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How buildings work

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by [Chris Woodford](#). Last updated: October 27, 2019.

Amazing buildings make amazing cities. But what makes amazing buildings so.... *amazing*? Apart from being lovely to look at and wonderful to work in, an amazing



Photo: Steel skeleton: You might look at a building and think the walls hold it up, but a modern building is just as likely to be supported by a hidden steel framework. In this partly constructed community center, a web of giant, interlocked, steel girders acts like a skeleton, resting on concrete foundations. Bricks are being built around the outside of the steel frame to give an attractive, traditional appearance, but they're largely cosmetic: the majority of the forces holding the building up are going to be supported by the steel inside.

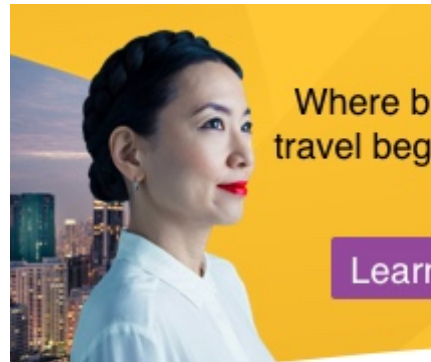
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How gravity works against buildings

All kids like building things! Whether we're stacking LEGO® blocks or playing cards in the living room,

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A building is quite often the product of very clever engineering. In other words, it's built not just on rocks or earth but on cutting-edge science and technology. Amazing buildings can withstand [earthquakes](#) and [plane](#) crashes. They can heat themselves using little more than the Sun's gaze. They use advanced materials in very advanced ways so you never have to [paint](#) the woodwork or clean the windows. Let's take a closer look at some of the science hiding inside the places where we live, work, sleep, and breathe!

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sticks in the forest, or sandcastles on the beach, we're all architects and builders at heart. Think back to the last time you made something in this way. What was the biggest problem you faced? One of the things that would have worried you was the possibility of your building toppling over once it reached a certain height. That's also true in the real world, where the number one problem any builder faces is keeping their structure upright.

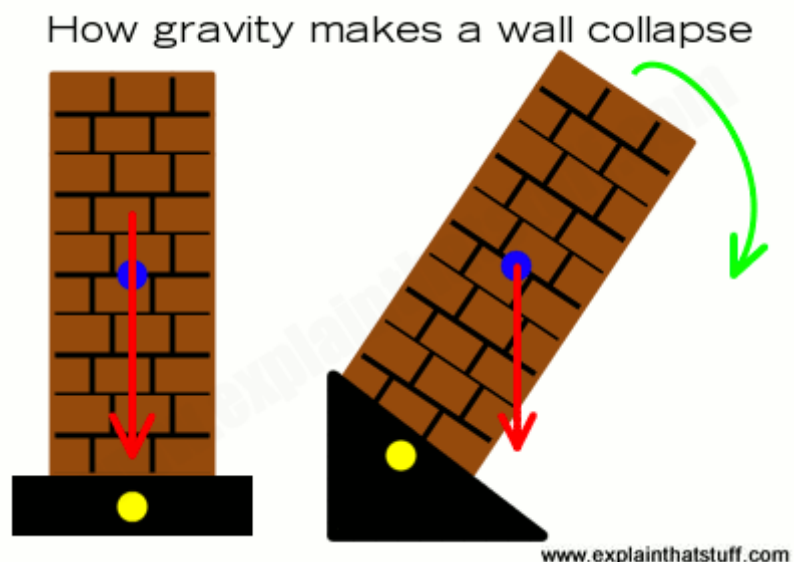
The trouble is all to do with gravity: the [magnetic](#)-like force of attraction between any two objects in our universe. On Earth, we see gravity as a tendency for things to fall toward the floor, but gravity always work two ways. If you drop a pen, it does indeed fall toward

the floor—but the floor also jumps up by a microscopic amount to meet it on the way! The force pulling your pen down toward Earth is exactly the same size as the force that pulls Earth up toward your pen.

Now gravity usually pulls things straight downward, but it can act in other ways too. Suppose you built a really tall [brick](#) wall. We can think of gravity acting on it in two different ways. We can see it as a collection of separate bricks, with gravity pulling on each one separately. Or we can think of it as a solid wall with gravity pulling on the whole thing, just as though all its mass were packed into a single point in its center. The place where an object's mass seems to be concentrated is called its [center of gravity](#). For a simple brick wall, the center of gravity is slap bang in the middle of the central brick.

