Constructopedia

Basic Statics & Mechanics

Basic statics

In this chapter we consider various ways to build strong constructions. A strong construction is vital to a robot, particularly mobile robots that tend to run into solid objects like walls, chairs, table legs … If the robot is not robust enough, it will soon enough cease to be mobile.

Below we first have a look at how to connect beams. After that we take this one step further and consider how we can build various kinds of frames on which to base our robot. We end the chapter with discussing how to connect beams at angles.

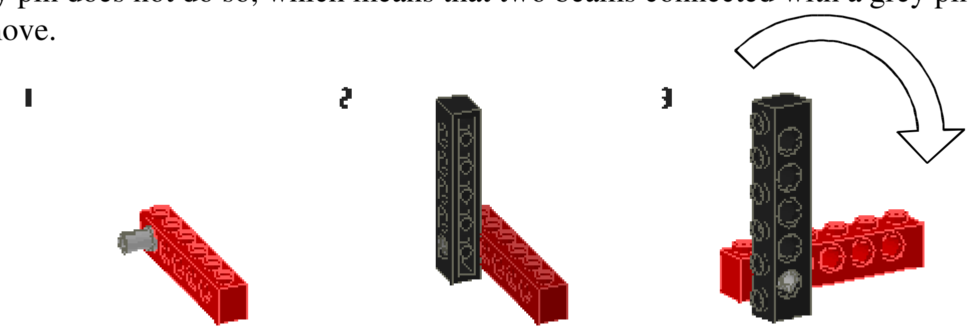
Connecting beams

The connector we use most in joining beams is the Technic pin. The Technic pin comes in several variants, as shown in Figure 1 below.

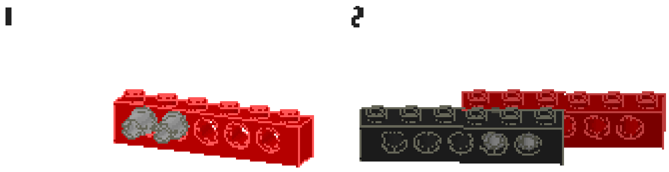
Figure 1 - Technic pins

From left to right, we have the 2u grey Technic pin, the 2u black Technic pin with friction, and the long 3u black Technic pin, the dark grey ¾ Technic pin, the blue long Technic pin with stop bush, and the grey Technic axle pin.

For our purposes, we are mostly interested in the two black pins, and the 2u grey Technic pin. The difference between the black pins and the grey pin is that the black pins provide friction. The grey pin does not do so, which means that two beams connected with a grey pin can still freely move.

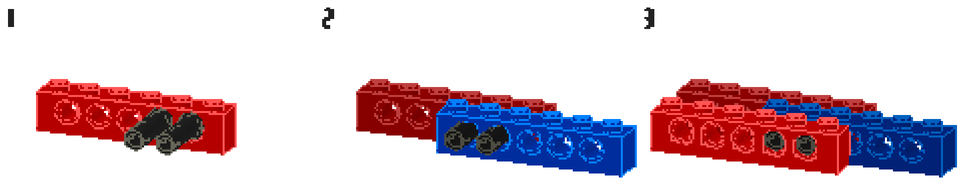


The black Technic pins allow for much less movement of the joined beams, because the pins cause friction. Surely, using several pins when connecting beams lengthwise disallows movement.



Yet, if you experiment with replacing the grey pins in the above structure with black pins, the construction will be more robust. With the grey pins, the structure still tends to “rattle”, whereas with the black pins the two beams are firmly fixed in place.

The long (3u) black Technic pin is useful when we want to connect several beams in parallel.



One useful application of the above structure is in building frames, to which we turn now.

Building frames

Ideally, we start building a robot on the basis of a *frame*. A frame should provide a basic, solid structure into which we can fit e.g. motor modules and (don’t forget!) the RCX brick.

One option would of course be to join beams in parallel until we have a broad enough base. Although this frame is useful, we propose a more open frame that in which we can easily put our modules.

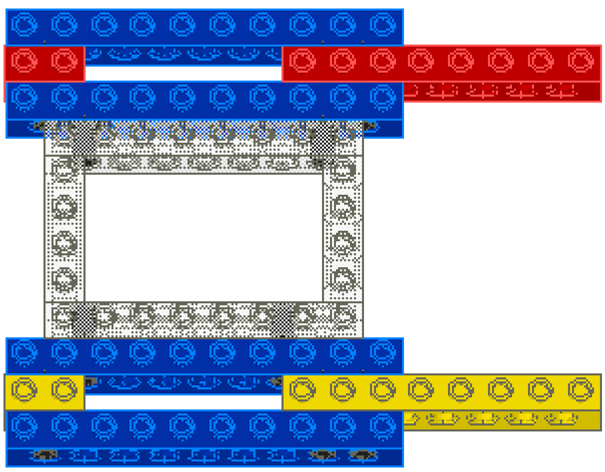
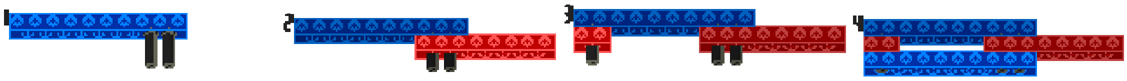
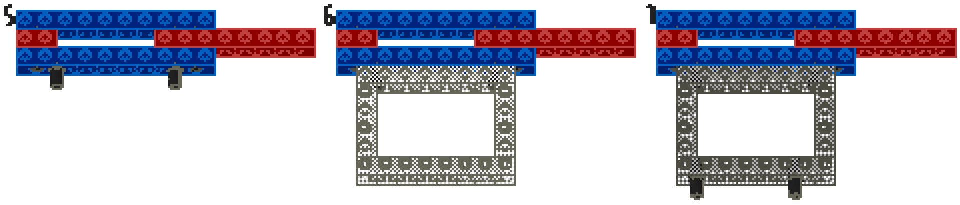


