Materials: structures

If you take a close look at the world around you, you will see trees, seashells, caves with stalactites and stalagmites, buildings, bridges, and many other constructions. They are all made up of what we call structures. As you will have noticed, some of these structures exist in nature and others have an artificial origin. Despite this, all of them carry out similar functions.

The function of a snail's shell is to protect its body in the same way that the walls of a building protect us from the cold and other meteorological phenomena. Tree trunks and branches have their leaves arranged at a certain height so that they can gain direct access to sunlight. Similarly, the structure of a building holds up its upper stories to lodge their inhabitants.

Celtic huts (Ireland)

Definition of structure

Generally, we can say that a structure is a group of elements capable of resisting forces without breaking, changing shape, shifting, or moving. Therefore, all structures must be resistant, rigid and stable.

For example, it is clear that if the wind moved, damaged or broke a tree so that it could not capture light, it would die.

Similarly, if a building collapsed from the action of the wind or an earthquake, it would no longer be habitable..

Functions of structures

Swiss Re Tower (London)

The first structures built by humans were huts. They met such basic needs as protection from the cold and other meteorological phenomena, and from wild animals.

As society has evolved, more complex structures have been developed to meet our changing needs.

Storage function

Since the advent of agriculture over 10,000 years ago, we have needed to preserve food. The first structures used as containers were taken directly from nature (such as dried pumpkins and hollow trunks), or made from clay (as in the case of amphorae).

AThese days we have more sophisticated containers such as *Tetra Packs*. But we do not just store food, we also need gas canisters, paint pots, and containers for all sorts of products.

Notice that in each case containers are structures that ensure that their contents are protected against external forces.

Achievement of height function

Very tall buildings have been designed and constructed in order to house people and objects within a limited surface area.

The cranes used in the construction of these buildings, telecommunications towers, as well as the electricity pylons which carry electrical energy from power stations to cities, are all examples of constructions which are made up of structures which reach significant heights above the ground.

Protection and shape maintenance functions

Many structures are used to protect fragile or delicate elements. For example, a computer's casing protects the circuitry inside it. The chassis of a vehicle protects the motor and its passengers from possible collisions.

In vertebrates, the skeleton fulfills the function of maintaining the body's shape. The same applies to tent poles or the planks of wood from which bookcases are built.

Coverage and creation of spaces function

Once a space is assigned for a certain activity, it is often necessary to cover it, mainly to protect it from meteorological phenomena. Arches, vaults and domes carry out this function. A great deal of human activity takes advantage of spaces that have previously been occupied by natural elements. This is the case with the walls of ports, which protect the boats from waves, and with the wall of a dam, which supports the weight of water contained in the dam.

Function of traversing geographic obstacles

In the past, geographic features such as rivers, canyons and mountains impeded communication between human populations.

A long time ago, bridges crossing rivers and canyons began to be constructed. Nowadays, extremely complex bridges are constructed, and adapted to the characteristics of their location.

Later, tunnels were built to cross mountains. The technology of tunnel construction has also advanced significantly, as demonstrated by the Seikan tunnel, which is some 53 km long and 100 meters below the sea bed. It links the Japanese islands of Honshu and Hokkaido.

Rigid, resistant, and stable structures

Structures must have three basic characteristics in order to fulfill their purpose. They must be rigid, resistant and stable.

- **Rigid structure**

In reality, all objects deform when subjected to a force, even if the force is small and the deformation almost imperceptible. For a given force, the deformation of an object will depend on its shape and the material from which it is made.

- **Resistant structure**

A structure must be resistant so that it does not break when hit. The key to making rigid, resistant structures is to use the appropriate materials and to design shapes which spread out forces throughout the entire structure.

- **Stable structure**

Stability is the other characteristic which, together with resistance and rigidity, every structure must have.
As we have seen, a structure is stable if it does not move when subjected to a force. The aim is that this movement is kept to a minimum, and that when the force is removed they return to their original position.

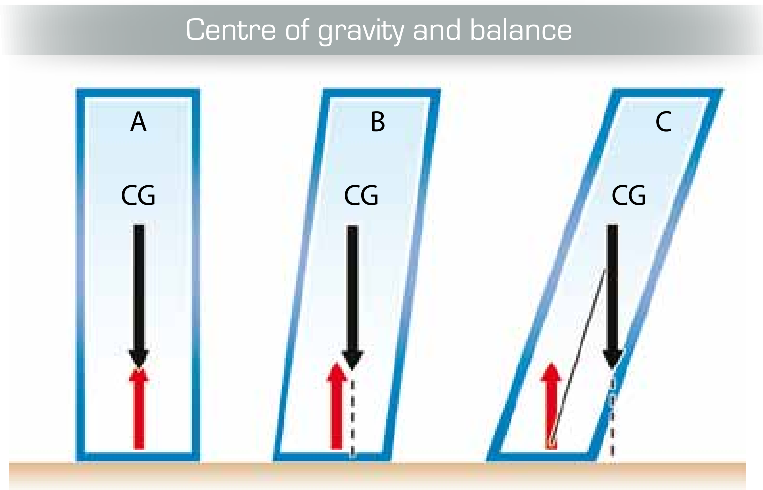
Center of gravity

The stability of any object or structure is closely linked to a concept called the *Center of gravity*.