So what makes a wall fall over? If the center of gravity is over to one side (if we've not built the wall straight or if we've built it on sloping ground), the force of gravity acting down will produce a turning effect called a **moment**. If the moment is small, the mortar between the bricks can resist it and keep the wall upright. But if the moment is too large, the mortar will break apart, the bricks will topple, and the wall will collapse.

Artwork: Why walls stay up and why they collapse. Left: If a wall is built upright or on flat ground, the center of gravity (blue dot) is directly above the center point of the wall's foundations (yellow dot), so the wall is stable. Right: But if a wall is built on sloping ground, the center of gravity is no longer above the center of the base. Now gravity (red arrow) creates a moment (green arrow) that tips the wall over. The higher the wall, the greater the mass above the center of gravity, the greater the turning force and the more chance the wall will collapse.



Now this doesn't just apply to single walls: it applies to

entire buildings. If a skyscraper is 200 m (650 ft) tall and a gale blows it hard at the top, there's a huge turning force trying to tip the whole building over to the side. That's why tall buildings need deep **foundations** (where a significant part of the building is constructed underground to support the part that's above ground). If something tries to push the top the building to one side, the foundations effectively resist and push it back in the opposite direction! In other words, they help to counter the moment that would make a building topple to one side.



Photo: Question: How do you build deep foundations for a tall building without digging away tons of earth? Answer: Use a foundation drill like this. These amazing drills can sink foundations over 30m (100ft) into the ground. Some can drill holes about 2.5m (8.2ft) in diameter! Find out more in our main article about [drilling technology](#).

How a building supports its own weight

It's not only sideways, toppling forces that buildings have to withstand. If you've ever picked up a brick or a piece of [stone](#) masonry, you'll know it's reasonably heavy. Now imagine how much all the bricks or blocks of stone in a skyscraper weigh. Add to that the weight of the floors and ceilings. And then, on top of that, the weight of all the office equipment, furniture, and people in the building. What you have is a gigantic lump of weight pushing straight downwards... which immediately raises two questions.

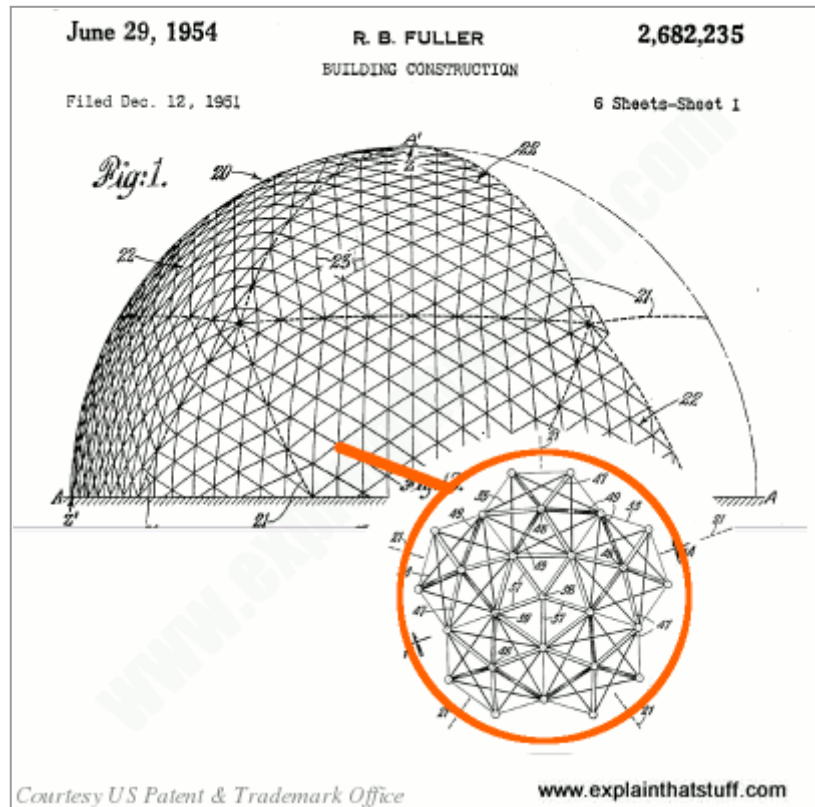
First off, why doesn't the whole building sink straight into the ground? Of course, if you build your skyscraper on quicksand or in the middle of a swamp, it might do exactly that! But most people build on reasonably firm earth (soil) or rock. There will be a certain amount of squeezing downward if you build onto earth, but once the soil is fully compressed (squeezed) it will be almost as solid as rock and further compression shouldn't be an issue. It is possible, however, if floods or drought make the earth too wet or dry, that the ground beneath the building could shift or sink. This problem is called **subsidence** and has to be tackled by pumping tons of [concrete](#) under a building to shore it up.