Figure 2 - Simple, open base frame

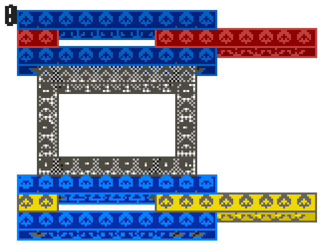
In steps 1 through 4 we build a frame side. Observe the use of 3u long Technic pins. Aside from lending more strength to the structure, the use of 3u pins also saves space.



In steps 5 through 7 we add a 8x6 transparent brick. Naturally, instead of a bare brick we might want to use a module.



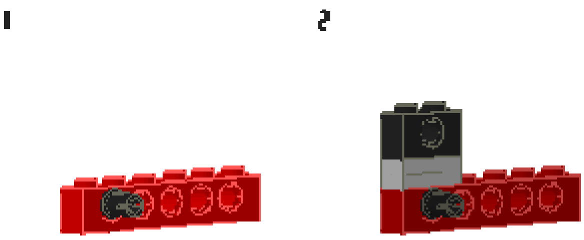
Before proceeding to step 8, build another frame side following steps 1 through 4. Then, in step 8, add the side to complete the frame.



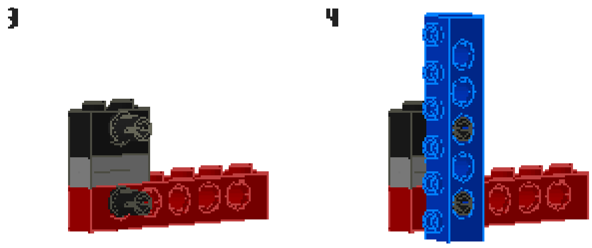
Connecting beams at angles

It may happen that we want to connect beams at angles, rather than in parallel. Most often, we need to connect beams at 90 degree-angles, either in a horizontal plane or a vertical plane.

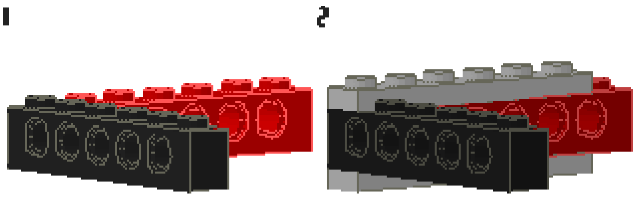
The vertical plane is perhaps the easiest. In step 1 we start with the horizontal beam, and insert a black pin to hold the bottom of the vertical beam. In step 2 we need to build up the structure for fitting in the next black pin. Because of the distance between holes in a beam, we cannot simply put two 2u beams on top of one another. Instead, we need to use two 1x2 plates, and then one 2u beam with a single hole.



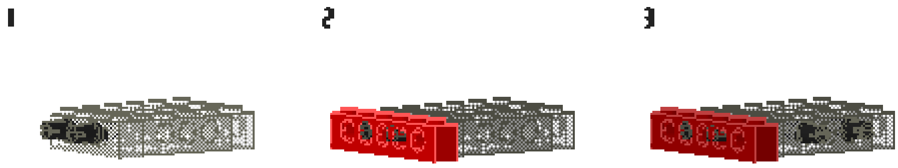
In step 3 we add the second black pin, and then fix the vertical beam in place in step 4.



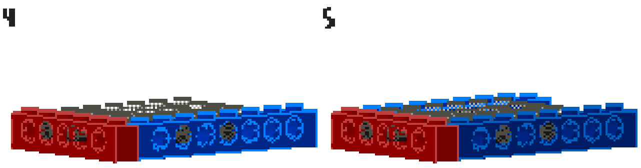
To connect beams that are at an angle in the horizontal pane, the easiest solution is to fix them using plates. (Instead of 1x6 plates shown below you could also use 3x2 angular plates.)



However, using just plates does not give you a very strong structure. Particularly when wheels are connected to such a structure, forces tend to dislodge the plates. A stronger construction can be formed by using one of the transparent frames (4x6 or 6x8). (As discussed in the section on modules, we also use these bricks as the basis for our modules.) In steps 1 through 3 we insert black Technic pins into the transparent frame, and connect one of the beams to it.



In steps 4 and 5 we add two additional beams, at the sides.



Other angles can be obtained using the lift arms, shown in the figure below.

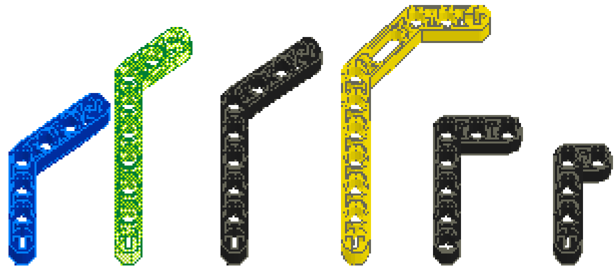


Figure 3 - Lift arms

To connect beams to a lift arm, again use Technic pins.

Finally, in case you need a non-orthogonal angle in any two of the X,Y, and Z planes, you can try the following construction. The construction consists of a corner base, and then a Technic angle connector. The latter come in various guises, for example Technic Angle Connector #4 has a 120 degree angle.

