Overcoming structural difficulties in LEGO® Technic

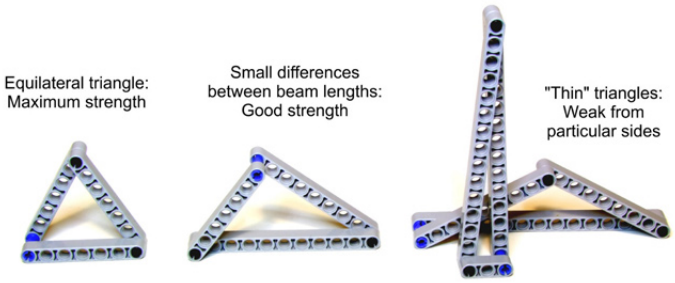
By Oton Ribic

Continuing in the direction we have set in the previous article “Efficient LEGO® structures”, this time we will take a look at several practical yet simple ways for Technic beginners to overcome the structural limits imposed by the LEGO parts, particularly the beams.

One of the basic principles of strong, light constructions is to take advantage of the fact that the beams offer excellent strength lengthwise (if pulled or compressed), while their resistance to sideways force (bending) is not as high. More precisely said, tendency to bend depends widely on the beam length, type, orientation and direction of the sideways force, but it will always give more than if exposed to lengthwise stress. Hence, any structure for which strength is paramount should be built to expose its beams as much to lengthwise forces as possible, while avoiding bending. This principle is by no means limited to LEGO constructions — it is, in fact, one of the core premises of mechanical engineering.

The basic element that follows this principle is — you have probably guessed — a triangle. It is not difficult to see why: applying force to any of its corners (i.e. joints) stresses its sides more or less lengthwise, which makes it inherently strong yet it remains very light as it requires only three beams. Therefore, constructions that rely on triangles with common sides as main structural forms (trusses) tend to be very rigid. For a vivid demonstration, try building a pictured structure. Admittedly, it is a somewhat extreme example and typical LEGO constructions do not need to go that far, but it nevertheless proves the point: used as a crane arm, it lifts several kilograms of load without the slightest sign of discomfort.

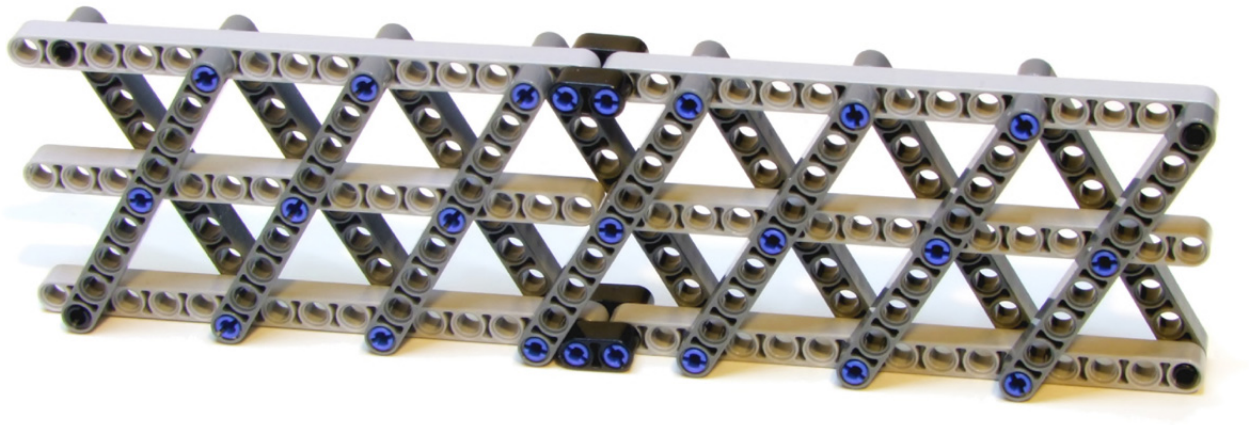
It should not be overlooked, however, that the strength of triangular structures depends on the ratios of the length their side. These triangles should ideally be equilateral, such as those in the example, and as long as their sides are at least of approximately similar lenghts, they will still provide good strength. On the other hand, very “elongated” triangles are significantly weaker and should be avoided.