The other question is why the building does not collapse down on itself. You can probably see that the bottom stories of a building are going to be under much more pressure (the force acting per unit of area) than the top stories, because they have to support more weight. So if you built the lower stories of a building from cardboard and the upper ones from brick, you'd run into problems quite quickly. But you might be able to build the lower stories from brick and the upper ones from cardboard. And you could even build the lower ones from cardboard if you used some extra supports (such as [steel](#) pillars) to help support the weight of the bricks in the stories up above.

How buildings balance forces

Buildings in the real world are not like towers made of LEGO® or sandcastles. Those structures are usually made of solid material, whereas a real-world building is mostly empty space. Not only that, but the "empty space" inside a building usually has to support the weight of people, office equipment, or factory machines. Having solved their first problem (how to make a structure that doesn't topple over), architects and builders immediately turn their attention to another problem: how to make a hollow building that can support its own weight and that of its contents and occupants. This comes down to understanding where the forces are in a building and how they are transmitted from one part to another—or, in other words, how gravity is channeled through the various parts of the structure.

Artwork: There's more than one way to balance the weight of a building. Instead of chaneling it through heavy vertical walls and horizontal floors, Richard Buckminster Fuller's famous geodesic domes distribute force evenly through an outer "skin" of interconnected triangles. This creates an uninterrupted interior space much more cheaply and using much less material. As he pointed out in his 1954 dome patent, you need 23kg (50lb) of wall and roofing material to shelter 900 sq cm (one square foot) of floor space, but you can achieve the same end with only 0.35kg (0.78 lb) of geodesic dome. That works out at about 600 times less building material! Furthermore, Fuller claimed his domes were strong enough to withstand winds of 240 km/h (150mph). Artwork courtesy of US Patent and Trademark Office from [US Patent 2,682,235: Building Construction](#) by Richard Buckminster Fuller, published June 29, 1954.



To make a building that is both strong and hollow, we need to put horizontal and vertical structures together to do different jobs. For example, the outside walls usually play a vital part in keeping the building up, while the inside walls help to separate one room from another and the floors (which are often ceilings too) give us something to stand on. But it's not quite that simple when you start to think about forces. Imagine you're sitting on a sofa in the middle of the floor on the top story of a large house. If there's no wall directly underneath the floor where you're sitting, what stops the sofa crashing through the floor? The total gravitational force acting downward (the weight of your body, the weight of the sofa, and the weight of the floor) is transmitted sideways through the structural members of the floor (which may be anything from simple wooden bars called **joists** to heavy metal ones known as **girders**) to the walls at the side. The force then channels down through the walls to the floor. The force of the walls pushing down on the floor is exactly balanced by an equal force when the floor pushes up on the wall. If that weren't the case, and the two forces weren't exactly balanced, either the walls or the floor would be moving. The fact

that buildings and structures *don't* move tells us that the forces acting on them must indeed be balanced—and that's why we call these sorts of constructions **static** structures.

If you've ever seen a building being demolished by a crane with a wrecker ball (a ball and chain), you will have noticed that buildings can stay up even with most of their walls knocked away. That's because some walls in a building are more important than others and not all of them support the building's weight. The main, structural walls are called **load-bearing walls** and they're usually built from solid brick or stone. Knock one of these out and a large chunk of your building will probably collapse. The other walls in your building may simply be cosmetic ones built from a lighter material such as plasterboard. You can easily remove these walls without affecting the building's ability to stay upright and keep its shape (which is known as its **structural integrity**).

Photo: A floor, wall, staircase, or any other structure has to be supported to stop it collapsing, but that doesn't mean it must be supported equally in all places. Though we tend to think of beams as needing support at both ends, if a beam is strong enough, you can support it at one end only. Any downward force you put on the beam travels down its length and is balanced at the single, supported end. A structure like this is called a cantilever and it was used to great effect in the long, reinforced concrete terraces of this famous building, [Fallingwater](#), designed by architect Frank Lloyd Wright. Photo by Jack E. Boucher courtesy of [US Library of Congress](#).