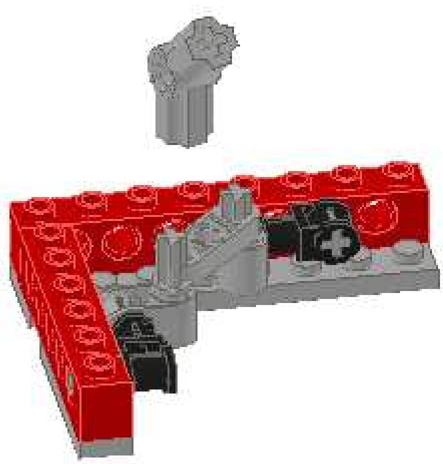
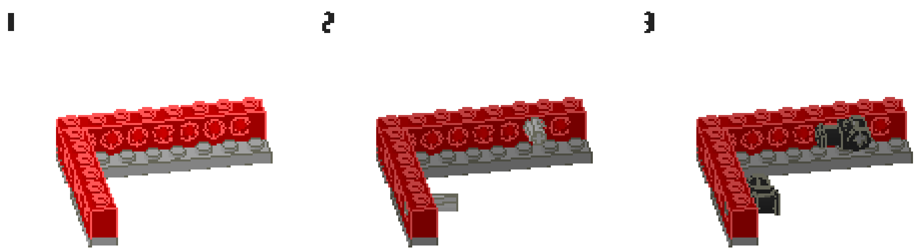


Figure 4 - Fixing beams under Y+Z angle

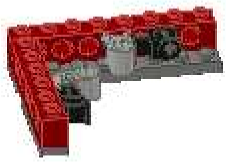
We first construct the base. In step 1 we quickly put together two beams. In step 2, we add the Technic Axle pins that will come to hold the main structure. In step 3, we fix two Technic connectors with axleholes to the axle pins.



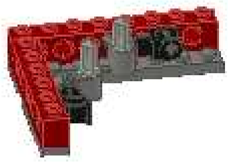
In the next steps we add the structure for connecting the angular connector to. In step 4 we add a notched 2u axle to each Technic connector. In step 5 we add to each axle a Technic Axle Joiner Perpendicular. In step 6, we add again two axle pins.

4

5



6



Finally, in step 7 we add a 1x3 Technic Lift Arm to the vertical axle pins. The Technic Angle Connector can be fixed to the lift arm using a 2u beam.

7

Basic mechanics

Standard gears & transmission ratios

The RIS comes with a variety of standard gears. We distinguish the gears by the number of teeth they have. A gear with 24 teeth is then identified as “a 24t gear.”

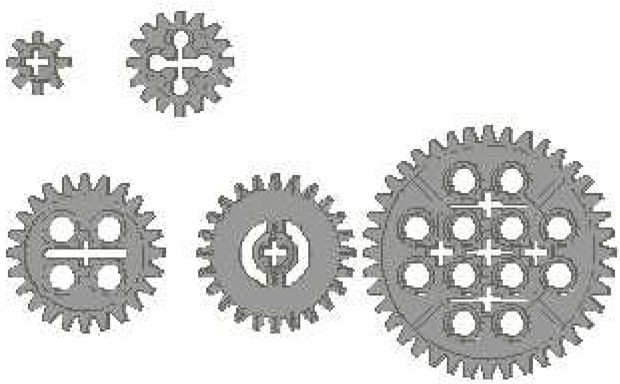


Figure 5 - Standard Lego gears

The standard gears are shown in Figure 5. On the top row you see the 8t gear and the 16t gear. The bottom row shows (from left to right) the standard 24t gear, the 24t crown gear, and the 40t gear.

The combination of different gears gives rise to different gear ratios. For example, if an 8t gear drives a 24t gear, then the ratio input/output is 3:1. This means that the 24t gear will turn 3 times slower than the 8t gear – it will, however, also provide greater torque (or rotational force). Higher torque means that you get more pulling power, traded off against less speed.

Not all combinations of gears line up on a single beam. Only the 40t, 8t and 24t line up together, and 16t gears line up together.

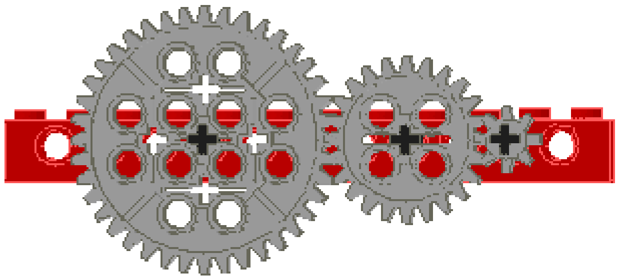


Figure 6 - 40t, 24t and 8t gears lined up

The 24t crown gear is convenient to change the axis of rotation. Otherwise, it acts just like a standard 24t gear.

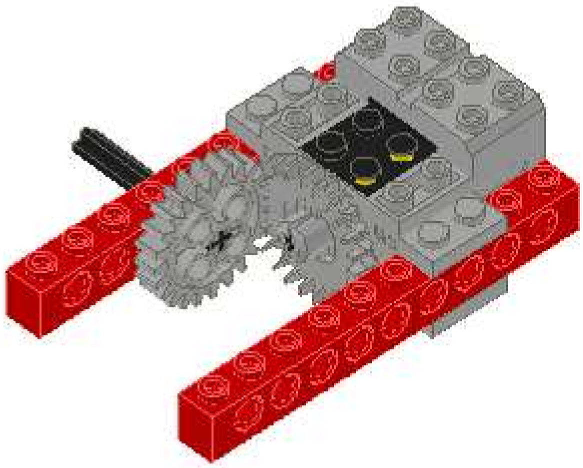


Figure 7 - Crown gear

The worm gear

The worm gear is a screw-type that meshes with the standard Lego gears. Each complete turn of a worm gear causes the gear to turn by just one tooth – meaning you get an enormous reduction! Important about the worm gear is that you can only have a force transfer from the worm gear to the standard gear, not the other way round.

