology is used to solve a problem, it must be appropriate for the situation. If it is not, it hasn't really solved the problem. Reflect on what you learned about structures in this section.

1. What were some of the solutions to technological problems you read about?

2. What factors must you consider when assessing the appropriateness of a technological solution?

3. How could you apply what you have learned about structural form and function in solving a technological problem such as how to build a summer outdoor shelter for your pet?

2.0 External and internal forces act on structures.

Key Concepts

In this section, you will learn about the following key concepts:

- material strength and flexibility
- forces on and within structures
- direction of forces
- structural stability
- modes of failure
- performance requirements

Learning Outcomes

When you have completed this section, you will be able to:

- use units of force and mass, and measure forces and loads
- identify tension, compression, shearing, and bending forces within a structure
- describe how forces can cause failure in natural and built structures
- infer how the stability of a model structure will be affected by changes in mass distribution and the foundation design

Tall, taller, tallest. Office towers allow large numbers of people to work and live in the same city block. Communication towers must stand high above their surroundings so that signals can be broadcast and received without interference from other structures or features on the landscape. It seems there's no end to how tall these types of towers can be. Or is there?

Imagine you've been asked to design the tallest possible tower that will withstand the force of a wind. What determines the ability of a structure—especially a tall one—to keep standing despite the push of air? What other forces affect structures? You will need the answers to these and other questions to be able to meet the design challenge at the end of this section.

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