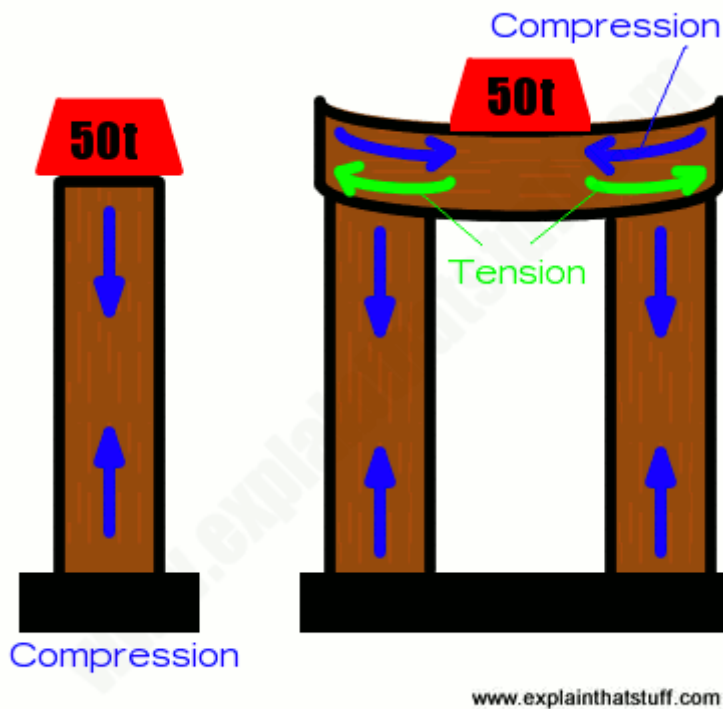
When skyscrapers were first built, they had elaborate wooden frameworks inside them to support their weight—lots of internal walls to support all the force pushing down from above. Gradually, though, as people found they needed (and often preferred) wide open spaces inside buildings for offices and factories, architects found ways of getting rid of the internal walls. Having slender pillars or columns was one obvious way to do this. Another option was to have extremely strong outer walls and sturdy horizontal girders running through the floors and ceilings to carry the weight of the building across to this "outer skin". A third option was to have a strong central core, sturdy floors running out from it like the petals on a flower, and only a relatively light outer skin made from steel or glass.

Tension and compression forces in buildings

Artwork: Left: The vertical wooden beam is in compression: it's being squeezed by the weight pushing downward and by the ground pushing back up. Right: An identical wooden beam, laid horizontally on top of two vertical beams, is in compression at the top and tension at the bottom, while the vertical beams that support it are both in compression.

"A building is not just a place to be but a way to be."

Frank Lloyd Wright



The parts of a building can behave in different ways when large forces act on them. Suppose, for example, you're back on the sofa in the middle of the floor on the top story of your house. Suppose I reach in through a window with a crane and place a 50-tonne weight onto the floor right next to you. It's quite likely the floor will immediately collapse and you'll fall through the hole I've just made. But what makes the floor collapse? Obviously, the beams supporting the floor cannot withstand the weight we're subjecting them to—but how exactly do they break? And why does the floor

collapse rather than the walls? The answer is all to do with tension and compression.

Suppose you have a wooden beam standing vertically. You can support lots of weight on top of it because there's something solid underneath transmitting the force of gravity directly to the ground. The more weight you put on the beam, the more you squeeze it. If you could measure the beam accurately, you'd see that it shrinks just a tiny bit with every extra bit of weight you pile onto it. When a beam is loaded like this, we say it's in **compression**: it's being subject to compressive or squeezing forces.

Now suppose you balance the same beam horizontally between two similar, vertical beams—much like balancing the floor of a house between the walls. If you pile weights onto the beam, it won't behave quite the same way as it did before. The entire beam will start to bend, but the top and the bottom will bend differently. The top of the beam will be squeezed (by compression forces) and it'll get slightly shorter, while the bottom will be stretched and it will become a bit longer. We say the bottom is in **tension** (it's stretching) and we call the forces that do this tensile forces.

We can keep piling load onto the beam for just as long as its internal structure can cope with these forces. At some point, the **wood** in the beam will splinter when the individual wood fibers can no longer cope with the tensile forces at the bottom. Then the beam will snap in two in the center, at the bottom, and the floor will collapse.