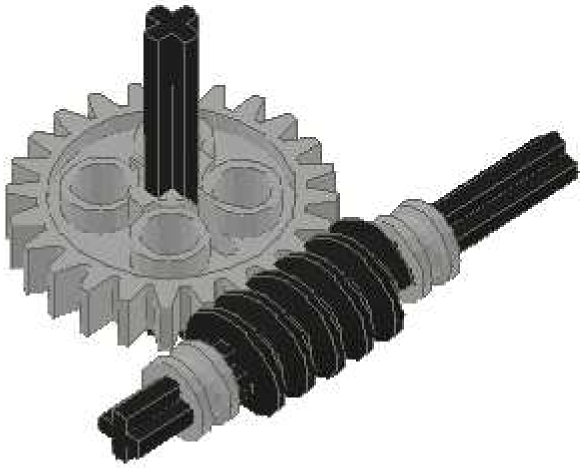


Figure 8 - The worm gear

The RIS also comes with a brick in which a 24t gear and a worm gear can be meshed compactly. This is the Technic Gear Box. There is only one way to drive the box, and that is to turn the axle of the worm gear, as you cannot turn the worm gear by turning the 24t gear.

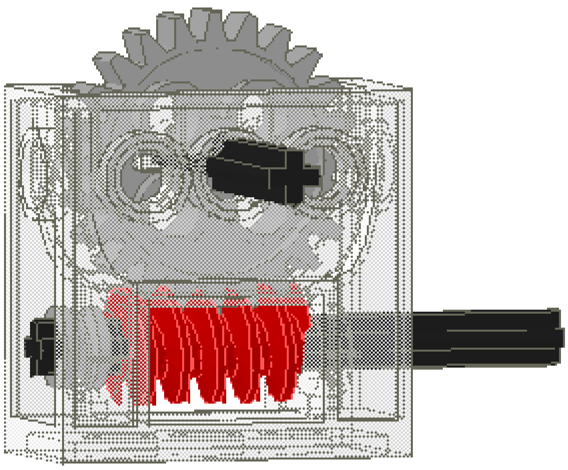


Figure 9 - The worm gear box

The clutch gear

The clutch gear looks like an ordinary 24t gear – except that it has this white casing. The clutch gear is often called a slip gear, for good reason. Inside the white casing is a clutch that enables the gear to turn as long as the force on the gear is below a certain threshold. If too much force is exerted, the gear simply slips, dissipating the force harmlessly.

When there is a danger of too much force being exerted by the gears, the clutch gear thus comes in useful. One application of the clutch gear is in the pump module of the *Ultimate Builders Set*.

The differential

The differential makes it possible to drive two wheels while at the same time allowing these wheels to turn at different speeds independently of one another – e.g. as is the case when making a turn.

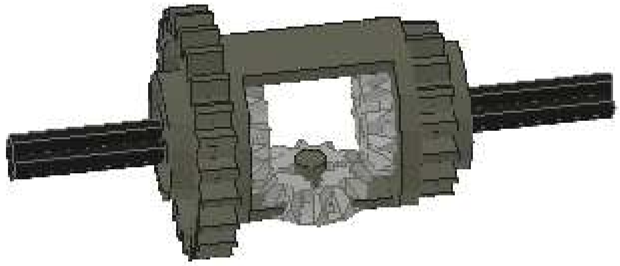


Figure 10 - the differential

Particularly when you are constructing a mobile robot that needs to make very tight turns, the differential really makes a difference. A basic setup for using the differential is shown below.

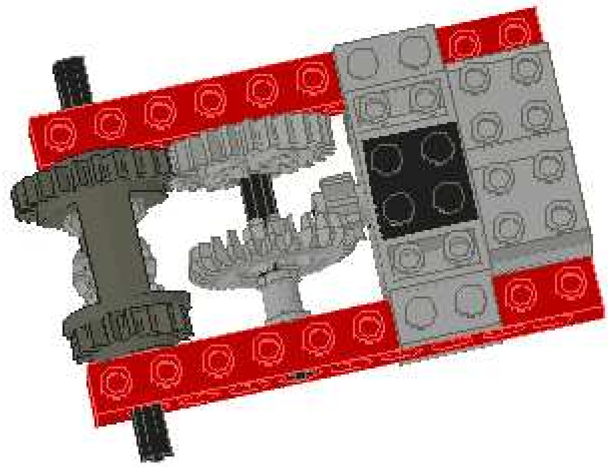


Figure 11 - Drive with differential

Modular design

Just like in programming, the basic idea behind modular design is that one isolates a particular functionality in a single, reusable module. Whenever you need the functionality the module provides, all you need to do is to build the module and plug it in. More complex functionality can be achieved by combining several modules.

The purpose to discuss how (abstract) modules can be connected to form a stable architecture, and to give you an insight in what modules can look like.

Connecting modules

A good basis for modules are the transparent 4x6 brick or the transparent 8x6 brick. Below we discuss several ways in which modules constructed on the basis of an 8x6 brick can be connected.

In the simplest case, two modules need to be connected at sides that have no protruding parts (e.g. axles). That means we can connect them directly using Technic pins, preferably the black Technic pins with friction.