The Center of gravity is an imaginary point where the entire mass of an object would be situated if it could be compressed. It is also the point in which its gravitational attraction to the Earth, that is, its weight, is concentrated.

Low center of gravity

The nearer the Center of gravity of a structure is to the ground, the more stable it is, and structures also tend to be more stable when their mass is concentrated near their bases. Therefore, low, wide structures are more stable than high, thin structures.



Vertical of center of gravity over the base

Another condition of a structure's stability is that a vertical line drawn through its Center of gravity would cut through its base.
If the line passes outside the base, the structure is not stable. This allows us to detect visually whether or not a structure is stable. If we see that parts of the structure are located far away from this vertical line, it is likely that the structure is unsound and that other measures must be taken to ensure its stability.

Other measures to achieve stability

If a structure does not meet the stability criteria mentioned previously, as sometimes occurs in the case of artistic sculptures, methods such as underground foundations that extend over a surface area far greater than the width of the structure are used. Another solution is the use of suspension cables.

Elements of structures

Foundations

Many structures, above all large structures like buildings or bridges, need to be built on a resistant base that supports their weight and prevents them from sinking. This base is called the **foundations**.

The foundations of bridges and buildings are usually below ground level. They are not usually visible, but their function is very important: without foundations, buildings and bridges would not be stable.

As they have to be very resistant, foundations are usually built out of reinforced concrete, in other words, a mixture of cement and other materials set around stainless steel rebars.

Supports

Supports, also called **pillars** or **columns**, are the elements that support or sustain the compression efforts generated by the loads which are external to the structure and its weight. They can be made of different materials, such as wood, concrete, brick, marble, etc. Some of the supports that we can find in our environment are the legs of a chair, the columns in underground parking lots or the pillars of a bridge.

Tensores

Suspension cables are the elements which prevent the other parts of the structure from separating. Therefore, their role is to withstand the forces of traction. They are normally made of wires or ropes of different materials.

Joists and beams

These are horizontal pieces that support weight along their entire length. As they are usually supported by other parts of the structure, joists and beams are responsible for withstanding flexion stress. The floors of a building are supported by beams. Bookshelves and bridge platforms perform the same function.

Walls

A **wall** is a vertical element which supports forces in its upper section and channels them down to its base. They usually support compression stresses but also often bear some shear stress.

Walls are one of the most common elements in structures in general, and in buildings in particular.

Millau Viaduct (France)

Arches

Arches are the structural elements that support loads and direct them to the pillars; they also connect areas which are isolated by geographical accidents such as rivers, canyons or cliffs.

Their functions, one of the most important ones within the elements of structures, are basically two:

- They spread the load between the pillars on which they are built.
- They can span relatively large spaces by means of small pieces.

Arches are traditionally built with components called keystones, which are narrower at one of their ends.
Keystones are subject to compression stress, which they transmit horizontally to the support points. As a consequence of bearing this force, the support points tend to separate.

Vaults and domes

There are other structural elements based on the arch but which have slightly different functions. For example, the loads carried by vaults are transferred to walls instead of pillars. A vault's main function is to cover the space between two walls or two rows of pillars.

Domes are used to cover and protect a variety of spaces.

Their original function is protection and, therefore, they have been used for a lot of time in the construction of simple dwellings. We can see examples of this in the yurts of Central Asia and the igloos of the Arctic.

Profiles

One of the most commonly used elements used to build structures are profiles. A profile is just the cross section of a bar. The majority of bars used in structures (beams, pillars, etc.) are not solid, but hollow. If they were solid, they would be too heavy and expensive to be used to build large structures. Thanks to profiles, we can build lighter, cheaper and more resistant structures.


Segovia Aqueduct

As we have seen, there exists a great variety of structures, natural and artificial, simple and complex. This is why they are so difficult to classify. One of the classifications, based on the elements used in the construction of the structure would be:

- Massive structures.
- Laminated structures.
- Framework structures.

Massive structures

Massive structures are made up of large elements which are usually solid and, therefore, quite heavy. As well as being stable and rigid, they are also characterized by their high resistance, for example, the walls of a building, dam or old stone church. Solid structures are also found in the pillars of Roman bridges and aqueducts.

Laminated structures

Laminated structures consist of flat surfaces that form boxes that protect the more fragile elements contained inside them. Examples of laminated structures include car chassis, computer cases and washing machine shells.