Like wood, concrete is good at withstanding compressive forces, but not so good at coping with tensile forces. Ordinary concrete is a superb material for making vertical walls, but it's much less effective for making horizontal floors because it's quite brittle: it will snap at a weak point just like wood if you pile too much weight onto it. You can make concrete much stronger by pouring it into a mold that contains a grid of rigid steel bars (often known as "rebar"). Concrete strengthened in this way is called **reinforced concrete** because the

steel gives the concrete extra strength and helps it to withstand tensile as well as compressive forces. Next time you see people constructing a huge concrete building, bridge, or other structure, take a look and see if you can see the steel reinforcement bars or rebar grid before the concrete is poured in.

Photo: Buildings have to cope with ever-changing loads from things like wind and the weight of the people inside. When architect Daniel Burnham completed his famously tall and thin Flatiron building in 1902, some people believed it would blow over in the wind. It earned the nickname Burnham's folly as a result. Although it certainly does channel winds down into the streets around it, the famous New York City landmark remains standing to this day. Photo by Carol M. Highsmith, courtesy of the [Carol M. Highsmith Archive](#), Library of Congress, Prints and Photographs Division.



Make way, heavy load!

Tension and compression aren't the only forces that buildings have to cope with. From the tallest skyscraper to the simplest bridge, every static structure also has to cope with varying loads. An office block will weigh far more when it's full of people, computers, desks, and photocopiers than it does when it's empty, and the people who build it have to take that into account. Similarly, bridges have to cope with varying forces both from things that drive over them and the weather, which can lead to bending and twisting (**torsion**) that might make them collapse. Every static structure has to be able to cope with a mixture of **dead loads** (its own basic weight) and **live loads** (the weight it carries when it's occupied or being used), so working out what those are and how big they will be is an important part of building design. You can read more about this in our detailed article on [bridges](#).

Cardboard constructions

Photo: Top: Placed upright, a cardboard toilet roll can support three heavy books. Bottom: Placed flat, it can't even support one!

If you have a hollow cardboard tube (such as a kitchen towel holder or empty toilet roll), you probably know that it's rather better at withstanding some forces than others. Try it! If you place the tube vertically, you can stand quite a lot of weight on the end. You could, for example, put quite a lot of heavy books on top of the tube without it showing the least signs of stress. The weight of the books will try to squeeze the tube downward. In other words, the tube is in

compression. Placed upright, cardboard tubes are structurally very sound because there are solid walls going all the way down from the top to the bottom to support any weight on top. Also, because the walls have a circular **cross-section** (you get a circle if you slice through them), the forces are spread through the structure: no part of any wall is loaded more than any other. Cardboard tubes are so strong that one Japanese architect, Shigeru Ban, has made a feature of them in lightweight temporary buildings, such as emergency housing for refugees.



But suppose you try to make the floors of a building out of cardboard tubes. You can probably see we're heading for trouble here straight away! If you place a cardboard tube horizontally and try to stand things on it, you'll soon squash it flat. That's because there's only hollow, empty space between the place where you're applying the force and the ground. The curved, cardboard walls are simply too thin to channel the forces around them so the whole structure collapses. In other words, cardboard tubes are not very good at withstanding compressive forces when they're placed horizontally.

What this tells us is that some materials work well in buildings when we use them in a particular way and they work badly if we use them in other ways. In other words, it's important to understand the properties of materials if you want your buildings to work effectively.

Choosing the best materials for a building

Steel, concrete, and wood are three of our most versatile building materials—but there are lots of others, including composite materials and plastics. Architects and engineers use many different materials in their constructions and choose one material instead of

“No design is possible until the materials with which you design are completely understood.”

another for a variety of reasons. Concrete is the material of choice for large structures such as [bridges](#) and tunnels, because it's strong, long-lasting, waterproof, fireproof, relatively inexpensive, and easy to mold into curved as well as straight shapes.

Ludwig Mies van der Rohe

Suppose you were designing a skyscraper. How would you go about choosing the materials? First you'd need to know how many stories high the building has to be. That's worked out by calculating how expensive the building land is, how much the building will cost to construct (an unknown, but you can guess roughly), and how much profit the owners want to make. Let's say you think the building will have to be 100 stories high. You can now estimate how much it will weigh and how much weight it will have to support on each floor. So you can start to design some sort of a structure that will support that much weight for that height into the air. Probably you'll use steel and concrete for the structural parts of the building (where the weight will be supported), but you won't want to build a solid concrete block! So you might hide the structural parts in the center of the building and make the outer parts entirely of [glass](#). But glass is heavy, so you'll need to factor its weight into your structural calculations too. And you'll need to figure out how the weight of the glass is going to be supported by the floor or ceiling of the story it attaches to, or by the outer steel skin of the building.