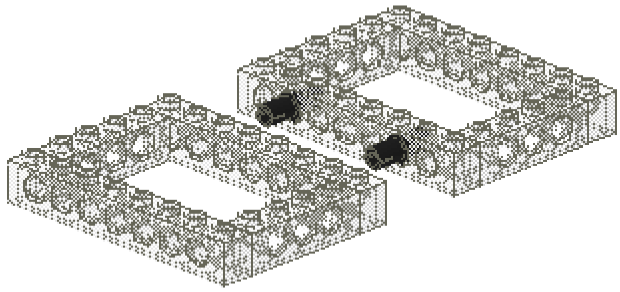


Figure 12 - Connecting 8x6 modules using Technic pins

Once the modules are joined, we can strengthen the structure using beams along the sides of the construction.

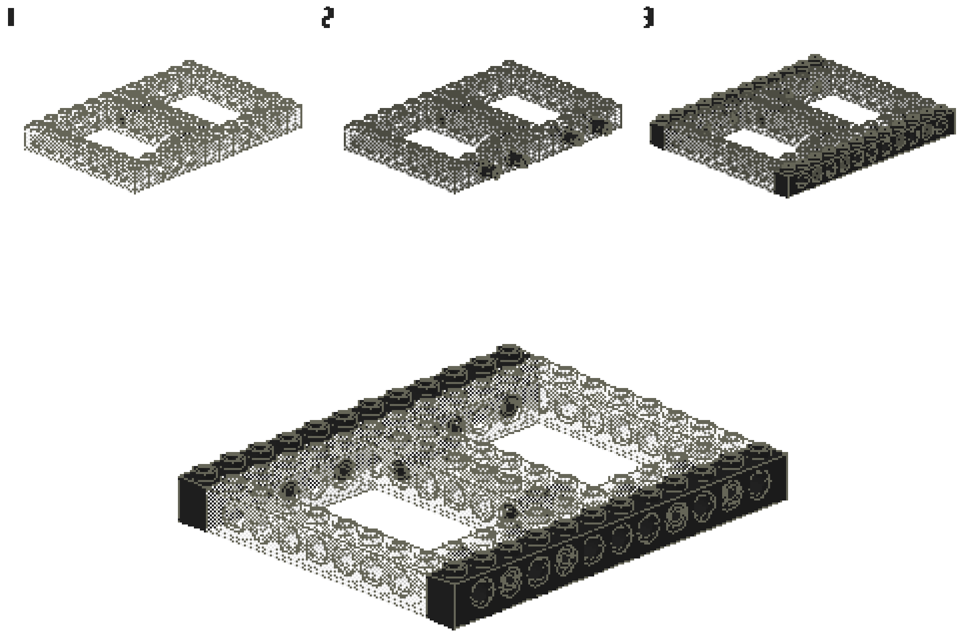


Figure 13 - Strengthened structure

It might also be the case though that we do have parts protruding. In that case, we can make use of the blue, long Technic pins with a stop bush at their end. The three steps below represent the basic idea. We fit both modules with pins with stop bushes (steps 1 and 2), and then use 2u axles (preferably the notched version) to connect the pins (step 3).

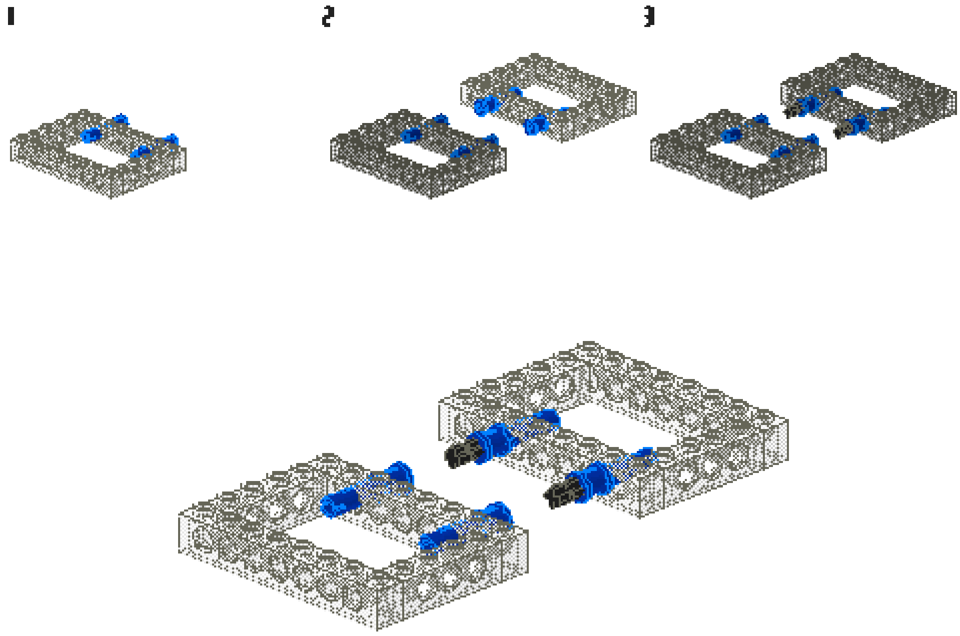
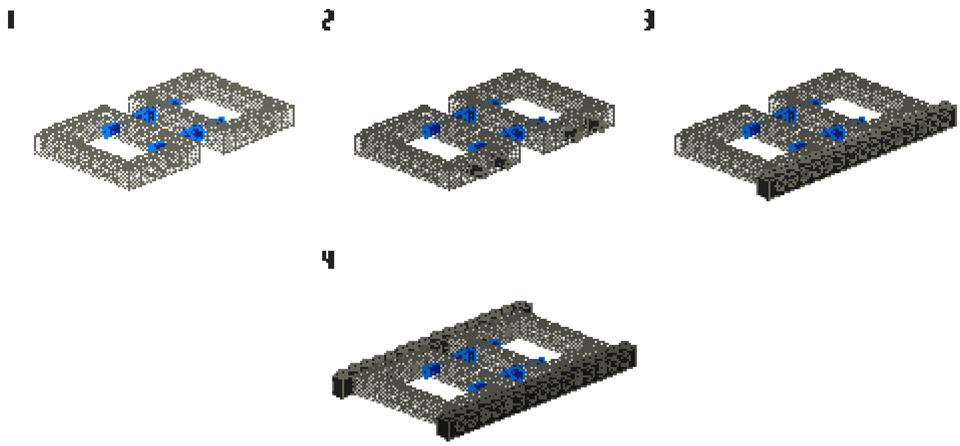