Despite their lightweight construction and high rigidity, triangular structures bring one practical difficulty: their frame dimensions are often difficult to work with and adapt to other components. For instance, the span between the edges of the two outer beams in the aforementioned example is 7.93 studs — perhaps close enough for some to be declared 8 studs long and uncomfortably vertically braced, but any serious builder would strictly avoid such blatant usage of brute force.

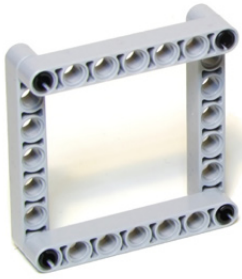
A more practical alternative is to rely on square, or more generally, rectangular structures which have been a mainstay of Technic construction since its beginnings. Studless rectangular structures offer good strength if compressed or pulled, but are usually sensitive to shearing (stress under which the sides remain constant but their angles change, i.e. square that deforms towards a rhombus), which is rather common in LEGO constructions. The solution is to reinforce their corners using parts that contain a right angle. One reinforced corner should suffice in theory, but in practice, the more the better. Technic frames, various L-beams, triangular plates, and many other parts can help.

However, rectangular structures built from studded beams do not suffer from this drawback, since their studs — if properly connected together with the plates — significantly resist

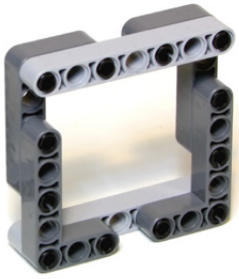


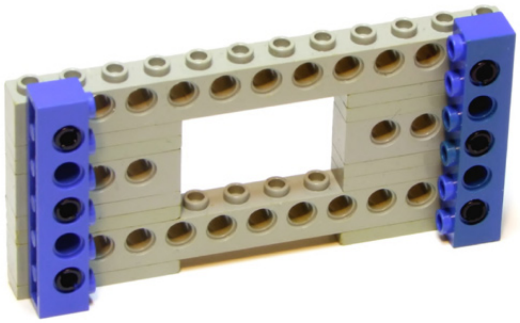
shearing. The price is paid in larger overall weight, and the choice between the two depends on the requirements of the model being built, as does the choice between the triangular and rectangular approach in the first place.

Basic restangular structure: Stron against direct side forces, but weak against shearing



Having corners reinforced, its resistance to shearing is greatly increased





A specific type of construction that rectangular structures are particularly suitable for are three-dimensional arms: their non-standard angles and diagonal lengths are usually impossible or at least impractical to reinforce using triangular structures. Instead, they can be easily built using cascaded Technic frames from all four sides with occasional additional reinforcing beams to prevent the frames from separating under strain, such as the one shown on the photo. Besides being simple and resistent against all types of deforming forces, it offers a useful feature: a 3 x 5 studs “tunnel” in its interior through which control axles, pneumatic hoses and other systems can be easily led.

Finally, on the topic of various Technic structures, one should always be aware of the risk of over-reinforcing. It is tempting to build extremely strong if possible, but a well-engineered construction should be reinforced only as much as necessary — and where necessary — to function as intended. Excessive reinforcements increase weight, complexity and reduce space that could perhaps be used for extra functionality. For example: a tower crane arm primarily needs to resist bending, while its vertical shaft is mostly subjected to compression (if the crane is balanced with a counterweight), and they do not need particularly heavy reinforcements against other types of deformations. There are, of course, constructions that need to resist all kinds of forces, such as car chassis or an aircraft hull, but while building even them, one needs to remain sensible as it is important to find a good balance between strength and lightness.

Stay tuned for the article in the next edition, where we will move on to dynamic structures and observe the behaviour of LEGO® parts that move!
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Conclusions: Technic Construction Quick Facts

- Good constructions should expose its beams to compression and tension primarily, as the beams are strongest when subjected to those forces.
- A simple and common method to achieve that is a truss, i.e. a structure consisting of beams in triangular forms that mostly share sides.
- To avoid impractical lengths and angles often encountered in trusses, rectangular structures are a good alternative, but for maximum strength they either need to be built from studded beams with separating plates in between, or have their corners additionally reinforced.
- Beware of over-reinforcements which imply unneeded weight and complexity. Try to estimate the forces that will be present in your construction, and reinforce primarily against them — only as much as necessary.