You'll also have to think about keeping the building's occupants warm and comfortable. If you're making the facade from glass, it's going to absorb huge amounts of solar heat (something known as [passive solar](#)). That's great in winter, because it will help to reduce heating costs, but in the summer it could make the building unbearably hot. So maybe you'll want to use some sort of tinted or reflective glass that cuts down the solar gain a little? To figure all this out, you'll need to understand something about the science of [heat energy](#) and how it travels around inside buildings.

"The materials of city planning are: sky, space, trees, steel and cement; in that order and that hierarchy."

Le Corbusier



Photo: Passive solar gain: the large glass windows in this spacious wooden building help to absorb heat energy from the Sun. Picture by Donald Aitken courtesy of [US Department of Energy/National Renewable Energy Laboratory \(DOE/NREL\)](#).

With the basic structure of the building decided, you'll turn your attention to the interior details. You might decide to make all the internal walls from steel panels that can be moved around as necessary to create flexible office space. Or maybe you

want to use wooden floors or paneling to create a warmer and more friendly feel? Hopefully, you'll opt to use properly sourced **sustainable** wood supplies. For that, you'll need to understand why cutting down trees has an environmental impact on places like tropical rainforests and how that can be minimized.

You can see that every aspect of a building's design needs meticulous consideration. Making a building is not just a matter of coming up with something that looks good. It's about creating a structure that can survive all the strains of the modern world. For that, you need to be just as much of a scientist as an engineer!

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- [Plastics](#)

Books

For younger readers

- [Structural Engineering: Learn it, Try it!](#) by Tammy Enz. Capstone, 2017. Experiment with different kinds of forces as you build bridges and other static structures.
- [Cool Architecture: 50 fantastic facts for kids of all ages](#) by Simon Armstrong. Pavilion Books, 2015. Fascinating facts about famous buildings around the world.
- [Architecture According to Pigeons](#) by Stella Gurney and Natsko Seki. Phaidon, 2013. An imaginative introduction to architecture for young readers by a pigeon named Speck Lee Tailfeather.
- [The Aspiring Architect: An Activity Book for Kids](#) by Travis Kelly Wilson. Trafford Publishing, 2013. A good activity-based introduction for children aged 8–10.
- [Eyewitness: Building](#) by Philip Wilkinson. Dorling Kindersley, 2000. A largely historical guide to buildings, mostly for readers aged 9-12. Philip Wilkinson's other architectural books, including [Super Structures](#) (DK, 2008), are well worth digging out.

For older readers

- [The Architecture of Happiness](#) by Alain de Botton. Penguin, 1995. How is architecture connected to our everyday wellbeing?
- [The New Science of Strong Materials \(or Why You Don't Fall Through the Floor\)](#) by J.E. Gordon. Penguin, 1991; Princeton University Press, 2006. This classic book explains how materials make all kinds of different structures work. It's very clear and easy to follow, with hardly any math content, and suitable for most readers from mid-teens onward. Inexpensive, earlier editions are fairly easy to find in secondhand bookstores.
- [How Buildings Work: The Natural Order of Architecture](#) by Edward Allen and David Swoboda. Oxford University Press, 1995.
- [Why Buildings Fall Down](#) by Matthys Levy and Mario Salvadori. Norton, 1992. An interesting and wide-ranging series of "forensic" investigations into why buildings and other structures failed catastrophically.
- [Why Buildings Stand Up](#) by Matthys Levy and Saralinda Hooker. Norton, 1990.
- [The Death and Life of Great American Cities](#) by Jane Jacobs. Knopf, 2016. A classic introduction to urban design, first published in 1961 and still well worth reading.

Careers websites

- [RIBA: Education and careers](#): All about how you can become an architect, from the Royal Institute of British Architects (RIBA).
- [Go Construct](#): A very comprehensive British website that explores the various different careers you can enjoy in construction, from building and surveying to architecture and civil engineering.
- [Architecture: Education](#): From the American Institute of Architects (AIA). There's lots of information about architecture courses and careers here.
- [Engineering Girl](#): Is engineering a man's job? Of course not: it's a job anyone can do. Lots of information here to encourage more equal opportunity in all kinds of engineering work.

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