Figure 14 - Modules ready to be connected

Next we connect the modules. We can strengthen the module by adding (for example) a 16u beam to along each long side of the construction. We fix the beams into place with Technic pins with friction.



The resulting constructing is displayed below.

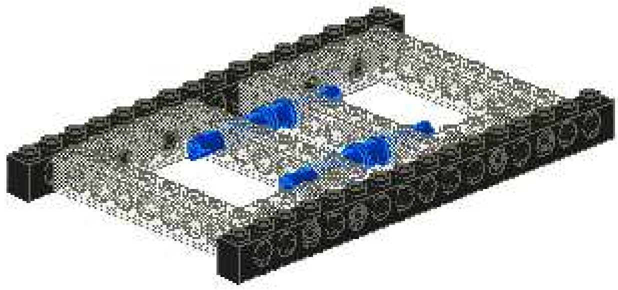
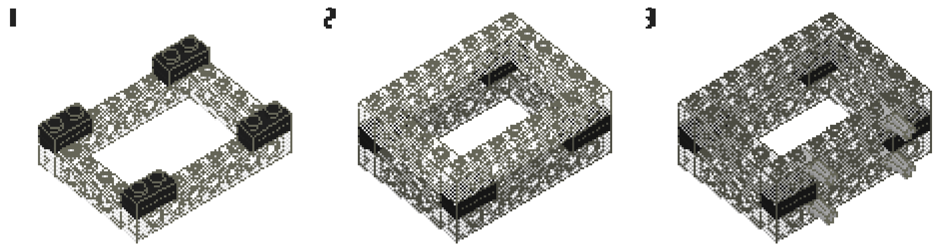


Figure 15 - Connected 8x6 modules structure

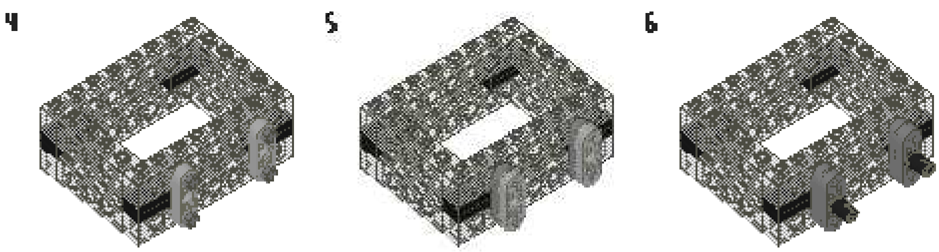
Adding rigidity

To add some further rigidity to a module, we can use 1xX Lift Arms to the side of a module. The following example shows the use of 1x3 Lift Arms. Convenient about use two 1x3 Lift Arms on top of one another is that a Technic pin can be fitted into the round hole of the Lift Arm. We can use this to connect another module with Lift Arms in the right places.

In steps 1 through 3 we build up a (basic) module structure. Observe that the stacks of 1x2 plates need to be two plates high, so that the holes of the transparent bricks line up correctly for the Lift Arms to fit.



Next, add the Lift Arms in steps 4 and 5, and (optionally) the Technic pins



The Lift Arms prevent vertically oriented forces to pull apart the module.

Module: Torque Gear module 1

The purpose of this torque gear module is to provide more torque (pulling power) at the expense of speed. The core of the module is formed by a worm gear unit. Altogether this module provides a gear ration of 40:1.

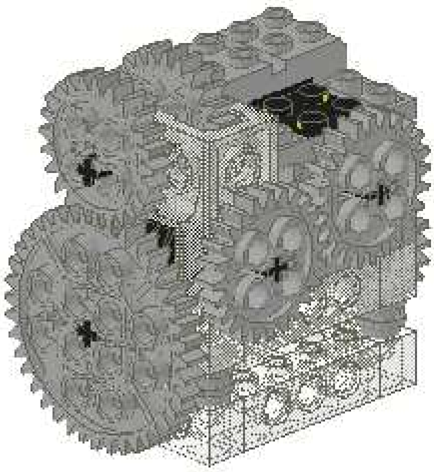
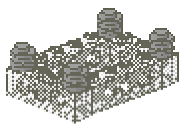


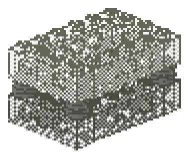
Figure 16 - Torque Gear module, 40:1 gear ratio

The module is based on a transparent 4x6 brick. Using stacks of (grey) 1x1 round plates, we create the basic structure in steps 1 and 2. In step 3 we add an 8u axle, with a 24t gear at one end and a 40t gear at the other.