Framework structures

The structures of frameworks are made up of long pieces like bars, tubes, beams, columns and cables, which join together to form a type of skeleton to achieve resistance, rigidity and stability.

Given their complexity, there are many different types. Basically, they can be grouped into the following categories:

- **Lattice structures:** The pieces cross horizontally and vertically forming a mesh like that made by the beams and columns in buildings or the feet and crossbeams of tables.
- **Suspension structures:** An important part of the weight of the structure is supported by cables attached to very strong columns or walls, as in suspension bridges.
- **Triangular structures:** In the city of Paris there is an example: the Eiffel Tower, the most visited monument in the world. It was designed by the engineer Gustave Eiffel for the 1889 World's Fair in Paris. After more than two years of construction, the tower, more than 300 meters high, became the tallest building at that time. Its structure made up of iron bars gave way to a lot of controversy, because it was a building which was very different to all the constructions made until that moment. We can appreciate that many of the iron bars are joined forming triangles. The reason is that the triangle is the only polygon that cannot be deformed and, therefore, it is a shape which provides great stability.

The Great Wall (China)]

Applications of structures

As we have seen, structures have many uses and can be found everywhere. Two of its most important applications are **buildings**, which shape our towns and cities, and **bridges**, which allow communication between our towns and cities.

The Louvre Pyramid (Paris)]

Buildings

Construction sites of new buildings are a common sight. Nowadays, really tall multi-storey buildings can be built very quickly. We are so used to this that we do not appreciate what an amazing feat it is. In fact, the construction of modern buildings is made possible by knowledge accumulated over thousands of years.

External forces

Firstly, a building must be able to withstand the force of the wind or of a potential earthquake, which could cause it to collapse. Therefore, before the construction of any building, one must find out the location's wind conditions, and the frequency and intensity of earthquakes.
The Taipei 101 building in Taiwan is one of the tallest buildings in the world, with a height of 509 meters and more than 100 storeys. As well as being resistant, it has a certain flexibility, which allows it to withstand gale force winds of up to 450 km/h by bending up to 2.5 meters in any direction. Also, in order to compensate for movement caused by earthquakes, Taipei 101 has a 700 ton pendulum inside it which would allow it to withstand an earthquake measuring up to 7 degrees on the Richter scale.

Weight

Secondly, a building must be able to support its own weight. To achieve this, the weight must be distributed along the whole structure, and the building must have good foundations on a suitable location.
On the Eiffel tower, in Paris, we can see that the whole structure rests on four columns, in such a way that its more than 10,000 tons are spread out over four parts. This is how stability and resistance are achieved.
All large buildings follow a similar strategy, using beams, columns and foundations. The columns of the lower storeys must support much more weight than those of the upper storeys and, therefore, are thicker and more resistant. Beams support the same weight no matter where they are and they are all equal.

Bridges

Like buildings, modern bridges are the product of years of accumulated knowledge. There have been many types of bridges throughout history, from the first attempts to cross small rivers to modern bridges that stretch for kilometers. Bridges can be divided into three main groups: beam bridges, arch bridges and suspension bridges.

Beam bridges

These bridges are based on wood or metal beams, which are placed horizontally to form a gangway from one side to the other of the obstacle which needs to be crossed.

Lattice structures can be added to increase the resistance of beam bridges. This also increases their rigidity. The main limitation of these bridges is that they can only cross relatively short distances.

One way of increasing the length of a bridge is to install pillars between the two sides. However, this complicates the construction process, for example, if the bridge crosses a river, dams and canals must be built in order to divert the water and install the pillars. This is impossible when dealing with deep rivers.

The bridge over Pontchartrain Lake that links the North American cities of New Orleans and Mandeville is one of the largest pillar bridges in the world. It has 9,000 cement pillars and is 38.6 km. in length.

The Eiffel Tower (Paris)

Arch bridges

Arch bridges evolved from beam and pillar bridges, with the pillars forming the base of the arches. The arches transmit the weight supported by the bridge to the pillars. This is how they achieve resistance and stability. The Segovia aqueduct is a bridge built by the Romans during the 1st and 2nd centuries AD with the aim of channeling the water that flowed from the Fuenfría springs to the town of Segovia. It is over 15 km long, and built out of 20,000 granite stones, without cement or any other type of substance between them. It is a spectacular example of an arch bridge.

Suspension bridges

The limitation imposed by the construction of pillars gave way to looking for another solution with regard to great rivers and stretches of sea, the so-called **suspension bridges**. In these bridges, the weight of the structure is borne by towers built on pillars on the bank of the river. This weight is transferred through suspension cables.

We can find one example in San Francisco, the Golden Gate. Built in the early 1930s, this bridge was a hugely complex and ambitious project for its time. It has achieved mythical status thanks to its location in San Francisco Bay, and its numerous appearances in films and television series.

The Golden Gate, San Francisco