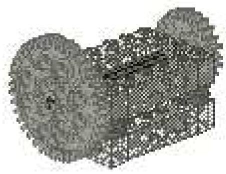
1



2

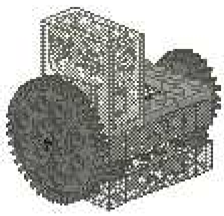


3

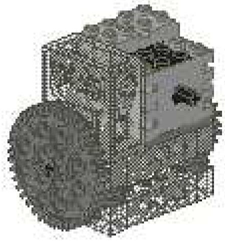


Next we add the worm gear case in step 4, and put one layer of tiles on the front long side of the top 4x6 brick, and on the remaining short side. This layer does not completely cover the brick – otherwise, we cannot fit the motor onto the construction in step 5. In step 6, we add the worm gear to the case, put an axle through it, and fix a half bush at the rear end of the axle.

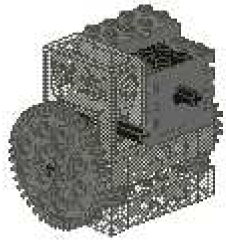
4



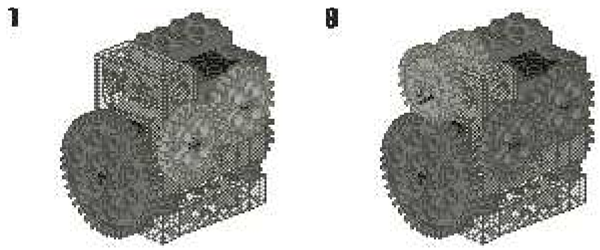
5



6



In step 7 we add a 24t gear to the worm gear axle, and another 24t gear to the motor to drive the worm gear. To complete the module, we add a 24t gear to the worm gear case, and connect another 24t gear to that using a 3u axle. The 24t gear on the outside drives the 40t gear.

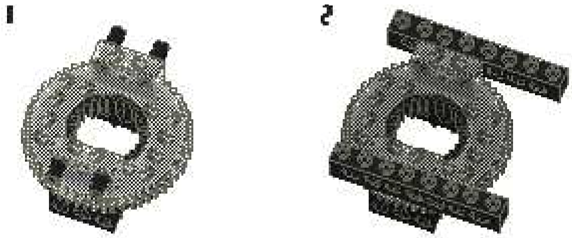


Module: Steering module 1

We build a simple steering module using the turntable part from the *Ultimate Builders Set* and a worm gear. The worm gear ensures that there is enough torque to steer the wheels, and that this is done in a slow enough speed (without having to slow the motor).

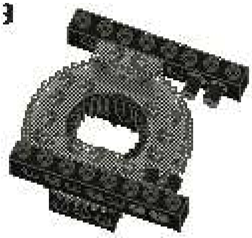
Figure 17 - Complete turntable steering module

In steps 1 through 4 we build up the basic frame, as illustrated below. To make sure the construction is sturdy enough, we use the black Technic pins („Technic Pin with Friction“).

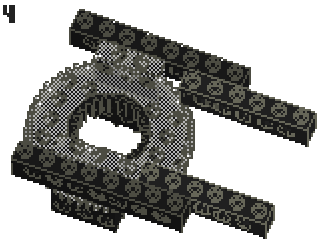


The beams we attach in step 2 are 8u beams. We complete the frame in step 4 with attaching two 6u beams.

3

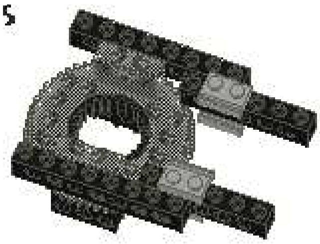


4

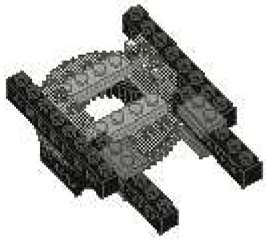


In step 5 we add the 2u plates with door rails to hold the motor block (which we add later in step 12). In step 6 we fix on the turntable twice two 4u plates stacked on top of one another.

5

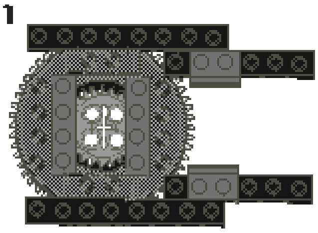


6

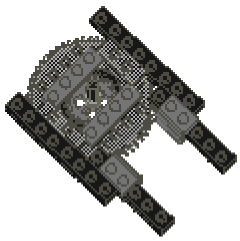


In the next steps we add the parts that enable us to turn the lower part of the turntable. In step 7 we fix a 24t gear in the lower, black part of the turntable, and stick a 5u axle with normal bush in the gear in step 8.
In step 9 we add the worm gear. The worm gear sits on a 6u axle, with a bush on one end, and an 8t gear on the other end. The axle is held in place with two 4u beams on either end, placed on the stacks of 4u plates. To let the worm gear drive the 24t gear, put an 8t gear on the axle of the 24t gear.

7



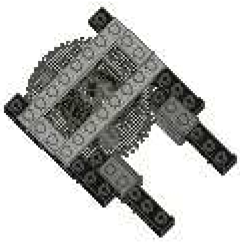
8



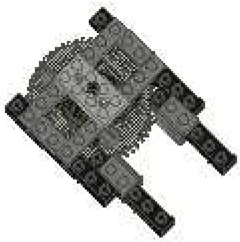
9

To hold the axle of the 24t gear in place, we add a rim of plates in step 10, on top of which we can then put a 4u by 2u plate in step 11. Step 12 completes the model by adding the motor, which drives the worm gear’s 8t gear using another 8t gear directly attached to the motor.

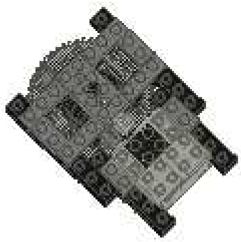
10



11



12



Module: Insect Legs

The next module provides insect leg-like movement. The module has one motor which drives four legs. To make a “complete” insect, you can either build two of these modules, or extend the current module to have six legs instead of four.

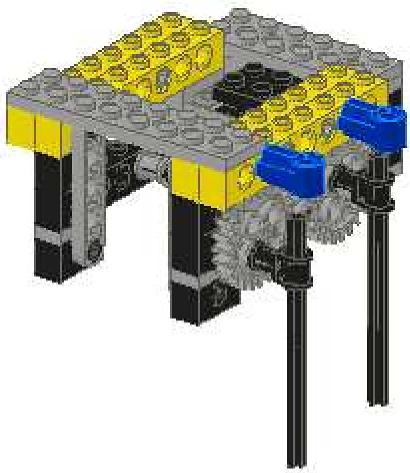
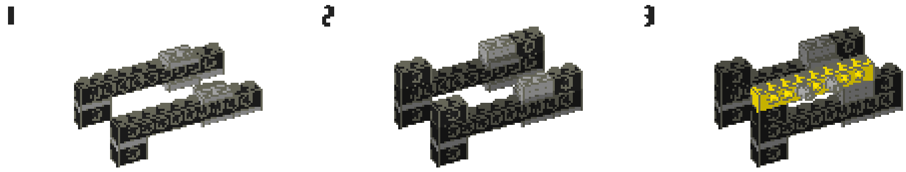


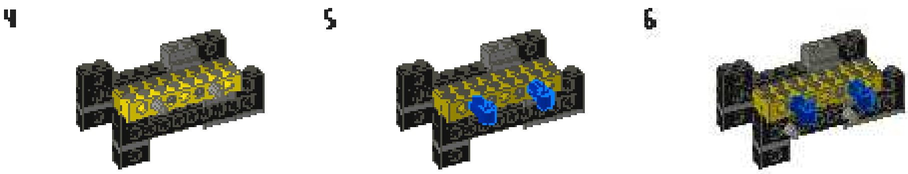
Figure 18 - Insect Legs module

The module is shown in Figure 18, with legs for one side showing. (Naturally, you also have to add legs to the other side!)

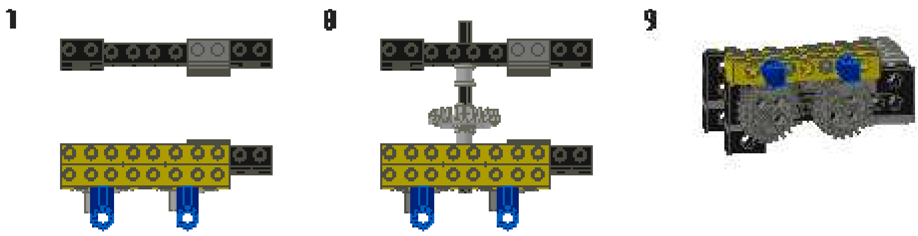
In steps 1 and 2 we start by building up the basic structure, using 10u beams. Observe we are using railed 1x2 plates on the right-hand side of the structure, where the motor is going to be. In step 3 we add an 8u beam and stick two Technic pins into it.



Onto the Technic pins we fix another 8u beam in step 4. The second 8u beam also gets two Technic axle pins, where we fit the blue angle connectors in step 5. These angle connectors will guide the legs, ensuring they remain in upward position. In step 6 we add two axle pins to the 10u beam.

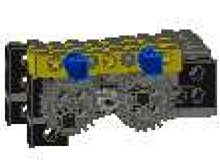


Onto these pins we fix two standard 24t gears in step 7. In step 8 we add a crown gear on an 8u axle, fixed in position using two bushes. Step 9 shows the module so far.



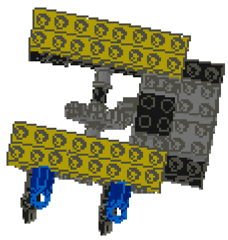
In step 10 we add 8t gears to the crown gear's axle, so that the axle drives the 24t gears on the outside. Also add to each gear a Technic Connector using an axle pin. The connectors are going to hold the legs. For step 11, go again through steps 1 through 6 to create the other side of the module. In step 12, add the motor. Use an 8t gear to drive the crown gear.

10



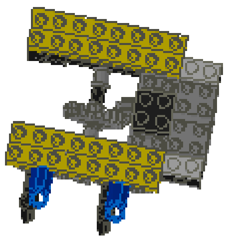
11

12



In step 13, attach the power cable to the matter, and add 1x2 plates to the side of the motor, such that in step 14 we can put a 2x6 Technic plate over the back of the motor. Also add a 2x8 plate to the front of the module, to make that part more rigid. Finally, attach two 1x5 Lift Arms to the front of the module, using ¾ dark grey Technic pins.

13



14

15

Finally, add the legs. As legs you should use axles of (at least) length 8u. Make sure that leg movement is synchronized "cross-wise": Left-front and right-rear should move up at the same time as left-rear and right-front are moving up. You can achieve this by plugging the Technic Connectors into "opposite" holes in the 24t gears.